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Translation

SEMICONDUCTOR PRODUCTION EQUIPMENT

By

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SEMICONDUCTOR PRODUCTION EQUIPMENT

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Annotation

[Text] The structural designs are described and the major characteristics are given in the book for the most widely used semiconductor production equipment; the requirements placed on the equipment are formulated, and practical recommendations are given for the major types of equipment for the operational checking of its good operating condition. The basic principles of comprehensive mechanization and automation in modern semiconductor production are set forth. The most characteristic production lines and production systems are described.

The book is intended for engineers and scientific workers involved in the production and application of semiconductor devices and integrated circuits.

Foreword

The fast pace of growth in the production of discrete semiconductor devices and integrated circuits poses one of the major problems in the sector: the continuous refinement of production process and instrumentation equipment, comprehensively mechanized and automated lines as well as systems as the major basis for their mass production. Because of the qualitative changes which have taken place in the production technology for devices in recent years, the demand for literature devoted to semiconductor production equipment is felt especially sharply.

The most characteristic domestic and foreign equipment used in the production of semiconductor devices is described in this book. The greatest attention is devoted to production process equipment for manufacturing mass produced types of transistors and semiconductor integrated circuits, the development of which is based on planar technology.

The three concluding chapters of the book are devoted to comprehensively mechanized lines and systems for the mass production of semiconductor devices and integrated circuits. Some of the general questions of comprehensive automation and mechanization of semiconductor production are treated here, including questions of the systemic approach to and optimization of the major parameters of comprehensively mechanized lines and systems when planning automated production processes, as well as questions of automation of transport operations between process cycles and control of the technological process and production of semiconductor devices.

Working with the book presupposes the familiarity of the reader with the fundamentals of semiconductor production technology. For this reason, questions of technology are not treated in the book and are touched on only in individual cases: in connection with the necessity of more completely explaining the operational principles or the structural design features of the equipment being described.

The book, in the opinion of the authors, will be useful both to equipment designers, production process engineers and other workers in the semiconductor industry involved with its operation, as well students in the higher educational institutes and technical schools in the appropriate specialties.

The introduction and Chapter 12 were written by P.N. Maslennikov; Chapter 1 by I.V. Kirichenko and P.N. Maslennikov; Chapter 2 by I.V. Kirichenko and K.A. Lavrent'yev; Chapters 3 and 4 by V.V. Rudnev; Chapter 5 by V.V. Stepanov; Chapter 6 by V.A. Nazarov; Chapter 7 by V.A. Nazarov and G.I. Kholin; Chapter 11 by G.I. Kholin; Chapters 8 and 13 by V.S. Shcherbakov; Chapter 9 by V.I. Kononov; Chapter 10 by K.A. Lavrent'yev and V.I. Kononov; Chapter 14 by V.V. Stepanov and A.D. Gingis; Chapter 15 by P.N. Maslennikov, V.A. Nazarov and G.I. Kholin.

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The authors will gratefully accept all remarks and proposals by readers directed towards the elimination of all possible deficiencies in the book, which they ask be sent to the following address: 101000, Moscow, Chistoprudnyy Boulevard, 2, Izdatel'stvo "Radio i Svyaz'".

INTRODUCTION

I-1. The Development of Semiconductor Device Production

The development of electronics has taken on a special role in the age of the scientific and technical revolution. The most important achievements of science and engineering are related to the use of electronic products, and primarily to the use of semiconductor devices (PP) and integrated circuits (IM) [IC]. In being one of the youngest sectors of industry, the semiconductor industry has developed at an exceptionally fast pace. The development and industrial production of semiconductor devices necessitated the creation of a large number of new technological processes and techniques. The methods developed at the dawn of the development of solid-state electronics for producing p-n junctions made it possible to set up the production of extremely simple point junction and later also alloy junction germanium devices. However, silicon technology was the basis for the modern semiconductor industry [1, 6]. The creation of diffusion techniques for producing p-n junctions and epitaxial methods of fabricating semiconductor films was of especial importance for the development of silicon semiconductor device technology. The development of oxide masking and photolithography, which comprise the basis of planar technology, made it possible to create integrated circuits [5].

The further development of semiconductor production was related to the continuous improvement of the techniques and equipment for planar epitaxial technology, directed towards substantially reducing the dimensions of components and increasing the level of integration of the devices being fabricated. The techniques of electron and X-ray lithography, ion-plasma and plasmochemical processing make fundamental improvements in silicon device technology. The indicated techniques opened up the possibility of developing the so-called submicron technology, which in the immediate future should become the basis for the production of devices with an increased level of integration.

I-2. Semiconductor Production, Its Complexity. General Requirements Placed on the Performance Level of Equipment and Production

Modern semiconductor production is a complex of complicated operations, from the input quality control of the raw materials to the final assembly of the finished device, its testing and packaging. When manufacturing semiconductor devices, it is necessary to perform tens and hundreds of production process and test and measurement operations, which require the use of special equipment. Thus, to fabricate a relatively simple technological type of semiconductor device, a silicon diffusion diode, it is necessary to use more than 80 pieces of special production process equipment, not counting the general purpose and typical hardware used in manufacturing operations. With the transition to the fabrication of more complex semiconductor devices and IC's, as well as the comprehensive mechanization and automation of production, the quantity and complexity of special equipment are also rising [4].

The majority of the processes known to modern engineering are used in the fabrication of semiconductor devices: metallurgical, chemical, electrophysical, thermal and mechanical metal treatment, welding, soldering, precision assembly; vacuum, electron, ion-beam, as well as diverse monitor, measurement and test equipment is employed to apply various kinds of coatings; electrical and non-electrical measurements, internal flaw detection techniques, etc.

The high requirements placed on the technology and equipment are determined by the specific features of the semiconductor device as a product*. The most important of them consists in the fact that the entire fabrication process for the device is performed on a single chip and within its volume, in which layers are produced having special physical properties, governed by the various concentrations of the doping impurities. A deviation from the specified production process modes in one of the operations can lead to the final rejection of the device as a whole. The fabrication complexity of a semiconductor device is also due to the extraordinarily small dimensions of the components. For example, when producing high frequency semiconductor devices, it is necessary to solder and weld electrode leads 8 to 10 μm in diameter to pads with dimensions of 20 x 70 μm, without disturbing the layers in this case which are located underneath them, the thickness of which is 3 to 5 μm.

It is specifically these features which primarily dictate the exceptionally high requirements placed on the overall technical level of the production: the purity of the raw materials, the stability and reproducibility of the production process parameters, on the organization of production, and as a result, on the equipment with which the semiconductor devices are manufactured. For example, germanium to satisfy the requirements of semiconductor production should contain no more than $0.2 \cdot 10^{-8}$ % foreign impurities, while pure silicon should be of a purity 1,000 times greater. The precision with which the temperature is maintained in diffusion furnaces during the heat treatment process of the original semiconductor material (at a level of 800 to 1,300° C) should be no less than ±0.5° C over the entire length of the working zone, etc.

The same high requirements are also placed on the purity and stability of the composition of the microclimate in which the devices are fabricated. For example, the dust content in gases should be no more than 2 dust particles per liter; the dust content of ordinary air amounts to about 20,000 dust particles per liter with a size of 0.5 μm or more. When fabricating devices, more than 10 kinds of energy vehicles are needed (nitrogen, argon, helium, dried air, hydrogen, hot gas, etc.).

The exceptionally high complexity of semiconductor production technology and the necessity of meeting the requirements cited above and many others are responsible for the need to create fundamentally new methods and tools as well develop and introduce a large number of types of special equipment, frequently custom-made equipment having no counterparts in other sectors of industry. Thus, the average precision in the fabrication of semiconductor equipment is two to three classes higher than in general machine building, and in a number of cases, exceeds the precision of the equipment used, for example, in watch

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*See the following for more details on the specific features of semiconductor production (Chapter 12, § 12-1).

making. The microscopically small dimensions of semiconductor device components have necessitated the use of special optical instruments and devices, which make it possible to execute and observe micromotions with a precision of down to 0.5 to 1.0 μm and less. Extraordinarily complex problems have been solved in the design of equipment to carry out numerous chemical engineering processes related to the use of especially corrosive chemical reagents such as hydrofluoric, nitric, sulfuric, hydrochloric acids, hydrogen peroxide, etc., as well as the use of various gases and mixtures of them.

High requirements are placed on the level of automation, and reliability of semiconductor equipment (primarily on the reproducibility of the production process parameters) as well as the stability of its operation. These requirements are substantially increased because of the problems of comprehensive mechanization and automation of the production of mass produced types of semiconductor devices and IC's.

I-3. Semiconductor Devices. Structural Components of Some Types of Semiconductor Devices

Each kind of device, which differs from another in its structural design and even more in its technology, requires the creation of a specialized set of production process and monitor and measurement equipment to set up industrial production. A schematic of the classification of semiconductor devices in terms of structural design and technological criteria is given in Figure I-1. Although it is not exhaustive, the indicated schematic assists in showing the manifold character and diverse nature of the complexes and groups of equipment used just for the production of semiconductor diodes and transistors.

Semiconductor devices consist of a number of elements which are common to practically all types in terms of their function. The major component of a semiconductor device is the chip of either a rectangular or more rarely a circular shape with the p-n junctions formed in it. For protection against external exposure and to improve the heat sinking, the chip is housed in a hermetically sealed package, the structural features of which are governed by the type of device, or it is sealed in plastic. The devices have internal and external leads for the electrical connections. The chip is either soldered (or glued) directly to the socket base or to the crystal holder.

We shall briefly deal with the configuration and structural features of the most widely used types of semiconductor devices.

Diodes. The most widespread groups of semiconductor diodes are point and surface contact (alloy and diffusion) types. The group of point contact devices includes high frequency and microwave diodes, as well as pulse and converter diodes based on germanium and silicon. The group of surface contact diodes includes low frequency rectifier and pulse diodes based on germanium and silicon, silicon zener diodes, varicaps based on germanium and gallium arsenide as well as tunnel diodes based on germanium, silicon and gallium arsenide.

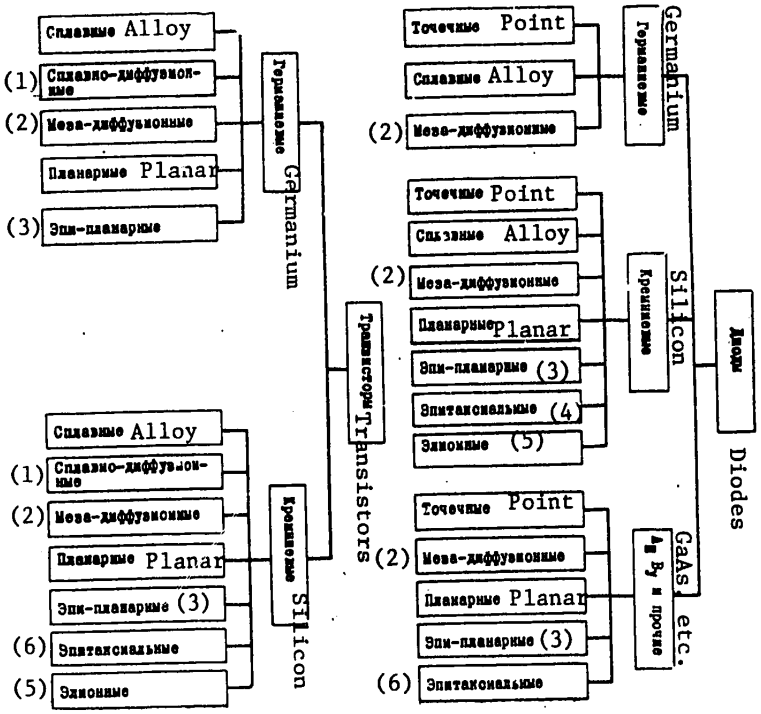


Figure I-1. The classification of semiconductor devices.

Key:
1. Alloy diffusion;
2. Mesa diffusion;
3. Epi-planar;
4. Epitaxial;
5. Elionic [sic];
6. Epitaxial.

Point contact diodes have become widespread because of the technological simplicity of their fabrication and low cost. Typical structural designs for point contact diodes are shown schematically in Figure I-2. The diode consists of the germanium or silicon chip 2, which is sealed to the crystal holder 1, the contact electrode 3 in the form of a thin sharpened metal needle and capsule 4.

The housing (capsule) for D2 and D104 type diodes take the form of a glass tube with Fernico inserts 5 sealed to it in the end faces. The semiconductor chip is soldered to the massive nickel crystal holder, which is inserted in the capsule and soldered to the Fernico insert using low temperature solder. At the opposite end, a similar electrode is sealed in the capsule, which supports the contact needle. The external leads 6 are usually circular, and sometimes ribbon shaped; they are fabricated from nickel or platinite.

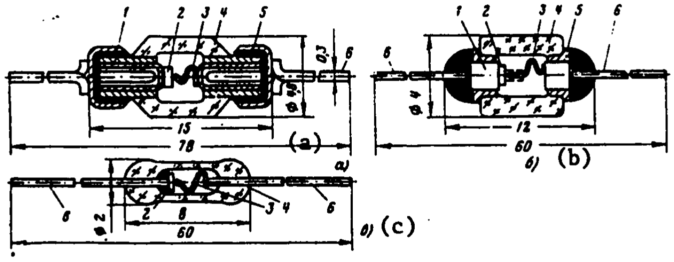


Figure I-2. Structural designs of point contact diodes.

Key: a. Germanium type D2;
b. Silicon type D104;
c. Germanium type D4.

In the all-glass D9 devices, the chip is usually soldered using low temperature solder directly to the end face of the platinic lead which is located inside the capsule. Sometimes, a very fine Fernico washer is placed between the chip and the end face of the lead to match the temperature coefficient of linear expansion. The second electrode takes the form of a platinic lead which is fused into the glass of the capsule.

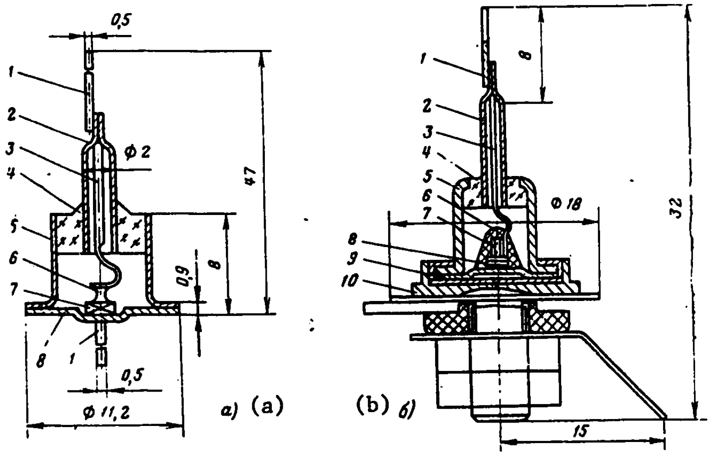


Figure I-3. Structural designs of alloy diodes.

a. The germanium D7 type;
b. The silicon D202 - D205 types.

Alloy semiconductor diodes are fabricated by melting alloys containing acceptor or donor impurities into the original semiconductor. Electron-hole junctions are produced in the overwhelming majority of cases in germanium surface contact diodes by melting indium into n-type germanium, while junctions in silicon alloy devices are fabricated by melting aluminum into n-type silicon or an alloy of tin and phosphorus (or gold and antimony) into p-type silicon. Structural designs of germanium and silicon alloy diodes are shown in Figure I-3. The germanium diode chip 7 with the fused in indium electrode 6 is soldered to the stamped steel chip holder 8. To protect the p-n junction against external exposure, the germanium chip is housed in a metal-glass capsule, consisting of the Fernico housing 5, glass insulator 4 and the Fernico tube 2 for the internal lead 3. The external leads 1 are connected to the chip holder and the Fernico tube.

The structure of a silicon alloy diode has much in common with the germanium diode. The chip 8 with the fused-in electrode 7 in the form of a small aluminum column is soldered to the copper base 9. The junction is housed in a capsule consisting of the Fernico housing 5, glass insulator 4 and Fernico tube 2. The interior lead 3 is connected to the aluminum column. External lead 1 is brazed to the Fernico tube. To improve the heat sinking, the diode is fastened to metal chassis 10, to which the current is fed by means of a threaded contact. The electron-pole junction is protected with varnish 6.

Transistors are one of the most widespread components in electronic systems. The advantages of silicon planar transistors [6] exerted an especial influence on the expansion of their wide scale applications in electronics. The first semiconductor triode, which was proposed in 1948 by Bardeen, Brattain and Shockley, was a point contact device. The point contact transistor is practically not used at all at the present time; the major type of transistor is the surface device. Field-effect transistors have been finding wide scale applications recently.

In terms of the maximum power dissipation, transistors are broken down into the groups of low (up to 0.3 watts), medium (from 0.3 to 3 watts) and high power (more than 3 watts) transistors; in terms of the maximum working frequency, they are broken down into low frequency (up to 3 MHz), medium frequency (from 3 to 30 MHz), high frequency (from 30 to 300 MHz) and SHF (more than 300 MHz) devices.

Surface contact transistors are broken down into alloy, diffusion, planar and epitaxial types according to the methods of fabricating the p-n junctions. Variants and combinations of these methods are also widely used (see Figure I-1). Transistors are also broken down according to the material used (germanium, silicon).

Without going into the structural design of alloy transistors, we shall move directly on to epitaxial planar transistors; this book is primarily devoted to the equipment for the production of this type of transistor.

The structural designs of the mass produced types of low power planar transistors are shown in Figure I-4: transistors encapsulated in metal and glass as well as in plastic.

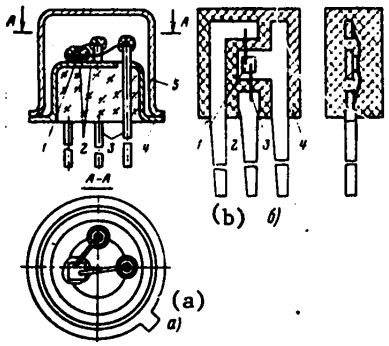


Figure I-4. Structural designs of low power planar transistors.

a. In a metal-glass package;
b. In a plastic package.

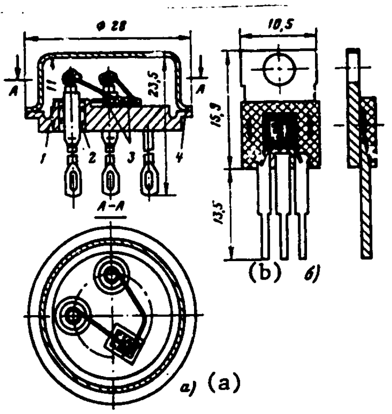


Figure I-5. Structural designs of high power planar transistors.

a. In a metal-glass package;
b. In a plastic package.

For transistors having a metal-glass package (Figure I-4, a), the chip with the p-n junctions 1 is soldered to the mounting base 4 and connected by the leads 2 to the cross-ties 3. The capsule 5 is either resistance or cold welded to the mounting base 4.

The structural design of transistors in a plastic package is the one most suited to the requirements of mass production (Figure I-4, b). The chip 1 is connected to the exterior flat leads of transistor 2 by wire leads 3. The advantage of such a structure consists not only in the low cost of the hermetic sealing plastic 4, but in the reduction of the labor intensity of the assembly operations, which are accomplished on a single traveling belt carrier, including the sealing operation, something which makes it possible to automate the assembly process.

High power planar transistors are shown in Figure I-5. A considerable power is liberated in the collector junction during the operation of such transistors, because of which it is necessary to improve the heat sink so that the temperature of the transistor components does not exceed the permissible level for the material being used. For this reason, a considerable massiveness of the package elements, the mounting base 1 and the capsule 4, a greater cross-section of the emitter, base and collector leads 3 as well as a special structural design for the feed-through insulators 2 are characteristic of power transistors (Figure I-5, a). The base of the package is made of copper or a copper insert is used. The bottom surface of the package is usually not painted so as to reduce the thermal resistance and improve heat removal from the package to the chassis or heat-sink.

Power transistors usually also have differences in the geometrical shape of the p-n junctions as compared to low power devices so as to not excessively increase

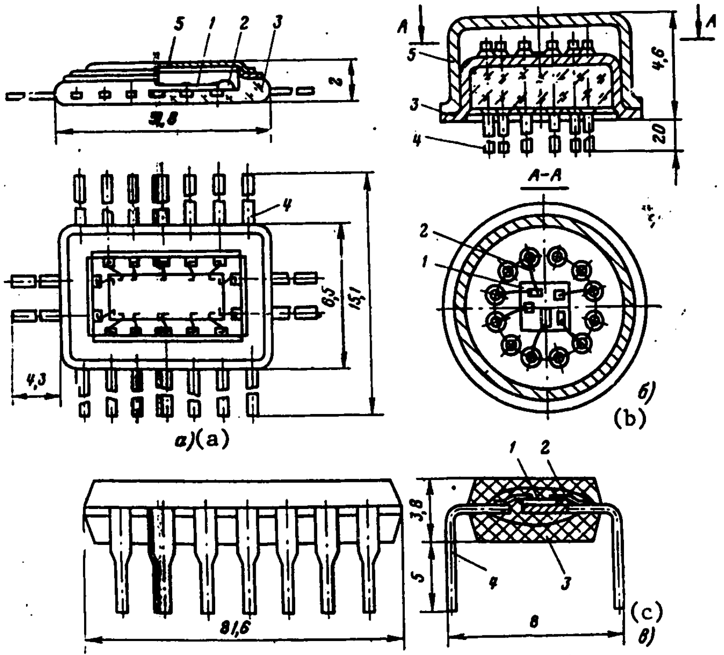


Figure I-6. Structural designs of integrated circuits.

a. In a flat metal-glass package;
b. In a circular metal-glass package;
c. In a plastic package;

Key:
1. Semiconductor chip;
2. Internal lead;
3. Package;
4. External lead;
5. Mounting base.

the emitter current density and at the same time, not increase the base resistance. Complex configurations of the junctions are used, making them in the form of strips or rings.

A power transistor in a plastic package (Figure I-5, b) differs from a low power type also in the special structural design of the collector lead and the complex configuration of the junction.

The external appearance of some mass produced types of integrated circuits is shown in Figure I-6. It is easy to see that the structural packaging of integrated circuits in circular metal-glass and plastic packages is a natural development from the similar structural design variants of transistor packages described above. Thus, chip 1 in the IC in Figure I-6b is mounted on base 3 and connected by leads 2 to its cross-ties 4. The hermetic sealing of the device, i.e., the connection of the cap 5 to base 3 is accomplished by resistance welding. The integrated circuit in the plastic package (Figure I-6, c) is in practice a structural design variant of the transistor shown in Figure I-4b, but with a higher degree of complexity in accordance with the functional complexity of the device. The detailed design of semiconductor diodes, transistors and integrated circuits is described in [1-3, 6].

I-4. Standard Production Process Schemes and the Major Steps in the Production of Certain Types of Semiconductor Devices

The technological production processes for semiconductor devices include a large number of operations which are executed in various sequences and can be repeated several times, forming a complete fabrication cycle. Standard production process

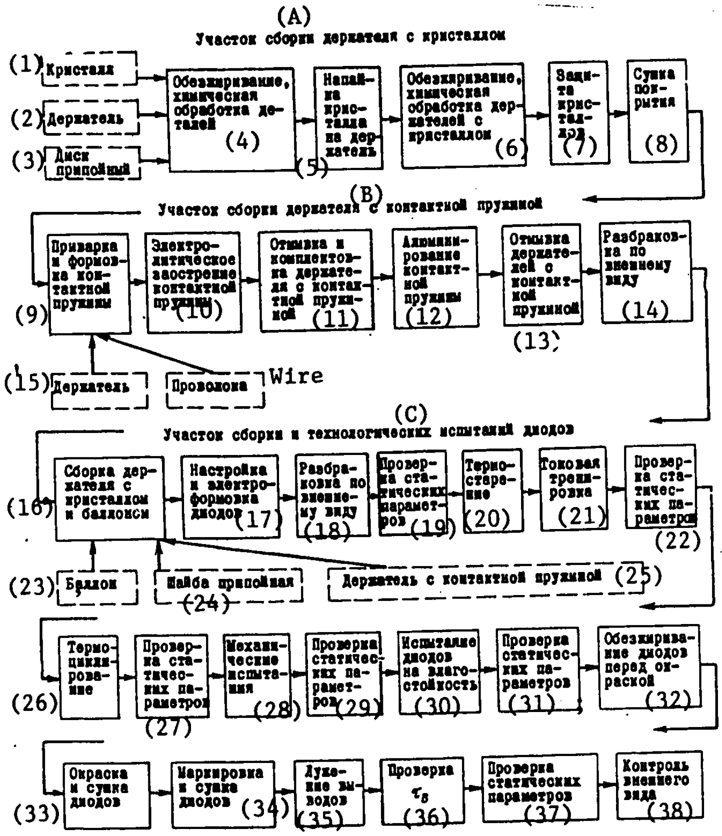


Figure I-7. The technological production scheme for point contact diodes.

Key: A. The section for the assembly of the holder and the chip;
B. The section for the assembly of the holder and the contact spring;

Key [cont.]: C. The section for the assembly and production process testing of the diodes;

1. Chip;
2. Holder;
3. Solder disk;
4. Degreasing, chemical treatment of the parts;
5. Soldering the chip to the holder;
6. Degreasing, chemical treatment of the holders with the chip;
7. Protective coating of the chips;
8. Drying the coatings;
9. Welding and shaping the contact spring;
10. Electrolytic sharpening of the contact spring;
11. Washing and putting together the holder with the contact spring;
12. Aluminizing the contact spring;
13. Washing the holders with the contact spring;
14. Quality control rejection based on external appearance;
15. Holder;
16. Assembly of the holder with the chip and the capsule;
17. Alignment and electroforming of diodes;
18. Quality control rejection based on external appearance;
19. Static parameter testing;
20. Heat conditioning;
21. Current burn-in;
22. Static parameter testing;
23. Capsule;
24. Solder washer;
25. Holder with contact spring;
26. Thermal cycling;
27. Static parameter testing;
28. Mechanical tests;
29. Static parameter testing;
30. Moisture immunity testing of the diodes;
31. Static parameter testing;
32. Degreasing of the diodes prior to painting;
33. Painting and drying the diodes;
34. Marking and drying the diodes;
35. Tinning the leads;
36. Check τ_B;
37. Static parameter testing;
38. Checking the external appearance.

schemes for typical semiconductor devices (Figures I-7 -- I-10) are given below. Thus, the technological production scheme for point contact diodes using the example of the D18 diodes is given in Figure I-7; given in Figure I-8 is the scheme for alloy diodes using the example of the D226 and D814 diodes. Further on, the production process scheme for planar epitaxial transistors using the example of the 2T-312 device is shown in Figure I-9. The major production process operations for planar epitaxial technology using photolithography are also employed in the production of semiconductor IC's, something which can be seen in Figure I-10.

It can be seen from the schematics given here that the methods of fabricating various semiconductor devices are extremely diverse. However, in all cases the semiconductor chip is subjected to a number of common basic production process operations.

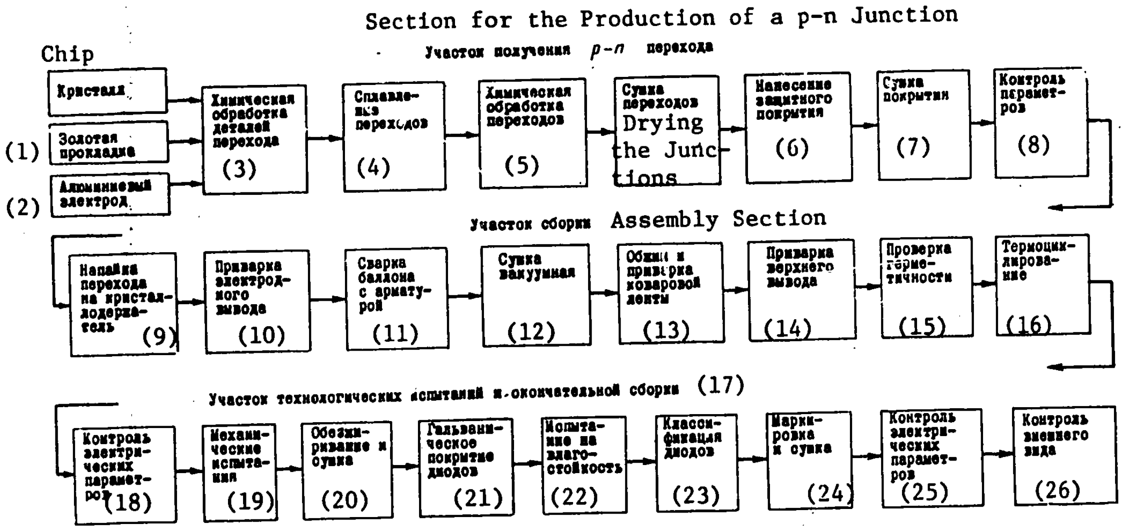


Figure I-8. Technological scheme for the production of alloy diodes.

Key:
1. Gold washer;
2. Aluminum electrode;
3. Chemical treatment of the junction parts;
4. Alloying of the junctions;
5. Chemical treatment of the junctions;
6. Application of a protective coating;
7. Drying the coating;
8. Checking the parameters;
9. Soldering the junction to the crystal holder;
10. Welding the electrode lead;
11. Welding the capsule to the fitting;
12. Vacuum drying;
13. Cogging and welding the Fernico strip;
14. Welding the upper lead;
15. Checking the hermetic seal;
16. Thermal cycling;
17. The section for production process testing and final assembly;
18. Checking the electrical parameters;
19. Mechanical tests;
20. Degreasing and drying;
21. Galvanic coating of diodes;
22. Moisture resistance testing;
23. Classification of the diodes;
24. Marking and drying;
25. Checking the electrical parameters;
26. Checking the external appearance.

The production technology for semiconductor devices can be broken down into several main steps.

The Fabrication of the Wafers. This step includes three groups of operations: mechanical machining of the semiconductor materials, the technical chemical treatment of the wafers and their quality control. The appropriate equipment is used for these operations.

The Fabrication of Structures with p-n Junctions. The major operation in this step is the operation of producing the p-n junction, and for this reason, the name of the semiconductor device is almost always determined by the designation of the processing method. Besides the group of equipment with which the p-n junction is produced directly, one can single out two groups of equipment which participate in the formation of the structures: equipment for producing films, i.e., for applying metallic, dielectric and semiconductor films to the wafer when making ohmic contacts, insulating coatings, thin film elements of microcircuits, etc.; equipment for the photolithography processes, i.e., for local etching, directed towards the formation of the microrelief in planar technology.

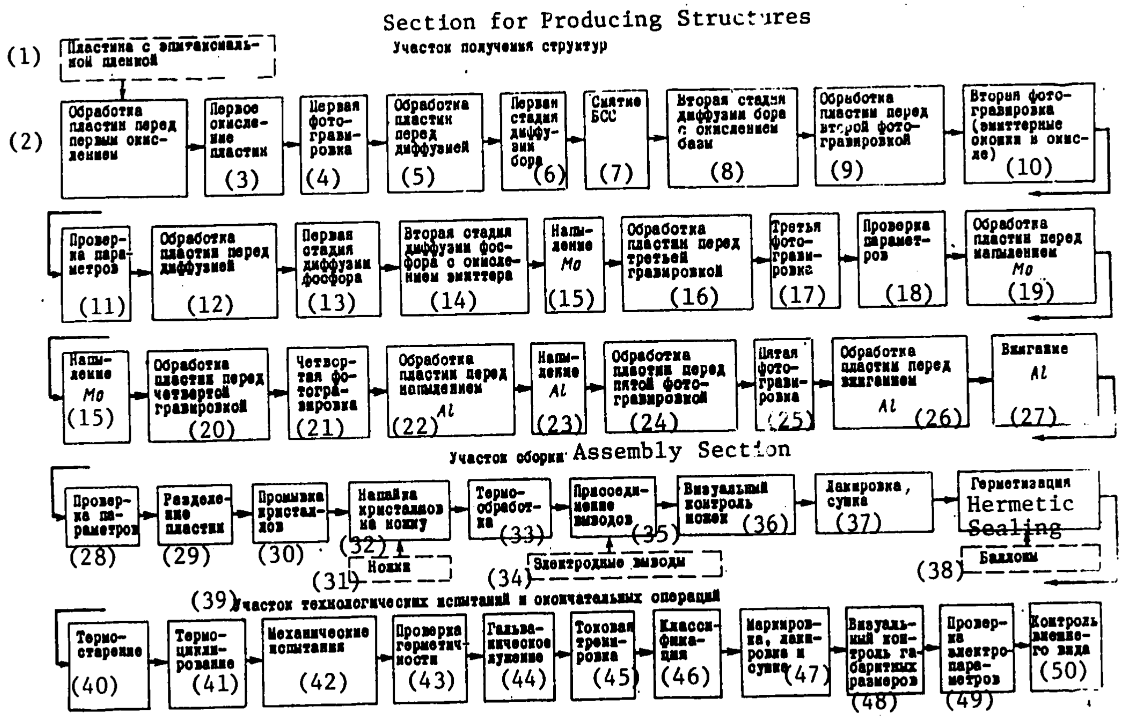


Figure I-9. The technological scheme for the production of planar epitaxial transistors.

Key:
1. The wafer with the epitaxial film;
2. Processing of the wafers prior to the first oxidation;
3. First oxidation of the wafers;
4. First photoengraving;
5. Treatment of the wafers prior to diffusion;
6. First boron diffusion stage;
7. Removal of the BSS [?quick setting mixtures?];

Key [cont.]:
8. Second boron diffusion stage with oxidation of the base;
9. Treatment of the plates prior to the second photoengraving;
10. Second photoengraving (emitter windows in the oxide);
11. Check of the parameters;
12. Treatment of the wafers prior to diffusion;
13. First phosphorus diffusion stage;
14. Second phosphorus diffusion stage with the oxidation of the emitter;
15. Deposition of Mo;
16. Treatment of the wafers prior to the third engraving;
17. Third photoengraving;
18. Check of the parameters;
19. Treatment of the wafers prior to the deposition of Mo;
20. Treatment of the wafers prior to the fourth engraving;
21. Fourth photoengraving;
22. Treatment of the wafers prior to the deposition Al;
23. Deposition of Al;
24. Treatment of the wafers prior to the fifth photoengraving;
25. Fifth photoengraving;
26. Treatment of the wafers prior to the burning-in of the Al;
27. The burning-in of the Al;
28. Check of the parameters;
29. Separation of the wafers;
30. Washing the chips;
31. Mounting bases;
32. Soldering the chips to the mounting base;
33. Heat treatment;
34. Leads;
35. Attachment of the leads;
36. Visual inspection of the mounting bases;
37. Varnishing, drying;
38. Capsules;
39. Section for production process tests and final operations;
40. Thermal conditioning
41. Thermal cycling;
42. Mechanical tests;
43. Checking the hermetic seal;
44. Galvanic tinning;
45. Current burn-in;
46. Classification;
47. Marking, varnishing and drying;
48. Visual checking of the overall dimensions;
49. Checking of the electrical parameters;
50. Check of the external appearance.

The Assembly of the Semiconductor Devices. This stage of the production combines three equipment groups: equipment for monitoring the structures on the wafer and separating the wafers into chips; equipment for mounting the crystal on the mounting base or strip as well as equipment for hermetically sealing the devices.

Measurement of the Electrical Parameters, Classification and Tests of the Devices. Besides quality control and test operations, other auxiliary finishing operations are performed in this stage of the production, including the marking and packaging of the finished device.

The breakdown into steps cited here most precisely corresponds to planar production technology for such devices, where the group method is used to produce p-n structures on a wafer. For other types of devices, the composition of the

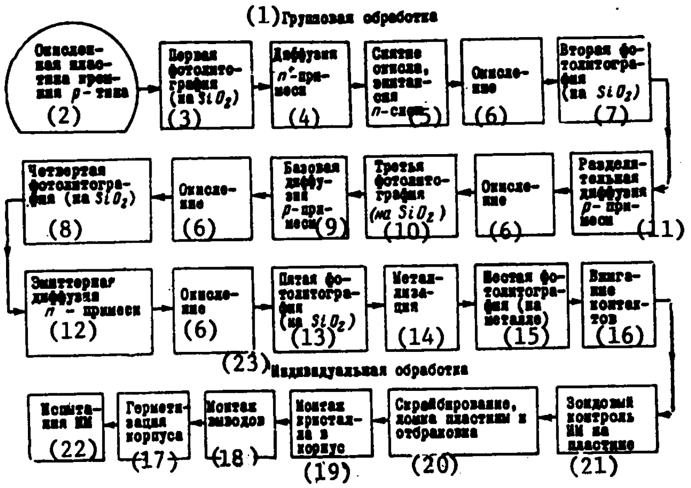


Figure I-10. Flow chart showing the production process for the fabrication of epitaxial planar structure integrated circuits with a buried n^+ layer.

Key:
1. Group treatment;
2. Oxidation of the p-type silicon wafers;
3. First photolithography (in SiO_2);
4. Diffusion of the n^+ doping impurity;
5. Removal of the oxide, n-layer epitaxy;
6. Oxidation;
7. Second photolithography (using SiO_2);
8. Fourth photolithography (using SiO_2);
9. Base diffusion of the p doping impurity;
10. Third photolithography (using SiO_2);
11. Separate diffusion of the p doping impurity;
12. Emitter diffusion of the n doping impurity;
13. Fifth photolithography (using SiO_2);
14. Metallization;
15. Sixth photolithography (in metal);
16. Burning-in the contacts
17. Hermetic sealing of the package;
18. Installation of the leads;
19. Mounting the chip in the package;
20. Scribing, breaking the wafers and quality control sorting;
21. Probe testing of the integrated circuits on the wafer;
22. Tests of the integrated circuit.
23. Individual processing.

production steps changes somewhat. The step by step production process scheme for silicon planar epitaxial transistors in a metal package is shown in Figure I-11.

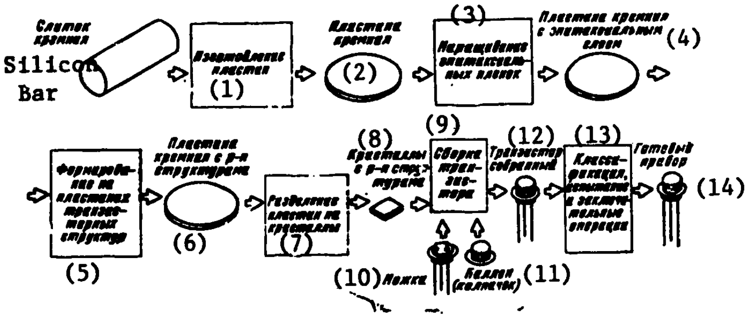


Figure I-11. The step by step production scheme for silicon planar epitaxial transistors in a metal-glass package.

Key:
1. Fabrication of the wafers;
2. Silicon wafer;
3. Build-up of the epitaxial films;
4. Silicon wafer with the epitaxial layer;
5. The formation of the transistor structures on the wafers;
6. Silicon wafer with the p-n structures;
7. Separation of the wafers into chips;
8. Chips with the p-n structure;
9. Assembly of the transistor;
10. Mounting base;
11. Capsule (cap);
12. Assembled transistor;
13. Classification, testing and final operations;
14. Finished device.

Besides the major processes, one can single out a number of auxiliary ones in semiconductor production which assure the requisite parameters of the production process media and energy vehicles (deionized water, inert gases and hydrogen, dust free air, etc.), as well as the preparation of the raw and semifinished products in the manufacturing phase of the production (the production of silicon bars, the fabrication of packages, etc.).

Part I.

Equipment for Fabricating Wafers and Producing Semiconductor Structures

Chapter 1. Equipment for Mechanical Processing of Wafers

The basic electrical characteristics of the device depend on the quality of the semiconductor wafer (chip). Therefore, the most important objective of the technology is to produce substrates which will be as close as possible to the original single crystals in terms of structure, chemical purity and defect content. A monocrystalline ingot grown by the Czochralski process or by zone melting crystallization is used as the starting material. This ingot contains a negligible amount of impurities, estimated at 10^{-9} to 10^{-10} percent. The ingot is in the form of a rod measuring from 8 to 150 mm in cross section and from 40 to 500 mm long. Wafers measuring from 0.5 X 0.5 to 10 X 10 mm and from 0.04 to 1 mm thick are made from this ingot.

Chips differ in dimensions, accuracy requirements and quality of the surface, depending on the type of device and the technological process for fabricating the chip. The requirements for the original wafers also differ accordingly. The strictest technical requirements are imposed on wafers to be used for fabricating planar devices and especially integrated microcircuits (IM's), large-scale integrated microcircuits (BIM's), etc. [5, 7]. For example, a silicon wafer 75 mm in diameter must meet the following specifications:

Nonflatness over entire surface, μ	≤ 0.5
Roughness, μ	≤ 0.05
Deviation of surface of wafer from specified crystallographic plane	≤ 1 deg
Thickness tolerance, μ:	
For IM's with dielectric isolation of elements	≤ 3
For IM's with concealed layers	≤ 25

The least rigid requirements are imposed on wafers intended for fabricating alloy power transistors and diodes:

Nonflatness, μ	≤ 10 to 20
Roughness, μ	≤ 5
Deviation from crystallographic plane	≤ 3 deg

From the large diversity it is possible to single out three basic technological processes for fabricating semiconductor wafers, which are used respectively in fabricating the three groups of semiconductor devices--alloy, mesaplanar and planar (fig 1-1). Wafers fabricated according to the first process have identically treated etched surfaces ensuring the best conditions for the wetting of electrode materials when they are fused into the chip. Wafers fabricated according to the second process have one polished surface and another ground surface. Wafers fabricated according to the third process are polished by means of an abrasive paste on both sides and one of the surfaces is treated additionally for the purpose of removing structural defects created by abrasive polishing. This side of the wafer is called the working side. Chemical-mechanical finish polishing makes it possible to produce wafers with minimum surface defects and the best flatness of the wafer's working surface.

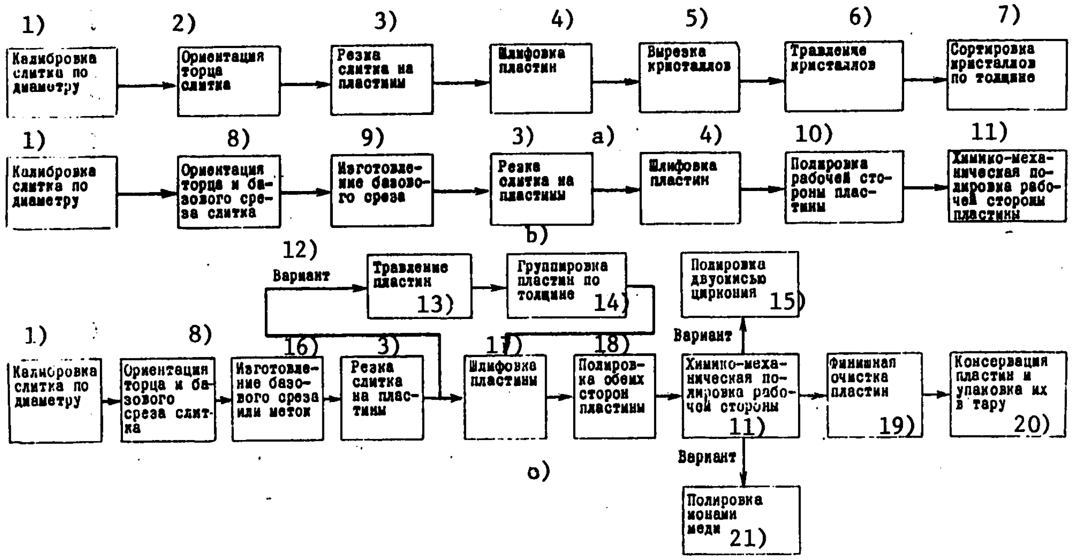


Figure 1-1. Simplified Technological Processes for Producing Semiconductor Wafers: a--for alloy and point-contact devices; b--for mesaplanar devices; c--for IM's and BIM's

Key:

1. Sizing of ingot in terms of diameter
2. Orientation of end of ingot
3. Cutting ingot into wafers
4. Grinding wafers
5. Cutting out chips
6. Etching chips
7. Sorting chips by thickness
8. Orientation of face and base cut of ingot
9. Making base cut
10. Polishing working side of wafer
11. Chemical-mechanical polishing of working side of wafer
12. Variant
13. Etching wafers
14. Grouping wafers by thickness
15. Polishing with zirconium oxide
16. Making base cut or marks
17. Grinding wafer
18. Polishing both sides of wafer
19. Finishing treatment of wafers
20. Preserving wafers and packing them in containers
21. Polishing by means of copper ions

A number of additional requirements are imposed on wafers for planar devices for the purpose of ensuring the high-efficiency performance of the subsequent operations of photolithography and dividing wafers into chips. In particular, enhanced precision of wafers with respect to diameter (± 0.2 mm), the presence on the wafer of a base cut or marks in the form of notches indicating crystallographic line [110], and a high finish for the wafer's surface are required. For the purpose of fulfilling these requirements the following operations are provided in the production process for fabricating wafers:

Sizing (cylindrical grinding) of the ingot in terms of diameter.

Crystallographic orientation and making a base cut.

Multistage finishing of wafers.

In addition to the above-named operations, the technological process includes a number of auxiliary operations: cleaning between operations, washing, drying, checking, cutting the ingot into billets and packing.

Before an ingot is processed the following electrophysical parameters are tested: resistivity, type of conduction, and the diffusion length and lifetime of minority carriers [8].

Mechanical processing operations--sizing, cutting, grinding, polishing--are especially important for the quality of the finished wafer, since when they are performed the chip is deformed with the formation near the treated surface of a layer of material whose structure differs from the ideal structure in its bulk. This layer is called the defect layer [7, 9]. Four zones with typical defects are distinguished in the defect layer:

The relief, 1; the crack, 2; the dislocation, 3; and the stressed, 4 (fig 1-2) [9].

The grosser the defects, the greater influence they exert on the parameters of devices. Therefore, the main objective of the technological process of fabricating semiconductor wafers is the guaranteed removal of the individual defects originating in mechanical processing. Individual allowances between operations, which also make it possible to eliminate defects (fig 1-3), are designated in relation to the depth of the defect layer.

It should be mentioned that the depth of the defect layer is not constant even for one and the same machine tool and technological process. Slight changes in the technological process--the degree of wear of the tool, the grain size and concentration of the micropowder, etc.--result in a change in the depth of the defect layer. Therefore, the allowance must be designated in terms of the highest value obtained in studying a specific technological process.

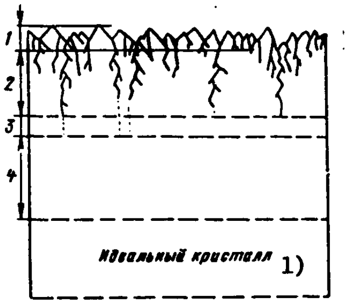


Figure 1-2. Structure of Defect Layer in Mechanically Processed Semiconductor

Key:
1. Ideal chip

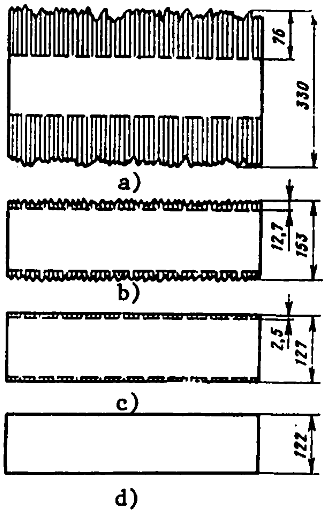


Figure 1-3. Diagram of Designation of Allowances Between Operations in Relation to Depth of Defect Layer: a--cutting; b--grinding; c--polishing; d--etching or chemical-mechanical polishing

Thus, equipment of the most varied nature is required for fabricating semiconductor wafers--electrophysical, mechanical and chemical technology. General-purpose machine tools are used extensively, such as cylindrical grinding (for sizing ingots), surface grinding (for making a base cut), ultrasonic (for cutting out round chips) and cutting-off (for cutting ingots into billets and for making a base cut). However, special equipment, which is discussed below, is used for performing key technological operations.

1-1. Equipment for Crystallographic Orientation of Wafers

Finding a specific crystallographic plane, determining the angle of disorientation of the surface of the end of an ingot relative to it and bringing the surface of wafers to be cut from an ingot into the specified plane with a tolerance, as a rule, of not greater than one degree (30' for some types of devices) are performed with special equipment by optical or x-ray methods [10, 11].

Optical Method

The operation of this apparatus is based on the method of orienting single crystals relative to light patterns, utilizing the specific features of the surface produced during chemical etching of a single crystal in selective etchants. The etched surface reflects light rays in a strictly specific direction. The reflecting surface is always in line with crystallographic plane (111). Deviation of the actual surface of the end of the ingot from crystallographic plane (111) results in deviation of the reflected beam on the screen by a certain value of d (fig 1-4, a), characterized by the angle of disorientation, α, of the real surface of the microsection from plane (111).

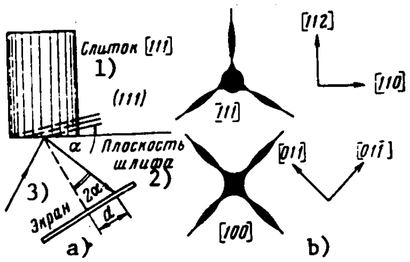


Figure 1-4. Diagram of Orientation of Ingot by Optical Method (a) and Light Patterns Obtained Thereby (b)

Key:

1. Ingot (111)
2. Plane of microsection
3. Screen

A 3-point star (fig 1-4, b) is a typical light pattern for an ingot grown along line [111], and a 4-point star for a [100] ingot.

A bench-type apparatus for orienting ingots by the light method is shown in fig 1-5. All of the apparatus's units and parts are mounted in a light-shielded case, 8: the optical system, consisting of a light source, 1, separated by a plate, 6; a condenser, 2; a diaphragm, 3; reflecting mirrors, 4, 5, and 10; a lens, 7, with sets of gears, 9 and 11, for setting the focus and aperture of the diaphragm, respectively; and a chip holder, 12, whose design makes it possible to install a stage for the oriented cementing on ingots; a moving plate, 18, which moves in ball guides; a catch for the moving plate, 19; a goniometer head, 20, which serves the purpose of measuring the angle of rotation of the ingot; reflecting mirrors, 10 and 13; a screen, 15, consisting of a frame, a groundglass, a sheet of acrylic plastic with a scale applied to it and two electric light bulbs which illuminate the glass with the scale from its ends; and an electrical unit, 22. The screen's axis passes through a slider, 14, which can be moved together with the screen in the direction of the optical axis. It is possible to move the screen in this direction by 36 mm and this is accomplished from a manual control by means of a flexible shaft and the drive screw of a lifting mechanism, 17. The screen can in addition be rotated on its own axis with its position fixed by means of a clamp. A mirror, 16, makes it possible to observe visually the light pattern of the reflection produced on the screen. The mirror is set in a position convenient for observing by means of knob 21.

Orientation is performed in the following manner. By turning the ingot manually on its axis the light pattern is set so that its ray points occupy a symmetrical position relative to the vertical axis of the scale and the center of the light pattern lies on the horizontal axis. The ingot is fastened in this position by means of the clamping screw of the chip holder. By turning the knob of the goniometer head, 20, the center of the light pattern is brought to the crosshairs of the axes and from the head's scale a determination is made of the angle of disorientation of the end of the ingot from the principal crystallographic plane.

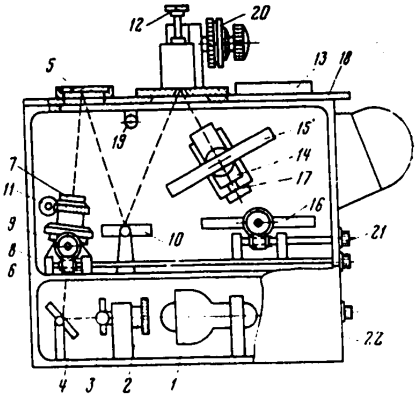


Figure 1-5. Unit for Orienting Ingots by the Light Method

X-Ray Method

Orientation of chips by the x-ray method is performed on general-purpose x-ray diffractometers of the URS-50IM, DRON-0,5 and DRON-2,0 types. The x-ray unit of the URS-50IM type (fig 1-6) has become the most widespread. It consists of a distributing unit, 1, a bench, 2, a pulse amplification unit, 3, a quantum counter, 4, a goniometer, 5, a protective shield, 6, and an x-ray source, 7. The unit is connected to the power line via an input stabilizer of the SN-1 type. The anode of the x-ray tube is protected by means of a massive metal enclosure and is water-cooled.

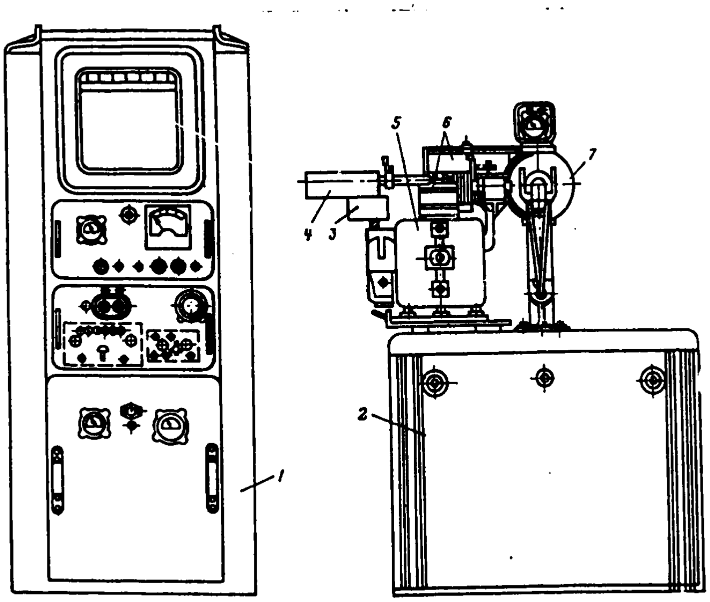


Figure 1-6. Type URS-50IM X-Ray Unit

An anode current stabilizer is provided in the unit in addition to the SN-1 voltage stabilizer for the purpose of ensuring high stability of the x-ray tube's radiation. Control of the voltage in the tube is stepwise (fig 1-7).

X-rays emitted from the window of the x-ray tube strike the specimen being studied, which is fastened at the center of the goniometer. The reflected waves strike the Geiger counter. A pair of particles--an electron and positive ion--appears in the counter as the result of the ionizing effect of the x-rays. With this a current pulse passes through the counter. The number of current pulses originating in the counter per unit of time is proportional to the intensity of the reflected x-ray beam.

Monocrystalline ingots of silicon and germanium are oriented by means of a special attachment consisting of a rotating unit, 1, and an electric control unit, 2 (fig 1-8). The rotating unit is installed on the goniometer. By means of it the ingot is clamped to the base surface and is rotated manually or by means of an electric motor relative to the horizontal axis.

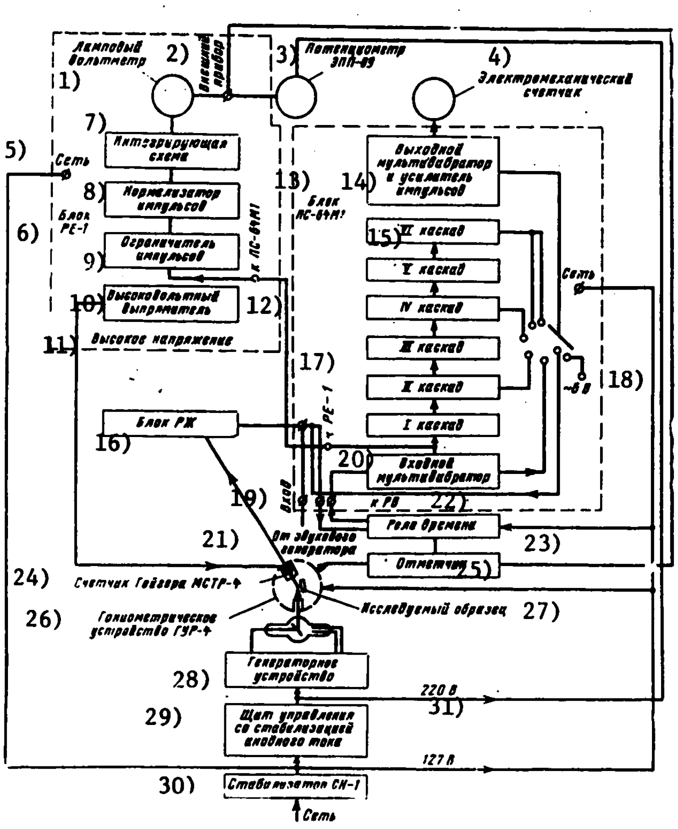


Figure 1-7. Structural Diagram of URS-50IM Unit

Key:

1. Tube voltmeter
2. External instrument
3. EPP-09 potentiometer
4. Electromechanical counter
5. Power line
6. RYe-1 unit
7. Integrating circuit
8. Pulse normalizer
9. Pulse clipper
10. High-voltage rectifier
11. High voltage
12. To PS-64M1

[Key continued on following page]

13. PS-64M1 unit
14. Output multivibrator and pulse amplifier
15. Stages I to VI
16. RZh unit
17. To RYe-1
18. Approximately 6 V
19. Input
20. Input multivibrator
21. From audio signal generator
22. To RV [time relay]
23. Time relay

24. MSTR-4 Geiger counter
25. Marker
26. GUR-4 goniometric unit
27. Specimen studied
28. Generator unit
29. Control panel with anode current stabilization
30. SN-1 stabilizer
31. 220 V

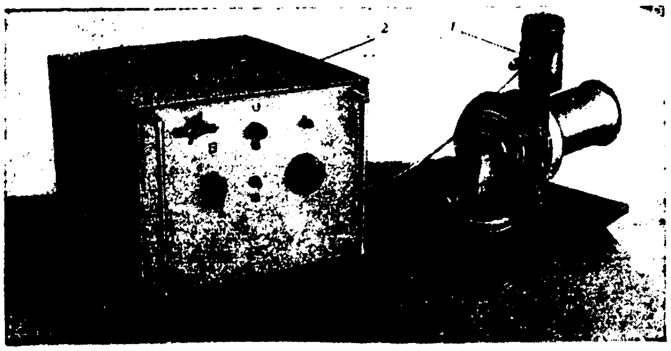


Figure 1-8. Attachment for URS-5CIM and DRON-0,5 X-Ray Unit for Orienting Silicon and Germanium Ingots

The ingot is set in a position in relation to the x-ray with which Bragg's law is fulfilled:

$$2d \sin \theta = m\lambda ,$$

where d is the distance between the chip's atomic planes, θ is the angle of incidence (reflection), m is a whole number and λ is the wavelength of the x-radiation.

The base cut is also oriented by means of optical and x-ray apparatus. Base cut plane (110) is determined most quickly and accurately when using an x-ray unit and a special attachment for it making it possible to orient the ingot in the vertical position of its axis. Here the x-ray is reflected from the side surface of the ingot, which simplifies finding plane (110).

1-2. Equipment for Cutting Semiconductor Materials

All methods originally used for cutting semiconductor materials--cutting with saw blades and wire with the use of abrasives--have completely given way to a more progressive method--cutting with diamond. The advantages of this method consist in high productivity and better quality of wafers.

The tool for diamond cutting is a ring-shaped wheel to whose inside edge have been applied diamond grains ranging in size from 40 to 60 μ.

All existing models of cutting machines can be divided into three types in terms of the method of positioning and feeding the diamond wheel:

Machines with a horizontally positioned stationary spindle (fig 1-9, a).

Machines with a vertically positioned stationary spindle (fig 1-9, b).

Machines with an oscillating horizontally positioned spindle (fig 1-9, c).

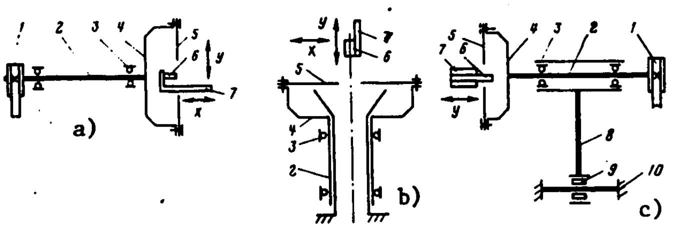


Figure 1-9. Simplified Mechanical Diagrams of Machine Tools for Cutting by Means of Diamond Wheels with an Inside Cutting Edge

In machines belonging to the first type the shaft, 2, of the spindle is positioned horizontally and rotates in bearing elements, 3, by means of a V-belt transmission, 1. On the shaft is fastened a drum, 4, with rings for attaching a diamond cutting wheel with an inside cutting edge, 5. The ingot, 6, is attached to a holder, 7, which is fastened to the machine tool's carriage, which accomplishes longitudinal--along the X-axis--and transverse--along the Y-axis--feeding. The spindle's shaft is solid and of small diameter and therefore small-diameter bearings are used.

A disadvantage of machine tools of this type is the wear of the carriage's guides, which is responsible for a loss of precision. In addition, there is a restriction on the length of an ingot which can be cut (76 to 90 mm); however, this disadvantage must be considered temporary--the employment of a vacuum remover for the cut wafer makes it possible to increase the length of an ingot to 500 mm and more.

In machine tools belonging to the second group the spindle's shaft is hollow. The shaft's diameter is selected so that the ingot passes freely inside it. The vertical position of such a shaft makes it possible to cut ingots of any length. However, the large diameter of the spindle's shaft requires the use of precision bearings of large size, which involves an increase in linear velocity and, consequently, the intensified wear of bearings. In addition, there are difficulties in lubricating the bearings and protecting them from the cutting fluid (SOZh). In machines of this type transverse and longitudinal movement of the ingot are accomplished by moving the carriage along the guides. Therefore, in them intensified wear takes place at the end of the stationary guide closest to the cutting wheel, since the greatest bending moment from the cutting force acts relative to the edge of the guide.

The design of machine tools of the third type is the best from the viewpoint of operating characteristics. A rotating arm, 8, installed on bearings, 9, is used instead of transverse feed guides. The entire spindle assembly with the drum, 4, and cutting wheel, 5, is fastened to it. The arm together with the spindle is rotated around a stationary axle, 10, attached to the bed of the machine.

Machine tools constructed according to the first design include the 2405, "Almaz-4", TS-21, TS-23 models, etc.; according to the second design, the ASM-10 and DS-350; and according to the third design--the 3,5X18 and 4,0X24 and "Almaz-6M" models.

Most models have been developed according to the first design. These machines are organized in the following manner (fig 1-10). On the upper base of the bed, 10, is installed a cast plate, 8, on which the main units of the machine are placed: the spindle, 6, with a head, 5, for attaching the cutting wheel; the carriage, 12, with a setting mechanism, 17, a microswitch, 15, and a feed control unit, 16; a feed mechanism, 3, with a reduction gear, 18, a control mechanism, 4, a brake, 2, and a shift lever, 1; the spindle drive, 7; and a protective enclosure, 14, with a system for supplying the cooling fluid. A rotating head, 13, is installed on the carriage, making it possible to turn the ingot in the horizontal and vertical planes, which makes it possible to cut the ingot parallel to a specific crystallographic plane. The head's scale value is 12'. A unit, 9, for feeding the cooling fluid is installed on the lower base of the bed. It consists of a tank and a centrifugal pump. An electrical equipment unit, 11, is fastened to the upper half of the bed behind a panel.

The interaction of mechanisms is illustrated in the mechanical diagram (fig 1-11) Rotation is transmitted from the motor, 10, through the V-belt transmission, 9, to the spindle, 8, with the head, 7, installed on it. The carriage, 5, (its top part) with the rotating head, 6, to which the ingot is fastened, is moved in the transverse direction under the influence of a weight, 3, along ball bearing guides, 11. The carriage returns to its original position by means of the shift lever, [illegible], which is driven into oscillating motion by means of an eccentric, 14, installed on a cam, 36. In longitudinal feeding of the ingot the carriage is moved along the guides, 12, by the action of the drive screw, 1, and nut, 2, fastened to the lower half of the carriage. The drive screw is driven into motion by a motor, 26, through a system of gears and cranks, 34.

Adjustment for the required cutting speed--the longitudinal feed rate--is accomplished by moving sector 40, which covers part of the teeth of ratchet wheel 39, depending on the specified rate. The transverse feed rate is set by means of a guide fastened to the frame of an indicator attached to the table, and a timing device. The mechanism for controlling the tranverse feed rate operates in the following manner. When the table, 5, moves, piston 38 forces oil through the gap between the body of hydraulic cylinder 44 and cone 43 into the space of the lower half of the carriage, 37. The rate of outflow of the oil determines the transverse feed rate and depends on the gap, which is set by means of screw 42. When button

41 is pressed the gap is expanded and, when necessary, the table is rapidly delivered to the extreme left position. An individual wafer is first cut from the ingot, with which the correctness of rotation of the ingot is checked for the purpose of arriving at the specified crystallographic plane. After the angle of rotation of the ingot is corrected, a wafer is cut off and from its thickness the cutting rate is corrected. These wafers are cut off manually and the following ones automatically. Lever 25 is accordingly placed in the "Manual Feed" or "Automatic Feed" position.

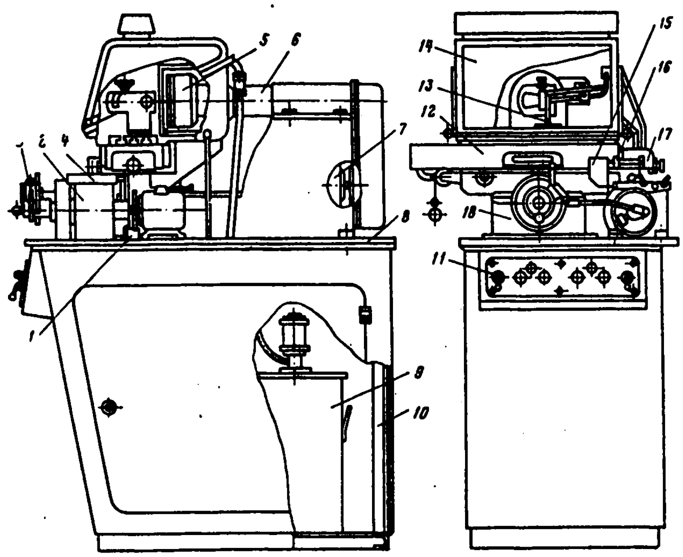


Figure 1-10. General Appearance of Cutting Machine

In the manual mode cam 17 occupies a position making it possible to raise and hold lever 16 at its top position. With this carriage 5 is fixed by means of stop 15. In order to free the carriage it is necessary to press on pusher 22. When lever 24 is turned cam 21 turns pin 20. Lever 18, following the profile of cam 23, frees lever 19, which is raised by means of pin 20. Table 5 is returned manually. In the "Automatic Feed" position of lever 25, cam 17 by means of lever 18 fixes lever 19 in a position whereby lever 16 is let down along the profile of cam 36. The upper half of the carriage--table 5--under the effect of weight 3 is moved in the transverse direction relative to the ingot's axis.

Longitudinal feeding at the cutting pace is accomplished automatically. At the end of a cut a screw closes the contacts of microswitch 4, which turns on motor 26 and electromagnet 30. The electromagnet turns block 29, which spreads shoes 27 of brake drum 28. After shaft 35 turns 360 degrees, cam 33 closes the contacts of switch 32, which cuts off motor 26 and electromagnet 30. Block 29 and brake shoes 27 assume their original position under the action of springs 31. One of the most ideal models of this type--the TS-23 machine--has longitudinal feed precision of a 0.001-mm step. This machine is distinguished by a high level of automation; The automatic loading of cut wafers into holder is provided for.

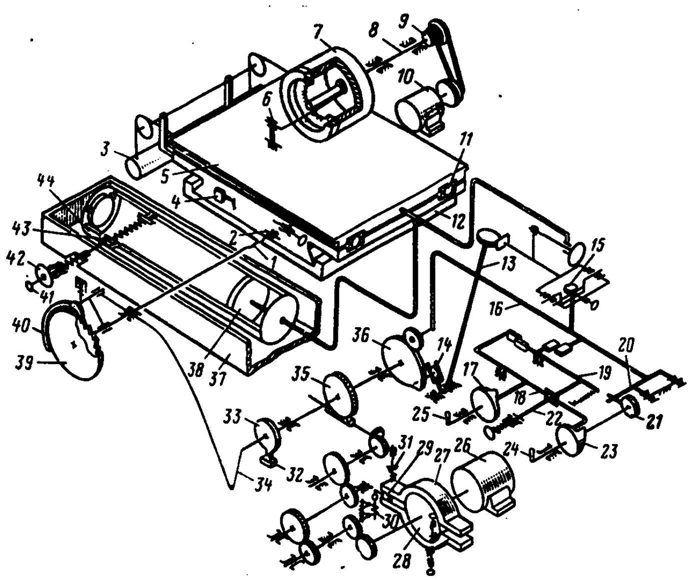


Figure 1-11. Mechanical Diagram of Diamond-Type Cutting Machine

Machine tools designed according to the second type (cf. fig 1-9, b) are distinguished by a vertically positioned spindle. This position makes it possible to increase the length of the ingot and to remove wafers automatically through the center of the spindle. However, increasing the diameter of the spindle and accordingly the size of the shaft bearings results in rapid wear. One machine of this type is the model ASM10A from the Okamoto firm (Japan). This machine makes it possible to cut silicon ingots up to 99 mm in diameter and 350 mm long. The rotational velocity of the spindle is 5000 r.p.m. The longitudinal feed range is 0.2 to 2.5 mm. The thickness tolerance of wafers which can be cut off is ± 0.005 mm for a diameter of 50 mm. The nonflatness and nonparallelism of wafers is not greater than 0.005 mm.

The main disadvantage of machines of the first two types is the wear of the table guides, which results in time in a loss in initial accuracy. In order to eliminate this, in machines of the 4,OX24 and "Almaz-6M" types the transverse feed is accomplished by rocking the entire cutting head, installed on bearings, whose wear is insignificant even after 10 years of use. A structural diagram of machines of this type is shown in fig 1-12.

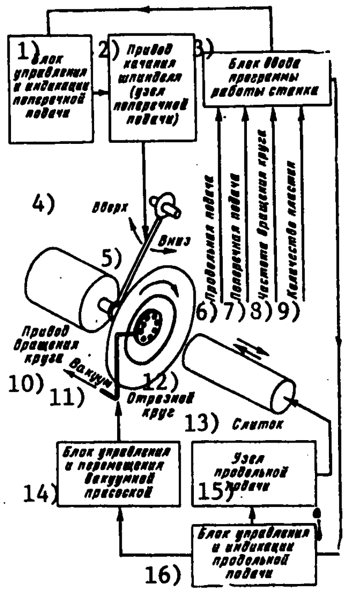


Figure 1-12. Block Diagram of Machine Tool for High-Precision Cutting of an Ingot into Wafers

Key:

1. Block for controlling and indicating transverse speed
2. Drive for rocking spindle (transverse feed element)
3. Block for inputing machine tool's operating program
4. Up
5. Down
6. Longitudinal feed
7. Transverse feed
8. Rotational velocity of wheel
9. Number of wafers
10. Drive for turning wheel
11. Vacuum
12. Cutting wheel
13. Ingot
14. Block for controlling and moving vacuum sucker
15. Longitudinal feed unit
16. Longitudinal feed control and indicating unit

The drive and drum with the tightened cutting wheel are fastened to a rotating arm and are rolled in roller bearings installed on an axle with preloading, i.e., with zero clearance. The spindle unit is rocked by means of a hydraulic drive to accomplish transverse feed. The transverse feed rate is set by means of the indicator of the unit for inputing the machine tool's operating program. Longitudinal feed of the ingot by a step is accomplished by means of a precision drive screw and a stepping motor. Control is accomplished by means of the longitudinal feed control and indicating unit. The longitudinal feed is set and monitored with a direct indicator. In inputing the operating program, in addition to the longitudinal and transverse feed the rotational velocity of the cutting wheel and the number of wafers to be cut off are set. The machine is outfitted with special rings for fastening the cutting wheel and for tightening it by means of a special hydraulic system. The wheel is stretched by means of oil pumped into a special annular space. Uniformity of tensile stresses and high-quality tightening of the wheel's fabric are thereby made possible.

All these design features of the machine make it possible to obtain high accuracy with high reproducibility. Maximum deviation in the thickness of cut-off wafers on the 4,0X24 machine is ± 0.007 mm. The machine makes it possible to cut wafers up to 101.6 mm in diameter and up to 609.6 mm long. The use of long ingots eliminates the operations of cutting an ingot into billets and of orienting the faces of ingots and reduces losses of expensive semiconductor materials on account of kerfs and on account of the reduction of waste when adjusting the machine for a cut. The rotational velocity of the cutting wheel can be set from 2000 to 5000 r.p.m. The machine is furnished with an automatic attachment for removing cut-off wafers and placing them in a special container with water. The attachment includes a vacuum sucker and a unit for controlling and moving the vacuum sucker mechanically connected to the longitudinal feed control and indicating unit. When the ingot is fed by a step the vacuum sucker moves close to the face of the ingot and is pulled toward the ingot. After the cutting-off operation the sucker with the cut-off wafer and ingot is removed from the cutting wheel by a distance of a feed step. The vacuum is shut off and the flexible elements of the sucker remove the wafer to bar guides from which the wafer drops onto a conveyer which carries it to the end of the machine and removes the wafer to a container with water. The automatic removal of wafers and automatic stopping of the machine when a specific number of wafers has been cut off make it possible for a single worker to attend simultaneously to five or more machines.

1-3. Equipment for Grinding and Polishing Semiconductor Materials

Modern grinding machines are divided into two basic types according to the type of tool used: machines for grinding with a free abrasive--an abrasive suspension--and machines for grinding with a bonded abrasive--abrasive wheels.

Machines for grinding with a free abrasive are in turn divided into two types: for one-side and two-side machining. For one-side machining wafers are cemented to heads in the form of metal disks with a ground working surface and are machined first on one side and then after recementing, on the other. With two-side machining both sides of the wafer are ground and polished at the same time.

With respect to the method of fastening wafers, the distinction is made between machines employing cementing, vacuum fastening and free laying in special flat separator holders [12].

In machines for one-side grinding, e.g., the V1M3 type (fig 1-13), rotary motion is transmitted from a motor, 1, through a worm reducer, 8, to a grinder, 2, with working heads, 4, installed on it. The heads, supported by roller bearings, 3, rotate on their own axes, at the same time making possible conditions for even grinding of wafers. A mixer, 6, with a motor, 7, serves the purpose of mixing the abrasive suspension in it, which is supplied to the grinder by means of a dropper, 5, at a rate of 60 to 80 drops per minute. Three heads are usually installed on the grinder. The grinder is made of cast iron or of glass--materials which are easily ground--and the heads of steel or Duralumin.

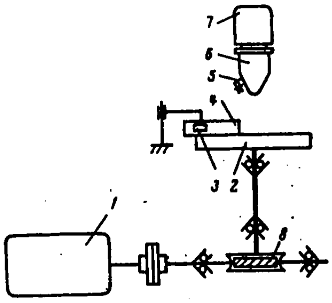


Figure 1-13. Mechanical Diagram of Machine for One-Side Grinding

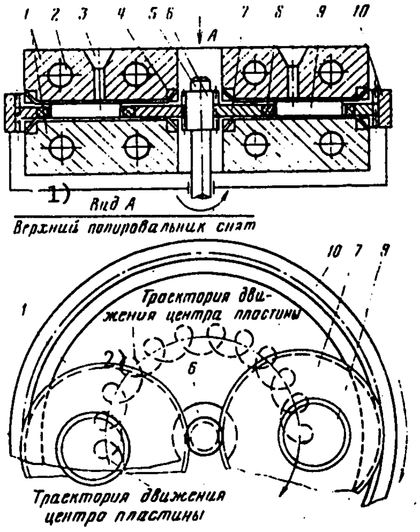
A machine for one-side grinding can at the same time serve the purpose of polishing wafers. For this purpose by means of a surrounding rim a soft fabric, usually artificial suede, is attached to the grinder, or artificial leather is cemented on. A mixture of diamond paste with a grain size of ASM 3/2, ASM 2/1 or ASM 1/0 with ethyl alcohol and transformer oil is used as the abrasive suspension.

When using chemically active suspensions consisting of micropowders of zirconium or silicon oxide, water and an alkali, chemical-mechanical finishing polishing is performed. In machines created specially for chemical-mechanical polishing, e.g., the SKhMP-1 and Yul MZ.105.004 models (fig 1-14), holders with the wafers are clamped to the polisher by means of special clamps, by means of which elevated pressure is applied to them. The pressure is created by a pneumatic cylinder and is transmitted through a rod--an intermediate mechanical spindle--fastened to bearing supports. There are no roller bearings in these machines. The model SKhMP-1, Yul MZ.105.004 and Speed FAM32 machines have tables with a larger diameter--680, 860 and 800 mm, respectively. These machines make it possible to machine wafers up to 100 mm in diameter. Four holders are installed on these machines and a great number of wafers are polished simultaneously: on the SKhMP-1, 20 wafers and on the Yul MZ.105.004 and Speed FAM32, 28 wafers 75 mm in diameter.

Machines for one-side machining make it possible to produce wafers having one surface of very high quality. However, the cementing and recementing of wafers severely worsens their geometry and precision characteristics.

The IO 19006, AL-2F, SDSh-100 and SDP-100 machines for two-side machining are used to produce wafers with a precise geometry. The main design feature of these machines is a planetary train which makes possible planetary movement of wafers between two grinders (fig 1-15), which also makes possible high plane-parallelism and planeness of machined wafers. The wafers to be machined, 9, are laid in the openings of toothed separators, 7, which engage with a center gear, 6, and a peripheral gear wheel, 10. Gear 6 is fastened to shaft 5. Gear wheel 10 and gear 6 are turned by a single drive in the same direction, but with different angular velocities. On account of this the separators move over the grinder and at the same time rotate on their own axles. Wafers are installed with the upper grinder raised. The abrasive suspension is fed to the grinding zone via openings, 3, in the top grinder, 1.

Figure 1-14. Machine for Chemical-Mechanical Polishing of Wafers



Key:
1. View A, top grinder removed
2. Mechanical trajectory of center of wafer

Figure 1-15. Diagram of Machine for Simultaneous Two-Side Grinding and Polishing of Wafers

In machines of the IO 19006 type the top and bottom grinders do not turn. In SDP-100 machines rotation of only the bottom grinder is provided for the purpose of reducing the wear of the separator's teeth and its deformation. Special spacers, 2, through which water circulates are provided in the body for the purpose of cooling the grinders. Machines for simultaneous two-side grinding are also used for polishing wafers. For this purpose recesses are made in the grinding wheels and by means of outside and inside steel rings, 4, suede is stretched over them. There are holes in the suede and in the top grinder for the purpose of feeding the abrasive suspension to the polishing zone. Protective fabric-based-laminate rings, 8, are used at the edges of wafers for the purpose of eliminating splitting. The clearance between the protective ring and the separator is 0.4 to 0.8 mm and between the ring and wafer 0.4 to 1.5 mm.

Machines for grinding by means of a bonded abrasive are divided in terms of grinding method into machines which operate by the surface (face) grinding method (fig 1-16, a) and by the infeed grinding method (fig 1-16, b). SASh-420M, SASh-100 and SASh-150 model machines operate according to the infeed grinding method. SPSh-1, MSh-259, SPShP-1 and MPS-R600 model machines operate according to the surface (face) grinding method.

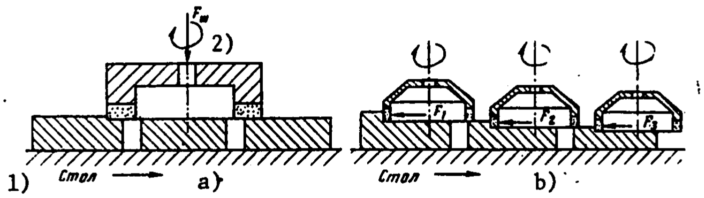


Figure 1-16. Diagrams of Surface (Face) (a) and Infeed (b) Grinding

Key:

1. Table	2. Grinding Force

Machines of the SASh-3 and SASh-420M type (fig 1-17) are designed for grinding wafers up to 60 mm in diameter and the SASh-150 to 150 mm in diameter. All these machine models are basically organized according to the same principle: three spindles with a rotational velocity of 9000 to 14,000 r.p.m. and a table with vacuum suckers rotating at a speed of 0.5 to 5 r.p.m. SASh-420M and SASh-150 machines have an intermediate mechanical spindle to whose shaft is fastened an abrasive disk of the AChK type. High-frequency generators power the electric spindles.

The bed is cast and massive and consists of two halves (an upper and lower) fastened to one another by means of a bolted connection. The spindle units and their drives, the oil film units, counterweights and other units are mounted on the top half and the turntable, turntable drive and power supplies on the bottom half.

The turntable is in the form of a flat thrust-type ball bearing with the balls arranged in three rows. The lower race is installed on four bearings whose height can be adjusted. The upper race is in the form of a base for installing replaceable housings with vacuum suckers. The working area of the turntable is covered with a removable cover made of acrylic plastic.

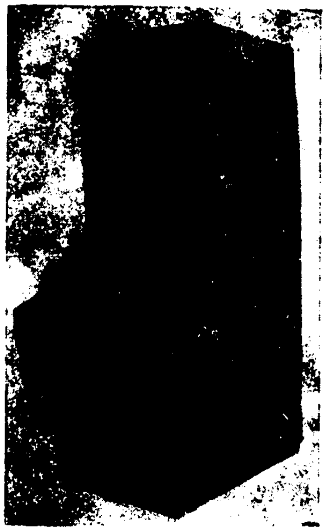


Figure 1-17. Type SASh-420M Diamond-Type Grinding Machine

The spindle is in the form of a cylinder on whose outside surface a trapezoidal thread has been cut. The spindle's shaft is installed on high-precision radial thrust bearings. In the lower half of the spindle there is a device for supply cooling fluid to the grinding zone through the inside space of the diamond wheel. Each spindle is driven into rotary motion by high-frequency electric spindles connected coaxially with the mechanical spindles via a centrifugal-action flexible coupling.

The vertical feed mechanism for the spindles is in the form of a screw-and-nut pair. A worm wheel is fastened to the nut. The drive is accomplished via the worm manually from hand wheels or automatically from a motor by means of a V-belt transmission. The spindles are moved vertically along cylindrical ball guides. For the purpose of reducing axial stresses in the spindle vertical feed mechanism and for exercising the option of having all clearances in the non-working direction, the spindles are balanced by means of counterweights with an excess weight of 25 to 35 kg. The bearings of the mechanical spindles, electrical spindles and turntable are lubricated by means of an oil film produced in the oil film unit.

A vacuum unit consisting of two pumps of the VNZ type is used for creating a vacuum in the turntable's suckers. A trap in the form of a sealed container is provided for the removal of water.

The electrical spindle drive consists of a type 12 GIS-2 high-frequency generator and a P-42 motor installed on a single panel and connected by means of a V-belt transmission.

The machine's units are mechanically connected in the following manner (fig 1-18). Table 9 is driven into rotary motion by means of d.c. motor 1, by means of a V-belt transmission and worm gearing. The spindles, 3, receive rotary motion from the electric spindles, 6, via a centrifugal coupling. The spindle unit is balanced by means of a counterweight, 5. The spindles with the abrasive wheel, 2, are fed vertically by rotation of the hand wheel, 8, which is coupled via a worm gearing with the drive screw, 7. Automatic feed is accomplished by means of a motor, 4.

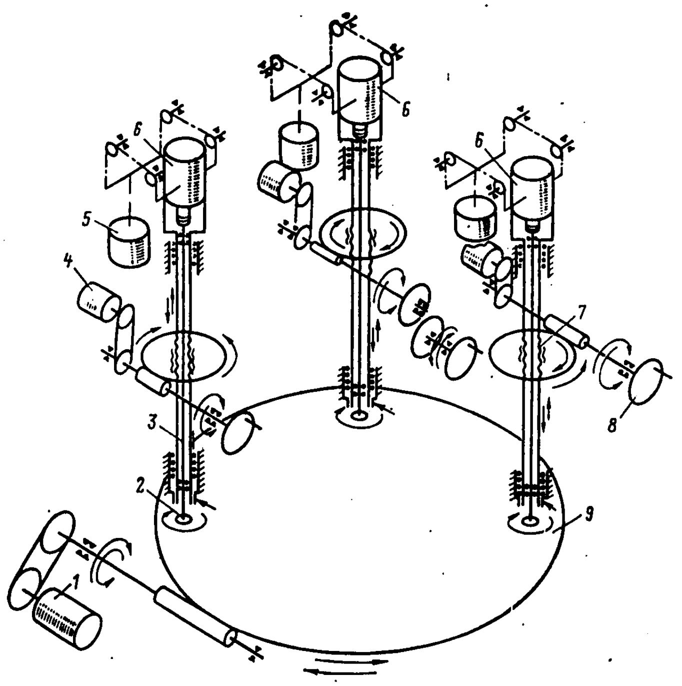


Figure 1-18. Mechanical Diagram of Type SASh-420M Diamond-Type Grinding Machine

Diamond wheels of the dish type (AChK) with grits of ASM 80/60, ASM 40/28, ASM 28/20 and ASM 14/10 are used for grinding on the SASh-420M machine. Using a fine-grit ASM 14/10 wheel guarantees the production of a surface finish of class 11 to 12.

The SPSh-1 type machine has two spindles independent of one another whose rotational velocity is 2400 r.p.m. The grinding platforms rotate at a rate of 350 r.p.m. Preliminary grinding is performed with one spindle--with an AS 12 diamond wheel for silicon or AS 5 for germanium--and finishing grinding on the other, with an ASM 40 for silicon or ASM 28 for germanium. The wafers are cemented to the platforms. The diamond wheel lies with its abrasive edge on the wafers. The wheel is lowered under the influence of the spindle's weight, F_{sh} (cf. fig 1-16, a).

Removable platforms (holders) for cementing wafers are provided for in machines of the SPSh-1, SPShP-1 and MSh-259 types. However, the use of a vacuum table is also possible in them. In one of the latest models from the Georg Müller firm (FRG), the MPS-R600, the table has vacuum suckers over its entire area, which makes it possible drastically to increase the loading of wafers and consequently the productivity of the grinding machine. With a table diameter of 600 mm, 36 wafers 75 mm in diameter or 92 wafers 50 mm in diameter are ground at the same time. The rotational velocity of the table is 0.8 to 20 r.p.m. The diameter of the grinding wheel is 300 mm. This machine makes it possible to produce wafers with deviation from planeness of 0.002 mm, deviation from plane-parallelism of 0.0025 mm and a wafer thickness deviation of 0.0025 mm.

Machines operating according to the infeed grinding method have become widely used for grinding off thick (up to 700 microns) polycrystalline layers in the production of integrated microcircuits with dielectric isolation. A layer of silicon 50 to 90 microns thick (cf. fig 1-16, b) is removed by three wheels of different grits during a single turn of the table. The entire allowance is ground off in 6 to 12 turns of the table, depending on the thickness of the wafer.

Chapter 2. Equipment for Chemical Processing of Wafers and Controlling Their Quality

Chemical processing equipment is designed for performing the production operations of etching, cleaning and washing wafers [13].

Etching equipment is used for performing the operations of etching ingots and wafers, which are done for the purpose of removing the defect layer originating in mechanical processing. Etching the defect layer on wafers makes it possible to eliminate the buckling of wafers (the Twyman effect), to reduce the allowance and to reduce rejects in the following operation of grinding.

Impurities are eliminated in the following sequence: mechanical particles--by cleaning in an ultrasonic bath and by means of various brushes; organic compounds--by treatment in boiling solvents of the trichloroethylene, acetone and benzine type; salts and metals--by boiling in redox solutions with the conversion of insoluble substances into easily soluble ones which are removed with the solution. At intermediate stages in the fabrication of wafers their surface is cleaned partially, pursuing one of the following goals:

The removal of impurities which can influence the accuracy of testing the wafer.
The removal of mechanical particles which are larger than the abrasive used in the following operation.

Preparation of the surface of wafers for the possibility of performing operations sensitive to impurities, such as chemical etching and chemical-mechanical polishing.

Cleaning to the full extent is performed only after the final mechanical operation. The purpose of this cleaning, called finishing, is to reduce the level of impurities on the surface of wafers to the level of impurities in the original single crystal. Usually the concentration of impurities in original single crystals of germanium and silicon is not greater than 0.0001 percent. This requirement is the most important for the entire complex of technological equipment.

2-1. Equipment for Etching Ingots and Wafers

For the purpose of etching silicon and germanium wafers, a number of pieces of equipment are used, the basic elements of which are the etching bath, the rinsing bath, a wafer drying unit, a table and a pressurized chamber with an air hole. Wafers are placed in special containers made of fluoroplastic.

A typical unit for chemical etching of wafers (fig 2-1) consists of three main parts: a chemical cabinet, 1, a pressurized chamber, 6, and a table, 3. On the rear wall of the cabinet there is an exhaust nozzle for the purpose of drawing off the etchant's vapors and in the top left half of the table, the etching vat, 5. During etching and preliminary rinsing of wafers the vat is hermetically sealed with a fluoroplastic lid. The etchant is forced by compressed nitrogen from the cooling vat, 2, into a measuring tank and from there enters the vat through a hand cock, 7. Nitrogen is fed by means of mechanism 12 when the pedal is pressed. Containers with wafers are rotated by means of drive 4. After etching, deionized water is supplied to the vat. Secondary rinsing in the deionized water takes place in a second vat, 8. This vat is supplied with a cover and an electric heater. The finishing washing of wafers takes place in vat 9, made of acrylic plastic.

The deionized water heater, 10, consists of a quartz tube inside of which have been placed three electric coils enclosed in quartz tubes. The heater is supplied with two float switches for checking the upper and lower water levels. The temperature of the water is regulated by means of a contact thermometer. On the outside the heater is covered with a jacket. In recent times the coil heaters have been replaced by more efficient quartz heaters with a current-conducting film. In these contamination of the deionized water by the coil is totally eliminated.

In table 3 there are two electromagnetic cocks, 13, and a mixing tank, 11. The electromagnetic cocks serve the purpose of draining the etchant from the vat into the mixing tank, 11, in which it is diluted with water before being discharged into a special waste-water disposal system. The front wall of the pressurized chamber is made of acrylic plastic and has two openings with rubber gloves fastened in them by means of rings. Locks for joining to other units are installed on the side walls of the pressurized chamber. Purified compressed nitrogen (fig 2-2) is supplied to both locks 1 and 9 through pipelines 23, 20 and 21 via cocks I and XII. Nitrogen enters 4-way pipe union 32 through pipe 22 and through pipes 30 and 34 enters below the unit's pressurized chamber, and through pipe 31 and cock VIII, into the blow-through lock, 6. Compressed air is fed through pipe 17. Passing through the pressure regulator, 13, it is divided into three branches:

through electromagnetic cock XIII into tank 15 for cooling the mixture; through an angle cock with a pedal control through pipe 18 into canister 12; and through pipe 40 with the same kind of cock into canister 16 with the etchant. Deionized water with resistivity of 2 to 3 MΩ•cm enters through pipe 24. From collector 11 the water is supplied to heater 8 through pipe 29 and electromagnetic cock IX, into vat 4 through pipe 33, cock VI and header 5, and into vat 3 through pipe 38, electromagnetic cock II and T-joint 44.

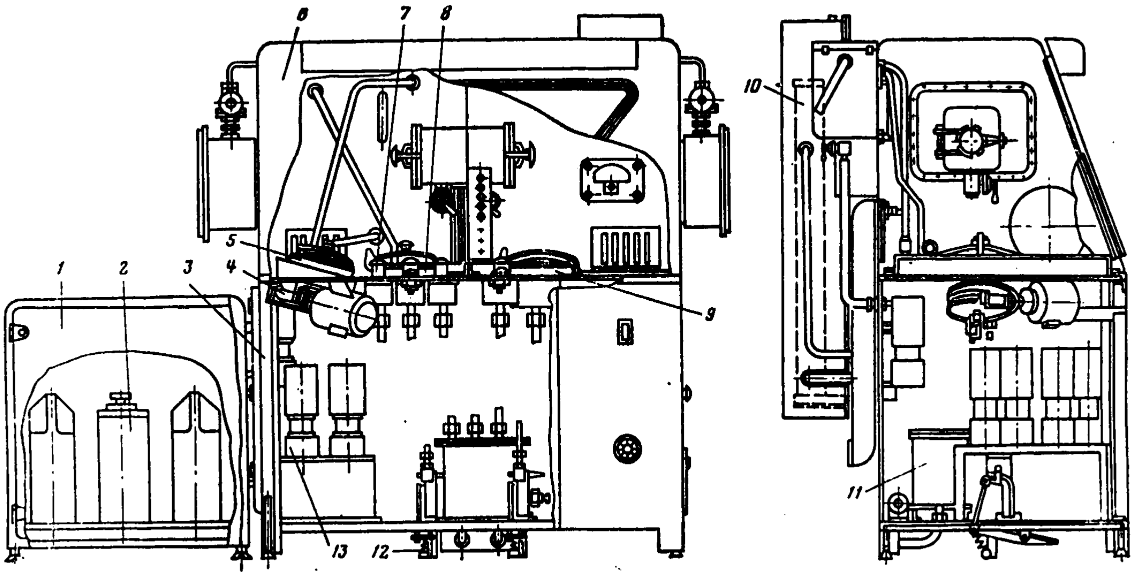


Figure 2-1. Unit for Chemical Etching of Wafers

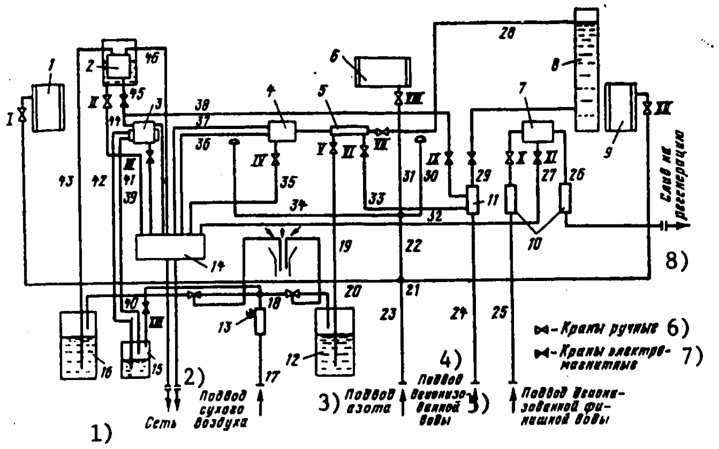


Figure 2-2. Technological Diagram of Unit for Etching Wafers

[Key on following page]

Key:

1. Power line
2. Dry air supply
3. Nitrogen supply
4. Deoinized water supply
5. Deionized finishing water supply
6. Manual cocks
7. Electromagnetic cocks
8. Drain for recycling

Deionized water with resistivity of 12 to 15 MΩ·cm is supplied to vat 7 for finishing washing of the wafers. When cock X is opened, water enters through pipe 25 with a water resistivity sensor, 10. From the vat the water enters for recycling through pipe 26, into which is built a second sensor.

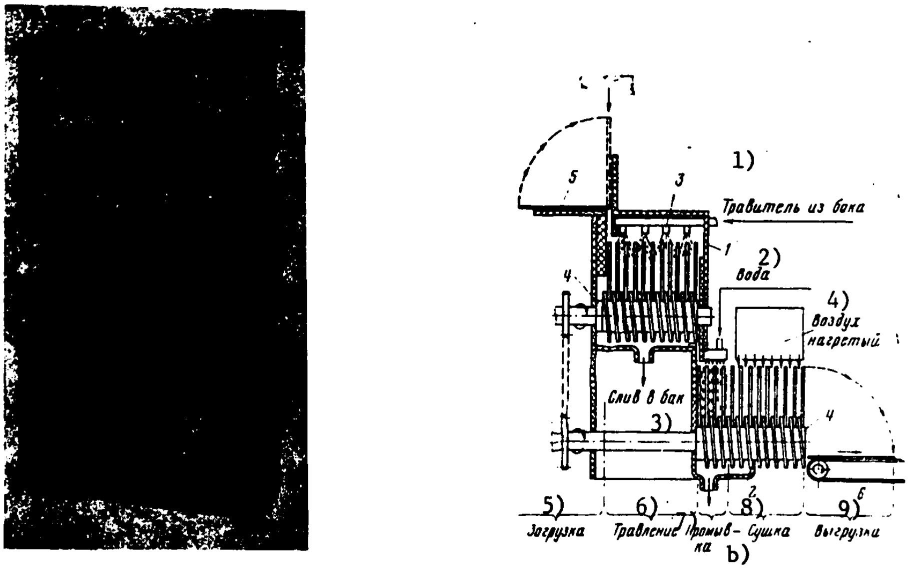
The prepared etchant is supplied from canister 16 through pipe 43 to measuring tank 2, connected by pipe 45 with electromagnetic cock III and by T-joint 44 with the etching vat, 3. Air and the excess etchant are removed from the measuring tank through pipe 46 to mixing tank 14. The etchant is drained from the etching vat into the mixing tank via electromagnetic cock III and pipe 39. The cooling mixture enters the jacket of the cooling vat, 3, through pipe 42 and leaves it through pipe 41.

Vat 4 is used for removing the protective coating (wax, chemical-resistant lacquer (KhSL), photoresist, etc.), applied to the untreated side of the wafer. A solution of hydrogen peroxide is supplied to the vat through pipe 19 via cock V and header 5 for the purpose of removing the protective coating. Hot deionized water is supplied from the heater through pipe 28 through cock VII and header 5. In washing the vat the water is drained through pipes 36 and 37 into the mixing tank. The solution of hydrogen peroxide is drained to the same place through pipe 35 via cock IV. The water is drained from vat 7 through electromagnetic cock XI and pipe 27 into mixing tank 14.

The wafers are loaded into a fluoroplastic container and are placed in the etching bath. The wafers are etched and prewashed automatically according to a predetermined program. After preliminary rinsing it is recommended that the wafers be held in an atmosphere of purified nitrogen for 2 to 3 min. An inner lock (cf. fig 2-1) is provided in the unit for this purpose. From this lock wafers are transferred to the finishing washing vat. The degree of washing of wafers is controlled automatically by the difference in resistivity of the deionized water in the vat's inlet and outlet. After finishing washing the wafers are transferred into a polystyrene transit container and are forwarded through a connecting lock for the next operation.

Wafers are loaded into the fluoroplastic container and are transferred to the transit container after etching both manually and automatically by means of special wafer loading and unloading units.

Instead of the usual etching and washing vats, in the automatic unit for dynamic chemical etching of wafers (fig 2-3, a) there are two chambers: an etching chamber, 1, and washing chamber, 2 (fig 2-3, b). Two fluoroplastic screws, 4, which turn in the same direction are installed in each chamber. The etchant is pumped by means of a pump into the etching chamber, 1, and is sprayed by means of jets, 3. The temperature of the initial etchant is held automatically in the range of +25 to +50 °C with an accuracy of ± 5 °C. The wafer, 5, is fed automatically by means of an unloading unit from the container into a tray and through a slot into the etching chamber. In the chamber wafers are moved along the threaded grooves of rotating screws 4 and at the same time rotate on their own axes, ensuring uniformity of etching over the wafer's area. From the etching chamber wafers enter the screws of the washing chamber where they are washed with deionized water and then they are dried by hot air and are removed by conveyer 6 to the unit for automatically loading them into containers. The etching process is performed completely automatically by the continuous-flow method. However, the etching method used in the automatic unit has an important disadvantage--it is practically impossible to control and maintain at a specific level and with the required accuracy the etching temperature over the entire area of the wafer and, consequently, it is difficult to control the etching reaction.



a)

b)

Figure 2-3. Automatic Unit for Dynamic Chemical Etching of Wafers: a--general view; b--schematic

Key:

1. Etchant from tank
2. Water
3. Drain into tank
4. Heated air
5. Loading
6. Etching
7. Washing
8. Drying
9. Unloading

In the etching unit (fig 2-4) the wafers, 1, are placed in fluoroplastic holders, 2, installed on the fluoroplastic gears, 6, of a screw rotator, 3, and are manually loaded into the vat, 5, with the etchant. The screw rotator, 3, is driven into rotary motion by means of shaft 4 around the vat's axis. The gears, 6, engage with gear wheel 7 and rotate the holders on their axes. The combined motion of the wafers—around their own axes and around the axes of the vat—is conducive to producing high-quality wafers. The screw rotator, 3, with the wafers is transferred manually from the etching bath to the washing vat, 8, with circulating deionized water.

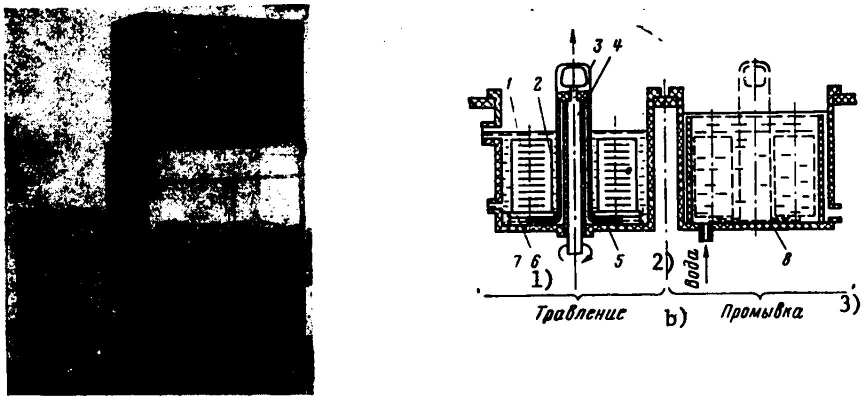


Figure 2-4. Etching Unit: a—general view; b—schematic

Key:

1. Etching
2. Water
3. Washing

Another variety of this etching variant is moving wafers in the etching vat with their simultaneous rotation around the axes of the vat and a multipocket holder which rolls over the inclined conical bottom of the vat. This motion ensures the most uniform etching of wafers.

Good quality of wafers is achieved when etching in a unit in which the etching vat rotates around its axis at an angle of 15 to 20 degrees. Wafers are adhered to fluoroplastic disks by means of wax or chemical-resistant lacquer and are placed on the bottom of the vat, called the bell. When the bell turns the disk rolls along its wall and in addition rotates on its own axis, which makes possible the uniform and controllable etching of wafers. A laboratory-type unit is installed in a fume cabinet. Wafers are washed in a vat standing alongside it and drying takes place in a centrifuge or in a drying cabinet with predrying by means of filter paper.

In addition to chemical methods of etching, other methods have become used ever more often, such as the electrochemical, thermal, ion and electron bombardment and plasma chemical methods [12, 28]. In these cases specific equipment is employed which, as a rule, is designed for carrying out the processes of cleaning the surface prior to oxidation and diffusion. Therefore, it is discussed in the appropriate chapters.

2-2. Equipment for Cleaning and Drying Wafers

Specific methods and the appropriate equipment are used for cleaning wafers, depending on the type of contamination of the surface of wafers.

After the diamond cutting of ingots, as well as after grinding by means of free micropowders, wafers are cleaned of sludge and abrasive particles in ultrasonic cleaning units in circulating deionized water. Wafers polished by means of diamond paste are cleaned of the paste and sludge in a unit for washing in a washing solution. After finishing chemical-mechanical polishing, wafers are cleaned successively in units for washing in detergents, in peroxide solutions and in a unit for the hydromechanical cleaning of wafers (a brush washer).

After each washing operation wafers are dried in a centrifuge which as a rule is a separate unit of the entire washing unit.

The basic elements of ultrasonic cleaning units are a dustproof cabinet, a vat for washing, a magnetostrictor and an oscillator. The magnetostrictor converts oscillations of electrical current of the appropriate frequency (20 kHz), which flows through the magnetostrictor's winding, into mechanical oscillations of the core. The oscillator serves the purpose of producing electrical current of the required frequency and power. The magnetostrictor's core is made of a permalloy or of nickel possessing the magnetostriction effect.

The operating principle of an ultrasonic cleaning unit consists in the creation of enormous local alternating-sign pressure on the surface of wafers as the result of the cavitation phenomenon, which consists in a discontinuity in a liquid on the surface of a solid and in the formation and then collapse of cavities. In the collapse of microcavities enormous local pressure pulses are created. The cyclicity of the effect of these pulses is determined by the frequency of the ultrasound. As a result of their repeated effect on the surface, solid particles found on it are separated and removed by the liquid medium from the surface of wafers. The water is made to circulate for the purpose of removing particles of contaminants from the vat.

Units for the mechanical cleaning of wafers are the most effective in removing solid particles and dust particles from the surface. A great number of types of units can be reduced to five basic systems (fig 2-5):

Cleaning rotating wafers by means of rotating brushes (fig 2-5, a).
Cleaning rotating wafers by means of a soft moving tape (fig 2-5, b).
Cleaning wafers laid on a rotating inclined table by means of a roller made of soft fur (fig 2-5, c).
Simultaneous 2-side cleaning of wafers by means of rollers made of soft fur (fig 2-5, d).

Cleaning wafers laid on a horizontal rotating table by means of a roller made of soft fur in combination with a strong jet of water (fig 2-5, e).

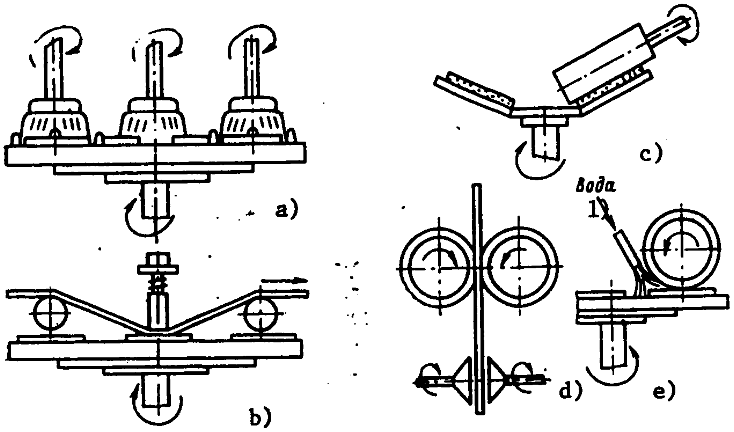


Figure 2-5. Schematic Diagrams of Units for Hydromechanical Cleaning of Wafers: a--brush; b--tape; c--roller on inclined table; d--simultaneous 2-side; e--roller on horizontal table

Key:

1. Water

Either rests or vacuum suckers are used to hold the wafers on the table. In the case of simultaneous 2-side cleaning the wafer is in a suspended state between two rollers. The wafer is fed to the cleaning position along guides.

Universal-type units for the chemical processing of wafers from the "Lada-1" complex are discussed below. This equipment is distinguished by the use of a uniform pressurized chamber, 1, with a block of filters, 2, making it possible to create a laminar flow of dustfree air from top to bottom, which makes it possible to perform all technological operations of cleaning and controlling wafers in a dustfree atmosphere (fig 2-6). In these units there are fluoroplastic vats, 3, (from one to three), for processing in corrosive media and one polypropylene cascade vat for washing in circulating deionized water. For example, in chemical processing units of the 0,8 ChKhN-100-001 and 0,8 ChKhN-100-005 type there are three fluoroplastic and one cascade vat each. The holders with the wafers are moved automatically by means of a moving mechanism in the first of these or manually in the second.

The fluoroplastic vat is furnished with a heater, 4. The maximum heating temperature is 120 °C and the accuracy of maintaining the temperature is ± 5 °C. These units are designed for washing wafers in peroxide-ammonia mixtures, in detergents and in various corrosive media.

The 08 ChUV-0008-002 ultrasonic washing unit is designed for washing wafers in an ultrasonic field, in corrosive media, e.g., in nitric acid, and for washing in deionized water. It contains an ultrasonic vat, one fluoroplastic vat with a heater and a single cascade vat.

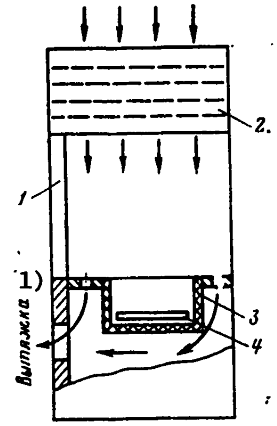


Figure 2-6. Diagram of Chemical Processing Unit

Key:
1. Exhaust

The 08 ChPVS-0/1500-004 wafer washing and drying unit consists of a box and a centrifuge with a turntable for placing holders with wafers on it. It is possible to load two or four holders simultaneously. Cleaning of wafers with deionized water prior to drying is provided for. The washing time of 50 to 240 s and drying time of 50 to 240 s, as well as the rotational velocity of the centrifuge of 200 to 1400 r.p.m., are set on a control panel. After termination of the required cycle the unit turns off automatically.

The 04ChShch-75/4-001 automatic hydromechanical washer consists of four tracks which operate independently of one another (fig 2-7). Each track has its own control unit.

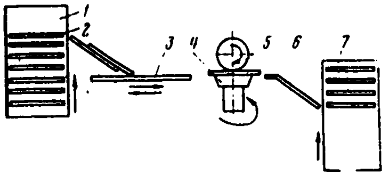


Figure 2-7. Diagram of Automatic Hydromechanical Washer

The holder, 1, with the wafers, 2, is placed on the platform of a loading mechanism. By means of a conveyer, 3, wafers are fed one by one to the platform of a centrifuge, 4, to which the wafer is fastened by means of a vacuum and undergoes the operations of cleaning, washing and drying. The surface of the wafer is cleaned by means of a rotating cylindrical brush, 5, with the simultaneous feeding of a washing solution or deionized water and with the wafer rotating on its own axis. Drying of the wafer is accomplished with a considerable increase in the rotational velocity of the wafer. The time for the performance of each operation--cleaning with the brush, first washing, second washing, drying--is set over one-second intervals over the range of 0 to 99 s. The washed and dried wafers enter a receiving container, 7, through inclined guides, 6.

The visual inspection unit consists of a dustproof box and an MMU-2 microscope.

In addition to the above, the "Lada-1" complex includes a number of units for serving the cleaning line, in particular, a unit for transporting and supplying reagents, a unit for heating deionized water, a water purification system, a water recycling unit, etc.

Units are put together in a cleaning line as a function of the specific purpose and technological process.

Still greater possibilities for putting together cleaning lines and sections are opened up with the modular design of units based on a dustproof box. The individual washing units are interchangeable and can be matched in one and the same pressurized chamber (box) in any combination. For example, if necessary, the first three boxes can be totally made up of ultrasonic cleaning units or can contain all types of units for carrying out the most complicated cleaning cycle.

2-3. Equipment for Controlling the Quality of Wafers

After finishing cleaning, wafers are checked for agreement with technical requirements or specifications. Some parameters--the diameter of wafers, the orientation of the surface with respect to the prescribed crystallographic plane, the absence of a defect layer, the length and orientation of the base cut--are guaranteed by the technological process. The remaining parameters are checked during a finishing check. Here the thickness of wafers, nonplaneness, nonparallelness, buckling, the degree of cleanliness of the surface, the roughness of surfaces, and the presence and length of marks, cracks, spots, bruises and chips are checked.

Thickness, nonplaneness, nonparallelness and the buckling of wafers are checked by means of clock-type indicators with a division value of 0.001 mm and S-III or S-IV equipment racks. More precise measurements of thickness are made with an IZV-2 optical measuring machine, which makes it possible to measure thickness with an accuracy of ± 0.0005 mm. For the purpose of obtaining reproducible results, indicators and measuring machines must be checked systematically against end gages or standard wafers.

In measuring thin wafers of large diameter this method results in considerable errors and in this case it is necessary to perform measurements on an MII-4 microscope. For this purpose a standard, e.g., a mask, is placed on the stage of the microscope and the microscope is adjusted for a sharp image of the lower surface of the mask. A note is made of the position of the stage's lifting screw. The mask is removed and the wafer being studied is put in its place. A sharp image is obtained of the surface of the wafer. The difference in the positions of the stage's vertical raising screw multiplied by the division value gives the amount of buckling of the wafer. In measuring buckling on the MII-4 microscope it is necessary to make sure that the direction in which the screw is turned when adjusting for the standard and studied surface is identical (from the bottom to the top). The accuracy of measurements of buckling is determined by the division value of the micrometer screw and can be brought to ± 0.0005 mm. More precise measurements of the geometrical parameters of a wafer are made on a laser interferometer of the UKP-2 type, from interference bands [11].

Instruments for non-contact testing of the geometric parameters of wafers have begun to be used ever more extensively in practice in recent times. These instruments make it possible to make measurements rapidly with high precision without scratching and contaminating the working surface of the wafer. Their operating principle is based on the change in the drop in pressure of air coming out of a nozzle or the change in the capacitance of an electrode-stage system when wafers of various thicknesses are introduced into it. For example, a capacitive pickup is used in the ADE Corp. (USA) model 6033 non-contact instrument for measuring thickness; the division value is 0.0001 mm and the measurement range is 0 to 1 mm. The instrument consists of a stage, a capacitive pickup and an electronics section with digital readout of the measured quantity. The operator places wafers down, moves them and removes them.

Units for automatically checking the geometrical parameters of wafers are being used ever more extensively, e.g., the UKTP-1, SPT-1, ST-100, etc.

The quality of cleanliness of the surface, marks, spots, bruises and chips are checked on units for the visual inspection of wafers. A typical visual inspection unit, e.g., the SA-710 and SA-720 models (fig 2-8), consists of the following main elements: cassettes, 1, an optical microscope, 2, a stage for the wafers, 3, a conveyer, 5, a manipulator, 4, and an electrical unit, 6. A straight-line system is used for feeding wafers for the loading, sorting and unloading of wafers. A high-speed belt feed mechanism conveys wafers from the loading position to the inspection stage and returns checked wafers to the appropriate classification cassette.

In model SA-710 and SA-720 units there is one cassette for good wafers and three cassettes for wafers which must be reprocessed. A counter is provided for each group of wafers. The capacity of a single cassette is 25 wafers up to 101.6 mm in diameter. The productivity of these units is 200 to 300 wafers per hour.

In all units visual inspection is performed by an operator by means of an optical microscope. MBS-1, MBS-2, MBI-11, MMU-3, MII-4 and MIM-7 microscopes are used in domestic units. Foreign firms use the EPY model microscope from the Zeiss and Nikon firms.

A so-called air cushion (cf. ch 5) is often used as a conveyer. Wafers are directed to a cassette by means of an air jet without touching the conveyer, which eliminates scratching them and contaminating the material of the conveyer. For example, in the model 5500 unit when the operator presses a foot pedal wafers are moved on an air cushion from the cassette being inspected to a stage with a vacuum sucker. The movement of a wafer for the purpose of inspecting its surface is accomplished by the operator by means of a manipulator. There is an automatic mode for moving a wafer at two speeds. Upon an instruction from a foot switch, wafers are returned to a cassette and rejected wafers are moved on the air cushion to the holding position and are transferred by the operator into the appropriate individual cassette.

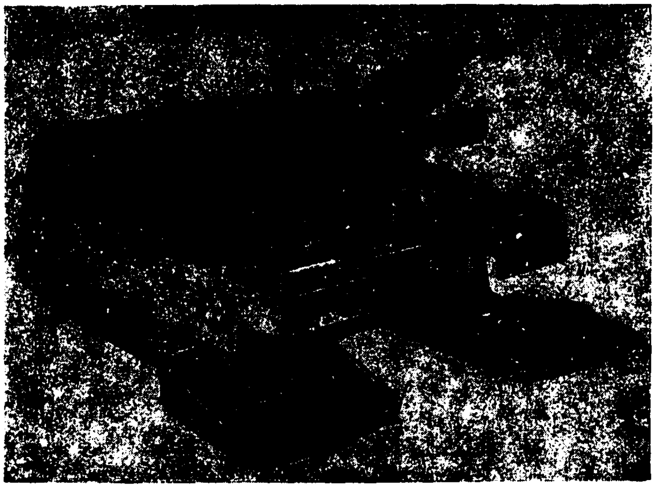


Figure 2-8. Unit for Visual Inspection of Wafers

Projectors, which considerably reduce operator fatigue, are often used in inspection units instead of an optical microscope. For controlling the quality of the cleanliness of wafers a projector is used for the purpose of measuring the wetting angle. A wafer is put into a chamber. A drop of liquid is applied to the wafer by means of a dispenser and this is then projected onto a screen. The wetting angle is measured by means of a scale graduated in degrees. The productivity of a unit of this type is not greater than 60 wafers per hour.

The amount of microcontaminants on the surface of a wafer can be estimated with an instrument of the ICh-2 type. This instrument consists of an X-Y stage, a ball-type sensor, a weight and a traction element. The instrument's operation is based on the dependence of the coefficient of static friction between two surfaces on the amount of contaminants. A polished steel ball has point contact with the surface being studied. The traction element links the ball with the core of an electromagnet by means of which the force of friction is estimated. The amount of contaminants on the surface is estimated from the instrument's readings and from a calibration curve. The instrument functions in the contamination range of 10^{-6} to 10^{-9} g/cm.

Some surface defects (buckling, nonplaneness, cracks, holes, etc.) are checked by means of laser interferometers--UKP-1 and UKP-2 units for inspecting polished wafers. The quality of the surface is judged from an interference pattern consisting of black and white lines and bands. However, the productivity of this kind of inspection is not high--from 60 to 100 wafers per hour.

Chapter 3. Equipment for Creating p-n Junctions

3-1. General Information on the Planar Process

The planar process is the basis of the fabrication of semiconductor structures. The planar process's principle is that all processes of the creation of semiconductor devices are carried out on one plane of semiconductor substrates, including ohmic contacts and protective coatings. The development of photolithography and diffusion technology and equipment, as well as the discovery of the masking and passivation properties of silicon dioxide, led to the invention of the planar process.

The technological sequence of operations for creating structures of devices is given in fig 3-1 and the process for producing transistors in fig 3-2 [5]. As is obvious from these figures, the entire technological process of the creation of transistors can be arbitarily divided into two groups of operations:

Operations by means of which doped layers are created by the deposition of epitaxial films and by the diffusion of impurities, masking and passivating coatings by oxidation or deposition from the vapor phase, and ohmic contacts by the deposition of metallic films.

Operations by means of which high purity of the surface of semiconductor wafers to be processed by chemical and plasma chemical methods is made possible and a pattern is created in an oxide film and metallic films by means of photolithography.

The subject of discussion of this chapter is the first group of operations (the second is described in chs 2 and 5). It must be mentioned that the technology for the fabrication of integrated microcircuits and large-scale integrated microcircuits is of course more complicated than that of transistors and requires additional operations to prevent stray coupling of their elements and to make possible the prescribed (necessary) electrical connections. For these purposes regions electrically insulated from the bulk of the chip, in which active elements are produced, are created in a chip. The two most widely used methods of creating the isolation of circuit elements are presented in fig 3-3. They are the method of isolation by means of p-n junctions and the method of dielectric isolation. The first method is simpler in terms of technology and it is less expensive. The second makes possible greater reliability and longevity, as well as enhanced radiation resistance.

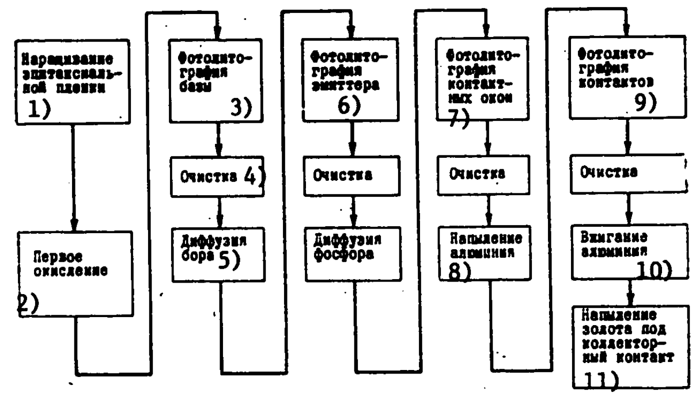


Figure 3-1. Typical Technological Process for Fabricating a Transistor Structure of the n-p-n Type

Key:

1. Growing epitaxial film
2. Primary oxidation
3. Photolithography of base
4. Cleaning
5. Diffusion of boron
6. Photolithography of emitter
7. Photolithography of contact windows
8. Spraying of aluminum
9. Photolithography of contacts
10. Brazing of aluminum
11. Spraying gold beneath collector contact

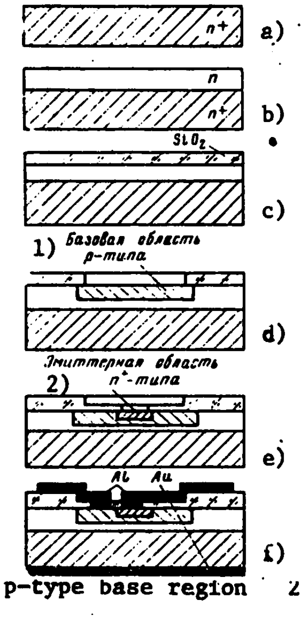


Figure 3-2. Technological Process for Fabrication of n-p-n Planar Transistor: a--starting wafer of n^+-type silicon; b--deposition of n-type epitaxial film; c--first thermal oxidation; d--photolithography of base and creation of base by diffusion of boron; e--photolithography of emitter by diffusion of phosphorus; f--photolithography beneath contacts and deposition of metals

Key: 1. p-type base region 2. n^+-type emitter region

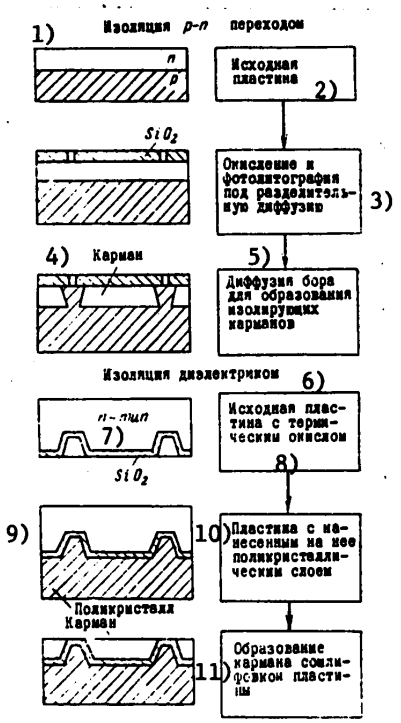


Figure 3-3. Two Methods of Isolating Active Elements of Integrated Microcircuits

Key:
1. Isolation by means of p-n junction
2. Original wafer
3. Oxidation and photolithography under separation diffusion
4. Pocket
5. Diffusion of boron for forming isolating pockets
6. Isolation by dielectric
7. n-type
8. Starting wafer with thermal oxide
9. Polycrystal
10. Wafer with polycrystalline film applied to it
11. Formation of pocket by grinding wafer off

The more complicated technology of fabricating integrated microcircuits (IM's) and large-scale integrated microcircuits (BIM's) includes the following technological operations: thermal oxidation of silicon wafers; diffusion of impurities for the purpose of creating doped films, including p-n junctions (in addition to diffusion, ion-implanted doping is also employed); epitaxial growing, as well as the deposition of polycrystalline silicon in creating electrically isolated regions by the dielectric isolation method; application of metalization, including multilayer and multilevel; low-temperature deposition of dielectric films from the vapor phase for the purpose of isolation in multilevel metalization and for protecting finished structures from the influence of the environment.

The planar process for the fabrication of semiconductor devices and IM's has been discussed by using as an example the process employing silicon wafers, since silicon both now and in the future will retain its dominant position in the electronics industry.

Thus, in order to create in silicon wafers active structures for discrete devices, IM's and BIM's, the following equipment is required: diffusion furnaces, ion-implanted doping apparatus, apparatus for epitaxial growing and apparatus for applying metallic and dielectric coatings.

1

3-2. Diffusion Equipment

In the production of semiconductors and integrated microcircuits a wafer is subjected to a number of high-temperature processes, including: oxidation--for forming on the surface of the substrate a film (silicon dioxide), which is used for the passivation of p-n structures, for masking the surface of the semiconductor from the diffusion of impurities, and as a gate oxide for MOS [metal-oxide semiconductor] devices and integrated microcircuits based on them; and diffusion--for creating doped layers in semiconductor substrates in forming active p-n junctions, isolation between elements, separating regions, etc.

Diffusion of Impurities

Diffusion is the process, caused by thermal motion, of the transfer of atoms in any material regardless of its state of aggregation. If atoms are distributed nonuniformly in the substance, i.e., a concentration gradient exists, then the directional flow of atoms takes place from a region with high concentration to a region with low concentration of the atoms of the material in question. Directional flow originates similarly to this also in the case of the origin of a temperature gradient in the material. In this case atoms diffuse from a region with a higher temperature (with higher energy) into a region with a lower temperature.

Processes of diffusion with a concentration gradient with constant temperature of the substrate are usually used in the production of semiconductor devices.

Let us discuss one important diffusion parameter which in fact determines equipment specifications. This is the diffusion coefficient:

$$D = D_0 e^{-\Delta E/kT}, \tag{3-1}$$

where $k = 8.63 \cdot 10^{-5}$ eV/deg is the Boltzmann constant, T is the absolute temperature, and D_0 and ΔE are fundamental diffusion parameters

(D_0 is a constant corresponding to the value of D with unlimited T and ΔE is the activation energy).*

Let us discuss the requirements for the stability of the maintenance of a specific temperature for diffusion furnaces. If we analyze equation (3-1), it can be observed that a change in temperature of a few degrees can result in a 2- and 3-fold increase in the diffusion coefficient, i.e., in the depth of occurrence of the doped layer. For example, the diffusion coefficient increases approximately 5-fold with every 100 °C increase in temperature from 900 °C.

In designing diffusion furnaces it is necessary to take into account the fact that the accuracy of maintaining the temperature in the furnace zone must be not worse than ± 0.5 °C with the condition of triviality of the time for transient temperature processes when putting wafers into the furnace as compared with the time for the diffusion process itself. In this case the variation in the depth of occurrence of impurities, e.g., of boron and phosphorus in silicon, will be in the range of one percent, which satisfies the technological requirements for producing p-n junctions for the complex class of microwave devices for transistors with a very thin base region (within the range of 0.1 μ), variation in which entails strong variation of the frequency properties of devices.

The need to maintain high temperatures is dictated also by the following facts. Of course, the solubility of an impurity in solids and, in particular, in semiconductors, is determined by the kind of impurity and the temperature of the process. The higher the temperature, the higher the solubility. In creating an emitter region for transistors it is necessary to take into account the fact that the concentration of the added impurity must be on the order of 10^{20} to 10^{21} cm^{-3}. This concentration can be achieved only with high temperatures (on the order of 1000 to 1300 °C). Thus, in designing diffusion furnaces it is necessary to 1) guarantee a temperature in the furnace over the range of 900 to 1300 °C, and 2) to guarantee accuracy in maintaining the temperature of not worse than ± 0.5 °C over the entire diffusion temperature range employed.

In carrying out the diffusion process, on the basis of requirements for high cleanliness in carrying out the process, quartz, alundum and polysilicon tubes are employed as the diffusion process chamber, having high melting points (higher than 1300 °C), a long operating life under high-temperature conditions, and high ("semiconductor") purity of their raw material.

Tubes made of quartz glass, which have high purity, low internal stresses, a small number of large bubbles, and also high transparency for ultraviolet and infrared radiation, are chiefly used for diffusion.

Tubes made of polycrystalline silicon are superior to quartz and alundum in purity of the material and permeability for alkali metals. Furthermore, the

---

*ΔE --the activation energy in diffusion--corresponds to ΔW --the height of the potential barrier which a particle must surmount in order to go from one position of equilibrium in the lattice to another, e.g., from one site or interstitial site, respectively, to another site or interstitial site.

lifetime of a tube made of polycrystalline silicon at a temperature of 1300 °C is almost 5-fold longer than for tubes made of quartz, since quartz crystallizes at this temperature and looses mechanical strength. The use of tubes made of polycrystalline silicon has been hampered by the complexity of the equipment for producing them.

Tubes with a round and, recently, a rectangular cross section are chiefly used as process chambers for diffusion processes. Tubes made of quartz glass are used chiefly. The size of the tubes' cross section depends on the diameter of the wafers being processed. In recent furnace models (e.g., of the SDO-125/V-15 type) tubes up to 150 mm in diameter can be used or tubes with a rectangular cross section with a diagonal of approximately the same size. The substrate holder (dish) and other elements of the loading unit located in the furnace's working space are also made chiefly of quartz glass.

Let us discuss the process of performing the diffusion operation in a furnace in which, consistent with the above, the tube and substrate holder are made of an especially pure heat-resistant material, e.g., of quartz glass, and the temperature in the diffusion zone is maintained with accuracy of ± 0.5 °C over the range of 900 to 1300 °C. Here it is necessary to take into account the following negative factors which must be avoided in designing diffusion furnaces:

Adding to a furnace a substrate holder with semiconductor wafers at room temperature introduces a disturbance of the static temperature conditions of the diffusion furnace, and a considerable time (10 to 15 min) is required for the purpose of establishing working conditions. During the transition period the accuracy of maintaining the temperature in the diffusion zone will vary, which will result in variation in the depth and distribution profile of impurities in the substrate. In addition, the rapid loading or unloading of wafers from the high-temperature zone results in the appearance in them of stresses and strains as the result of thermal shock.

Holding the substrate holder and silicon wafers at high temperatures for a prolonged period can result in bonding of substrates with one another and with the substrate holder. This is especially characteristic of tubes and substrate holders made of quartz.

The depth and distribution profile of impurities in the substrate vary with an unstable feed rate of the gaseous diffusant and its uneven distribution over the tube's cross section.

Shortening the duration of transient conditions in the furnace during loading is achieved by using a special temperature restoration unit which boosts the furnace's supply power during loading, or by using preheaters (a prechamber) in which wafers to be loaded are heated to a temperature 180 to 200 °C below the furnace's operating temperature.

Bonding of the substrate holder with the reactor tube can be prevented by a vibrating movement of the substrate holder, accomplished by means of an automatic loader.

Diffusion units have been created for diffusion processes which include, as a rule, 3- or 4-tube diffusion furnaces with dustfree cells with laminar flows, automatic loaders, gas cabinets, and also programmers for a minicomputer. If there are several of these complexes, then one more computer is used for controlling processes in all diffusion complexes, as well as a conveyer used for the purpose of making possible transport flows of containers with wafers to each furnace and from them to the site of the process flow control station. An automated 4-tube diffusion system is presented in fig 3-4, consisting of a 4-tube diffusion furnace of the SDO-125/4A type, 9; automatic loaders mounted on a single base, 7; a dustfree cell with laminar flow, 8; a cabinet for the automated control of the delivery of gas to the diffusion furnace, 1, which in turn consists of a computer interface, 2, a power supply, 3, a peripheral input console, 4, a programmer, 5, and a signaling unit, 6; and a cabinet for controlling the system with a programmer and computer interface, 10, consisting of a channel control unit, 11, a flowrate sensor unit, 12, and a temperature sensor unit, 13.

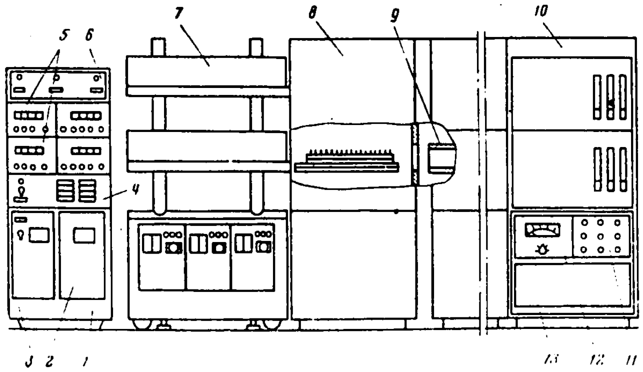


Figure 3-4. Automated Diffusion System

Let us discuss the components of diffusion equipment.

Diffusion Furnaces

Three- and 4-tube diffusion furnaces are used at the present time in the electronics industry. In order for the diffusion process to be reproducible, a temperature zone with nonuniformity in distribution of the temperature of ± 0.5 °C is required. The length of this zone determines the furnace's produtivity and usually equals 600 mm.

Single-zone furnaces with three (the SDO-125/3-12 and SDO-125/3-15) and four (the SDO-125/4A) thermal modules are used in the industry at the present time.

Structurally, a diffusion furnace has two parts: thermal heating chambers and a frame-type base with electrical units. The heating chambers are attached to the frame-type base.

Located in the frame-type base are the units for supplying electric power to the heating elements and for automatic control of the furnace's operating mode with unified temperature controls of the RYePID-1 or BPRT-1 type. The heating chamber includes a heater cartridge and a quartz reaction tube. The heater cartridge can be of two types: with a heating element covered with a thin layer of a ceramic coating based on pure alundum, and with a heating element without a coating. Two types of heater cartridges are shown in fig 3-5 [4]. A heat-resistant wire 5.5 mm in diameter wound into a coil is used as the heating element. When electric current passes through it it is heated to a temperature making it possible to produce in the reaction tube a maximum temperature on the order of 1350 °C. In order to control the temperature distribution profile over the entire zone, the heater is made of several sections, mainly of three. Contacts for connecting to individual electric power supplies are led outside from each section by means of wires made of the same heat-resistant material. The coil's winding pitch is determined by the installation of ceramic insulators, and their projecting ends serve as a support for a ceramic muffle tube.

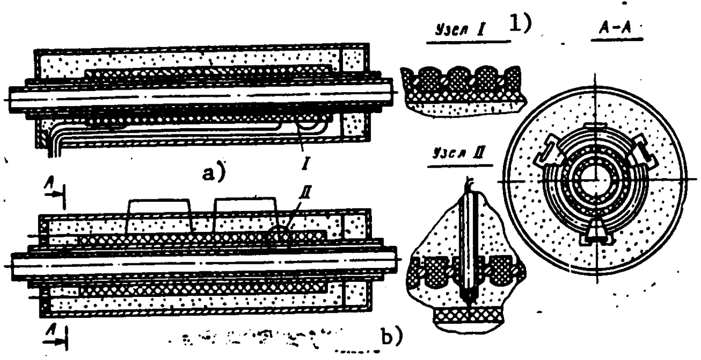


Figure 3-5. Design of Heater Cartridges: a--with ceramic covering based on alundum; b--without covering

Key:

1. Unit I

The center heating section makes it possible to produce uniform heating at the center of the zone, and the two end ones, equalization of temperature for the ends of the center section.

Control of the temperature in a diffusion furnace is accomplished by means of platinum - platinum-rhodium thermocouples and a temperature control unit of the RYePID-1 or BPRT-1 type connected to the power supply. Five thermocouples are used. The thermocouples are placed at the center of each section and at the ends of the center section. It is possible to become acquainted in greater detail with control of the temperature of diffusion furnaces in [4], for example.

In order to reduce the area occupied and the number of dustfree cells and of other systems, diffusion furnaces are arranged either side by side or end to end. In this case the dustfree cells with laminar flow are united into a single one in which automatic loaders are used. The gas systems are also united into a single unit.

Automatic Loaders

With an increase in the diameter of wafers being produced there was an increase in rejects of wafers in diffusion operations, caused by the origin of high internal stresses when loading and unloading wafers from high-temperature furnaces. For the purpose of eliminating these rejects, as well as rejects associated with bonding of the quartz substrate holder directly to the quartz tube of the furnace, automatic loaders are used (fig 3-6) with a reversing mechanism making it possible to add wafers to the furnace and remove them smoothly.

Figure 3-6. General View of Automatic Loader

Automatic loaders perform the following functions:

Putting wafers into a diffusion furnace at a certain speed which can be adjusted by degrees, e.g., 100 to 200 mm per min.

Rocking the substrate holder (dish) in the high-temperature zone (roughly 2.5 mm/ /min over a range of 20 mm).

Unloading wafers from the high-temperature zone at a certain speed (e.g., 25 to 100 mm/min).

In order not to introduce contaminants, the automatic loader's pusher rod is made of quartz of the same purity as the tube and dish. Thus, the use of automatic loaders drastically reduces rejects of wafers, especially of large diameter, eliminates error on the part of the operator and reduces the labor intensiveness of the diffusion operation. In addition, the reproducibility of the characteristics of doped layers from batch to batch of wafers is increased.

Dustfree Cells

Dustfree cells are installed at the inlet to diffusion furnace reactors for the purpose of ensuring cleanliness in transferring wafers from a container into substrate holders and in putting them into diffusion tubes (cf. ch 13).

Automated Gas Cabinets

The automated gas cabinet is designed for preparing, delivering, regulating and monitoring flows of vapor-gas mixtures in the diffusion and oxidation of semiconductor wafers.

As a rule two cabinets are provided in diffusion systems for delivering to the quartz tubes mixtures of vapors of the diffusant with argon and for supplying dried or moist oxygen.

Mechanical diagrams for diffusion (fig 3-7, a) and oxidation (fig 3-7, b) are presented in fig 3-7. There are three lines in the cabinet for the diffusion process: for supplying inert gas for blowing tubes through and for freeing them from the atmosphere's air; for supplying oxygen; and for delivering to the reactor a vapor-gas mixture of inert gas and diffusant. Electromagnetic valves for closing lines, rotameters for monitoring the gas flowrate, flow regulators, and stabilizers for a specific gas flowrate are used in the system. Liquid compounds, e.g., BBr_3, PCl_3 and $POCl_3$, or gaseous, B_2H_6 and PH_3, are used as a rule for the diffusion of boron and phosphorus into silicon. In individual cases methods of diffusion from a parallel source or from a deposited surface source--a film containing a diffusant--are used.

The principle of diffusion from a parallel source consists in the fact that the source of the diffusant and the silicon wafers are placed parallel to one another: The source is above horizontally lying wafers. A gas medium flow passes between them. Vapors of the impurity diffuse through the gas, strike the surface of the silicon and form there a surface diffusant source--a film of liquid glass, e.g., borosilicate, $B_2O_3 \cdot SiO_2$.

The surface source--a film containing the diffusant--can be formed by the high-temperature deposition of doped films of SiO_2 or by depositing films of a disperser of a similar composition by the method of centrifuging followed by vitrification.

The use of single-zone diffusion furnaces with a simplified gas system is required in all of the above-named methods.

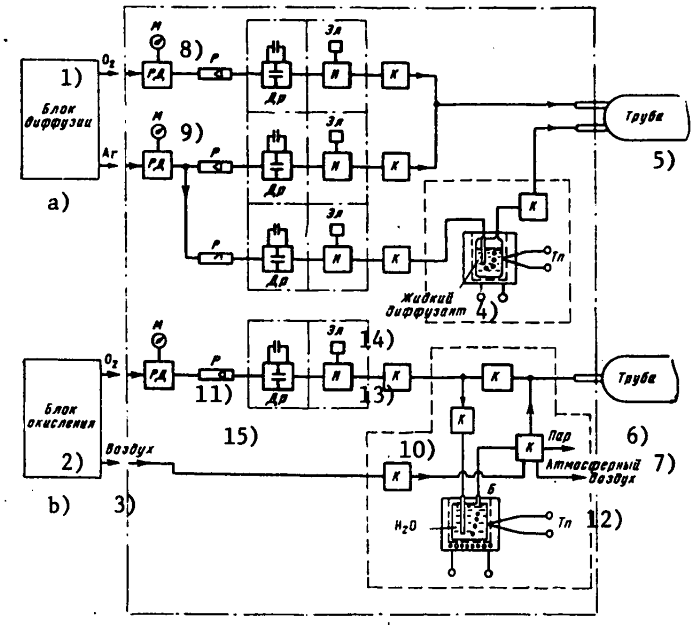


Figure 3-7. Diagram of Delivery of Gases and Diffusants to Diffusion Furnaces: a--for diffusion; b--for oxidation; RD--pressure regulator; M--manometer; K--electromagnetic valve; R--rotameter; Tp--thermocouple; N--flow regulator; SM, El--motor; Dr--choke

Key:

1.	Diffusion unit	9.	Manometer
2.	Oxidation unit	10.	Electromagnetic valve
3.	Air	11.	Rotameter
4.	Liquid diffusant	12.	Thermocouple
5.	Tube	13.	Flow regulator
6.	Vapor	14.	Motor
7.	Atmospheric air	15.	Choke
8.	Pressure regulator		

Plasma chemical methods of cleaning, which have replaced liquid chemical, are being used extensively in recent years. The equipment used for these purposes has small overall dimensions and increases the percentage of the yield of suitable structures. The operating procedure of a diffusion system with a plasma chemical cleaning unit (fig 3-8) is as follows: The holder with the wafers enters, from the automatic loader, the plasma cleaning module and through it enters the diffusion furnace. For the unimpeded travel of holders with wafers from the furnace to the automatic loader and vice-versa, swing-away sealing covers have been made at the ends of a module's quartz tubes.

It should also be mentioned that also promising for diffusion processes is the use of radiant infrared heating, which makes possible a short time for the furnace to warm up and a maximum degree of cleanliness in carrying out the process.

Figure 3-8. General View of "Plasma-modul' FT" Prediffusion Plasma Chemical Cleaning Module for 3-Tube Furnace

3-3. Equipment for Ion-Implanted Doping Processes

Ion implantation is the introduction of ionized atoms of an impurity into the surface layer of a substrate as the result of imparting to these atoms high kinetic energy (from keV to MeV). As the ion advances in the substrate it gradually loses energy on account of electronic and nuclear deceleration and ultimately stops in the substrate at the appropriate depth from the surface. The basic distinction between the ion-implanted doping method and thermal diffusion is in the method of imparting energy to impurity atoms: In thermal diffusion it is thermal, on account of the high temperature (on the order of 900 to 1300 °C), and in ion-implanted doping it is electrical on account of the ionization of vapors of the impurity substance and of their acceleration with the application of a high potential difference.

The advantages of ion-implanted doping over thermal diffusion consist in the following capabilities:

Doping solid substrates with atoms of any substance regardless of its maximum solubility.

Doping at any temperature right down to very low.

Creating in the substrate a concealed layer at some distance from the surface of the substrate.

Producing non-deep (on the order of 0.1 μ and less) doped layers, including multistage.

Producing a high degree of purity of an introduced impurity.

Doping a substrate through a protective layer.

Controlling with high precision the depth and distribution profile of impurities in a substrate by changing the energy and dose of introduced impurity ions.

Among the disadvantages can be numbered the complexity of the equipment and residual radiation defects in the substrate.

The following are necessary to accomplish ion-implanted doping:

Ionizing the impurity substance.

Imparting to the impurity ion the appropriate energy in order to introduce it at the prescribed depth in the substrate.

Separating impurity ions by mass from undesirable elements.

Directing ions to the surface of the substrate in order to introduce them.

As is obvious from this sequence of operations, ion-implanted doping apparatus must include the following main units: an ion source, an accelerating tube, a mass separator, and scanning and receiving equipment.

Ion-implanted doping units are classified by the method of acceleration (fig 3-9). If the acceleration of ions is accomplished before the mass separator, then these units are called units with preacceleration (A). If the unit is based on the acceleration of impurity ions after the mass separator, then this unit is a unit with postacceleration (B).

If low energy of ions is required (up to 50 keV), then an accelerating tube is not used in the unit and the acceleration of ions is accomplished on account of an extraction potential applied in the ion source (C). In these units the magnet and receiving unit are under ground potential, which ensures electrical safety for the work of operating personnel and work convenience.

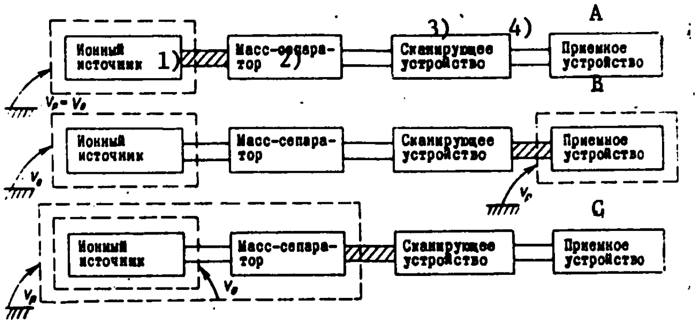


Figure 3-9. Classification of Ion-Implanted Doping Units by Method of Acceleration: U_0--ion extraction voltage; U_p--accelerating voltage

Key:

1. Ion source
2. Mass separator
3. Scanning unit
4. Receiving unit

Units of type A are used for low energies and any ion mass, but the weight and overall dimensions of the electromagnetic separator increase drastically with an increase in energy. In units of type B the magnet is under ground potential and they are thus electrically safe; therefore, it is possible to use large magnets for the mass separation of ions of heavy elements and, by using an accelerating tube before the receiver, to accelerate ions to high energies. The disadvantage of these units is that the receiver is under high potential.

Units of type C are used to produce beams of ions with low mass and high energy. Here the magnet and ion source are under high potential and the receiver under ground potential.

Ion Sources

An ion source is designed to ionize vapors of substances introduced into it and to extract ions of atoms (molecules) of this substance into an ion conductor or accelerating tube. It consists of the following elements: a discharge chamber connected by an opening with the ion conductor or accelerating tube, and a unit for extracting and focusing ions.

With the introduction into the chamber of a gaseous substance, a plasma forms in the discharge chamber. The ionization of vapors or a gas takes place by the collision of electrons with atoms (molecules) of the introduced substance. A discharge in the chamber is usually produced at low pressure of $(13 \text{ to } 1)\cdot 10^{-1}$ Pa, in order to make possible the required density of the plasma. The discharge chamber is usually placed in a magnetic field for the purpose of increasing the probability of the collision of an electron with atoms (molecules).

With respect to the method of creating the plasma, ion sources are divided into ion sources with a high-frequency discharge, with discharge from a heated cathode, and from a cold cathode.

A schematic diagram of a source with a high-frequency discharge is shown in fig 3-10. It is economical and simple in design. However, this type of source is characterized by a large spread in the energy of ions, its operation becomes unstable at high temperatures, it does not make it possible to produce currents of high density, and it also requires controlling a great number of parameters in the process of its operation. As a rule it is designed for operating with gases. The operating principle of a high-frequency source is as follows. A gas discharge is ignited in the chamber, forming a plasma on account of a high-frequency magnetic field with a frequency of 10 to 40 MHz created by coil 1. A potential difference on the order of 3 to 5 kV is applied between the anode in the upper half of the chamber, 3, and the extracting electrode (the cathode), 2. High-frequency ion sources make possible low current (hundreds of microamperes to single numbers of milliamperes), are designed for low power, and are simple in design.

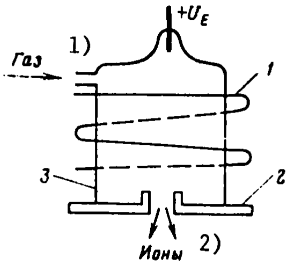


Figure 3-10. High-Frequency Ion Source

Key:
1. Gas
2. Ion

A Penning ion source in which discharge with a cold cathode is employed is presented in fig 3-11. In the discharge chamber of this source a self-maintained glow discharge is created, originating as the result of the applied potential difference (on the order of 5 to 7 kV) between a cold cathode, 4, and an orificed anode, 6, an of the application of a longitudinal magnetic field created by coil 1. The anode, anticathode, 3, and cathode are electrically isolated by means of insulators, 5. Aluminum, beryllium, uranium and other cathodes having a low sputtering coefficient are usually used in order to increase the service life of the cathode (reduce its sputtering).

The cathode is coated with an oxide film in order to increase ion-electron emission. The anticathode, 3, serves the purpose of forming a plasma front and the extracting electrode, 2, in addition to its main purpose, of focusing the beam.

Sometimes the transition of a Penning discharge into an arc discharge in the absence of a magnetic field is employed for the purpose of producing an arc discharge. With this it is possible to increase the extraction of ion current from the source.

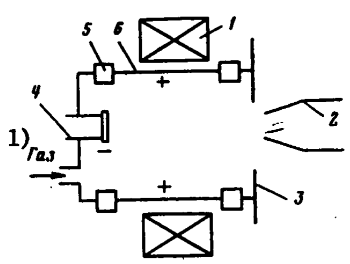


Figure 3-11. Structural Diagram of Penning Ion Source

Key:
  1. Gas

A Nielsen ion source is shown in fig 3-12. By means of this source it is possible to produce ions of substances from liquid and solid compounds, as well as from gases. It consists of a tungsten hot cathode, 4, an electromagnet, 1, an extracting electrode, 3, an anticathode, 2, and insulators, 8. A crucible, 6, with a heater, 7, making it possible to heat the crucible from 170 to 900 °C, is employed in order to vaporize liquid and solid sublimating materials. Cylinder 5 serves as the anode. By means of this ion source it is possible to produce strong beams of gaseous elements and chiefly of hard and high-melting elements including boron, carbon, aluminum, silicon, iron and the like.

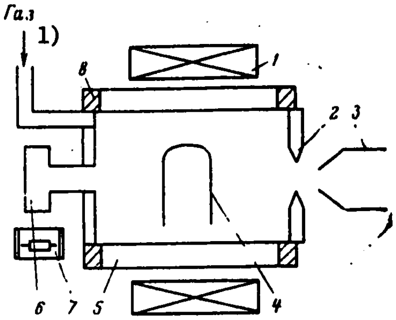


Figure 3-12. Nielsen Ion Source

Key:
  1. Gas

The schematic diagram of a Morozov slit-type ion source, by means of which it is possible to produce ion beams of the ribbon type with a circular cross section, is shown in fig 3-13, a. A thermionic cathode, 3, with a screen, 4, heated by a heater, 2, serves as the electron source. An applied magnetic field of

$H \sim 4 \cdot 10^5$ A/m promotes the formation of a beam of electrons moving toward the anode, 8.

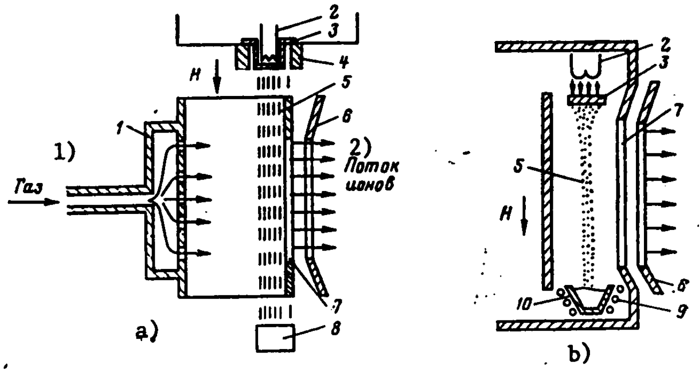


Figure 3-13. Morozov Ion Source: a--for gaseous substances; b--for solid substances

Key:
1. Gas
2. Ion beam

The plasma, 5, forms with the admission of gas through the gas distributor, 1. In the diagram in fig 3-13, b, a crucible, 10, with the substance, which must be vaporized into the discharge zone by means of heater 9, serves as the anode. The shape of the ion beam is determined by the shape of slit 7 and of the opening in the extracting electrode, 6. By means of this source it is practically possible to produce ions of any substance, including high-melting, as well as multiply charged ions.

One of the most widespread is an ion source of the duoplasmatron type with an arc discharge developed by Ardenne. Its fundamental difference from ion sources of other types consists in double contraction of the plasma (fig 3-14), i.e., concentration of the plasma in the required region of the discharge chamber by means of electric and magnetic fields, 6, of the appropriate configuration. The methods of forming the plasma are as in the preceding source.

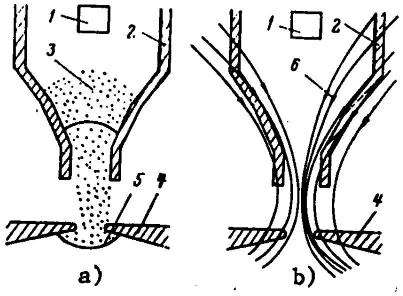


Figure 3-14. Diagram of Electric and Magnetic Contraction of Plasma in Duoplasmatron: a--electric contraction of plasma; b--magnetic

An additional anode, 2, of the appropriate shape, the potential across which differs from the potential across the main anode, 4, is introduced for the purpose of contracting the plasma by means of the electric field. As a result, an additional potential difference is created inside the channel and between the cathode, 1, and main anode, 4, an electric double layer, 3, is formed, which focuses and accelerates electrons into the region of the opening of the main anode. With this the ionization efficiency is increased, which results in an increase in the concentration of ions extracted through the anode opening and in the formation of a distinct plasma boundary, 5, in the outlet from anode 4. Electric contraction of the plasma is illustrated schematically in fig 3-14, a, and in fig 3-14, b, magnetic contraction of the plasma on account of a strong inhomogeneous magnetic field. Here the additional electrode, 2, and the main anode, 4, are the magnet's pole pieces. As a result, the concentration of electrons and therefore the ionization efficiency are increased. Inserts made of high-melting materials--molybdenum or tungsten--are fastened inside the electrodes for the purpose of increasing their heat resistance.

Accelerating Tube

The accelerating tube is designed for accelerating ions and depending on the type of unit it is placed before or after the mass separator. The additional focusing of the ion beam is also accomplished by means of it.

As indicated previously, accelerating tubes are not used in units in which low ion energies are required (on the order of 40 to 50 keV), since the acceleration of ions in them takes place on account of the use of an accelerating electrode at the outlet of the ion source. For the purpose of producing a uniform distribution of voltage along the length of the accelerating tube, it is usually made sectional by alternating electrodes, 1, with insulating rings, 2, and by employing a voltage divider, 3 (fig 3-15).

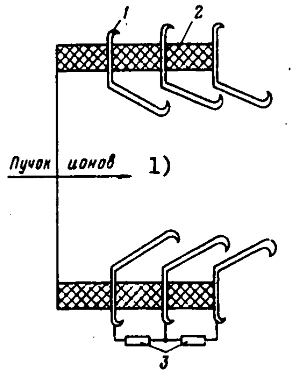


Figure 3-15. Multisection Accelerating Tube

Key:
1. Ion beam

As an insulator are used materials which have a high breakdown voltage and which do not release and do not transmit gases, since there must be a high vacuum inside the tube. Porcelain and special epoxy compounds are chiefly used for insulating rings. The metal electrodes, 1, are made in a shape which reduces the space charge formed in the dielectric insulating ring, 2, and which changes the mechanical trajectory of ions.

Mass Separator

In order to facilitate the creation and control of ion beams it is best to introduce the doping impurity in the gaseous state into the source. But it is difficult to obtain in the gaseous state such substances as phosphorus, boron, arsenic, etc., used for creating doped layers in silicon; therefore, gaseous compounds of these substances are used, such as diborane, phosphine, arsine, etc.

The ion beam, which consists of a whole number of impurity elements, must be cleaned of undesirable elements upon entry into the substrate. Mass separators are employed for these purposes. They are divided into two types with respect to operating principle: magnetic separators and electromagnetic filters.

Ions with the same charge and energy will be deflected at different angles in a transverse magnetic field depending on the mass of the substance. By reversing the magnetic field it is possible to produce beams of the prescribed composition in the outlet of the sector magnets of mass separators. This method of separating pure substances is considered the most effective. The relationship between the parameters of the magnet (radius, r_0, angle of turn of the ion, θ, magnetic induction, B), the mass of the ion, M, its charge, q, and the accelerating voltage, V_0, is presented below:

$$(M/q)U_0 = Kr_0B^2 ,$$

where K is determined by the angle of the sector (magnet).

Consequently, if the appropriate value of magnetic induction, B, is selected with constant assigned design dimensions of the magnet, then in its outlet, with radius r_0, it is possible to separate through the slit an ion beam with mass of M/q.

Magnets of the sector type with an inhomogeneous magnetic field are usually used for the purpose of increasing resolution. A diagram of an ion-implanted doping unit with a magnetic mass separator of the sector type, 4 (the sector angle equals 90°), and of an ion source, 1, with an accelerating tube, 2, is presented in fig 3-16. The beam of ions of the doping substance, passing through the collimating opening, 3, is scanned by means of potentials supplied to the electrodes, 5, over the surface of the substrates placed in the receiving chamber, 7. The beam current is measured periodically by means of a probe, 6. The radius of the magnet is determined by the accelerating voltage and the mass of the substances used for doping,

$$r_0 = \sqrt{2MV_0/qB^2} .$$

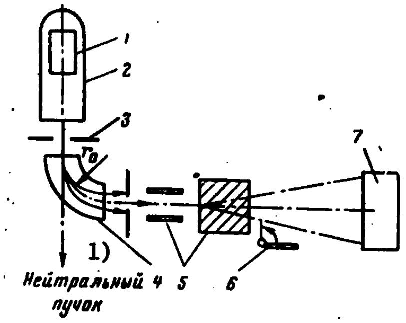


Figure 3-16. Design of Ion-Implanted Doping Unit with Magnetic Mass Separator

Key:

1. Neutral beam

The design of these mass separators is very simple, but for accelerating voltages of hundreds of kV and for great masses of ions of doping impurities (e.g., phosphorus, arsenic and the like) electromagnets with large dimensions and heavy weight (several tons) are required.

Units with postacceleration have begun to be used in recent times. In this case the preacceleration of ions before the mass separator is slight (15 to 20 kV); therefore, the dimensions of the electromagnet are drastically reduced.

A similar effect for the mass separation of an ion beam can be accomplished if it passes through a filter in which the magnetic field acts along the path of the beam and the electric field acts orthogonally to the magnetic field and consequently to the ion beam. This is a so-called E X B filter (fig 3-17).

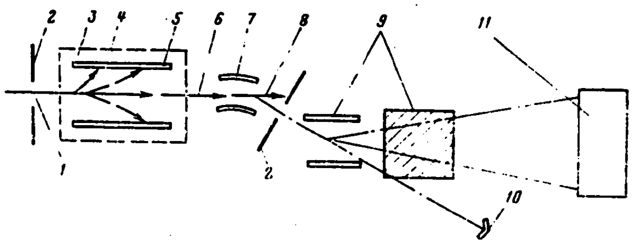


Figure 3-17. Design of Ion-Implanted Doping Unit with Mass Separator of the E X B Filter Type

The mass-separated beam will continue its straight-line motion and the ions of other masses will be introduced into the walls of an ion conductor. This mass separator is simple in design: It consists of a small-size permanent magnet, 4, and electrodes, 5. The original ion beam of doping impurities, 1, passing through the collimator, 2, is separated by means of an E X B filter, 3. The disadvantage of this filter is the fact that together with the ion beam, 6, a neutral beam, 8, of undesirable substances passes through it. In order to eliminate this, in the filter's outlet there is a system for deflecting the ion beam by means of an electric field, 7, with a collimator, 2. As in the unit shown in fig 3-16, the ion beam is scanned by means of electrodes, 9, over a substrate placed in a receiving chamber, 11, for the purpose of producing a doped layer uniform over the depth and surface of the substrate. A probe, 10, serves the purpose of periodically checking the ion beam's current. On the basis of the use of mass separators of one type or another, as well as of the convenience of putting together elements of the entire unit, various designs of ion-implanted doping units are employed (fig 3-18): of the horizontal type (fig 3-18, a and b), of the vertical type (fig 3-18, c to e), with sector magnet mass separators, 2 (fig 3-18, a, c, d), and mass separators, 4, of the E X B filter type (fig 3-18, b and e). The ion sources, 1, and receiving chambers, 3, are selected on the basis of the specific application of the unit.

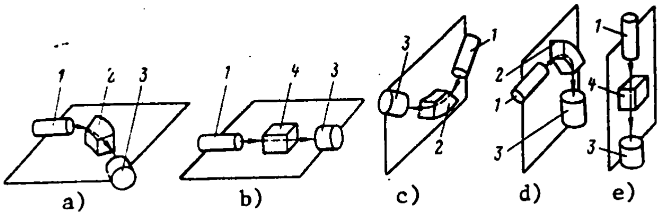


Figure 3-18. Design of Ion-Implanted Doping Units

Receiving Unit

The receiving unit is designed for loading semiconductor wafers, moving them beneath the ion beam, doping and heating. The cross-sectional area of the ion beam is as a rule several square millimeters and the beam is nonuniform over its area. Therefore, for the purpose of doping wafers with high uniformity it is necessary to move either the beam over the wafer or the wafer relative to the beam. The first method is used most often--scanning of the beam as in a television tube. In the doping process, for the purpose of annealing radiation defects which originate in wafers, they are heated by means of heaters to a temperature of 200 to 700 °C.

Additional focusing lenses are employed to increase the intensity of the beam. Depending on the design of the unit, they are placed in front of the mass separator or behind it in front of the beam scanning system. Electrical and magnetic quadrupole lenses (duplex and triplex) are usually used.

Vacuum System

The vacuum system is an important part of the apparatus. It is necessary to maintain a high vacuum on the order of $1.3 \cdot 10^{-4}$ to $1.3 \cdot 10^{-6}$ Pa in the vacuum ion conductor for the purpose of ensuring high purity of the ion beam. However, for making it possible to produce an ion beam of high intensity it is necessary to introduce into the ion source a high concentration of the doping substance, which is accomplished at a pressure of 13.3 to 1.3 Pa. A differential evacuation system which increases the vacuum in the receiving chamber to $1.3 \cdot 10^{-5}$ to $1.3 \cdot 10^{-6}$ Pa is created between the ion source and the receiving chamber. As a rule the receiving chamber is furnished with powerful high-vacuum evacuation equipment with freezing or other traps which prevent the entrance of oil vapors from oil-vapor and mechanical vacuum pumps, or with oilless evacuation equipment, chiefly turbomolecular pumps, as well as with metal vacuum seals.

The "Vezuviy-2" [Vesuvius-2] ion-implanted doping apparatus is widely used in the series production of semiconductor devices (fig 3-19). The control rack is shown on the left in the photograph. The postacceleration principle is used in this apparatus; therefore, the magnetic mass separator has small overall dimensions and low weight. The preliminary acceleration is up to 20 keV and the subsequent up to 130 keV on account of the use of a multisection accelerating tube. The total maximum accelerating voltage is 150 kV and the minimum 20 kV. The receiving unit is under high potential.

Figure 3-19. Ion-Implanted Doping Apparatus of the "Vezuviy-2" Type

The ion source is of the arc type with a transverse magnetic field. At the outlet of the accelerating tube the boron and phosphorus ion beam current is a maximum of 100 μA and 300 μA, respectively. The number of wafers up to 80 mm in diameter which can be loaded at the same time is not greater than 40. Vertical scanning of the beam is accomplished by means of the electric field and horizontal by mechanical movement of the substrates. An integrating dosimeter is used to monitor the doping dose. The apparatus is compact and has small overall dimensions. The area occupied without auxiliary space is 18 m^2. The apparatus is simple and reliable.

3-4. Equipment for Producing Epitaxial Films

Methods for the deposition of atoms from the vapor or liquid phase onto solid substrates are employed for the purpose of producing monocrystalline semiconductor films. This process is called epitaxial if crystallization of the deposited material takes place on oriented monocrystalline substrates with the repetition of their structure. The distinction is made between homoepitaxial, autoepitaxial and heteroepitaxial growing of films. In the first case the deposited substance and the substrate are identical and in the second different. At the present time successes have already been achieved in the deposition of, for example, silicon monocrystalline films on sapphire and quartz substrates and substrates made of spinels.

Two trends exist in the epitaxial growing of semiconductors on substrates of a different substance, including on dielectric substrates. The first is the deposition of a thin layer of a molten semiconductor with its subsequent oriented crystallization. The second is the epitaxial growing of layers of a semiconductor during crystallization from a melt, a melt solution and the gas phase.

Methods of epitaxy from melts, solutions and the gas phase have become the most widespread in the production of semiconductor devices. Epitaxy from melts makes possible high structural perfection and purity of films, and by this method it is possible to produce layers of such materials as indium antimonide and gallium antimonide, which are difficult to produce by means of gas transport reactions.

Epitaxy from the gas phase includes the deposition of monocrystalline films by the vacuum deposition method (thermal vaporization, ion-plasma spraying, electrical firing) and by the method of gas transport reactions.

Vacuum methods make it possible to produce films of very high quality, but they require a superhigh vacuum and are poorly productive.

The reduction of a tetrachloride ($SiCl_4$) or a trichlorosilane ($SiHCl_3$) and the pyrolysis of a silane are widely used gas transport reaction methods. A vapor-gas mixture of the appropriate composition passes over a substrate heated to the appropriate temperature, being deposited in the form of monocrystalline layers of the substance or compounds in question. These processes are usually accomplished in quartz reactors.

The equipment created for carrying out epitaxy by these methods is relatively inexpensive, uncomplicated and highly productive.

Depending on the composition of the reactive gases, deposition processes can differ in the type of reaction, which has an influence on the individual designs of reactors. For example, the basic difference between epitaxy processes for silicon and gallium arsenide is the fact that in the first case this reaction is endothermic and in the second exothermic.

Therefore, in growing silicon, where its deposition results in the absorption of energy, for the repeated performance of the epitaxy process without the walls of reaction chambers becoming overgrown, it is necessary to hold them at a temperature below the deposition temperature. For these purposes heating, either high-frequency induction or by means of infrared lamps, is employed. In the deposition of gallium arsenide from chlorides accompanied by the release of energy it is necessary to heat the walls for the purpose indicated above. In these cases it is desirable to use resistive heaters making it possible to heat the walls of chambers or to make reaction chambers out of heat-absorbing materials.

Liquid epitaxy methods are also used for semiconductor compounds of the $A^{III}B^{V}$ type in the industrial production chiefly of optoelectronic devices.

Equipment for Gas Epitaxy

The design of equipment designed for epitaxy according to the method of gas transport reactions is characterized by 1) the type of epitaxial reactor, 2) the method of heating substrates, and 3) the gas distribution system.

Epitaxial reactors are divided into three types: horizontal, vertical and cylindrical. (A classification of reactors according to other features--the direction of gas streams relative to the substrate, heating of substrates, etc.--is given in [14].)

This division according to type of reactor is based on the difference in the position of the substrate relative to the reactor's axis and the direction of flow of the reaction gas and is traditional.

The three types of reactors are shown in fig 3-20. Horizontal reactors (fig 3-20, a) are the simplest and do not have any moving parts inside. The vapor-gas mixture stream in them is supplied parallel to the surface of the substrate and the axis of the reactor. Usually inside the tube there is a holder made of graphite, 3, coated with silicon or silicon carbide, which is mounted on quartz slides or rectangular supports with a certain pitch, α . The quartz or metal tube, 1, has a circular or rectangular shape. The vapor-and-gas mixture in the inlet nozzle passes through a grille, which forms a turbulent flow, as the result of which good mixing of the working mixture with the gaseous doping substance is achieved. Preliminary heating of the vapor-gas mixture is carried out in order not to introduce a disturbance into the reactor's temperature zone. In the outlet the exhaust mixture is cooled to 50 °C and is burned up in an outlet unit (scrubber). The graphite substrate holder with the substrates, 4, in this case is heated from a high-frequency oscillator through a work coil, 2.

In a vertical reactor (fig 3-20, b) a quartz dome, 5, is used as the reaction chamber and the substrate holder, 7, made of graphite coated with silicon or silicon carbide as in a horizontal reactor, is mounted on a rotating platform, 9, which is driven into motion by a shaft, 8. The vapor-gas mixture enters the chamber through a rotating tube, 6, and, being repelled by the quartz dome, is directed toward the substrates, 4. In this case the graphite substrate holder is heated from a high-frequency oscillator by means of a work coil, 2. In this reactor the vapor-gas mixture can be also supplied directly through the top part of the dome. In both cases it enters perpendicularly to the substrate and spreads over it.

The cylindrical reactor (fig 3-20, c) consists of a quartz or steel chamber, 5, in which there is a graphite substrate holder, 7. The substrates, 4, are placed in it on an incline, which prevents them from falling out of the grooves. As a rule, the substrate holder is driven into rotation for the purpose of uniform contact between the vapor-gas mixture and the surface of the substrate and of mixing the mixture; here it is heated by a high-frequency oscillator by means of a work coil, 2, separated from the reaction chamber by means of a quartz cylinder, 9.

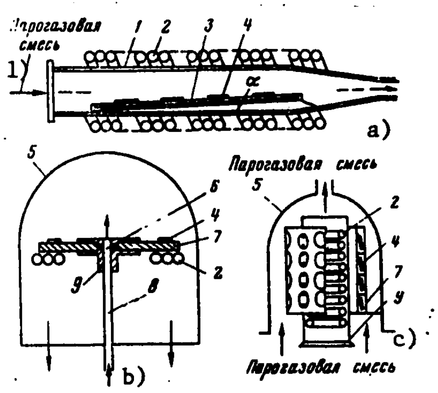


Figure 3-20. Construction of Epitaxial Reactors: a--horizontal type; b--vertical type; c--cylindrical reactor

Key:
1. Vapor-gas mixture

The vapor-gas mixture is fed into the reactor either from below, as illustrated in the drawing, or from above along the substrate holder. In some types of cylindrical reactors the mixture is fed through a slit inlet perpendicularly to the axis of the substrate holder.

Substrates are heated by means of 1) a high-frequency oscillator via a work coil, 2) infrared heating by means of quartz halogen lamps, and 3) resistive heaters.

The heating method plays an important role in choosing the type of reactor. A high-frequency heater is used most widely, since then only the substrate holder made of highly conductive material together with the wafers is heated, and the walls of the quartz tube remain cold. Therefore, the reactor's walls do not become overgrown with the reaction products of the vapor-gas mixture.

When outside resistive and lamp-type infrared heaters are used, the substrate holder together with the wafers and the quartz reactor tube are heated, as in diffusion furnaces. Since a lamp-type infrared source has a higher temperature than an incandescent source, the power radiated by it belongs to a shorter waveband (1 to 3 μ), in which quartz glass is practically transparent. This results in less heating of the walls of the reactor tube.

High-frequency and infrared heating systems are less interial than resistive heaters and easily make it possible to perform multilevel heating cycles of short duration. All three kinds of heating are approximately identical with respect to the unit input of power.

All three types of reactors are currently used in the industry. Epitaxy units with a horizontal reactor are simpler in design but are distinguished by higher consumptions of working gases and a greater spread in the thickness and resistivity of deposited films. Units with vertical and cylindrical reactors are complex in design but make possible a smaller spread in the thickness and resistivity of deposited films. Cylindrical reactors make possible the highest productivity and the lowest consumption of working gases.

The reproducibility of the thickness and resistivity of epitaxial layers depends basically on the design of the reaction chamber and heating system, as well as on the reproducibility of gas and temperature parameters, i.e., on the gas distribution system and the system for controlling the temperature in the reactor.

A typical system for supplying gas to the reactor is described in the following chapter (sec 4-2).

The construction of the reaction chamber of a UNES-2P-V unit with a vertical reactor is shown in fig 3-21. The bottom flange, 15, is fastened by means of clamps, 21, to a plate-type base, 1. Seals 16, 13 and 14 ensure airtightness in the bottom half of the reaction chamber, which consists of two coaxial tubes--an inside quartz tube, 7, and an outside one made of acrylic plastic, 8. Water circulates between them for the purpose of cooling the quartz tube, which is heated by radiation from a pyramid-type substrate holder, 10. The upper flange, 6, makes airtightness possible in the upper half of the reactor by means of seals 2 and 3. A substrate holder made of graphite, 10, is fastened to a support, 11, and a centering flange, 19, and is rotated on a shaft sealed by means of gaskets, 17. This entire unit is fastened in flange 18.

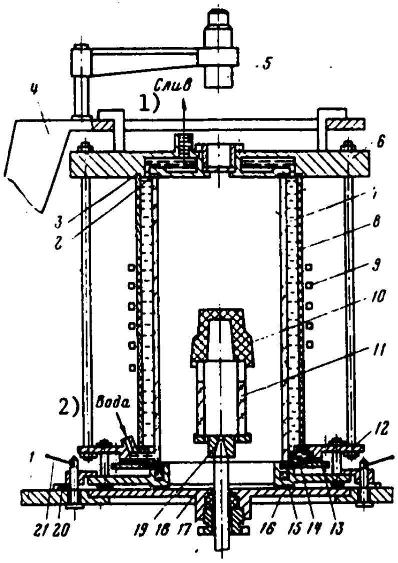


Figure 3-21. Construction of Reaction Chamber of UNES-2P-V epitaxy unit

Key: 1. Discharge 2. Water

A high-frequency induction heater, 9, and the reaction chamber, tightened by means of flanges 6 and 12, are fastened to a bracket, 4. The temperature is measured by means of an optical pyrometer, 5. If the reaction chamber has not been fastened by means of screw clamps, microswitch 20 blocks the switching on of the high-frequency heating system.

The substrate holder, 10, is in the form of a polyhedral truncated pyramid. Wafers are fastened to it at an angle of 5 to 7 degrees to the vertical axis. It is made of graphite coated with a carbide layer. Uniform heating and equalization of the concentration of the vapor-gas mixture on the surface of wafers are produced by rotating the pyramid. This mixture is fed from above parallel to the reactor's axis and is removed from below.

In a UNES-2P-V unit it is possible to perform the epitaxial growing of n- and p-type layers, the deposition of films of silicon dioxide, as well as etching with hydrogen chloride. It is possible to bring heating of wafers up to 1300 °C.

The cylindrical reactor of the UNES-2P-KA industrial epitaxial growing unit is shown in fig 3-22.

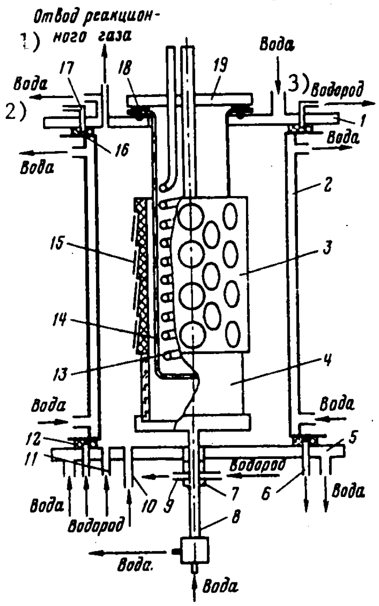


Figure 3-22. Construction of Reaction Chamber of UNES-2P-KA Epitaxy Unit

Key:

1. Discharge of reaction gas
2. Water
3. Hydrogen

The reactor's shape-forming parts are a flat upper flange, 1, a cylinder, 2, and a lower flange, 5, which form the airtight space of the reactor. Inside the reactor there is a hollow cylindrical substrate holder, 3, with the wafers, 15, placed on several tiers. The vapor-gas mixture is fed from below through a pipe connection, 10, and discharging takes place through three water-cooled pipe connections for discharging the reaction gas. The annular zone between the wall of the reaction chamber and the substrate, 3, is blown through through two pipe connections, 11, in the lower flange of the reactor. In addition, the annular spaces between the two concentric rubber gaskets, 16 and 12, of the upper and lower flanges, as well as the sealing rings, 7, of the rotating shaft, are blown through with nitrogen through pipe connections 6, 9 and 17 for ensuring the reliability of seals. A quartz bulb, 14, inside of which a high-frequency work coil, 13, is placed, is inserted into the inside space of the substrate holder, 3. The substrate holder is placed on a quartz support, 4, placed on the flat disk of a water-cooled rotating shaft, 8. The quartz bulb is sealed by means of a rubber ring-type gasket, 18, and flange 19.

The temperature profile over the height of the substrate holder is equalized by changing the spacing of the work coil's turns: a local increase in temperature by compressing the turns, and a reduction by stretching them.

The UNES-2P-KA unit is designed for the large-lot production of silicon epitaxial structures. It is possible to perform gas etching in it, as well as to produce coatings of silicon dioxide and nitride. The operating temperature range is from 900 to 1300 °C.

Equipment for Liquid Epitaxy

Liquid epitaxy has assumed an industrial scale in the last five or six years. The impetus for this development was the demand for solid-state lasers, light displays and other optoelectronic devices based on the use of $A^{III}B^{V}$ compounds and solid solutions based on them. This method makes it possible to produce heterojunctions. The process occurs with the release of heat, i.e., is exothermic. As a result, for the purpose of forming an epitaxial film it is necessary to lower the temperature of the substrate with the solution melt layer on it. The temperature drop must take place in keeping with a specific law for various substances. The process can be divided into the following process steps. The elementary substance--a solid binary or ternary solution--is melted in an appropriate low-melting substance which is chemically inactive with respect to the solution and substrate, most often in a metal. Then the solution melt is brought into contact with the substrate and after the establishment of thermal equilibrium between the is cooled in keeping with the appropriate law for the purpose of epitaxial deposition of a film onto the substrate.

For some materials the epitaxial deposition of layers from a solution melt is performed with the existence of a temperature gradient created along the substrate. Impurities for producing doped epitaxial layers are introduced into the solution melt either during preparation of the charge before its melting or from the gas phase after melting. The excess solution melt is mechanically removed from the substrate after deposition of the epitaxial layer. Then the substrate with the deposited layer is cooled to room temperature.

On the basis of this technological process it is possible to formulate requirements for epitaxial equipment:

1. The heating furnace must be a quick-response one and have a heating temperature range of 300 to 1100 °C, making it possible to satisfy requirements for melting a charge of the various materials used for liquid epitaxy. The accuracy of maintaining the temperature is ± 0.75 °C. For units with a continuous epitaxial deposition cycle it is necessary to have several temperature zones: a zone for melting the charge and heating the substrate; a zone for bringing the solution melt into contact with the substrate and for holding for a certain time; a zone with a temperature gradient in the temperature reduction direction for making the epitaxial deposition process possible; and a zone for the cooling of substrates.

2. A mechanism or device for bringing the solution melt into contact with the substrate must be provided in the reaction chamber.

3. Before deposition onto the substrate, the solution melt must be produced in a crucible which is chemically inactive with respect to it.

4. The material of the reaction chamber must also be chemically inactive with respect to the substrate and solution melt.

5. Gases which are chemically active with respect to the substrate and solution melt must not be used when carrying out these processes in the reaction tube. Therefore, in the reactor either a flow of a purified neutral gas is created or evacuation is created by means of vacuum pumps.

The last requirement is satisfied by equipment which is distinguished by the method of creating the appropriate atmosphere in the reaction chamber--of the open or closed type. In a unit of the open type a neutral gas, most often mixed with purified hydrogen, enters the reactor continuously throughout the entire process and this gas, breaking down oxides on the surface of the solution melt, makes possible the occurrence of a reduction reaction. In units of the closed type a vacuum is created in the reactors. In some cases, before contact between the solution melt and the substrate hydrogen is introduced into a reactor of the clo type for the purpose of breaking down the oxide layer formed on the surface of the melt, and then evacuation is again performed right up to the final cooling of the substrates with the deposited layers.

Reaction chambers are subdivided into the following types with respect to the method of bringing the solution melt into contact with the surface of the substrate:

A reactor with an inclined holder (fig 3-23, a), in which the solution melt, 2, with the substrate, 1, placed in the holder, 3, which is streamlined by a neutral (nitrogen or argon) or reducing (hydrogen) gas in a quartz tube, 4, are brought into contact by changing the tilt of the reactor relative to the rest, 5.

A reactor in the form of a rotating cylinder (fig 3-23, b), in which the solution melt, 2, is brought into contact with the substrate, 1, by turning a graphite cylinder, 8, 180 degrees from the position shown in the drawing, and by lifting the substrate by means of lifter 7, until it makes contact with the surface of the solution melt.

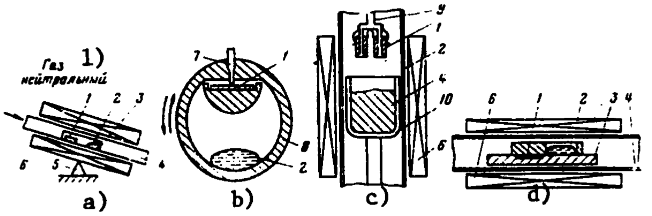


Figure 3-23. Reactors for Liquid Epitaxy: a--employing the rotating cylinder method [as published]; b--employing the rotating cylinder method; c--employing the wetting method; d--employing a container of the cylindrical case type

Key:
1. Neutral gas

A reactor of the vertical type (fig 3-23, c), in which substrates, 1, fastened to a holder, 9, are immersed by means of a moving rod into the solution melt, 2, which is in a crucible, 10. This type of reactor is designed for working with solution melts possessing heightened reactivity for the formation of oxides. When the substrates are immersed into the melt they rupture the oxide film and make contact with the melt in bulk.

A reactor with a container of the cylindrical case type (fig 3-23, d), in which a pool, 2, is moved along a holder, 3, with substrates, until the solution melt makes contact with the substrates.

All these reactors are put into a quartz tube, 4, and are furnished with a heater, 6, making possible the required temperature conditions.

There are also other varieties of reactors which differ in the principle of bringing the substrate into contact with the solution melt. Reactors with a container of the cylindrical case type have become most widespread in industry. It is possible to cite as an example the continuous industrial unit for producing epitaxial films of GaP.

The reaction chamber, by virtue of the sectional structure of the heating furnace, has several temperature regions (Figure 3.24a): the region of fusion of the Ga solvent from room temperature T_k to the point A; the region of dissolution and saturation of the melt with polycrystalline GaP (AB); the region of epitaxial growth of the GaP layer on the monocrystalline substrate of GaP (BC) and after that, the region for substrate cool-down and the removal of the melt from its surface (CT_k).

The installation operates in the following manner (Figure 3.24b): the cylindrical case type containers move from left to right along the quartz guide rails 8, which are positioned in quartz tube 9; these containers consist of graphite holder 2 with two substrates 3 positioned in the grooves and graphite tray 1 with the solution-melt 4, which has the ability to move in the graphite holder. The containers, in passing through the two temperature regions of the furnace T_kA and AB, at point B lock the light beam of laser 5 on light disk 11 through slot 10 in holder 2. As a result of this, mechanism 6 matches the tray to the holder so that the melt-solution 4 comes in contact with substrates 3. The container, in passing through the temperature region (BC), where the GaP epitaxial film grows on the monocrystalline GaP substrate, moves the tray to the initial position by means of return mechanism 7, separating the melt 4 from the substrates 3 and removing the solution-melt which has not undergone a reaction. Then the container is fed into the region for cooling and unloading the wafers. The epitaxy process is performed in a flow of a mixture of nitrogen and hydrogen gases, which are cleaned of oxygen and moisture. Tellurium is used as the hardener to obtain the epitaxial layers of n-type GaP.

Gas screens 3 (Figure 3.24c) are used in this installation to prevent the intrusion of atmospheric gas into the reaction chamber. Moreover, dust-free boxes 1 are used in it, which assure the high purity of the air environment in which the loading and unloading of the wafers and charging with the solvent take place.

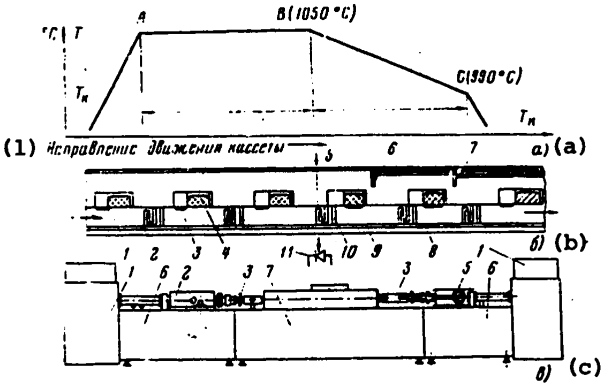


Figure 3.24. The temperature cycle during the growing of epitaxial GaP films (a); basic schematic of the reactor with the cylindrical case containers (b); the continuous exposure installation for the epitaxial growth of GaP layers from the liquid phase (c).

Key: 1. Direction of holder travel.

To increase the productivity of the installation, the loading and unloading process has been mechanized and automated by means of devices 2 and 5. The control units for gas systems 6 and the control and regulation of the temperature 7 in the reaction chamber 4 are built into the housing of the installation.

To apply multilayer epitaxial films, several trays with the solution-melt are placed in the container, where these trays are brought in contact with the substrate in turns for the sequential deposition of the specified layers of the substances.

3.5. Equipment for the Production of Alloy Junctions

The alloying technique is used at the present time primarily to obtain low frequency semiconductor devices and ohmic contacts.

The alloy process takes place in three steps:

--Local wetting of the semiconductor surface with the metal;

--Dissolution of the surface layer of the semiconductor in the volume of the melted metal;

--The formation of the junction layer (the p-n junction or the ohmic contact) as a consequence of the crystallization during cooling of the semiconductor dissolved in the melt.

A furnace with a controlled environment and holders in which the geometric matching of the semiconductor substrates to the metal electrodes being fused in at that point where it is necessary to produce the alloy region are needed to produce an alloy junction.

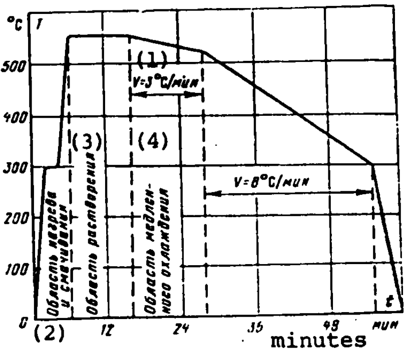


Figure 3.25. Temperature profile of the process of melting indium into germanium to produce a p-junction.

Key:
1. V = 3 °C/min;
2. Region of heating and wetting;
3. Dissolution region;
4. Region of slow cooling.

As an example of producing a p-n junction in germanium chips by means of melting in indium, we shall consider the requirements placed on the temperature profile of a conveyor furnace (Figure 3.25). To form a flat and even front edge for the melting-in, it is necessary to heat the semiconductor--metal pair and cool them following the formation of the melt at a definite rate.

As can be seen from the figure, the metal is melted during the wetting process and it flows over the surface of the semiconductor in that part of it where there is to be an alloy junction. For this reason, the holder with the wafers is kept in the furnace for 1 to 3 minutes at a temperature on the order of 300° C (100 to 150° C higher than the melting point). Moreover, the presence of foreign films and especially oxides, is impermissible for normal wettability of the surface. For this purpose, the melting-in process is carried out in a reducing medium (pure hydrogen), having beforehand subjected the internal portion of the heating furnace and holder to a careful cleaning.

After the completion of the wetting step, the temperature is increased sharply (up to 550° C) to dissolve the surface of the semiconductor with the metal melt. In this case, because of diffusion at the boundary of these substances, there is the formation of a junction layer. The time needed to establish thermodynamic equilibrium is governed by the dissolution rate of the semiconductor in the metal and the speed of diffusion of the atoms in the melt, and for the given case, fluctuates in a range of 5 to 12 minutes. Following this, the system is slowly cooled initially with a temperature gradient on the order of 3° C/min and thereafter at 8° C/min to recrystallize the formed alloy and to form the p-n junction between the original n-germanium and the recrystallizing p-germanium. In the case of rapid cooling, because of the difference in the thermal expansion coefficients of germanium and indium, the melting-in region can develop cracks.

Thus, for a periodic exposure installation, the furnace should have a programmer for the heating and cooling of the holders with the substrates, while in continuous exposure installations, the furnace must be made as a sectional design, where the temperature is maintained in accordance with the specified alloying temperature cycle. To obtain germanium semiconductor devices, a maximum temperature on the order of 700° is needed, while for silicon devices, the temperature is on the order of 1,000° C.

The thermal installations for the production of alloy semiconductor devices can be classified according to the following parameters:

--According to the working atmosphere - as vacuum and gas installations;

--According to the type of heaters - with direct heating, in which the working channel of the furnace is at the same time the heater, and with indirect heating, in which silite [electrical insulating material] rods, wire and other heaters heat the reactor tube;

--According to the operating principle - as periodic exposure furnaces, in which the loading, the process and the unloading are performed after each input into the working channel, and as continuous devices, for example, conveyor installations;

--According to the working temperature - as low temperature (up to 700° C) and high temperature (up to 1,000° C).

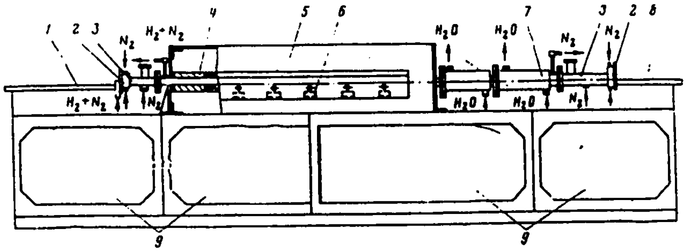


Figure 3.26. Conveyor furnace for the production of germanium alloy semiconductor devices.

To obtain alloy devices, primarily low power diode matrices, electron beam installations are used in addition to thermal installations, in which the instantaneous local heating and melting-in are accomplished by a focused electron beam. When this method is used, the depth of the melting-in region depends on the accelerated electron beam energy, while the geometric dimensions of the p-n junction are governed by the diameter of the electron beam. However. the technique of alloying in conveyor furnaces is used more often in industry, which provides for high output and economic efficiency by virtue of the simplicity of the structural design of the installations and their low cost.

We shall consider the structural design of the SK 11/16·10 = 6 conveyor furnace, intended for producing p-n junctions by means of alloying (Figure 3.26). The installation consists of a heating chamber 5 and muffle tube chamber 4, the gas feed system for nitrogen and hydrogen 3, the gas screen devices 2 as well as the charging area 1 and the unloading area 8 as well as the refrigerator 7.

All of the assemblies of the installation are mounted in a welded metal housing made of stainless steel in which the electrical power supply control and temperature regulation units 9 are contained.

The square cross-section heating chamber is lined (12) with pairs of upper and lower heating sections 6 made of nichrome, which are faced with porcelain plates and brick for thermal insulation. The muffle tube 4 runs through the inside of the heating sections, in which the temperature profile for the heating at a maximum temperature of up to 700° C is set. Each heating section has its own temperature regulator, which makes is possible to produce various temperature profiles along the heating chamber and assure stabilization of the temperature proflie during the operation of the furnace.

Thermocouples are placed directly in the muffle furnace to monitor the temperature in the working region. There are gas screens 2 at the edges which prevent the intrusion of air into the working region of the furnace. An adsorber is installed at the entrance to the furnace for additional drying. The refrigerator takes the form of a system of water-cooled tubes.

Prior to the start of the process, the muffle tube is flushed with an inert gas, after which the hydrogen is fed into it. The parts being alloyed are loaded in cassette holders. Stainless steel is used as the material for the cassette holders which have dimensions of 40 x 8 x 65 mm. The conveyor takes the form of a net belt. The cassette holders run through the appropriate temperature zones on the conveyor belt, the speed of which is adjusted by a motor in a range of 30 to 120 mm/min.

CHAPTER FOUR EQUIPMENT FOR FILM PRODUCTION

It is necessary to apply various films which perform the functions of protective, insulating and masking coatings, as well as ohmic contacts, current carrying paths, etc. in the production of semiconductor devices and integrated circuits. Metal, semiconductor and dielectric film serve these purposes, including films of various alloys, compounds and solid solutions (15). The deposition of these films is accomplished by means of vacuum deposition, deposition from the gas phase as well as precipitation from the liquid phase. Equipment for the application of films using the first two methods is treated in this chapter.

4.1. Vacuum Film Deposition Equipment

A vacuum installation for the precipitation of films of various materials consists of the following major assemblies and units:

--The film precipitation unit;

--The vacuum exhaust systems;

--The electrical power supply and control units.

In turn, the deposition unit consists of a chamber, a vaporizer, substrate holder, substrate heater and sensors for monitoring the precipitation rate or thickness of the films.

The vacuum exhaust systems include the initial vacuum preliminary exhaust line, and the high vacuum exhaust line with the cutoff valves and traps for the oil diffusion pumps.

The electrical power supply and control units for the installation and the deposition process consist of the power supplies for the vaporizer, the vacuum exhaust equipment, the cutoff valves and gates, as well as the substrate heaters; the monitor units for the vacuum system, the control of the mechanisms for moving the substrate holder and the operating modes of the vaporizer and the monitoring of the film parameters during precipitation (primarily the thickness of the films or their deposition rate).

We shall consider a vacuum chamber with a vaporizer, a substrate holder and sensors for the deposition rate or film thickness.

Depending on their function, vacuum chambers are of the dome type, spherical, cylindrical or rectangular. The shape of the chamber is governed by the requirements for the maximum filling of it with substrates and other devices for atomization of the material, as well as minimum volume. The greater the volume of the chamber, the greater the capacity required for the exhaust equipment. Installations with dome type and cylindrical chambers are the most widespread.

The vaporizers are placed inside the vacuum chamber. Depending on the method of vaporization, they are broken down into three types: with thermal heating and vaporization of the material; with the bombarding of the material by ionized gases and its atomization; and with thermal vaporization and precipitation of the vaporized material in the ionized state.

We shall treat these types of vaporizers in detail.

Thermal vaporization is accomplished in the following ways:

--Heating the material in a resistive type vaporizer when an electrical current is passed through it;

--Heating the material with electron bombardment;

--Heating the material by passing an electric current through it;

--Heating the material with a laser beam;

--Radiofrequency induction heating of the material being vaporized;

--By electrical explosion, i.e., by passing a high power electric pulse directly through the material being vaporized, where this pulse assures explosive vaporization.

Resistive Vaporizers

Difficultly fusible metals and ceramic crucibles, for example, nitrides, carbides, oxides, etc., in which the materials being vaporized are placed, can be used as the vaporizers.

The choice of the materials for the heater and crucible is determined primarily by the following major requirements:

1. The vapor pressure of the material of the heater should be low at the working vaporization temperatures.

2. The material being vaporized should, in the melted state, wet the material of the heater very well, thereby making a good thermal contact.

3. It is desirable to have minimum chemical interaction between the material of the heater and the substance being vaporized.

Vaporizers with wire or strip shapes, in the form of small dishes, etc. are used for the vaporization of low temperature substances and alloys.

The shape of the material being vaporized also has an influence on the structural design of the vaporizer. For example, one can use a vaporizer, the structure of which is shown in Figure 4.1a, for finely dispersed (granulated or powdered) substances. This substance is fed from hopper 2 through the shute or tube to small dish 3, and being vaporized, is precipitated on the substrate 1. For a continuous feed of finely dispersed substances to the vaporizer, the hopper is usually vibrated either electromagnetically or mechanically.

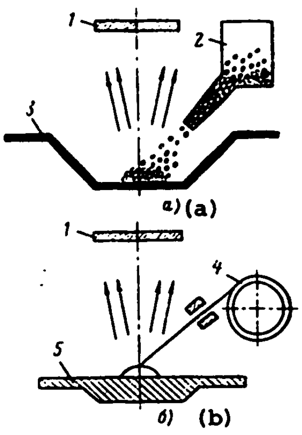


Figure 4.1. Thermal vaporizers.

Key:
- a. For the vaporization of finely dispersed substances;
- b. For the vaporization of a wire.

When a substance in the form of a wire is used for vaporization, coils with the wire wound on it beforehand are used (Figure 4.1b). Such a coil 4, which is unrolled by means of a mechanical drive, brings the wire in contact with the heater 5 for thermal vaporization and precipitation of the film.

Drawbacks to resistive vaporizers are:

--The short service life;

--The contamination of the deposited films with the material of the vaporizer or the product of the chemical interaction of the material of the vaporizer with the substance being vaporized;

--The impossibility of vaporizing difficultly fusible materials.

Electron Beam Vaporizers

The electron beam method of vaporizing materials is becoming increasingly widespread and has the following advantages:

--The capability of producing a high power concentration (up to $5 \cdot 10^8$ W/cm^2) and a very high temperature, which makes it possible to vaporize any materials, even difficultly fusible ones at a rather fast rate;

--The capability of moving the heated zone by virtue of deflecting the electron beam with electrical and magnetic fields to vaporize substances having a large area;

--The long service life of the vaporizers.

Drawbacks to the technique are the complexity of the structural design and the high cost of the vaporizer and its electrical power supply.

At the present time, vacuum deposition installations use electron beam vaporizers with power levels of from 4 to 15 KW with water-cooled copper crucibles. Electron guns with strip and annular cathodes are the most widespread.

The structural configuration of an electron beam vaporizer with a power level of 7.5 KW with Pierce optics and a strip electron beam, which produces the direct heating of the substance being vaporized. The magnet system 2 is used to rotate and focus the electron beam 8 on the molding of the substance being vaporized 5, where the electrons are emitted from thermionic cathode 6, so as to prevent the intrusion of the substance being vaporized into the electron beam. A tungsten cathode 0.2 mm thick and 1 mm wide is installed in the groove of the focusing Pierce electrode of gun 7. A massive copper crucible 4 has a center through-hole 35 mm in diameter and is cooled by flow-through water to prevent the alloying of the copper with the substance being vaporized. It is secured to the base 3 and makes it possible to load a molding [of the substance being vaporized] with a diameter of 35 mm and a length of 75 mm. This molding 5 is fed into the vaporization zone and automatically maintained at the specified height. The maximum rate of precipitation, for example, of aluminum on the substrate 1, amounts to 4.5 μm/min where the distance between the crucible and the substrate is on the order of 210 mm.

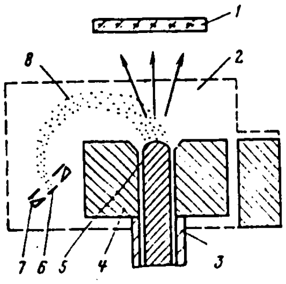


Figure 4.2. Structural configuration of an electron beam vaporizer with a strip cathode.

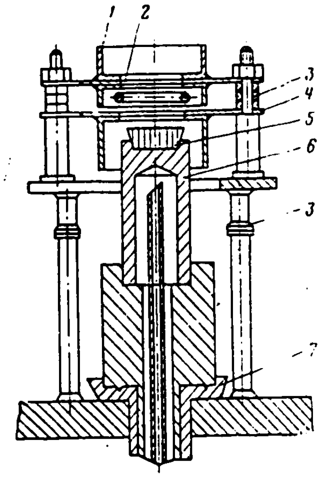


Figure 4.3. Electron beam vaporizer with a ring cathode.

In an electron beam vaporizer with an annular cathode, the gun takes the form of a diode system (Figure 4.3). The ring cathode 2 with a diameter of 15 mm is fabricated from tungsten wire with a cross-section of 0.63 mm. The focusing electrodes (the upper electrode 1 and the lower one 4) are manufactured from sheet steel 0.7 mm thick. The focusing of the electrons emitted by incandescent cathode 2 is accomplished by means of the calibrated washers 3, which make it possible to change the spacing between the upper and lower focusing electrodes, as well as anode 6. In step with the decrease in the height of molding 5, the electron system is lowered downward to maintain the initial focusing of the electron beam. The distance from the plane of the cathode ring to the plane of lower focusing electrode is 3 mm. A high voltage of 10 KV is applied to anode 6 through the high voltage entrance 7.

Pulsed vacuum deposition techniques, those using electrical explosions and lasers, are favorably distinguished from continuous methods by the following:

--They provide for higher film deposition rates;

--The high rate of occurrence of nuclei leads to a reduction in the minimum possible thickness of solid films, while the energetic excitation of the condensate atoms leads to a reduction in the temperature for aligned growth;

--They assure the preservation of the composition of the original material when depositing films of multiple component substances, something which is not always possible with continuous vaporization.

The electrical explosion technique makes it possible to obtain metal films of satisfactory quality under low vacuum conditions of down to $1.33 \cdot 10^{-3}$ Pa. In the simplest electrical explosion vaporization scheme, a discharge current from a bank of capacitors is passed through a weighed amount of the material being vaporized, as a result of which, the material explodes. The explosion products take the form of a mixture of vapor and finely dispersed liquid drops of the vaporized substance. The efficiency of atomization by means of electrical discharge depends on a quantity, which characterizes the excess stored energy, E/E_*, where $E = CU^2r$ is the stored electrical energy, C is the capacitance of the capacitor, U is the applied voltage and E_* is the sublimation energy of the substance.

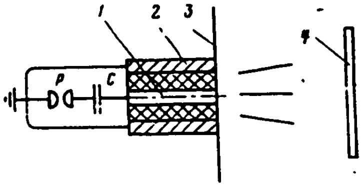


Figure 4.4. Schematic of an explosive vaporizer.

At the maximum discharge network voltage of 5 KV and a capacitance of 140 μFd, the thickness of the copper film applied with one explosion amounts to more than 3 μm with a nonuniformity of ±10%. Various structural designs and electrical circuits are possible for the realization of the electrical explosion. The most effective is the use of those installations for local gold plating. A simplified schematic of a device for foil atomization consists of two coaxial insulated electrodes 1 and 2 (Figure 4.4), to which the foil 3 is pressed, where the foil is fed through a flat glass capillary. When the high voltage pulse is applied to the electrodes with the closure of discharger P, the energy stored in the capacitance C is discharged through the foil, as a result of which it explodes and precipitates in the form of a film on substrate 4. Nozzles of the appropriate configuration, for example, a Laval nozzle with a small critical cross-section, are placed on one hand, between electrodes 1 and 2 and the substrate 4 for the gas dynamic control of the flow of the substance being vaporized. During the process, the nozzle presses the foil against the end faces of the electrodes. In this case, the portion of the foil explodes which is bounded by the inside diameter of the nozzle. Then the nozzle is lifted up, the foil is advanced one step forward and the explosion is repeated. The weight of the foil exploded with a single pulse usually amounts to 0.005 g. The condensation rate in the case of an electrical explosion amounts to 10^3 - 10^4 μm/sec.

The essence of the laser vaporization technique consists in the fact that laser radiation acts on the substance being vaporized, the energy of which is converted to heat. In contrast to the electrical explosion method, the laser technique is more suited for production processes, since it is not necessary for it to specially prepare the samples in the form of wires or foil. The laser beam is directed from the outside through an optically transparent window onto the material being vaporized, which is positioned inside the vacuum chamber. In this case, the vaporization of the material takes place, as a rule, without the formation of a liquid phase. When producing multilayer structures, the substances being vaporized are placed on a small rotating stand, and they are exposed to the radiation in a specified sequence. A laser pulse with a power of 1 to 2 Joules and a width of $2 \cdot 10^{-7}$--$3 \cdot 10^{-8}$ sec is usually employed.

Installations have been built for the deposition of dielectric films using CO_2 lasers with a power of 30 watts, which operate both in CW and in pulsed modes. An installation has been built for producing metallic and semiconductor films, which is equipped with three solid-state lasers. In the case of laser vaporization of metallic (Mo, V, Nb) and semiconductor films, the effective growth rates are approximately 10^5 Å/min.

Metallic, semiconductor and dielectric films which are extremely diverse in terms of structure and thickness can be produced by the laser deposition technique. To obtain films of easily fusible metals and alloys, the components of which differ little in terms of elasticity, it is expedient to use laser deposition only in those cases where it is necessary to provide for very high purity in the process or to reduce the nonproductive consumption of materials.

Cathode Sputtering Sources

The process of generating films by cathode sputtering differs substantially from thermal vaporization. Specific features of the cathode sputtering process are:

--A lower rate of deposition of the films;

--The atomization of the target and the precipitation of the film in the discharge;

--The atomization is done at a lower vacuum of 1 to $1 \cdot 10^{-2}$ Pa.

The principle of cathode sputtering consists in the fact that a flow of gas ions accelerated from several hundreds of electronvolts up to several kiloelectronvolts, which in bombarding it, knock out particles of the material. The deposition rate which is provided by the diode method is 100 to 500 angstroms/min. If the medium in which the discharge takes place is a chemically active one, then when bombarding the target and with its atomization, complex compounds are precipitated on the substrate. Such precipitation is called reactive.

Thus, two conditions are necessary for cathode sputtering:

1. The creation of a plasma from the gas introduced into the chamber.
2. The acceleration and directing on the target of the flow of ions for its atomization.

Ion sources are broken down into diode and triode types according to the type of plasma creation and target atomization.

In a diode source, the electron flux is formed by virtue of autoelectron emission. Ionized gas atoms bombard one of the electrodes, the cathode, which is simultaneously the target for the atomization. The precipitation of the material is accomplished at the anode. In this case, if the target being atomized is metallic, then the atomization uses direct current, and if it is a dielectric, then the atomization uses alternating current. In this case, with negative polarity the target is atomized, and with positive polarity, the accumulated negative charge is picked off of it.

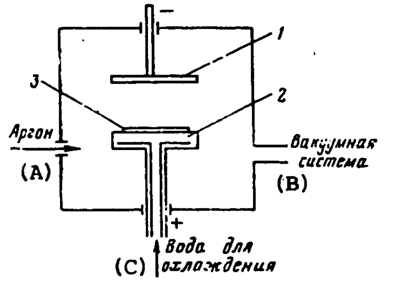


Figure 4.5. Schematic of a diode atomization source.

Key: A. Argon;
B. Vacuum system;
C. Water for cooling.

A diode system is the simplest one and consists of a cathode 1 and anode 2, on which the substrate 3 is placed (Figure 4.5). The cathode target is the source of both the material being atomized and the electrons which maintain the discharge. A vacuum of $1 \cdot 10^{-3}$ to $1 \cdot 10^{-4}$ Pa is created in the working chamber with the electrodes, after which, an inert gas is fed into it at a pressure of up to 1.3 to 13 Pa. When high voltage (1 to 5 KV) is applied to the electrodes, a glow discharge is ignited. The positive plasma ions, accelerating in the region of the dark cathode space, bombard the cathode, atomizing its surface.

In a triode source, the third electrode performs the function of a thermionic cathode, increasing the electron concentration, and this means, also the concentration of the ionized atoms of the working gas. In this case, this increase in the gas ions is possible with a reduction in its pressure, which provides for purer conditions for film precipitation. Moreover, the presence of a thermionic cathode makes it possible to bring the target closer to the substrate, increasing the precipitation rate. In diode systems, the anode to cathode spacing should be no less than the width of the dark cathode space. If a magnetic field is applied axially to the thermionic cathode in the discharge gap, then the plasma density can be increased without increasing the concentration of electrons. This is achieved in that the electrons move in a spiral in the axial magnetic field. In this case, their path to the anode is increased by several times, and this means that the probability of multiple collisions of an electron with the atoms of the working gas and its ionization also increases.

In conventional triode atomization chambers, the target and the substrate are in the region of the ionized working gas, and for this reason, the temperature of the substrate can reach several hundreds of degrees. To reduce it, it is necessary to make the substrate holder water-cooled. This drawback is eliminated in that the ion source is made as a slotted design, from which the plasma is removed and directed by means of an additional electrode so as to preclude the immersion of the substrate into the plasma. Such ion sources can operate at a pressure on the order of $1 \cdot 10^{-3}$ Pa (for comparison: diode atomization is accomplished at a working gas pressure of no less than 1 Pa, and the usual triode atomization at 10^{-1} to 10^{-2} Pa).

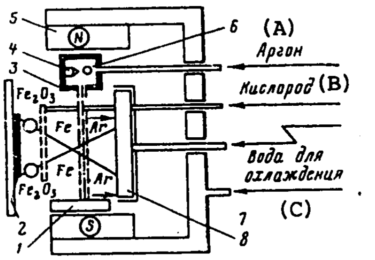


Figure 4.6. Schematic of a triode atomization source.

Key:
A. Argon;
B. Oxygen;
C. Water for cooling.

A triode type ion source with a plasma ejector is shown in Figure 4.6. Its operational principle is as follows. A plasma of the working gas, for example, argon, is excited in the discharge chamber 3 by means of thermionic cathode 6, which is usually made of tungsten wire, and the anode 4. The flow of ionized gases is removed through a slot in the discharge chamber by means of the potential difference applied between the chamber 3 and the collector 1. The plasma is focused and localized close to target 8 by means of magnet system 5. As a result of this structural design for the ion source, the substrate 2 is not immersed in the plasma, and therefore, its temperature will be low. The atomization of the target 8 is accomplished by applying a high voltage to it (100 to 1,000 volts). In order for the atomization of the target to take place from the front, which faces substrate 2, it is placed in shield 7, which covers the rear and side portions of the target. A provision is made for feeding chemically active gas into the region between the substrate and the target for reactive atomization in this source. The reactive application of Fe_2O_3 on a photographic template and the Fe target is shown in the figure.

Sample operating characteristics of the triode ion source cited above are:

Voltage at the anode of the discharge chamber	40 to 60 volts
Magnetic field intensity	$24 \cdot 10^3$ A/m
Anode current	20 A
Target voltage	3 KV
Target current	up to 1 A
Working pressure of the gas fed in for the atomization	$(3 \text{ to } 4) \cdot 10^{-2}$ Pa

Because of the high power dissipation in the discharge chamber and at the target, the electrodes and the chamber are water-cooled.

A variant of the diode atomization system is the magnetron source. Discharges in magnetron sources occur in crossed electromagnetic fields, as a result of which, high deposition rates of the metals and alloys are attained (on the order of 2 μm/minute where the distance from the target to the substrate is 60 mm [16]). A magnetron source with a plane cathode is depicted schematically in Figure 4.7a. The magnetic field applied perpendicular to the electric field acts on the electrons emitted by field emission cathode 1 and which move to anode 2 with the action of the electric field applied between the cathode and the anode. In crossed electrical and magnetic fields, the path of electron motion is increased, as a result of which, with the introduction of the working gas into the source, greatest concentration of gas ions is achieved. With a gas pressure on the order of $1 \cdot 10^{-1}$ Pa, one can obtain greater ion current densities (0.2 A/cm^2). The ions, subject to the action of the electrical field, are directed to the cathode, bombard it, atomizing with a considerable intensity. The atomization region 5 is governed by the region of intense plasma focusing by the magnetic and electrical fields. The substance being atomized is precipitated on substrate 6. The magnet system 3 is mounted in a water-cooled housing 4. The trajectory of the electron path e in the crossed electrical E and magnetic H fields is shown in Figures 4.7b and c in the case of a flat (Figure 4.7b) and hollow cylindrical cathode (Figure 4.7c). The magnetron system is used to atomized metals, semiconductors and dielectrics.

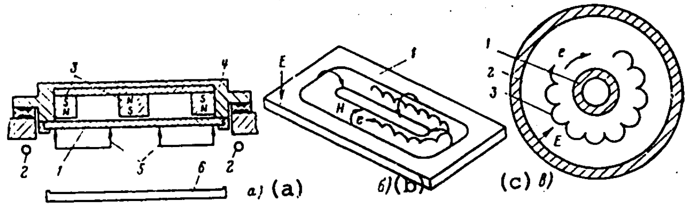


Figure 4.7. Schematic of a magnetron atomization source.

Key:
- a. Magnetron atomization source;
- b. The trajectory of electron motion in a magnetron with a flat cathode;
- c. The trajectory of electron motion in a magnetron with a cylindrical cathode and anode.

In the case of the atomization of dielectrics, just as in the diode systems described earlier, RF sources are used instead of direct current sources.

The rates in the case of RF atomization amount to approximately 100 Å/min, a figure which is several times greater than the deposition rate in conventional diode systems.

Ion-Thermal Equipment

Ion-thermal deposition of thin films is a combination of two methods: thermal vaporization and ionic precipitation. There are several variants of ion-thermal deposition in this case: thermal vaporization with the formation of ions of the substance being vaporized by means of exposure to an argon plasma and the high frequency ionization of the substance being vaporized itself; high frequency thermal vaporization with the simultaneous ionization of the vapors of the substance being vaporized, etc. The following three types of ion-thermal vaporization are the most widespread:

--Resistive and electron beam vaporization of the material with the subsequent ionization of it by the working gas plasma (in this case, reactive deposition of films is possible) in dual chamber systems;

--Resistive and electron beam vaporization with ionization of the vapors of the substance without the participation of the working gas, for example, by means of RF induction;

--RF thermal vaporization with the simultaneous RF ionization of the vapors of the substance being vaporized.

In all cases, the ions of the vaporized substance are transported to the substrate by an electrical field applied between the crucible and the substrate, and are deposited on it. The substrate potential can vary (0 to 10^4 volts) depending on the requisite crystalline structure and adhesion of the film to the substrate. For example, at low substrate temperatures, it is necessary to increase the potential so as to obtain satisfactory adhesion of the film to the substrate.

Ion-thermal film deposition sources are pictured schematically in Figure 4.8.

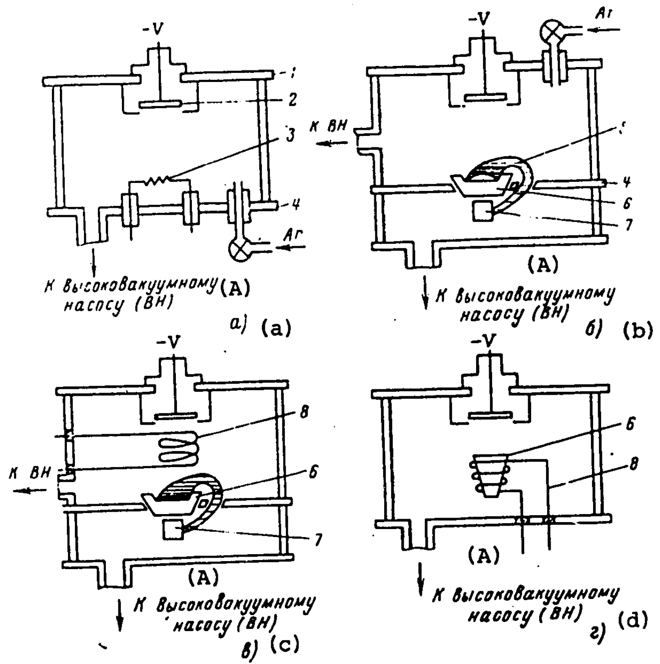


Figure 4.8. Schematics of an ion-thermal atomization source.

Key:
a. With a resistive vaporizer;
b. With an electron beam vaporizer;
c. With high frequency ionization;

Key [cont.]: d. With high frequency atomization and ionization.

A. To the high vacuum pump (BH).

A flow of the substance being vaporized is produced in the chamber (Figure 4.8a), equipped with upper 1 and lower 4 flanges, to which the substrate 2 and the resistive vaporizer 3 are fastened. Its ionization is accomplished by virtue of collisions with the ionized atoms of the working gas, for example, argon at a pressure of $1 \cdot 10^{-1}$ Pa. The preliminary ionization of this gas is accomplished by an electrical field between the substrate 2 and the vaporizer 3. The action of this same field also causes the ionic precipitation of the vaporized material.

In the case where an electron beam vaporizer is used (Figure 4.8b), a two-dimensional installation with a stop shield in intermediate flange 4 is employed.

The electron gun 7 and crucible 6 are placed in the lower high vacuum chamber in which a pressure sufficient for the normal operation of the electron beam vaporizer is maintained: $P \leq 1 \cdot 10^{-3}$ Pa. The electron beam 5 passes through the diaphragm stop into the second chamber, in which the atomization and precipitation of the film take place. The pressure in the second chamber on the order of $1 \cdot 10^{-1}$ to $1 \cdot 10^{-2}$ Pa is produced by means of feeding in a gas through an infiltration flow regulator. The material being vaporized is ionized by the method described above and deposited on the substrate. The third type of ion-thermal vaporizer (Figure 4.8c) operates using the same principle as shown in Figure 4.8b, only the ionization of the vaporized material is accomplished by the RF induction unit 8. A working gas can be fed in only for the reactive precipitation of thin films.

The fourth type of ion-thermal vaporizer is the simplest one and makes it possible to operate in a high and ultrahigh vacuum (Figure 4.8d). In it, the vaporization of the substance from crucible 6, which is positioned on flange 4, is accomplished by means of RF heating from the induction unit 8. At the same time, the vaporized material is ionized by means of this induction unit, and the material is precipitated on substrate 2, which is fastened to the upper flange 1. Reactive precipitation of films with a complex composition can also be accomplished in this type of vaporizer by admitting a chemically active gas into the chamber.

The merits of such equipment are:

- --The fast precipitation rate, which is characteristic of thermal vaporization, in conjunction with the high energy of the condensing particles, something which is inherent in ionic atomization methods;
- --The homogeneity of the resulting films without additional rotation of the substrate, since it is surrounded on all sides by the ions of the material vaporized in the gas discharge.

A drawback is the considerable complexity of directly monitoring the coating thickness during the precipitation process.

The rate in the case of electron beam vaporization reaches 5 μm/min. In this case, 100% coverage of relief substrates can be accomplished without the use of various planetary systems. Moreover, the use of the ion-thermal technique of deposition makes it possible to deposit films with a complex composition, including carbides, nitrides, oxides, etc. at high rates without high temperature heating of the substrates.

Installations for the Vacuum Application of Films

The requirements placed on thin film application technology can be formulated in the following manner:

--Uniformity of the film thickness over the entire relief of the substrate;

--Reproducibility of the film parameters from batch to batch and from process to process;

--The capability of applying several layers or one layer of a complex composition.

The first three requirements can be satisfied by such a structural design of the device inside the chamber that it is possible to move the substrate relative to the vaporizers by means of planetary rotation, while the latter can be satisfied by the use of several vaporizers operating simultaneously.

A planetary unit is shown in Figure 4.9 in which the convex hemisheres with the wafers fastened in them execute rotating motions about its axis and the axis of the vaporizer. The inclination angle of the hemishere relative to the normal to the vaporizer is chosen as a function of the step. The greatest angle relative to the vaporizer axis and the center of rotation of the sphere which is used is 90°. Such structures are basicly used for thermal vaporization, in which the beam of vaporized atoms obeys the vaporization law applying to vaporization from a point or a plane.

An important parameter for the use of vacuum installations from the viewpoint of economic efficiency is productivity. The time expended for auxiliary operations is curtailed to increase the productivity:

--The time for loading the wafers in the substrate holders and unloading them following the application of the films;

--The time for getting to the working vacuum from atmospheric pressure and cooling the substrate down to the temperature which allows for the admittance of the atmosphere.

These time losses can be eliminated by means of semi-continuous and continuous exposure installations, where the loading and unloading operations for the wafers are combined with the thin film application operations.

Automating the operation of such installations makes it possible to change over to conveyor type flow lines, which are the most effective equipment in industry, leads to a reduction in the number of attending personnel, and consequently, has a positive impact on improving the quality of the applied films by virtue of eliminating subjective operator errors.

However, it must be noted that although the application of the principle of continuous deposition of thin films, by virtue of the use of lock type loading and unloading devices increases the productivity and makes it possible to realize constant vacuum conditions (the concentration and composition of the residual gases, thermodynamic equilibrium of the vaporizers and heating devices, etc.), which leads to an improvement in product quality, semi-continuous and continuous installations are economically efficient only for large series production. For small series production, periodic exposure installations are economically efficient.

Figure 4.9. A planetary substrate holder.

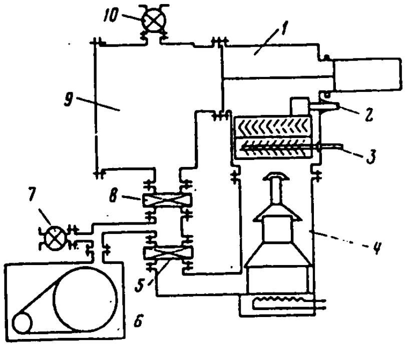


Figure 4.10. Schematic of the vacuum system for a periodic exposure installation for the application of films.

The vacuum systems can be identical in both types of installations. New structural components appear in the continuous and semi-continuous units: lock devices. For this reason, here we will consider the principle structural configurations of the vacuum, vacuum equipment as well as the lock devices and those inside the chamber.

A schematic of the vacuum system of a periodic installation is shown in Figure 4.10: valves 8 and 5 serve for switching the initial vacuum exhaust of the residual gases from the precipitation chamber 9 and the high vacuum pump 4. To prevent the intrusion of oil vapors from pump 4 into the chamber, two traps are inserted between them: one is water-cooled with oil vapor reflector 3 and the second is cooled with liquid nitrogen, 2. High vacuum cutoff valve cuts the working pump 4 off from chamber 9 when air is admitted into it through valve 10 to replace the substrates, load the material being vaporized, etc. Valve 7 serves to admit air into mechanical pump 6 which is shut down. Such a vacuum system can also be used in semi-continuous installations which have individual independent vacuum exhaust systems.

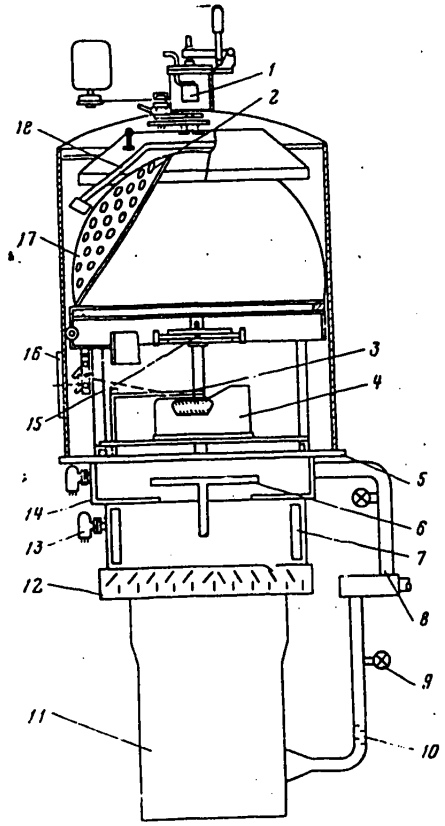


Figure 4.11. The structural design of a vacuum installation for the application of films.

Figure 4.12. The UVN-73P-1 industrial installation with a periodic thermal vaporizer.

An example of a periodic exposure vacuum installation with the unit internal to the chamber is shown in Figure 4.11. In this installation, the wafers 2 are fastened to three planetary hemisheres 17, which are held with levers 18. The vaporization of the material is accomplished by an electron gun with crucible 3, which has a protective shield 4 to trap secondary electrons. Infrared lamp 15 with a temperature sensor is used to heat the substrates before and during the application of the film. A quartz metering instrument 1 is used to monitor the film thickness. Visual observations of the operation of the units and mechanisms are made through inspection window 16 with a mirror periscope, which prevents it being coated. The unit internal to the chamber with the dome is fastened to plate 5. The electrical entrances, as well as the fastening of the diffusion pump 11 to the nitrogen trap and the water-cooled trap 12 are accomplished through the transition connecting flange 14. The chamber is isolated from the high vacuum pump by blocking valve 6. The initial vacuum exhaust line 8 with valve 9 for the connection of a leak detector, as well as trap 10 and ionization manometers 13 are also shown in the figure.

The UVN-73P-1 and "Elita" industrial installations can serve as examples of periodic exposure installations. The first of them (Figure 4.12) is widely used to apply thin metal films in the production of semiconductor devices. The metal is vaporized by the thermal method by means of heating the walls of a titanium diboride crucible with an electron gun. The working chamber is cylindrical with a horizontal arrangement. The wafers are fastened to a drum on the inside. The installation operates in a semi-automatic control mode for the mechanisms and the process.

The second installation (Figure 4.13) is designed for the application of metal films of difficultly fusible metals by means of ion-plasma atomization of them. The reactive atomization method in a chemically active gas medium can also be used to apply dielectric films in it. A triode type ion source is employed in the installation. A provision is made for feeding a bias voltage to the substrate to clean it prior to the application of the films. The wafers are secured to a rotating carousel. The installation operates in an automatic control mode for the mechanisms and in a semi-automatic control mode for the thin film application process.

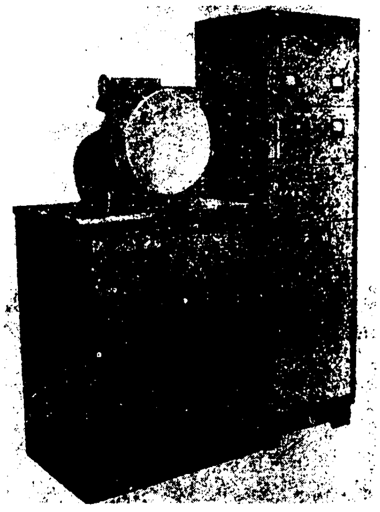


Figure 4.13. The industrial "Elita" periodic ion-plasma atomization installation for difficultly fusible metals and the reactive precipitation of dielectric films.

An example of a semi-continuous vacuum system design using an electron beam vaporizer is the "Elana" installation, which is depicted in Figure 4.14; a block diagram of it is shown in Figure 4.15. The installation consists of three sections: two lock chambers for loading 12 and unloading 3 the flat cassette holders 4 and the working chamber 8. Each chamber has its own individual initial vacuum and high vacuum exhaust systems, consisting of the mechanical initial vacuum pump 1 with absorption trap 2 and the high vacuum oil diffusion pump 13 with a nitrogen trap placed between the pump and the cutoff valve. The vacuum is measured in the chambers by means of thermocouples and ionization sensors 10 with the vacuum gauge 6.

The operational principle of the installation consists in the following. The residual gas is initial pumped out of the entire installation, and then with the cutoff valve 1 and slide valve 2 closed, air is admitted through magnetic infiltration flow regulator 1 into loading chamber 12. After the vacuum is eliminated in it, cassette holder 4 is placed on the guide plates. After a high vacuum is attained, the cassette holder is moved by means of magnetic coil 5 into the working chamber. The transporting unit 7, which provides for the uniform travel of the cassette, passes it over heater 11 consisting of infrared lamps to increase the adhesion of the films being applied, and then inserts it in the second chamber with two narrow slots for the film application. The precipitation of the films is accomplished in the second chamber by means of an electron beam vaporizer with a copper water-cooled crucible 9, in which the material is continuously fed into the atomization zone in step with the atomization.

Figure 4.14. The "Elana" semi-continuous installation with the panels removed.

After the application of the film to the substrate, the cassette holder is extracted by means of magnetic coils 5 from the working chamber and brought into the unloading chamber.

In the operating installation, a high vacuum is maintained for the entire time so as to prevent the intrusion of atmospheric air from the loading and unloading chambers into the working chamber. For these purposes, all of the chambers are separated from each other by high vacuum slide valves, and from the inital vacuum and high vacuum lines by gate valves, magnetic valves KM, as well as electrically and manually driven valves, VEP and VRP. Air is admitted into the chambers and the mechanical pumps by means of the electromagnetic flow regulator N and the manual flow regulators NR.

4.2. Film Precipitation from a Gas Phase

The most widely used techniques for chemical precipitation from a gas phase are the following:

--Thermal decomposition, or pyrolysis, in which a gaseous initial compound is broken down and its components are precipitated on the substrate. Depending on the decomposition temperature, they are broken down into low temperature (less than 600° C) and high temperature (more than 600° C);

--Hydrogen reduction of the vapor of the working compound at an elevated temperature;

--Reduction with metal vapors (for example, Zn or Mg vapors) to precipitate metals from their halogenides.

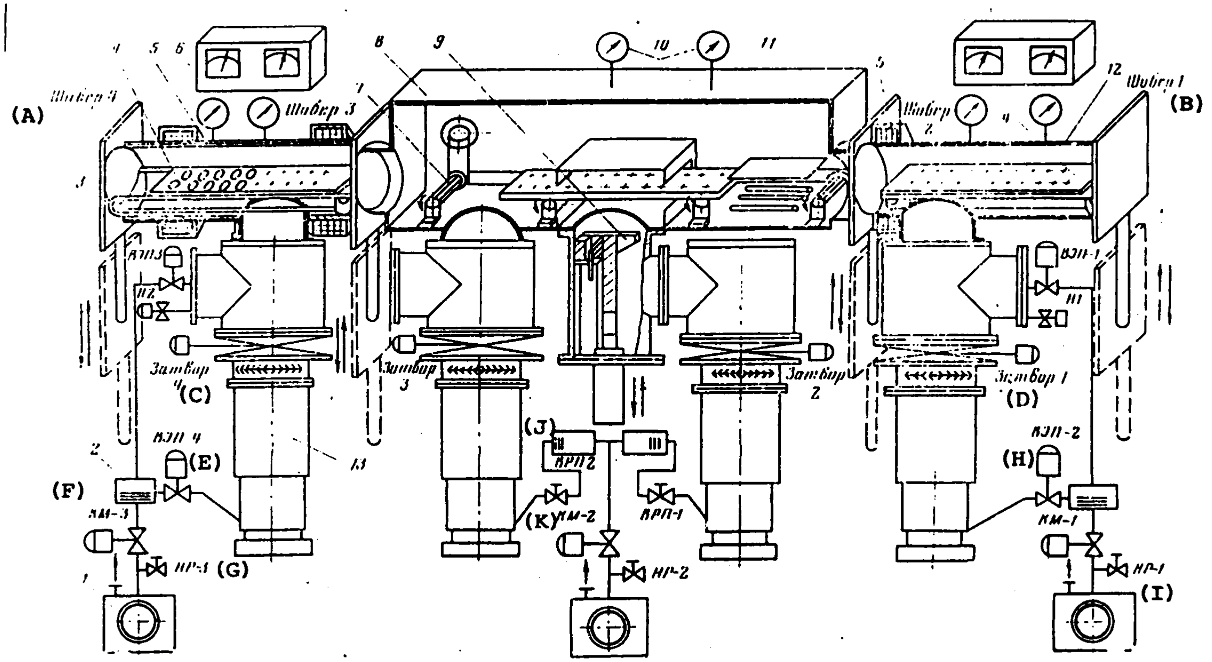


Рис. 4-15. Структурная схема установки полунепрерывного действия с электронно-лучевым испарителем.

Figure 4.15. Structural configuration of a semiperiodic installation with an electron beam vaporizer.

Key:
- A. Slide valve 4;
- B. Slide valve 1;
- C. Cutoff valve 4;
- D. Cutoff valve 1;
- E. Electrically driven valve 4;
- F. Magnetic valve 3;
- G. Manual infiltration flow regulator 3;
- H. Electrically driven valve 2;
- I. Manual infiltration flow regulator 1;
- J. Manually driven valve 2;
- K. Magnetic valve 2.

The most widespread precipitation technique is a thermochemical reaction, for example, the oxidation of the monosilane SiH_4. Doped and undoped layers of oxides can be applied using this method at low temperatures (200 to 250° C). This technique makes it possible to attain high rates of deposition: up to several thousands of angstroms per minute, a figure which is 50 to 100 times greater than the precipitation rate of an oxide using the pyrolysis of tetraethoxysilane at 600 to 700° C as well as improve the quality of the oxide and the adhesion of the oxide layer to the substrate.

The method is based on the monitored oxidation of monosilane with oxygen in dilute mixtures with inert gases, in accordance with the reaction:

$$SiH_4 + O_2 \rightarrow SiO_2 + H_2O$$

and provides for the possibility of doping silicon dioxide with boron, phosphorus, arsenic and other impurities during the precipitation process.

The following processes have been developed at the present time to obtain passivating coatings:

--Precipitation from a gaseous phase at normal pressure;

--Precipitation from a gaseous phase at low pressure;

--Precipitation from a gaseous phase in a plasma.

Types of reactors in installations for chemical precipitation from a gaseous phase are described in §3.4.

An example of an installation with a reactor operating at normal pressure and at low temperature (less than 700° C) is the "Oksin-3" installation. The structural design of the reactor of this installation which is intended for the precipitation of silicon dioxide films, both phosphorus doped and undoped films, is shown in Figure 4.16. Three reactors, arranged one on top of the other, are used in the installation to increase its productivity. Square cross-section reactor tube 4, which is made from stainless steel or quartz, has the flanged end secured in head 10 of plate 9 and is sealed with washers 8 and 11 made of silicone rubber. Diffuser 7 with twin gas injection to feed the working gases from the gas distribution 7 into the working region through connecting tube 12 is positioned in head 10. The open end of the tube is secured in the clamping unit by means of moving clamps 6 with adhesive washers 5 made of silicone rubber.

The clamping device is fastened to the fan ventilation housing 2 of the mounting stand. The spend gases are exhausted into the exhaust ventilation through the open end of the tube.

The electric heater 3 is made in the form of tubes 16, which are built into graphite plate 17 along with thermocouple 15. The quartz plate 13 with the substrates 14, on which the dielectric layers are applied, is placed on the graphite plate.

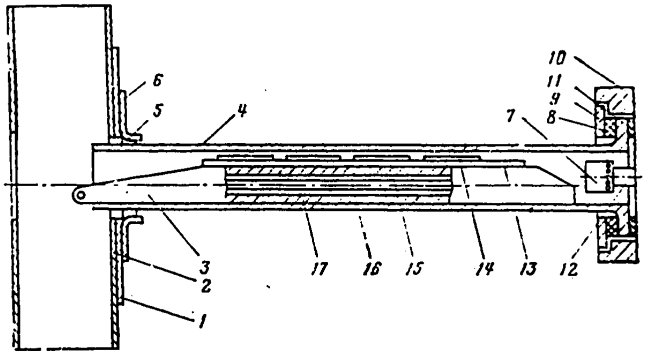


Figure 4.16. The structural design of the reactor of the "Oksin-3" low temperature silicon oxide precipitation installation with an internal resistive heater.

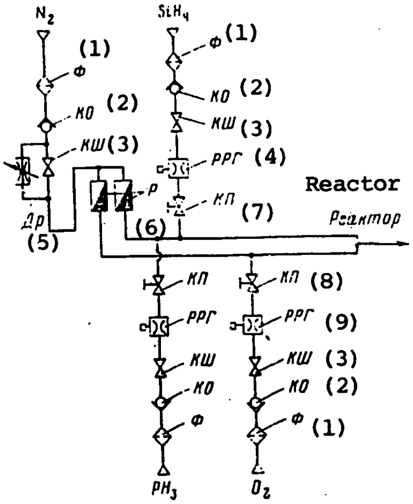


Figure 4.17. Pneumatic configuration of the gas distribution system for the "Oksin-3" installation.

Key:
1. Filter;
2. Check valve;
3. Ball valve;
4. Gas flow rate regulator;
5. Restrictor;
6. Direct reading flow meters;
7, 8. Pneumatic valves;
9. Gas flow rate regulator.

The temperature in the reactor does not exceed 600° C.

The gas distribution system for the input and regulation of the feed of the working gases into the reactor, in particular, silane, oxygen, nitrogen and the doping gas phosphine or diborane, is shown in Figure 4.17. A filter F is installed at the system input to scrub the gases. In the figure, one line is used to indicate each gas. Where necessary, one can increase the number of regulated channels to feed in appropriate additional gases. The gas distribution components are connected to each other and to the main delivery lines through pipe filters made of stainless steel. Gases can be fed into the installation both from tanks and from a centralized network. A specific feature of the operation of the gas system of the installation is the capability of the simultaneous operation of all reactors. The gas system consists of the nitrogen, oxygen, phosphine and monosilane feed lines as well as the disposal line.

We shall consider the operation of the gas distribution system. Nitrogen is fed in through the filter, the check valve KO, which prevents the reverse flow of the gas, and the ball valve KSh, to the direct reading flow meters R, which serve for monitoring and regulating the nitrogen consumption when diluting the monosilane and phosphine with it. A choke Dr is inserted in parallel with the ball valve, where the choke is intended for providing for the requisite gas rate of flow with the constant flushing of the reaction chamber.

The phosphine feed line also starts from filter F. Then follow the check valve KO to prevent the back flow of the gas, the [ball] valve KSh, the gas flow rate regulator RRG with a digital display, a pneumatic valve (non-return) KP, which allows or cuts off the gas access to the system. The oxygen and silane lines are similar. The gas mixture is fed via two separate lines directly into the reactor.

The installations for film precipitation at low pressures have a number of advantages over the preceding type. At low pressure (1 to 66 Pa), the free path length of the molecules of the regulating gas in the chamber is increased. This makes it possible, by placing the wafers vertically and close to each other, to increase the productivity of the installation (from 80 to 150 wafers/cycle when depositing polysilicon with a thickness of 50,000 Å or silicon nitride with a thickness of 1,000 Å) and does not require a gas vehicle. The substrate holder is heated simultaneously with the heating of the quartz tube, according to the type of diffusion furnace. Dielectric films produced in such systems are distinguished by their high homogeneity and large coefficient of coverage of the relief steps of the substrates. The precipitate adheres to the hot wall of the tube, while the low pressure of the gas does not cause the particles to circulate in the tube. For this reason, the films are distinguished by a minimal number of defects (less than two pores in a wafer with a diameter of 75 mm). However, because of the vertical arrangement of the wafers, the gas flow to the substrates is encumbered and the film deposition rate is reduced.

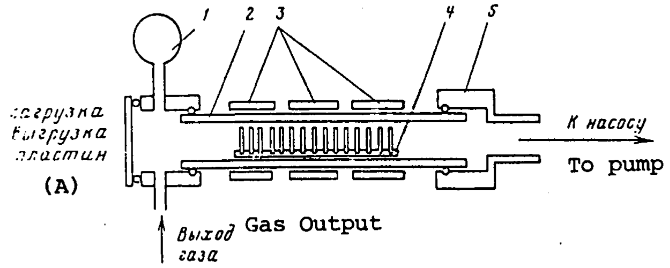


Figure 4.18. Structural design of the reactor of an installation for chemical precipitation from a gas phase at low pressure.

Key: A. Wafer loading and unloading.

A schematic of a reactor with hot walls, which operates at low pressure, is shown in Figure 4.18.

The reaction chamber is a circular quartz tube 2, heated by the three zone resistance heater 3. The tube is secured at the two ends by the flanges 5. The substrates are inserted at a spacing of 3 to 5 mm from each other in substrate holder 4, which is set in the reaction chamber through the left flange 5, which serves for loading and unloading the wafers, and then the cover is closed. The chamber is exhausted from the opposite end of the tube by a mechanical vacuum pump. There is an opening in the left flange for the admission of the reaction gas, the flow rate of which is regulated by pressure transducer 1.

A comparatively new method of film precipitation from a gas phase is the plasma chemical technique. A glow discharge plasma is usually employed. The chemical activity of the reaction gases increases in a glow discharge, as a result of which, for example, silicon nitride films in the reaction of silane with ammonia can precipitate on substrates which are heated up to 300 to 500 ° C, instead of 900° C with the high temperature interaction of the gases indicated above.

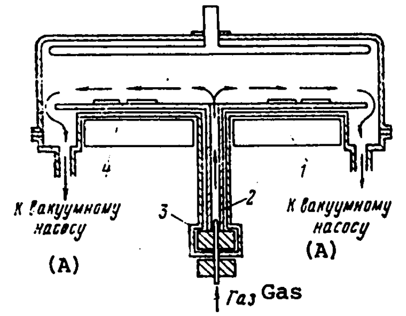


Figure 4.19. Structural design of the reactor of a plasma chemical precipitation installation.

Key: A. To the vacuum pump.

High frequency radiators are used as the plasma excitation sources. The gas pressure, high frequency radiation power, plasma density distribution over the substrate holder, composition of the gases and the temperature of the substrate all influence the uniformity of the thickness and composition of the films.

One of the major factors which has an impact on the uniformity of film thickness is the homogeneity of the plasma density. High frequency capacitor type induction units are used for these purposes, where the electrodes in the forms of discs are arranged parallel to each other. One of them (the lower one) is the substrate holder.

The structural design of a capacitor type reactor for the plasma chemical precipitation of silicon nitride films is shown in Figure 4.19. The working chamber is fabricated from stainless steel. Substrate holder 4 with the plates is one of the high frequency electrodes and is fastened to shaft 2, through which the working gas feed system passes. The substrate holder is rotated by magnetic drive 3 to provide for uniform precipitation of the films on the wafers. The substrate holder can be heated from heaters 1, which are located outside the chamber, up to a temperature of 200 to 300° C, so as to assure satisfactory adhesion of the films in the substrate as well as their density. The pressure in the chamber is maintained at a level of 26.6 Pa, which assures the stability of the glow discharge. The nonuniformity in the film thickness runs up to 5 to 7% and the rate of growth of silicon nitride films is 300 to 400 Å/min at a power dissipation of 0.5 KW. The silicon nitride films obtained in these reactors at low substrate temperatures are used for the passivation and protection of semiconductor devices. Silicon, silicon dioxide and other films are produced by the technique of plasma chemical precipitation from the gas phase.

CHAPTER FIVE EQUIPMENT FOR PHOTOLITHOGRAPHY PROCESSES

Phololithography is one of the major steps in semiconductor production, which governs the quality of the entire technological process as a whole.

Photolithography includes the following main operations:

--The surface preparation of the semiconductor wafer;

--The formation of the photoresist layer;

--The formation of the photoresist relief;

--The formation of the relief in the oxide or metal;

--The removal of the photoresist layer.

In accordance with the steps in the photolithography production process, the equipment is classified according to function:

--For processing the surface of a wafer;

--For applying and heat treating the photoresist;

--For matching and exposing, developing and heat treating;

--For the etching operations.

The processes and techniques of photolithography are in the stage of continuous refinement; this is also related to the diversity of the equipment used for the same processes. For example, the application of photoresist is accomplished by means of centrifuging and atomization methods; developing uses immersion and pulverization methods; heat treatment uses convection and infrared heating, as well as microwave energy in a vacuum and at elevated pressure (thermal compression technique).

Besides the direct improvement of the production processes, the level of automation of photolithographic processes has a direct influence on the improvement in the quality of processing the wafers and boosting productivity. Problems of stabilizing the production process modes, transporting the wafers and eliminating operator contact with the wafers are the ones being primarily solved here.

The first stage in the automation of the photolithographic process was the construction of a series of automatic units which perform the individual production process operations by the group method in accordance with a specified program:

--The photoresist developer unit of the Kulicke and Soffa Industries Company (U.S.);

--The five-position installation for applying photoresist, Macronetics Model 1201 (U.S.): the one and two position units for photoresist application of Plat-General (U.S.).

However, these installations have a serious drawback: the loading, unloading and transporting of the wafers from the working positions to other operations are accomplished manually. Domestic equipment of similar type, with which the "Taran" and "Korund" lines are equipped, also have the same drawbacks. The first attempt to design a domestic computer controlled production complex was the APL automated flow line. The photolithographic operations are carried out on the line using the group method. The photoresist is applied by means of centrifuging from a group drip pan simultaneously for ten wafers, which are located in the common spindle of the centrifuge (Figure 5.1). The developing is done by atomization of the developer. The heat treatment is accomplished by the thermal compression technique, something which has a positive effect: the heat treatment operation is eliminated and the removal of the photoresist is facilitated.

However, all of the high productivity equipment mentioned above, installations with group processing of the wafers, do not meet the major requirement of modern technology: absolute reproducibility of the production process modes for each wafer in a batch.

Recent years in the field of semiconductor machine building have been characterized by the transition from installations which perform individual production process operations to the development of automated lines and complexes.

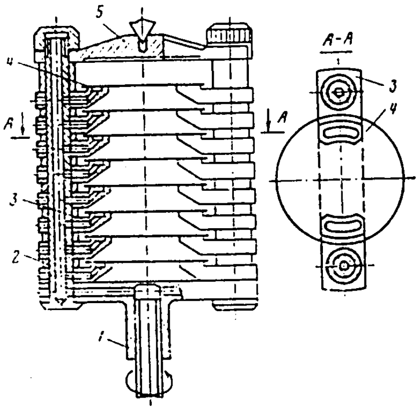


Figure 5.1. A device for applying photoresist coatings by means of group centrifuging.

Key:
1. Base;
2. Receiver;
3. Vacuum suction fitting;
4. Wafer;
5. Cover.

Yet another important trend is observed as concerns photolithography lines: a transition from group processing of the wafers to individual processing, which best meets the main requirement of the production process: its reproducibility.

In step with the refinement of the technology using individual wafer processing, and as a result of solving questions of transporting them to the processing position, it became possible to move on to the next step in the design of automated photolithography lines. In 1971, the Japanese company Toshiba designed an automated photolithography line in which the entire production process is accomplished using a single cassette holder. The American company Industrial Modular Systems Co. [39] developed a system for transporting the wafers on an air cushion, and automatic units were designed using this principle for the application and developing of the photoresist, which had a high productivity and devices for automatically loading and unloading the holders. The first attempts to design automated photolithography lines in domestic industry were the UNT-80 and AFS-100 lines, where the principle of transporting the wafers on an air cushion was employed and a single cassette with a capacity of 30 wafers was used. In the process of operating these lines, a number of deficiencies were ascertained, both structural and production deficiencies, the main one of which was the insufficient reliability of the equipment.

Photolithographic equipment sets and lines, which are based on the following operational principles, most completely satisfy the requirements of the problems posed:

--Individual treatment of the wafers using the "holder to holder" technique;

--Automatic feed of the wafer from the holder to the working position and its reloading into a receiving cassette holder, something which precludes contamination from hands and the damaging of the wafers;

--The control of the sequence and duration of the production process operations by means of a control unit or microcomputer;

--Operation in accordance with a specified program which assures absolute reproducibility of the production process modes, precluding the influence of subjective factors on the production process.

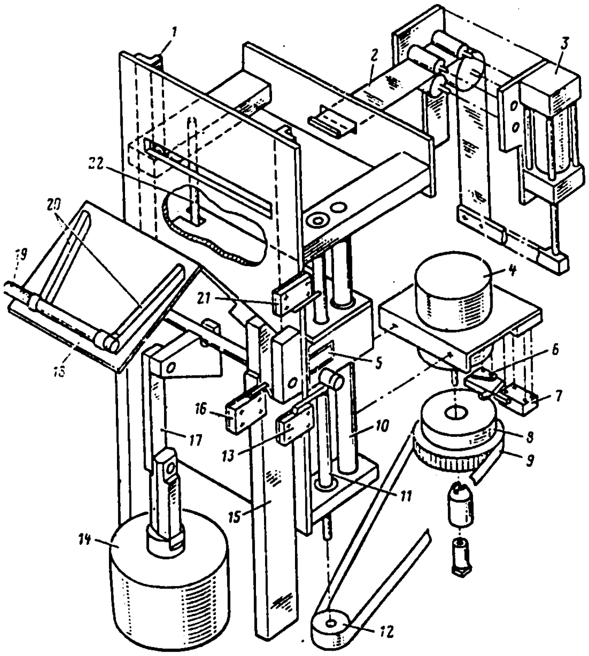


Figure 5.2. A universal loading and unloading mechanism.

Key to Figure 5.2:
1. Guides;
2. Push rod;
3. Pneumatic cylinder;
4. Electric motor;
5. Coupling;
6. Pusher;
7. Microswitch;
8. Pulley;
9. Belt;
10. Guide;
11. Motion screw;
12. Pulley;
13. Microswitch;
14. Pneumatic cylinder;
15. Support post;
16. Microswitch;
17. Pull bar;
18. Pneumatic tray;
19. Photocell;
20. Guides;
21. Microswitch;
22. Rod.

An important organizational component in the functioning of an automated line is the set of cassette holders which make it possible to create universal loading and unloading mechanisms and implement the organizational principle of the production: the operator works only with the cassette holder. The standard structural design of such a mechanism from the "Lada-125" line is shown in Figure 5.2. The photolithography lines which have been developed by various companies make it possible to not only curtail the expenditures for manual labor, but also to optimally limit the intervention of the operator in the production process.

Macronetics and the III Companies put together a line from modular units for hydromechanical washing, application of the photoresist, developing and IR heat treatment. The Cobilt Company produces the Autofab-IV photolithography line, in which there is rigid coupling between the installations. A cassette holder with a multi-shelf configuration with the starting wafers is installed at the input to this line, and the holder is removed at the output with the topological figure already on the plate.

Thus, there are two trends in the construction of photolithographic lines:

--The joining of modular units to individual loading and unloading posts for wafers into holders, which can be rigidly joined in pairs, structurally and in terms of the power supply [lines of the III Company and the Class-1000 line of the Macronetics Company (U.S.), and the "Lada-elektronika" and "Lada-125" (USSR)];

--A rigid line in which the wafer loading and unloading posts are located at the beginning and the end (the "Autofab-IV" line of the Cobilt Company).

The Uniplane 4 000 line of the Kasper Company (U.S.) occupies a special position among those treated here; this line includes centrifuge cleaners, developers and furnaces. The Uniplane 4 000 line is made from modules, each of which can operate independently of the other under the control of its own microprocessor or as part of an overall comprehensive system with complete coupling between the modules in both the forward and reverse directions [18]. The lines described here are distinguished by the transport systems for the wafers, which can be conditionally broken down into three types:

--Wafer transport on an air cushion (Figure 5.3);

--Combination transport (on an air cushion and using a transport carriage) (Figure 5.4);

--Wafer transport on polyurethane belts in a strictly horizontal plane with a smooth change in the carriage travel speed at the outset of the motion and when stopping (Figure 5.5).

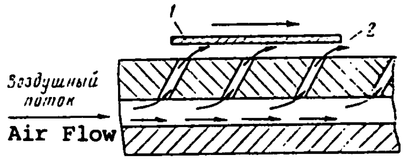


Figure 5.3. The wafer transport system using an air cushion.

Key: 1. Wafer;
2. Carrying flow.

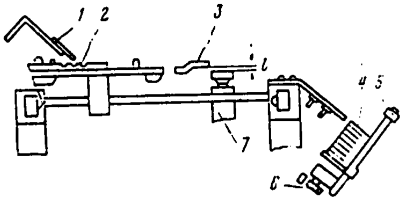


Figure 5.4. The carriage and unloading mechanism.

Key: 1. Sloped tray;
2. Wafer;
3. Cleaner;
4. Holder;
5. Loader;
6. Drive;
7. Centrifuge cartridge.

The latter principle of moving the wafers being processed is the most expedient one, since it precludes shock contact of the end face of the wafer and the loading and manipulating devices: the edge of the cassette holder, the carriage stops, clamps, guides, etc. Such microshocks have been observed in the first two transport methods and have led to damage to wafers, the formation of silicon crumbs and dust, and consequently, to the contamination of the photoresist film, and the fouling and failure of moving mechanisms.

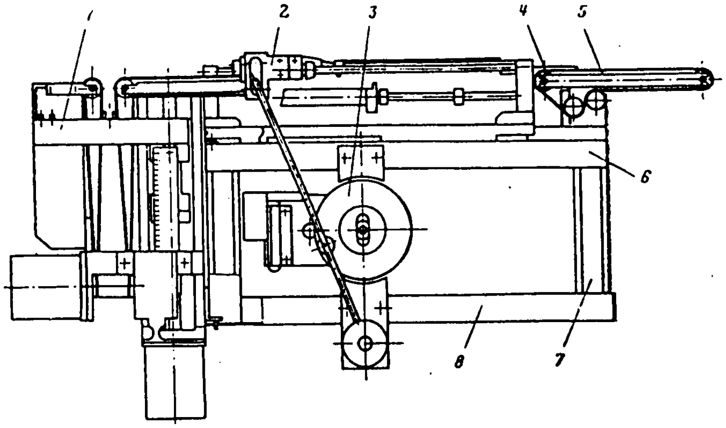


Figure 5.5. The transport system in the "Lada-125" line.

Key to Figure 5.5:
1. Wafer loader;
2. Transport carriage;
3. Carriage drive;
4. Wafer throw-off ejector;
5. Transporter;
6. Upper plate;
7. Support stand;
8. Lower plate.

5.1. Equipment for Preparing the Surface of Wafers

The quality of a photolithographic process is governed in many respects by the preparation of the wafer surface, and for this reason, cleaning is one of the most important operations in semiconductor technology, on the effectiveness of which the electrophysical properties and percentage output of good devices depend.

Surface contamination can be broken down into physical-chemical and mechanical. Physical-chemical contaminants are ionic or neutral impurities adsorbed on the surface which form monolayers and influence primarily the parameters and reliability of the devices. Primarily chemical cleaning methods are used to remove them where these methods are based on the desorption of the impurities when the wafers are treated in solutions, gaseous media and in a plasma [5]. The particles take the form of clusters of the material with dimensions of 0.1 μm and greater.

The complete removal of contaminants is one of the difficult problems in the processing of wafers, for the solution of which primarily physical cleaning methods are employed, which in turn include ultrasonic and mechanical treatment. Of the physical cleaning methods, hydromechanical washing is being successfully used of late, which is coming to replace traditional techniques: polishing with cambric fabric and washing with brushes. The function of a hydromechanical washing installation is to remove mechanical formations: particles of silicon, quartz, dust, etc. from the surface of the wafers.

To assure washing effectiveness, it is necessary to use a fluid with a high degree of purity and to deionize the water, which is filtered through filters with pores of 0.2 μm or less, as the washing medium; the washing is accomplished directly prior to the process which is sensitive to contamination; hydromechanical washing should follow chemical cleaning (in the case where two types of cleaning are combined), since hydromechanical cleaning makes it possible to eliminate those contaminants for which chemical cleaning is not effective. The washing quality and the duration of the production process cycle are governed not only by the reagents used, but also by the material and the structure of the brushes. The brush material should meet the following requirements: it should not change its initial properties in water; it should wash the wafers in accordance with the production process requirements; it should not introduce additional contaminants and defects which have an impact on the quality of the devices; and it should not permit mechanical damage to the wafers being processed.

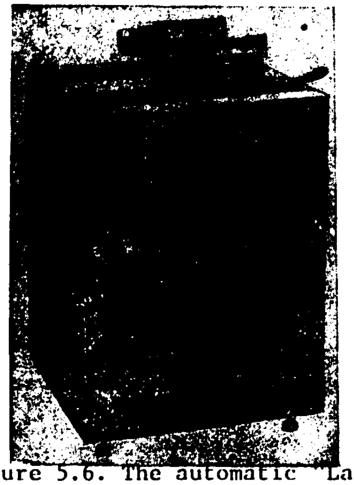


Figure 5.6. The automatic "Lada-125" hydromechanical washer.

Individual treatment of the wafers with a rotating brush, where the wafers are located in a centrifuge cartridge, is employed in the hydromechanical wafer cleaning installations of the "Lada-elektronika" and "Lada-125" (Figure 5.6). The ejection of wafers from the holders onto the transporter, the transporting and placing of a wafer in the working position, the treatment of a wafer, the removal of a treated wafer and its output - all of these operations are performed automatically in a standardized unit for moving wafers, which is the basis for automatic equipment for the hydromechanical cleaning, application and developing of the photoresist. Between cleaning cycles, a brush is flushed with deionized water, washing solution or another fluid which is used for treating the wafers. A brush which is shifted with respect to the center of the wafer and which rotates counter to the wafer motion is used in washing installations with brushes of the 1100 SD series of the Solitec Company. A stream of liquid constantly fed from the center of the brush flushes away contaminant particles. The washing of wafers with cylindrical and conical brushes is shown in Figure 5.7. Along with cleaning wafers with a brush, a number of companies, Macronetics, Cobilt and Kasper, use jet cleaning of wafers. This method is especially effective when removing contaminants from etched channels, where a brush does not reach. The spray cleaning system consists of a well protected atomizing attachment made of tungsten carbide and a stainless steel pump, which delivers a high pressure. The cleaning solution is filtered, and then fed to the rotating surface of the wafer as a pulsed jet stream at a pressure $2.75 \cdot 10^5$ --

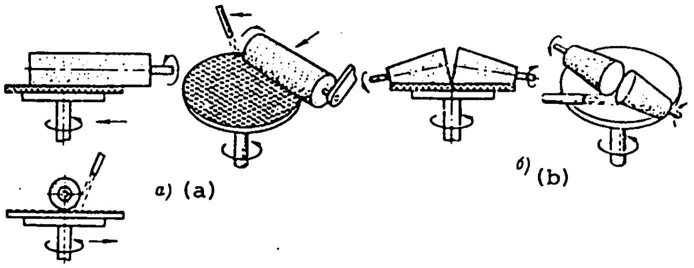


Figure 5.7. Schematics showing wafer washing.

Key: a. With a cylindrical brush;
b. With conical brushes.

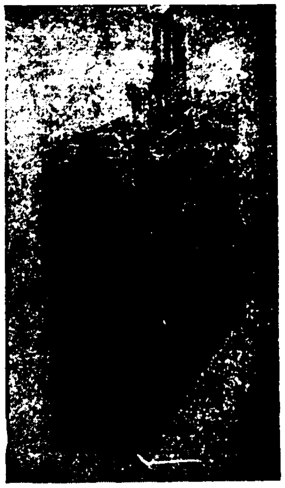


Figure 5.8. The automated Macronetics (U.S.) jet wafer washer.

$2.75 \cdot 10^6$ Pa, depending on the adjustment. During the cleaning cycle, the chamber is hermetically sealed for operator safety (Figure 5.8). In the Kasper hydromechanical cleaner, which is incorporated in the uniplane line, a combination of washing with brushes and atomization of a washing solution under pressure is employed.

5.2. Equipment for Producing a Photosensitive Layer

The production of a photoresist layer is the initial operation of the photolithographic cycle itself, in which the quality of the photolithographic process of a hole is established. The following major requirements are placed on it: high adhesion of the photoresist to the surface of the wafer, uniformity of the photoresist film thickness over the wafer and reproducibility of the thickness from wafer to wafer, a minimal number of puncture holes and the absence of flows of the photoresist to the back side of the wafer.

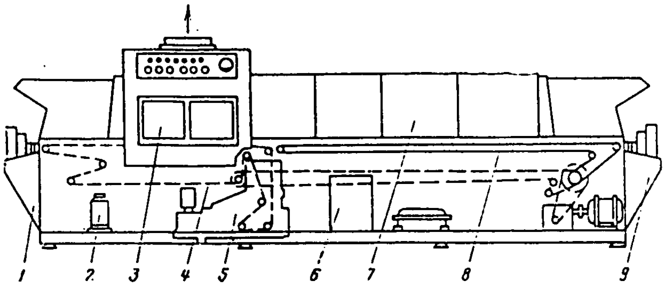


Figure 5.9. Schematic of the unit for applying a photoresist by means of atomization.

Key:
1. Device for loading the semiconductor wafers;
2. Tank for the photoresist;
3. Chamber for the application of the photoresist;
4. Net conveyor;
5. Wafer washer;
6. Pneumatic cabinet [sic];
7. Infrared furnace;
8. Infrared furnace conveyor;
9. Receiver for the processed wafers.

Modern equipment for producing a photosensitive layer, just as for hydromechanical cleaning and developing, is based on the modular equipment principle and incorporates the module for applying the photosensitive layer and module I for the heat treatment of the layer. The existing methods of applying the photoresist include: immersion, rolling, atomization and centrifuging; the latter two techniques are the most useful in IC technology.

The model 265N unit of the In-Line Technology (U.S.) Company can serve as an example of a unit for the application of a photosensitive layer by means of atomization. The unit makes it possible to produce photoresist layers from 0.5 to 2 μm thick with a uniformity of ±6%. The unit is equipped with an automatic loader and unloader. The loading and unloading positions are protected by a plexiglass hood, under which a constant flow of air is provided which is filtered through 0.3 μm pores. The atomizer executes a reciprocating motion over the transporter with the wafers at a variable frequency of up to 60 motions/min [19] (Figure 5.9).

Atomization is the most universal technique for producing a photosensitive layer and applying it to a wafer in the form of a finely dispersed aerosol. The photoresist is broken up into small droplets by a gas flow, which flows around the jet as it exits the nozzle of the injector (Figure 5.10).

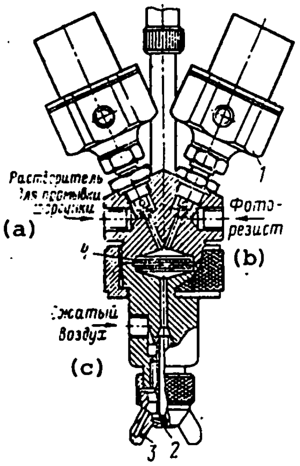


Figure 5.10. Injector for the atomization of photoresist.

Key:
1. Pneumatic valve;
2. Feed hole for the atomized jet of the photoresist;
3. Holes which shape the photoresist flare with compressed air;
4. Filter.

a. Solvent for flushing the injectors;
b. Photoresist;
c. Compressed air.

The merits of the technique are the capability of producing coatings in a large range of thicknesses with rather good reproducibility and a slight scatter in the thickness, as well as the capability of applying the photoresist to profiled surfaces. However, the most widespread method of applying photoresist, as before, remains centrifuging.

During centrifuging, the boundary layer adjacent to the substrate is produced by means of the equalization of the centrifugal and cohesion forces. With a certain approximation, the layer thickness is governed by the viscosity of the photoresist, so that:

$$d = k\sqrt{\nu/\omega} \qquad (5.1)$$

where d is the thickness of the photoresist layer; k is a coefficient which takes into account the concentration of the photoresist; ν is the viscosity; and ω is the angular rotational speed of the centrifuge.

The centrifuge run-up time has an influence on the uniformity of the photoresist layer [5]. To reduce this influence, it is necessary that:

$$t_{run} < 12/\omega \qquad (5.2)$$

For the most useful centrifuge speeds, the run-up time is $t_{run} < 0.1$ sec [20]. The requirements placed on the production process equipment are determined from the requirements placed on the quality of the photosensitive layer:

--The drying of the wafers with nitrogen or with dried and cleaned air (with a dew point of -65° C) prior to the application of the photoresist;

--A centrifuging speed stability in a working range of 500 to 6,000 r.p.m. (a permissible instability of ±5%);

--Minimal and fixed run-up time of the centrifuge (0.1 to 0.15 sec);

--Constancy of the dosage of the photoresist;

--Stability of the centrifuging time.

These requirements are made more stringent for equipment which is intended for processing large diameter wafers, for which the production of a uniform photoresist coating is a problem because of the high linear speed of the edges of the wafers when they are centrifuged at the specified angular speed [21].

Figure 5.11. The "Lada-125" automated unit for the application of photoresist.

The modern photoresist application equipment of Macronetics, III, In-Line Technology, "Lada-elektronika" and "Lada-125", though differing in the system for wafer transport, the number of tra and the diameter of the wafers which can be treated, execute the processing cycle using a common principle: the automatic output feed of the wafers from the cassette holders; the automatic transportation of a wafer to the processing position (centrifuge platform); nitrogen flushing of a wafer; apportioned feed of the photoresist to a wafer; centrifuging a wafer at a specified speed; and automatic transport to the next production process operation. The sequence of the operations, the time for their execution and the centrifuging speed are specified on the control panel of the automatic unit. The automatic unit for the photoresist application which is incorporated in the "Lada-125" line is intended for processing wafers with diameters of 75, 100 and 125 mm (Figure 5.11). The readjustment of the automated unit from one diameter to another reduces to replacing the cutter which provides for centering the wafers on the centrifuge platform, since the loader is adapted for operation with any of the three standard dimensions of the holders and does not require readjustment, while the guides of the transport carriage move to fit any size depending on the wafer diameter.

The control panel has three buttons in all for simplicity in operating the automated unit ("stop", "start", "return"). Changing processing modes is accomplished at the control console, which is covered with a panel and is opened only when

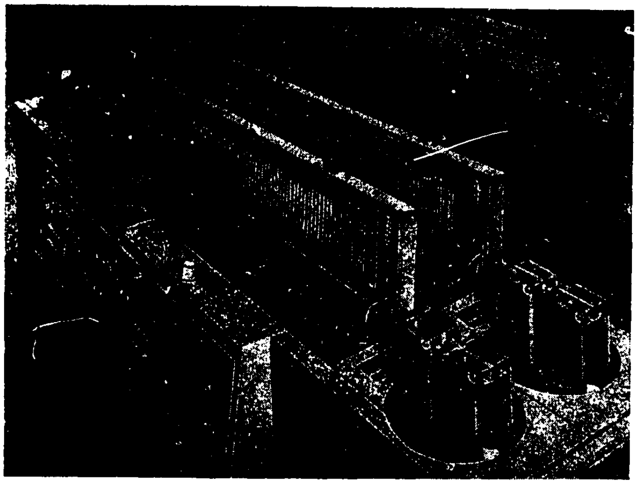


Figure 5.12. Infrared treatment unit (German Democratic Republic).

setting up the automated units. The production process operations are carried out in accordance with the program set on the control console or from a computer. An important feature of the line is the presence of an upper annular exhaust at the working positions of the automatic units (bath-centrifuge), which prevents the intrusion of spray and vapors of the production process media to the wafer during the processing, as well as their contamination of the mechanisms of the automatic units. All of the equipment units in the line automats are made from standardized modules and differ only in the use of a particular assembly which determines their production process assignment. For example, by hanging a bracket on a unit with a brush drive, we have a hydromechanical washer; by hanging a bracket with a dropper, we make an applicator; by hanging a bracket with injectors, we obtain a developer. The control units are the same for any of the three automated units and differ only in the interchangeable panel for the switching of the production process modes for treating the wafers. Optimum productivity is achieved through the functioning of one or two tracks.

Heat treatment operation I, which completes the process of producing a photosensitive layer, has the purpose of removing volative components from the film. To provide the masking properties, it is necessary that this operation does not lead to a weakening or to point breaks in the photoresist layer, which can occur during rapid evaporation of the solvent [5].

Infrared heating is used for the heat treatment in modern photolithography lines. Infrared lamps (Figure 5.12) [the unit made by the UEB Elektromat Company (GDR)] and dark infrared radiators are used as the heaters.

Figure 5.13. The "Lada-125" infrared conveyor furnace.

Figure 5.14. The automated "Lada-125" photosensitive layer developer.

The domestic heat treatment units incorporated in the "Lada-elektronika" and "Lada-125" lines are equipped with "dark" IR radiation sources in the form of a thin current conducting film applied to a sheet of quartz glass. The heat treatment in IR conveyor furnaces of the "Lada" type (Figure 5.13) is accomplished in the relatively short time of 2.5 to 5 minutes with continuous nitrogen flushing. The duration of the heat treatment is set by the travel speed of the conveyor. The temperature is maintained automatically in the furnace with an ultimate deviation in the zones of the heaters of ±5° C, which is permissible even for heat treatment II of the photoresist, which requires greater precision in the maintenance of the temperature. Infrared conveyor heat treatement installations, just as all automatic "Lada-125" lines are made in a two track variant. Each track operates independently of the other. While in the IR conveyor heat treatment unit incorporated in the "Lada-elektronika" line the shutdown of the conveyor curtain means the shutdown of the entire module, in the "Lada-125", with the shutdown of one track of the furnace, the other can continue to operate.

5.3. Equipment for Producing Relief in a Photosensitive Layer

Developing a photosensitive layer is a process on which the precision of the reproduction of the geometric dimensions of the topological elements depends.

In the developing process, because of the different rates of solution of the exposed and unexposed portions of the photoresist film, a relief image of the topology is produced in the developer [20]. The technique of atomizing (or pulverizing) the developing solution is the primary one in the modern equipment of both the leading foreign companies (Macronetics, GCA, III, Kasper) and domestic industry ("Lada-elektronika", "Lada-125") (Figure 5.14).

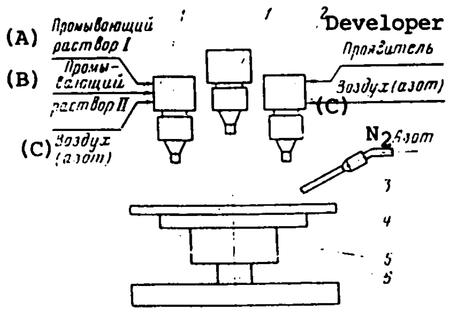


Figure 5.15. The pulverization wafer treatment technique.

Key:
1. Washing injector;
2. Developing injector;
3. Nozzle;
4. Wafer;
5. Centrifuge holder;
6. Centrifuge.

A. Washing solution I;
B. Washing solution II;
C. Air (nitrogen).

The pulverization method (Figure 5.15) is advantageously distinguished from the obsolete method of immersion developing in that it makes it possible to speed up and automate the developing process. The developing cycle in the "Lada-125" automated line consists in the sequential execution of the following operations: developing; first washing; second washing; and drying.

The time for the execution of each operation is adjusted in a range of from 0 to 99 seconds in discrete steps of 1 second.

Provisions are made for operating the automated units in three modes: automatic, semiautomatic and manual.

5.4. Pattern Matching and Exposure Equipment

In the execution of the photolithography process, operations of transferring the image of the IC components and semiconductor device from the photographic template to the wafer, coated with the photoresist film, and the precise matching of the image of the IC components on the photographic template to the image on the wafer are of great importance.

The main characteristics of semiconductor devices and integrated circuits, and in the final analysis, the yield of good devices, depend on the quality of the performance of the pattern matching and exposure operations.

Several methods exist for transferring the photographic template image to the wafer.

The contact technique: the photographic template, after being matched, is brought in contact with the wafer, after which the photoresist is exposed with ultraviolet rays through transparent portions of the figure on the photographic template. The exposure quality depends in many respects on how complete a contact is made between the photographic template the wafer, and how precisely the images of the photographic template and the wafer are matched up.

Photolithography with a constant gap between the photographic template and the silicon wafer: this method is similar to the contact method, but following the matching of the images of the photographic template and the wafer, a gap of from 5 to 20 μm is maintained between them which prevents damage to the photographic template.

The projection technique: the photographic template image is projected onto the wafer through a special high resolution objective lens.

The electron lithography process for the generation of IC topology as a result of the nonthermal action of an electron beam on the resist [sic].

The holographic technique is a process of photographically recording the image, in which case, the wave pattern of the light scattered by the objective is registered on the photoresist; the capability of reproducing the optical pattern of the photographic object is assured in this case.

The X-ray radiography is the process of exposing the photoresist with soft X-rays with a wavelength in a range of 5 to 50 Å.

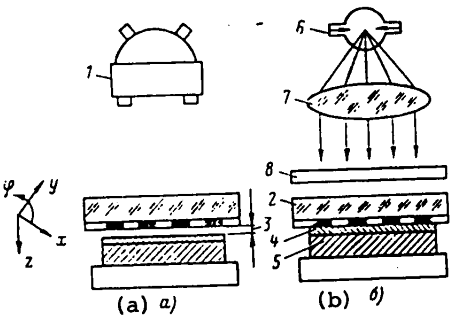


Figure 5.16. Basic configuration of a contact exposure and matching unit.

Three methods of image transfer have found practical application in production at the present time: contact, projection and electron beam exposure.

In light of the high requirements placed on the match-up precision (the error should not exceed fractions of a micron), this process is carried out on special precision equipment: image exposure and matching installations which are complicated optical-mechanical complexes. The installations are characterized by the method and precision of matching, the resolution, the contact quality, the productivity, the service life of the photographic templates (the wear rate) and the permissible dimensions of a wafer.

The basic configuration of a contact unit for exposure and matching is shown in Figure 5.16. The major components of the installation are the microscope 1 for visually monitoring the matching process, photographic template 2, at a definite distance from which 3 (the spacing is less than the depth of focus of the microscope) wafer 4 is positioned. During the match-up process (Figure 5.16a), the wafer is moved along the X and Y coordinates and with respect to

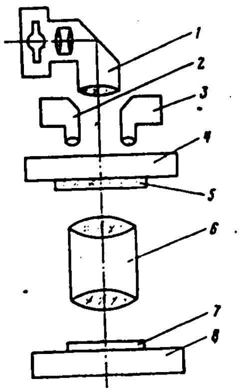


Figure 5.17. Basic configuration of a projection exposure and matching unit.

the angle ϕ on coordinate table 5. After the match-up has been made with the requisite precision, the wafer comes in complete contact with the photographic template and it is exposed (Figure 5.16b) by the high pressure mercury vapor lamp 6 through shutter 8 and condenser lens 7, which provides for the requisite illumination uniformity over the entire surface of the substrate. Projection matching and exposing installations make it possible to avoid contact between the substrate and the photographic template, which improves the durability of the photographic template and promotes an increase in image resolution.

Projection photolithography systems are subclassified as the following types according to the method of generating the image on the substrate: with simultaneous transfer of the image in the field of the wafer; with sequential multiplicative transfer of the image; and with sequential scanning transfer of the image. These systems (Figure 5.17) contain the illuminator 1, the matching and focusing device (manual or automatic) 2, the match-up monitor unit 3, the match-up manipulators 4, on which photographic template 5 is placed, which is projected through objective lens 6 onto wafer 7, which is positioned in the manipulator (coordinate table) 8. The projection objectives can be the same for the different photolithography systems. Images of the elements of a semiconductor device to be exposed can be transferred by means of them from the photographic template to a wafer with a working field of up to 50 to 80 mm.

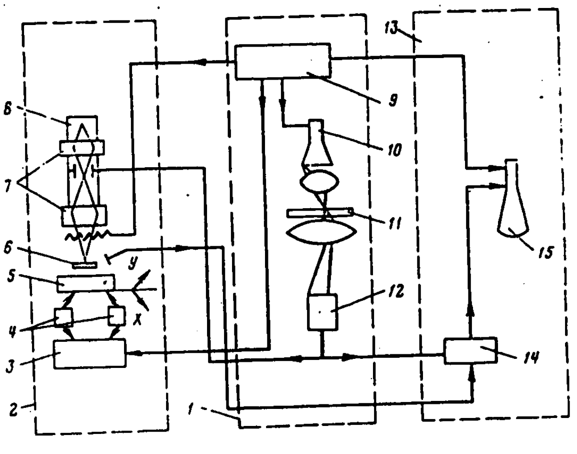


Figure 5.18. Basic configuration of an electron beam exposure installation.

Electron beam exposure installations consist of a large number of complex devices [22]. The typical electron beam exposure unit (Figure 5.18) consists of three major assemblies: the photocopier or remote copier 1, the electron optics column with the exposure chamber 2 and the video monitor 13. The electron beam from kinescope 10, in passing through the focusing device, scans the topology on photographic template 11 and transfers the information to photomultiplier 12. The information from the photomultiplier is fed to the control unit 14 of the video monitor with kinescope 15 and controls the electron beam which is generated by electron gun 8 and electron lenses 7. The electron beam acts on the photoresistive layer on the surface of substrate 6. Block 9 serves to control the beam deflection system and drives 3 and 4 for moving coordinate table 9.

In other types of installations, the control of the electron beam motion is accomplished by means of a specialized computer, into which a program is fed which provides for the requisite topology on the substrate.

The technique of matching the photographic template and substrate with visual monitoring of their position relative to each other by means of base markers (matching characters) has become the most widespread one in microelectronics. The matching process can be carried out by the operator, who visually monitors the mutual position of the photographic template and the substrate, and moves them by means of the micromanipulator until they match. In the case of automatic matching, a photoelectric device analyzes the position of the matching marks on the substrate and the photographic template, generates an error signal, which is fed to the micromanipulator drive and causes the substrate to move. In the case of complete matching, the error signal disappears and the drive is cut off.

The precision and productivity of matching installations with visual monitoring depends in many respects on the subjective aspects of the operator also (visual acuity, etc.).

As a result of refining the structural designs for the major and auxiliary mechanisms of contact matching and exposure installations using visual monitoring, a productivity of more than 100 pieces/hr and a matching precision of 0.5 μm (Table 5.1) have been successfully achieved [23].

We shall consider the structural design of contact matching and exposure installations in more detail as well as the major requirements placed on their component assemblies.

The major mechanisms of matching and exposure installations are the following:

--The match-up micromanipulator;

--The mechanism for orienting the plane of the substrate;

--The template holder;

--The loader;

--The contact exposure unit;

TABLE 5.1. Comparative Characteristics of Contact Match-Up and Exposure Equipment with Visual Monitoring

Parameters	EM-576 USSR	CA-280 OH Cobilt U.S.	J & B 2108 VEB Electromat GDR	CA-2020 Cobilt U.S.	CA-300 Cobilt U.S.	PLA-520A Canon Japan	PLA-500A Canon Japan
Error in matching the elements of the phototemplate and the substrate, μm	0.5	0.5	0.3	0.125	0.75	-	-
Size of the minimum image element on the substrate, μm	2	1	1	1	2	0.5	3
Substrate diameter, mm	60, 76, 100	up to 100	up to 76	up to 100	up to 76	up to 100	up to 125
Productivity, pieces/hr	160	-	130-150	-	-	90-100	100
Microscope magnification, times	94, 257, 208	-	200	-	-	-	-

--Microscopes for visual monitoring.

The Match-Up Micromanipulators. The matching process places a number of requirements on micromanipulators, the most important of which are the following: a micromanipulator should assure independence of the coordinate motions, sufficient dimensions of the fields, high sensitivity, a definite algorithm for the motions, and motions in a plane parallel to the plane of the photographic template. Because of this, there are various structural designs for match-up micromanipulators.

One of the first structural designs of a match-up micromanipulator was a rotating coordinate motion table with guides for rolling and a screw drive. The sensitivity of the manipulations during the final matching in this type of micromanipulator depends on the kind of drive and the stiffness of its coupling to the table. A drive from a micrometer screw transmission is most frequently used. To assure sensitivity of the microdrive down to tenths and hundredths of a micron, a two stage drive with a lever transmission for the fine step is employed [24]. A two stage lever drive is also used in micromanipulators with a two-coordinate table. Besides the screw and lever drives, an eccentric drive is used for rectilinear motions in micromanipulators with a two-coordinate table on roller guides. A screw mechanism is used in the majority of cases as the rotation drive in the manipulator, though sometimes a worm gear drive with power locking.

Drawbacks to the coordinate-rotational design of micromanipulator tables are the complexity, cumbersome nature and difficulty in assuring that the three motions are parallel in the plane of the photographic template.

In micromanipulators with a flat table and a pantograph drive, the lack of parallel motions of the plane of the photographic template is reduced because of the fact that the number of working surfaces is reduced (two). However, micromanipulators with a pantograph drive do not provide for the requisite independence of the coordinate motions during the matching [23].

The structural design of a micromanipulator with a magnetostrictive drive is of interest. A drawback is the small motion field [23].

Manipulators are capable of providing a motion precision of ± 0.1 μm, but the actual precision of a match-up with visual monitoring usually amounts to ± 1 μm.

The mechanisms for orienting the plane of the substrate perform two major functions: they arrange the substrates strictly parallel to the working plane of the photographic template and move the substrate with high precision when contacting the photographic template. The major requirements placed on the orientation mechanism are precision in the vertical motions of the substrate, the preservation of the working surfaces of the photographic template and the substrate during orientation, as well as assuring a complete contact between the substrate and the photographic template and minimal displacements of the matched substrate when it is contact with the photographic template. In the majority of the well-known exposure and match-up units, the orientation of the plane of the substrate relative to the photographic template is accomplished by means of a small spherical table. Following the equalization of the plane of the substrate, the position of the sphere is clamped by means of a vacuum. A small table on three floating supports is also used for the orientation of the plane, however, the friction in this case between the substrate and the photographic template and the normal force is somewhat greater than when a small spherical table is used. The precision of the vertical motions of the substrate and the displacement of the substrate when in contact with the photographic template depend on the precision and stiffness of the guides and the points of application of the resulting force during contact. The resulting vertical load vector runs through the center of gravity of a triangle, drawn through the points of contact of the substrate and the photographic template, and rarely coincides with the center of the substrate.

The most diverse types of guides are used in the well-known installations: cylindrical sliding guides, prismatic roller guides with power locking, guides in the form of a parallelogram with flexible hinges [22, 24, etc.].

The orientation mechanism, following the match-up, presses the wafer against the photographic template and assures contact between the surfaces. The quality of the resulting figure during exposure depends to a great extent on how complete the contact was between the substrate and the photographic template. The change in the dimensions of the elements and the increase in the photometric wedge, which occur as a result of diffraction phenomena and multiple light reflections from the surfaces of the wafer and the metalized photographic template, are in direct proportion to the gap between the template and the wafer.

The difficulties of producing a tight contact are due, first of all, to local uneven places on the wafer with a height of up to 1 μm, which occur during the polishing process, during epitaxy and even during photolithography itself; and secondly, they are due to distortions of the wafer because of exposure to various production processes, especially heat treatment. However, the considerable ratio of 1/100 - 1/250 between the thickness (usually 0.2 to 0.3 mm) and the diameter (20 to 75 mm) imparts adequate elasticity to semiconductor wafers [25].

To assure contact between a wafer and a photographic template, a provision is made in a number of orientation mechanisms for power clamping of it by means of pneumatic cylinders or a lever mechanism, in which the clamping force is produced by an adjustable compression spring.

A more refined approach is to press the wafer against the photographic template using air pressure following the creation of a vacuum between them.

Loaders and Template Holders. In installations intended for working with emulsion photographic templates, the thickness of which changes little, the latter are secured to a template holder on the bottom, to the nonworking surface by means of a vacuum. In installations which allow the use of photographic templates, the difference in the thickness of which runs up to several millimeters, mechanical fastening of the photographic template in a template holder is employed (for example, by means of a bayonet lock).

The wafers are loaded by means of satellites, arranged on the rotating disk of the installation, or by means of moving from the loading position into the working zone, and then to the unloading table by means of a push rod. Further automation of the wafer unloading and loading in pattern matching installations led to the appearance of a pneumatic transport system with a device for the preliminary orientation of the wafers to line up with a cut out segment or a cut out groove [23].

The Contact Exposure Assembly. The contact exposure assembly includes a light source, an optical device to produce a light flux, a mechanism for controlling the transmission of the light flux and a housing for holding the light source.

The optical device in a contact exposure assembly is intended for producing a uniform light flux with a parallel bundle of rays in a definite range of wavelengths over the entire exposure field. The exposure field diameter in modern installations should amount to more than 75 to 100 mm, while the scatter in the illumination over the entire field should not exceed 5 to 10%. Such parameters can be assured by special systems of quartz condensers, having from 1 to 5 lenses. Moreover, in order to segregate a particular wavelength which is most suitable for the photoresist being used from the overall radiation spectrum of the lamp, it is necessary to have a set of appropriate light filters

[22]. Uniform illumination over the exposure field is one of the major requirements for a high quality photolithographic process. The illumination system plays an important part in this case.

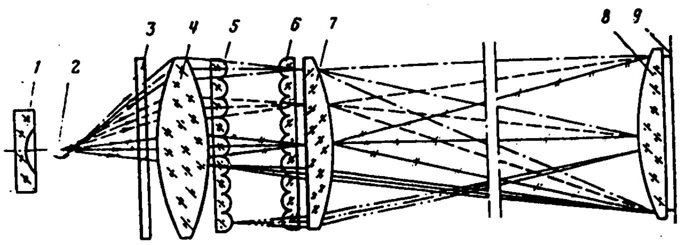


Figure 5.19. Optical configuration of a scanning illumination system.

A scanning raster illuminator satisfies this requirement (Figure 5.19) [26]. The light source (a DRSh-250 lamp, 2, in the focal plane of spherical mirror 1) projects through the thermal filter 3 with condenser 4 onto lens raster 5; following magnification by the lenses of raster 6, the mutually superimposed light spot images of the source (the number of spots corresponds to the number of raster lenses) are projected through lens 7 to the plane of the photographic template 9 (close to lens 8).

In this case, the high uniformity of the illumination of the photographic template is accompanied by a reduction in the influence of spatial and time instability of the light flux from the DRSh lamp.

The mechanism to control the transmission of the light flux, the shutter, is needed so as to set the requisite exposure time, which depends on the sensitivity of the photoresist. The exposure time can fall in a range of from 1 second to 2 minutes and more, and for this reason, the major requirement placed on the shutter consists in the fact that the opening and closing time of the blind be on the order of 0.05 to 0.1 sec, while the relative actuation error does not exceed 10%. Electromagnetic shutters which meet these requirements are used in modern installations.

The light, condenser and shutter are housed in a single block. The block makes it possible to correctly adjust the lamp relative to the optical axis of the quartz condenser and protect the operator and light sensitive materials against the harmful effect of ultraviolet radiation. The structural design of the housing should assure normal thermal conditions for lamp operation. In the majority of installations, the housings for the lamps are air-cooled [22].

Visual Inspection Microscopes. The precise mutual positioning of the matched structures is determined by means of a microscope for the visual observation and quality control of the matching.

The major requirement placed on the microscope consists in the fact that it should provide for a clear image of the two structures being matched, which are located in different parallel planes at a certain distance from each other during the match-up time, as well as during the time when the quality of the matching is monitored after the pressing of the wafer against the photographic template. In contact exposure and matching installations, the following parameters characterize the microscope: the overall magnification determines the structure image scale; the resolution determines the smallest visible size of a structural element; the depth of focus determines the working gap during the match-up time; the field of view determines the observation area; and the working distance determines the thickness of the phototemplate glass and the structure of its holder.

These parameters are interrelated, depend primarily on the characteristics of the objective used and are designed using the laws of optics.

The basic design quantity is the numerical aperture of the objective, which is estimated from the formula:

$$A = n \sin u$$

where n is the index of refraction of the medium; u is the angle formed by the rays from the point source, positioned on the optical axis of the objective in the first main focal plane, to the ends of the diameter of the objective.

The numerical aperture defines the overall useful resolution of the microscope and the resolving power: with an increase in the aperture, the objective resolution increases ($\delta = 0.61\lambda/A$, where λ is the wavelength of the light), but the depth of focus decreases ($\Gamma = \pm \lambda/2A^2$). The decrease in the depth of focus is accompanied by more stringent requirements placed on the quality of the substrates, on the precision of the positioning of the wafers, the manipulation of them, etc. Thus, if an objective has an aperture on the order of 0.5, then the resolution will be about 0.6 μm, while the depth of focus will be on the order to 2 to 3 μm, which makes it very difficult to match-up actual semiconductor wafers which frequently have a considerable curvature.

To match-up elements with dimensions of 2 to 5 μm, it is necessary that the objective have an aperture of at least 0.2, then the useful magnification will be 200 x, the depth of focus will be on the order of 10 to 15 μm while the working field will be about 1 to 3 mm. However, such a working field for a microscope is many times less than the size of a wafer. For this reason, it is impossible to check the match-up quality over the entire wafer and it is easy to allow an angular shift, because of which considerable linear error occur in the matching of the elements remote from the working field. This circumstance has led to the design of special microscopes, which make it possible to observe in the field of view of the ocular two sections of the wafer being matched-up at the same time where these sections are a certain distance apart. The structural designs of two field microscopes can vary: with a separate (split) field and with a double field.

The images from the two objectives are brought to the field of view of the ocular independent of each other, where this field is split into two sections so that the image from the right objective falls in the right portion of the field of view while that from the left objective falls on the left side. The operator has the capability of simultaneously observing both portions of the wafer being matched (split field microscope).

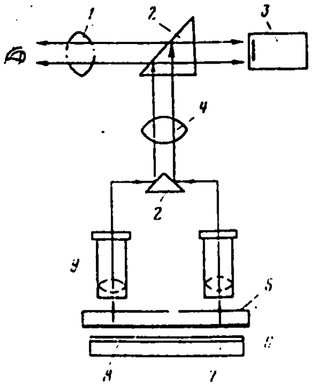


Figure 5.20. Optical configuration of a microscope with a built in TV camera.

As a rule, microscopes are used which have a magnification which changes continuously or discretely in a range of from 40 to 80 x (survey) to 100 to 400 x (precise matching); the minimum image size is 1 μm.

In step with the miniaturization of topology, observing using standard microscopes having a magnification up to 400 x and a resolution in a range of 1 μm is made difficult. At the present time, equipment has been developed in which the microscope magnification can be switched in steps to 500, 1,000 and 2,000 x. Such microscopes have a high resolving power of 0.45 μm. Moreover, a remote camera is incorporated in one of the blocks of the microscope optical system, which makes it possible to observe the topology on a screen, determine the presence of dust and defects in it, etc. The operational principle of a microscope with a built in television camera can be seen from Figure 5.20. Wafer 8 is located on stage 7, where the photographic template 5 with the topological figure 6 is placed a certain distance from the wafer. The image of the wafer surface and the topological figure of the photographic template are perceived by the eye through the objective 9, the field splitting prism 2, intermediate lens 4, beam splitting prism 2 and ocular 1. A portion of the rays is fed through the beam splitting prism to the vidicon of TV camera 3. One such exposure and matching installation with a television screen is the unit made by the American company III.

It must be noted that units for matching with visual monitoring and with contact exposure are the most widespread at the present time.

A drawback to the contact technique is the rapid wear of the photographic template.

The automated EM-576 unit can be cited as one of the industrial models of a matching and exposure installation. An automated cassette holder for transporting the wafers and a device for their preliminary orientation are included in the unit, which makes it possible to use it both independently and incorporated in automated photolithography lines. The installation makes it possible to use both contact exposure and exposure with a gap.

Its main parameters:

Productivity (without taking the match-up time into account), wafers/hr	160
Match-up error, μm	0.5
Minimum size of the components on a semiconductor wafer with contact exposure, μm	2
The diameters of semiconductor wafers for the case of exposure with a gap, mm	60, 76, 100

The installation can operate under conditions where vibrations act on it in a frequency range of 1 to 5 Hz with an amplitude of no more than 5 μm.

The installation includes:

--A precision manipulator and match-up microscope, by means of which a high precision is obtained in the matching of images on a photographic template and semiconductor wafer;

--An illuminator, which provides for good reproducibility of the minimal image elements over the field of the wafer;

--An automated cassette type transport unit for the wafers and a device for their preliminary orientation;

--Interchangeable attachments for semiconductor plates and photographic templates of different standard sizes.

The EM-576 installation can be used either independently or incorporated in the equipment for automated photolithography lines.

5.5. Equipment for Producing Topological Relief on a Substrate

The formation of the topological relief on the substrate completes the photolithographic cycle, which contains the following operations:

--Etching (masking, insulating, protective, conductive and other layers);

--Removing the photoresist;

--Washing (prior to diffusion, metalization and passivation).

These operations can be carried out based on the use of chemical or plasmochemical methods, the specific differences in which are responsible for substantial structural design and functional differences in the equipment used for these methods.

The chemical wafer processing technique is characterized by the following:

--The corrosiveness of the reagents and because of this, the necessity of using closed working volumes, and corrosion resistant structural materials for the functional blocks;

- --Thermostatic temperature control of the working volumes, and because of this, the necessity of using units for stabilizing and controlling the production processes;
- --The necessity of neutralizing the chemical reagents.

The plasmochemical method makes it possible to perform several, and in the future even all of the operations indicated above without using liquid reagents. The wafers are treated in a low temperature oxygen or carbon halide gas plasma, excited in the working volume of the chamber by means of a high frequency or microwave discharge.

Plasmochemical etching provides for greater resolution and control of the etching profile, and reduces lateral undercut etching as compared to chemical fluid etching, which brings about an improvement in the precision of the geometric dimensions of the topology. Various plasmochemical processes may be carried out sequentially in a single chamber. The moment of completion of each process can be easily registered by means of optical spectrum, mass spectrometry, laser, interferometric and other physical contactless testing methods. All of this creates the conditions for the complete automation of the production processes for surface treatment. Moreover, the plasmochemical method of surface processing excludes or considerably reduces the use of chemical reagents, which not only curtails capital expenditures for the construction of cleaning facilities, but also eliminates the contamination of the environment by chemical production wastes.

Universal installations which are incorporated in universal equipment for the chemical treatment of wafers can be used to execute the operations enumerated above for the formation of topology by chemical means.

The functions of the complex are:

- --The cleaning of the wafers prior to the first oxidation;
- --The etching of the oxide layers, the boron silicate and phosphorus silicate glasses;
- --The removal of the photoresist both from the oxide layers and from the metallic surfaces;
- --The cleaning of the oxide layers and the metallic surfaces following the removal of the photoresist;
- --The etching of the metal and silicon.

The complex consists of seven independent lines, where the package is put together depending on the technical function of the installations for the chemical treatment, washing and drying, processing in organic solvents, ultrasonic and hydromechanical washing as well as with quality control units.

The system is filled with reagents from mobile transport blocks and the chemical reagents and deionized water for washing are fed from ultrapure water systems with recycling. All of the equipment of the complex is of a modular block design and can be put together in production process lines which are tied together with the power supply systems. The number of installations which can be assembled into a line is governed by the technological processes and the requisite productivity.

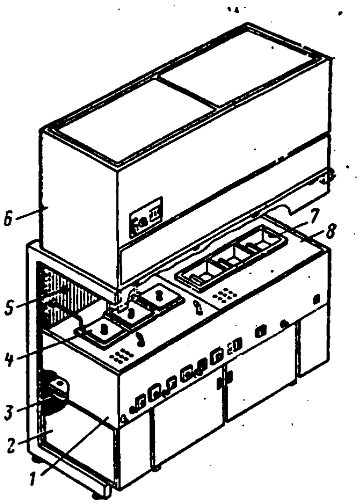


Figure 5.21. A unit for the chemical treatment of wafers.

The most typical is the structural design of the 084KhP-100-004 chemical wafer processing unit (Figure 5.21).

The unit consists of production process and dust removal blocks.

The wafer treatment technique is a cassette holder group type system and has two standard cassette sizes for products either 65 or 75 mm in diameter. Production process block 1 on base 2 is placed on a support for the mounting of the dust removal unit 6. The production process unit is made in the form of a bath made of wood particle board lined with polypropylene. A perforated grate 8 with holes for the placement of the production process baths is located on the flange edge of the bath.

The wafers are chemically treated in various reagents in teflon bath 4, which has an immersion heater. Teflon baths 4 are equipped with ejectors to exhaust the oxygen after the production process is completed. Acid diluted with tap water is drained out at the bottome of production process unit 1 and then through drain pipe 3 to the station for cleaning the industrial effluents. The next step is the washing of the wafers with deionized water and is accomplished in the cascade washing bath 7. The cassette holders with the wafers are moved manually.

For the purpose of preventing dust getting onto the wafers being processed from the production room, the production process blocks are placed in dust removal units 6, which create a laminar flow of dust free air.

The requisite temperature modes are automatically maintained and signal light 5 signals the conclusion of the production process operations.

The controls are located on the front panel of the production process unit.

The technical data on the unit

The number of wafers which can be processed simultaneously, pieces	50
Reagent heating time (volume of 3 liters) to 100° C, minutes	30 ± 5

Reagent working temperature, °C	+50 to +120, ±5
Power consumption, KW	2.3
Overall dimensions, mm	1,915 x 945 x 470

The remaining units of the complex are likewise of a modular block design with maximum utilization of standardized modules.

Plasmochemical Treatment Equipment. The major requirements placed on installations for plasmochemical processing are [27]:

--High uniformity of the distribution of the electrically neutral radicals, atoms and charged particles throughout the entire volume of the reaction space;

--The reproducibility of the energy state of the plasma with respect to time and from process to process;

--High stability of heat and mass exchange in the reaction space;

--Monitoring of the moment of completion of the etching process for one material.

Only when equipment meets these requirements can a high uniformity of surface treatment be obtained.

To meet the requirements indicated above, plasmochemical processing equipment should be controlled with respect to many parameters: pressure, gas flow rate, discharge power, frequency of the RF electrical field and temperature of the wafers.

A high frequency electrical discharge in a low pressure gas is used to obtain a low temperature gas plasma in plasmochemical processing units.

Depending on the kind of operation performed, various techniques can be used to obtain and sustain a plasma as well as various structural designs for the reaction discharge chambers.

For example, a high frequency electrodeless discharge in a cylindrical quartz chamber is used for the removal of photoresist, while a low pressure electrode diode discharge is used in planar metallic reactors for etching.

Plasmochemical processing is carried out with group loading of the wafers, which are placed in the discharge chamber, which is hermetically sealed with a cap by means of a vacuum produced by an initial vacuum pump. Upon reaching a pressure of 40 to 60 Pa, while the initial vacuum pump is running constantly, the variable working gas infiltration is actuated, i.e., a dynamic vacuum is produced which is governed by the geometry and structural design of the chamber and electrodes, as well as the method of excitation and the intensity of the applied RF electric field.

Reaction-discharge chambers of installations for the electrodeless excitation of a discharge are shown in Figure 5.22. Planar reactors with a diode excitation system are shown in Figure 5.23.

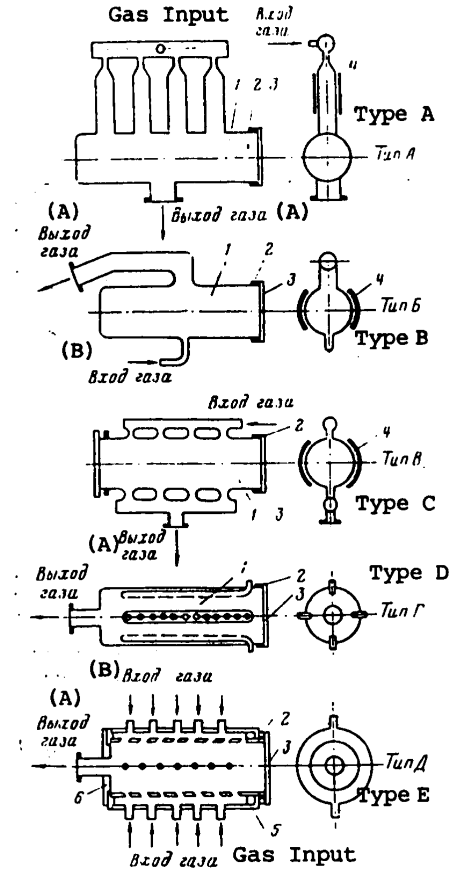


Figure 5.22. Types of reaction discharge chambers.

Key:
1. Reactor;
2. Cap seal;
3. Cap for the reactor;
4. Linings;
5. Receiver;
6. Cap.

A. Gas output;
B. Gas input.

The homogeneity and stability of the plasma in the reaction discharge chamber depend on the pressure in the chamber at the working frequency of the RF field and the structural design of the electrodes [28].

The power of the RF generators in plasmochemical treatment units in cylindrical reaction discharge chambers with electrodeless excitation of the discharge usually amounts to 300 to 1,000 W, while in planar reactors with diode excitation of the discharge, it is 1.5 to 3 KW, and in some cases, 6 KW.

We shall treat the structural design and operational principle of the domestic "Plazma-600" plasmochemical unit for photoresist removal and prediffusion cleaning of the surface of semiconductor wafers (Figure 5.24) with electrodeless excitation of the discharge by means of inductive coupling.

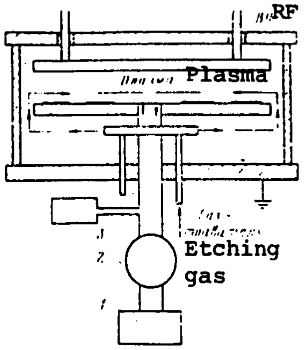


Figure 5.23. A planar reactor with an electronic RF discharge excitation system.

Key:
1. Vacuum pump;
2. Restrictor;
3. Manometer;
4. Lower electrode and stage for the wafers;
5. Upper electrode;
6. Wafers.

The Technical Data for the Installation

Productivity (per photoresist removal operation), wafers/hr	300
Simultaneous loading of the reaction chamber, wafers	up to 50
Diameter of the wafers which can be treated, mm	up to 80
RF generator:	
Output power, watts	600
Working frequency, MHz	13.56 ± 1%
Working pressure of the oxygen in the chamber, Pa	$(0.6\text{-}1.3) \cdot 10^2$
Oxygen rate of flow, liters/min	0.36

The major assemblies of the installation are (Figure 5.24): the vacuum exhaust block 1, the reaction discharge chamber and RF generator block 2, and the control block 3.

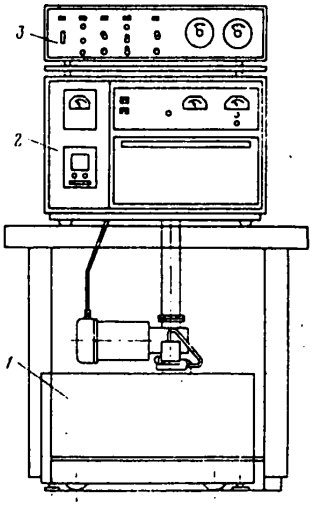


Figure 5.24. The "Plazma-600" plasmochemical unit for photoresist removal.

The low temperature plasma is formed in the chamber at a vacuum on the order of 60 to 133 Pa, when a RF voltage is fed to the indicator placed around the chamber.

Wafers can be sequentially treated in two gas plasma media in the installation. When oxygen is admitted into the chamber at a pressure of up to 133 Pa, atomic oxygen and oxygen ions are formed with the action of the discharge, which have a high chemical reactivity. They oxidize the photoresist, forming volatile compounds as a result of the chemical reactions.

The final products of the photoresist decomposition reaction are CO, CN, CO_2 and H_2O, which are exhausted from the chamber by a vacuum pump.

When freon-14 is admitted into the chamber at a pressure of from 40 to 70 Pa, the action of the discharge forms atomic fluorine, which as a result of the chemical reaction cleans the surface of the wafers of oxides and contaminants.

The chamber and generator block includes the reaction-discharge chambers, the RF generator, the vacuum gauge and the ventilation system for cooling the chambers and generator units.

The chamber takes the form of a quartz tube, which is hermetically sealed in front with a door, and is connected to the vacuum system at the rear. The tube is ringed with the RF induction unit coils.

The process is automatically controlled (creating the specified vacuum, feeding in the working gas, exciting the discharge and breaking the seal). Both automatic and manual operating modes are provided in the installation using two programs: with a single gas (photoresist removal) and with two gases (photoresist removal and prediffusion cleaning).

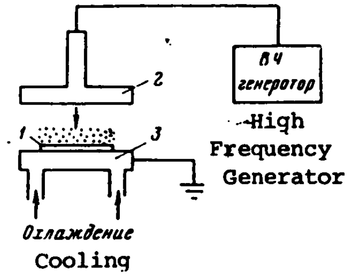


Figure 5.25. Schematic showing a diode discharge in a reaction chamber.

Installations with planar reactors, having diode electrode excitation of the discharge, make it possible to efficiently utilize the plasma to etch silicon dioxide and aluminum with a high level of rarefaction. The Plasafab 3200 unit of the Electrotech Company (England) can serve as an example of such equipment. The installation is an automated rotor type unit with a diode system for plasma excitation. The wafers are positioned horizontally in the reaction chamber. A schematic of a diode discharge in a reaction chamber is shown in Figure 5.25. Wafer 1 is placed between the electrodes in a stainless steel vacuum chamber. One electrode 3 is a water-cooled wafer holder; the gas which forms the plasma between the high frequency field electrodes is admitted to the chamber through the upper electrode 2. The active radicals of the dissociated gas react with the wafer surface, forming a volatile compound. Water-cooled holder 3 makes it possible to maintain a constant temperature for the wafers and protect the photoresist against destruction. The productivity of the unit is 200 wafers/hr with diameters of 76 or 100 mm.

Besides the plasmochemical technique for treating the surface of semiconductor wafers, another method of precision processing is also being developed at the present time: ion-chemical. It is distinguished from the plasmochemical method by the higher energy of the plasma beam of ions and the radicals of fluorine and chlorine containing gases, which is directed onto the wafer being processed at a pressure of (1 to 5) $\cdot 10^{-2}$ Pa. This technique has a great future with the transition to micron and submicron topology.

The development of plasma and ion chemical techniques for precision treatment of the surface of semiconductor materials makes it possible to create a completely "dry" photolithographic process.

Quality Control During Photolithography

Checking the quality of photolithographic treatment in the production of semiconductor devices and integrated circuits is accomplished visually.

The use of optical and mechanical means for monitoring the geometric dimensions of micron and submicron structures is difficult because of the inadequate resolution and depth of focus of light optical instruments. Thus, the unevenness of the edge of an element of semiconductor structures 1 μm wide amounts to about 0.1 μm. The resolving power of the test equipment should be at least 3 to 5 times greater, i.e., should amount to 0.02 to 0.03 μm [30]. When checking microtopology using a conventional microscope, the measurement error is ± 0.5 μm. This estimate shows the unsuitability of optical and mechanical means for quality control of semiconductor structures with micron and submicron dimensions of the elements.

Scanning electron microscopes [31, 32] are being increasingly utilized for this purpose at the present time, where these microscopes make it possible to nondestructively test objects with a resolving power of 100 to 300 Å. However, considering the comparative complexity of electron optical quality control techniques, it is expedient to perform quality control operations at that stage in the technology which has the greatest impact on the production process as a whole. For this reason, it is important to check the quality of structural elements on the photographic template. Quality control of metalized photographic templates using a scanning electron microscope makes it possible to determine the existing distortions of the image, the unevenness of the edge of elements, breaks and pores in the chromium layer, unetched areas and other defects, and thereby reduce the number of rejects in photolithographic operations.

5.6. Equipment for Fabricating Photographic Templates*

The basic tool for producing spatial topology for semiconductor devices and integrated circuits in the photolithographic process is the photographic template. A photographic template takes the form of a transparent substrate, coated on one side with a film which does not pass the actinic radiation, in accordance with the regions which form the specified topological figure. The substrate can be made from optical glass, while the masking film can be made from chromium, metal oxides and other materials.

Photographic templates are manufactured in accordance with the following production process scheme:

--The execution of the original of the topological drawing to an increased scale (200:1, 500:1 and more);

--One-time or multiple reduction of the primary original;

--The execution of the master photographic template by means of printing the images on its working surface (multiplication);

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*The description of the equipment for the fabrication of precision photographic templates as a support production process goes beyond the scope ot the subject of this book, and for this reason, only some individual explanatory data are given below based on materials from the literature [23, 33], which contains considerable material on the question touched upon here.

--The fabrication of photographic copies from the master template (working photographic templates).

The primary original of the drawing of the topology for the photographic template can be produced in two ways:

--By cutting the figure into an opaque varnish film applied to sheet glass;

--By means of phototypesetting using image generators.

In the first case, precision coordinatographs are used, and in the second, phototypesetters. The intermediate reduction of the original is accomplished with reduction cameras, while the final reduction of the photographic template topology and the multiplication are carried out using a scanning camera or photographic duplicator.

To fabricate working photographic templates, the equipment described above as well as photolithographic techniques are employed.

Coordinatographs are broken down according to the kind of control of the motion of the cutting tool, into manual and automatic types, and can differ in the coordinate system employed (cartesian, polar, mixed), as well as in the precision of the execution of the boundaries of the topological elements. The productivity of a coordinatograph is usually related to the precision of the execution of the topological figures. Considerable precision is achieved with a comparatively low output productivity (slow motion of the cutting tool).

Originals of a photographic template topology figure with dimensions of 750 x 750 and 800 x 800 mm for a precision in setting the boundary of a figure element of ± 50 μm and a repeat precision of ± 25 μm can be made on manually controlled coordinatographs, for example, the EM701 and EM707 respectively.

In automated coordinatographs, the working tool moves in accordance with a specified program with computer control. Because of this, an automated coordinatograph contains a set of equipment similar to a production process automated control system of the first functional algorithmic level (see Chapter One): data input-output peripherals, a computer, equipment for controlling the motion of the drawing tool, a control console and various indicating instruments. The major functional unit of an automated coordinatograph is the drawing table.

Primarily low productivity and the cumbersome nature of the equipment can be numbered among the drawbacks to the technique of fabricating originals using coordinatographs.

Characteristic Technical Specifications for Automatic Coordinatographs (Given for the EM-703)

Maximum size of the original, mm	1,200 x 1,200
Minimum step, μm	25

Drawing precision, μm	± 50
Repeat precision, μm	± 25
Resolution, μm	25
Travel speed along the coordinate axes, mm/sec	100
Data input	from punched tape
Data coding	Binary-decimal
Data input rate, characters/sec	1,500
Area occupied, m^2	30

Reproduction cameras for the intermediate reduction of a photographic template original are photographic installations for precise photography and contain the following major assemblies which are characteristic of such installations: a system for uniform illumination of the original, fastening devices for the original, an optical system, a cassette holder with the photographic plate and functional support equipment. The major units of the camera are mounted on a massive cast support bed, which is usually mounted on shock absorbers.

Technical Specifications for the EM-513 Reduction Camera

Maximum size of the plane table of the original, in mm	1,300 x 1,300
Maximum working field of the original, mm	1,200 x 1,200
Dimensions of the photographic plate, mm	90 x 120, 60 x 90
Original reduction scale	30, 40, 50
Conditions for transilluminating the original:	
Screen brightness, Nit	5,000
Brightness nonuniformity, %	up to 10
Motion of the photographic template in the image plane, in mm:	
Horizontally	90
Vertically	100
The precision of photographic plate motion, mm	± 0.002
The precision of the repeat setting of the original, mm	± 0.1
The precision in checking the image dimensions, mm	± 0.002
Exposure time, seconds	0.5 to 999
Overall dimensions, mm	8,600 x 1,790 x 2,165
Weight, kg	2,700

Reproduction cameras, just as coordinatographs, are rather cumbersome.

New methods of producing images, which make it possible to replace the operations of cutting the photographic template original and its intermediate reduction with a single process are based on the utilization of scanning image generators or microphototypesetting installations. When generating images by means of scanning, the light spot moves relative to the photographic plate, for example, by means of using line by line (raster) scanning and modulating the light intensity in accordance with a program corresponding to the photographic template topology. It is expedient to use a laser as the light source.

The realization of a universal scanning image generator involves difficulties of assuring resolution and operational speed. Because of this, the scanning method is usually combined with phototypesetting. Thus, the technique of outline scanning is realized in the form of one of the operating modes of the EM-539 image generator [34].

Microphototypesetting is based on the sequential exposure of fragments (typesetting elements) of the photographic template on the photographic plate. Microphototypesetters contain an automated coordinate table, program and typesetting element generator controllers, an optical projection system and a light source.

Technical Specifications for the EM-549 Phototypesetter

Coordinate table travel, mm	140 x 140
Error in the positioning of the coordinate table, μm	± 0.5
Rotation angle of the typesetting aperture stop, degrees	45
Average productivity, exposures/hr	2,400
Maximum travel speed of the coordinate table, mm/sec	5
Reduction scale	1:10
Minimal width of the image lines, μm	10
Maximum dimensions of the square, μm	3,000 x 3,000
Deviation of the actual dimensions from the nominal, μm	1
Edge unevenness, μm	1
Radii at the corners of elements, μm	1.5
Exposure time, sec	0.1 to 10
Current	Alternating
Voltage, volts	380 x 220
Frequency, Hz	50
Air pressure, atm	4 to 8
Maximum power consumption, KW	2
Area occupied, m^2	20

The master photographic templates are made using optical or mechanical multiplication methods. The former employ lens or mirror raster scans while simultaneously photographing a large number of reduced images of the topological figure of the photographic template, while the latter are based on the sequential, step by step photographic printing of single images. An example of an optical multiplication unit is the EM-514 scanning photographic camera. The scanning objective of this photographic camera contains no less than 1,500 short focus lenses, positioned with a step of 0.8 mm. The working field of the screen is 300 x 300 mm and the reduction scales of the camera are 200 x and 300 x. The camera is used for the multiplication of images with minimum element dimensions of about 20 μm.

Photoduplicators based on sequential photographic printing with the moving of the photographic plate contain an automatic coordinate table, an exposure assembly (illuminator, optical system, etc.), measurement instruments, as well as controls and structural support. We shall give the basic technical specifications for such photoduplicators using the example of the EM-522 unit:

Maximum travel of the table, mm	80
Positioning precision, μm	± 0.2
Positioning reproducibility, μm	± 0.2
Reduction scale, times	10
Intermediate photographic template dimensions, mm	50 x 50, 70 x 70
Master photographic template dimensions, mm	70 x 70, 100 x 100

Mechanical multiplication systems are the best developed and the most universal at the present time. However, the development of precision electronic multiplication systems up to the level necessary for industrial applications will be a reality in the next few years.

PART II EQUIPMENT FOR THE ASSEMBLY AND QUALITY CONTROL OF FINISHED DEVICES. FINISHING OPERATIONS

CHAPTER SIX Equipment for Separating Wafers into Chips

The geometric shape of the chips used in the mass production of semiconductor devices is the most diverse: circular, square, rectangular and polygonal; however, square and rectangular chips are the most widely used. The side of a chip varies from 0.25 mm up to several millimeters.

The following methods of separating wafers into chips have found application at the present time:

--Scribing with a diamond cutter;

--Laser cutting;

--Separation using diamond disks;

--Separation using cutting arrays.

Scribing with a diamond cutter is a rather high output operation as compared to other types of wafer separation, especially when producing small chips (in a range of 0.35 to 1.0 mm). The advantages of the technique are also the easy resetting of the cutter for square and rectangular chips of various sizes and the servicing simplicity. However, there are drawbacks inherent in the method of scribing using diamond cutters:

--The difficulty of scribing SiO_2 and polysilicon;

--The occurrence of dust-like formations which get on the surface of the structures being scribed (the dust is the disintegrated cut material);

--The influence of the quality and condition of the cutting edge of the diamond cutter on the shape of the scriber groove, and as a consequence, on the quality of the breaking of a wafer into chips;

--The necessaity of performing a supplemental breaking operation on the wafers along the scriber lines;

--The presence of an improper geometrical shape of the cut surface (shear surfaces, violation of the rectangular shape, etc.);

--A deterioration of the break quality and an increase in rejects with a reduction in the ultimate ratio of chip length to thickness (this ratio should be no less than 3:1 for germanium and 4:1 for silicon).

The expanding use laser cutting of semiconductor wafers in industry is due to a number of advantages of this technique:

--There is no cutting tool which wears;

--The electronic control of the laser beam makes it possible to adjust the parameters of the cutting channel in a wide range: from producing the shape of a scriber "notch" to completely cutting the wafers apart and separating the chips from each other.

Draw backs to this method are the necessity of using complex equipment for the process and the possibility of droplets and vapors of the material getting on to the surface being cut.

A promising method of separating semiconductor wafers into chips is notching or completely cutting them apart using rapidly rotating thin disks, coated with diamond dust. A merit of the method is the possibility of producing chips with a good geometric shape and precise dimensions, as well as the possibility of cutting apart structures on which beam or strip leads are formed. Moreoever, where a polycrystalline layer is present at the surface of the semiconductor wafer, cutting with rotating disks yields a more stable and high quality separation than does scribing.

Separation by means of cutting arrays or wires is less productive than using the methods indicated above. In all of the latter methods, it is necessary to provide for feeding an abrasive suspension to the surface of the materials being cut, something which is extremely undesirable in some cases. However, good separation quality and the capability of cutting apart relatively thick wafers provide for the rather wide scale use of these methods in industry.

At the present time, wafers of semiconductor materials with an increased diameter (more than 100 mm) are being introduced into the technological process. The requirements placed on the precision of the geometric dimensions of chips are increasing, especially for devices with an increased level of integration. It must be noted that the most promising method of separating large diameter wafers into chips is cutting with diamond disks.

6.1. Equipment for Separating Wafers by Means of Scribing

The EM-201A and EM-201B diamond cutter scribers [35] (Figure 6.1) have found wide applications in domestic industry. The unit has the following technical specifications:

Range of steps, mm	0.01 - 39.99
Discrete setting step, mm	0.01
Maximum feed travel length, mm	75
Length of a scribing run, mm	40 - 85
Number of double runs per minute	from 15 to 60
Pressure of the cutter on a wafer, N	0.125 - 2.5
Precision in making lines during a step, mm:	
0.01 to 15 mm	± 0.005
15 to 30 mm	± 0.006

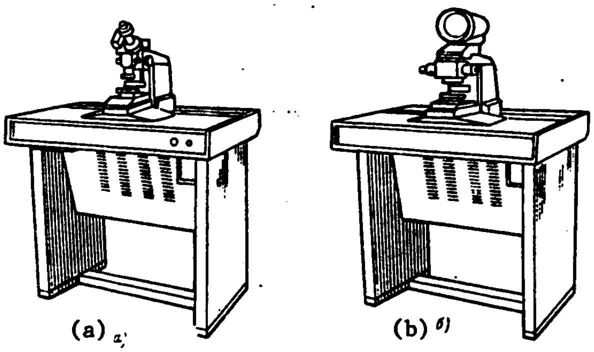


Figure 6.1. General view of scribing units.

a. EM-201A;
b. EM-201B.

The scribing installation has the following specific design features. The scribing speed is set by selecting interchangeable gears. The length of a working run is regulated to match the diameter of the wafer being scribed. A correcting linear rule is used in these models which improves the precision of the step feed motion mechanism. The nut and screw of the feed mechanism have forced lubrication. A sophisticated structural design of the cutting head provides it with a low inertia. A precision mechanism for setting the cutter loading force has been introduced. The cutting head can be rapidly aligned outside the machine, where the changeover from the previously used cutters with a circular tool post to cutters with a square tool post significantly curtails the setup time and improves the scribing precision. The EM-201B model is provided with a projector and is recommended when processing large diameter silicon wafers and sitall [ceramic glass similar to pyroceram] substrates. Vacuum suction provides for the restraint of the wafer being cut. One can scribe wafers held on adhesion substrates in the installation also: polyxylaxane strip, viniproza [sic], etc.

A significant factor which determines the quality of separation is the manner of breaking the scribed wafer. The most widespread method of breaking is rolling a small roller along the scribe lines with the application of a certain force on the surface of the wafer. In this case, the wafer either moves between two elastic plastic substrates, or in an envelope (from which one can exhaust the air and which can be hermetically sealed), or on an elastic base. A number of practical data on scribing and breaking silicon wafers with a thickness of no more than 0.3 mm in the production of chips 0.45 x 0.45 mm for transistors is given in [37].

It has been established from production experience that one can obtain a minimal width scribe groove which makes it possible to have high quality separation of a silicon wafer into chips using a diamond cutter with a sharpened angle of 150° and an angle of inclination of the cutting edge to the plane of 5 to 6°.

Changing the scribing speed in a range of 10 to 50 double runs per minute has little influence in practice on the scribing quality.

The orientation of the crystallographic planes of the wafer does not influence the process of making the scriber groove, but can have a decisive importance when separating the scribed wafer into chips. The best results are obtained when scribing wafers grown in the (100) plane along the traces of the (100) planes. The working of the back side of a wafer (polishing or etching) makes it possible to improve the breakout quality following scribing. This is explained by the removal of the surface layer of the wafer strengthened by polishing. Thus, the determination of the correct combination of scribing modes (speed, pressure, point angle and setting of the cutter) as a function of the initial conditions (wafer material, coating thickness, etc.) makes it possible to produce a scriber groove of minimal width (no more than 5 μm) and depth (2 to 3 μm), which assures effective and high quality separation while preserving the specified geometric parameters of the chips. The scriber notches are made with minimal destruction of the wafer surface layer. The stresses are concentrated in the scriber grooves and are governed by the boundaries of the next break.

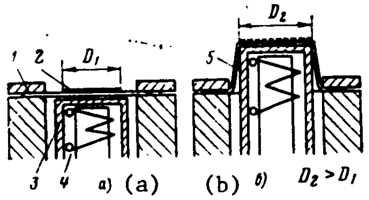


Figure 6.2. A device for stretch tensioning scribed wafers.

a. Before stretching;
b. After stretching.

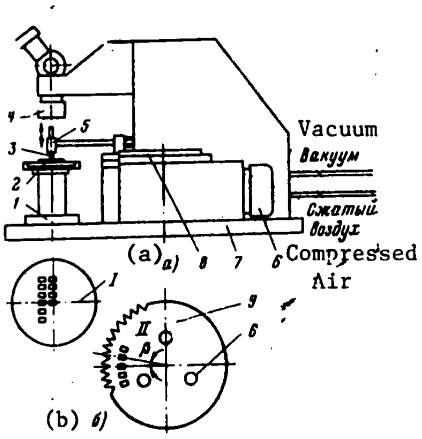


Figure 6.3. Device for placing chips in a chip holder.

To separate scribed wafers into chips, an installation for breaking semiconductor wafers can be used which provides for the oriented separation of scribed wafers positioned between flexible transparent viniprose films, one of which is the satellite carrier. The breaking is accomplished by rolling a spring loaded steel roller into mutually perpendicular directions, corresponding to the scriber lines. The breaking force is uniformly distributed over the generatrix of the roller, which prevents mechanical damage to the chips. Wafers with diameters of 25 to 60 mm and thicknesses of 0.1 to 0.3 mm can be broken apart in the unit, with chip dimensions of from 0.45 x 0.45 to 3 x 3 mm. The breaking force is adjusted in a range of 50 to 118 N, depending on the wafer and the chip dimensions. A study of the process of breaking scribed wafers showed that the quality of a break depends to a significant extent on the roller diameter and material of the substrate.

Following the breaking, the satellite carrier with the oriented chips secured to it is subjected to stretching tension. The film tensioning unit provides for uniform stretching of the satellite carrier, something which makes it possible to create the optimal spacing between the chips for their subsequent oriented loading. The basis for the tensioning (Figure 6.2) is the plastic flow of the film carrier material with exposure to temperature: the satellite carrier 1 made of viniprose with the broken wafer 2 placed on it is caught in the clamping device of the tensioning mechanism; the stretching of the film is accomplished by stage 3 with heater 4 mounted in it, the temperature of which is monitored and adjusted. The small stage is secured to the push rod of a pneumatic cylinder, the construction of which makes it possible to adjust the speed of the working and no load motions. Following of the completion of the stretching, the heater is turned off and the small stage is cooled by a flow of water fed into its interior cavity. Cooling is provided to speed up the shaping of the carrier. Following cooling down to a temperature of 50° C, the film with the chips which is formed in the shape of a small cup 5 is removed from the clamping device.

The placement of the chips with a specified orientation in multicell cassette holders is a necessary operation for the subsequent automation of assembly processes [36]. A desk top unit for placing chips with dimensions of 0.5 x 0.5 mm in an annular cassette holder with 180 cells is depicted in Figure 6.3a. An operator fills a cassette holder in 5 to 10 minutes (depending on the operator's skill) using such a device.

In the device, the semiconductor material wafer 1 is fed to the manipulator stage 2. The wafer is broken into chips which are separated from each other and placed on a transparent substrate. The operator orients each chip with respect to the intersection, which is observed in microscope 4. The vacuum suction attachment 3, which executes an up and down motion and with lever 5 moves from position I to position II (Figure 6.3b), is precisely positioned relative to the intersection; the suction attachment places the chip in the cell of cassette holder 8, after which the cassette holder is rotated through the angle β.

The device has an electric motor drive 6, a system of drum program mechanisms, pipes to create the vacuum in the suction attachment when transporting the chip as well as to feed compressed air at the moment the chips are placed in the cell of the holder.

To prevent possible vibration when the mechanisms are operating, the entire unit is mounted on plate 7. Holder 8, when being set on the stage of the unit, is centered in the internal annular groove with the bands of the three wide bearings 9, one of which moves while the other two are stationary. The holder is rotated through the angle β by virtue of the precise pitch of the teeth of the outer gear ring and the pawl which fits in the slot between the teeth during locking.

The automated all-purpose EM-202A installation is widely used in semiconductor production for separating a scribed semiconductor into individual chips. The operating speed of travel of the breaking rollers is regulated in the unit, and there are interchangeable breaking rollers of different diameters and interchangeable holders for securing wafers of various diameters. The major technical specifications of the unit are:

Maximum diameter of a wafer which can be broken up, mm	60
Diameter of the breaking rollers, mm	3, 6, 10, 12, 16, 20
Breaking roller pressure, Newtons	0.49 - 49
Rate of travel of the breaking rollers (continuously adjustable), mm/sec	0.8 - 6

The automated EM-436 unit is used to place chips in a multirow rectangular cassette holder. The installation is designed to remove chips which are arranged with a specific orientation on an adhesive strip, and place them in the cassette holder where the number of positioned chips is determined beforehand by means of a photoelectric sensor.

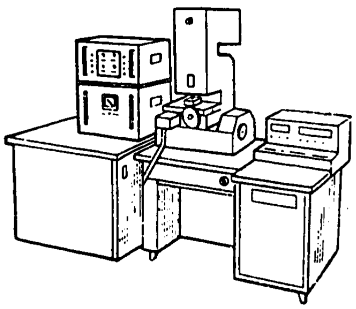


Figure 6.4. A laser production process installation

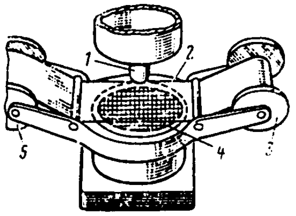


Figure 6.5. Structural design of a laser scriber which prevents contamination of the wafers.

A number of installations have been designed for laser scribing and cutting of semiconductor wafers, which differ in terms of their composition, the kind of laser used and structural design of the various devices. A domestically produced laser production process unit (Figure 6.4) makes it possible to produce clean square edges of chips, a deeper groove than even with diamond scribing while sparing silicon wafer area (the number of chips on a wafer is increased by 5%).

A pulsed yttrium aluminum garnet with neodimium laser is used in the installation.

The main technical specifications of the production process laser installation are:

Cutting speed, mm/min	60
Width of a cut with the defect region, mm	0.12
Wafer thickness, mm	Up to 0.25
Wafer diameter, mm	Up to 60
Pulse repetition rate, pulses/sec	12, 25, 50, 100

In accordance with another technique (Figure 6.5) [38], the laser beam, passing through optical system 1, scribes the wafer 4; the melted silicon collects in droplets, which adhere to the plastic film 2. Since the film is fed from roller 5 and wound on roller 3, the adhering droplets do not fall on the wafer. Because of the fact that the film is transparent to the laser beam, it does not create any obstacle to the scribing.

Specialized equipment complexes have been designed for the operations of separating wafers into chips. One of these complexes is the TAS-1000 system of the Teledyne Company (U.S.) [39]. It must be noted that such systems are most applicable where there is a sufficiently large chip production volume, i.e., in cases where entire plants specialize in the production of chips and these chips are then sent to other enterprises.

The widely used technique of removing the chips by means of a pneumatic suction attachment has significant drawbacks: the very small force for pulling a chip away from the carrier and the necessity of sealing the edges of the suction attachment and the surface of the chips so that a vacuum capture is accomplished. The necessity for sealing requires precision methods in the fabrication of the tip pieces of the vacuum attachments. For this reason, it is of interest to remove chips following scribing using electromechanical tweezers [41]. To pick up a chip with electromechanical tweezers, following the scribing the wafer is placed on an adhesive elastic strip and broken up by a tool moving along the scribing line which produces the breaking pressure. Then wafer 1 (Figure 6.6) is placed on prismatic knife 3, from which the chip 2 is removed by the jaws 4 of electromechanical tweezers 5. The capture is accomplished by virtue of the compression of annular spring 6 of the electromechanical tweezers with the action of solenoid 7. Spindle 8 of the chip positioner has the capability of executing cyclical turns through a certain angle to accomplish the "biting" when removing a chip and execute a reciprocating motion to transfer the removed chip to the placement position.

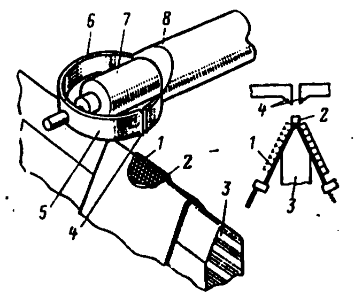


Figure 6.6. Schematic showing electromechanical tweezers.

An advantage of electromechanical tweezers is the capability of producing a considerable clamping force on the chip when grasping it and as a consequence, producing a considerable force to pull the chip away from the substrate.

6.2. Other Kinds of Equipment for Separating Wafers into Chips

Automated machine tools with rapidly rotating disks (up to 45,000 r.p.m.) made of diamond chips in a rubber-like binder. The disks are assembled into a composite tool like an agricultural disk (for group cutting), are easily cleaned and are less inclined to clogging with silicon dust. When completely cutting through the wafers, there is no necessity for a breaking operation. The width of the cut fluctuates in a range of 40 to

100 μm. The cutting speed runs up to 30 cm/sec (when working with a single disk). The region of the destroyed layer does not exceed 12 μm. There are machine tools which make it possible to cut wafers apart with diameters of up to 127 mm. The securing of a wafer in the case where the cut does not go all the way through is accomplished by means of an adhesion carrier or by means of a glue-on label. With the installation using several disks, several tracks are cut immediately in a single pass, something which improves the productivity. The service life of a diamond cutting disk reaches 28,000 cuts when cutting wafers with a diameter of 50 mm to a depth of 0.25 mm. Reinforced disks are used to cut ceramic substrates.

The domestically produced SRP machine tool for cutting wafers into chips using a wire which forms a grid matching the dimensions of the chip has the following cutting scheme. Two cutting devices with the wire wound on are mounted on moving slides. This makes it possible to simultaneously cut two wafers of semiconductor material glued to a glass substrate. The matching of the wire to the separating track is accomplished through an auxiliary optical device. The working pressure during cutting is produced hydraulically. After the wafer is cut apart in one direction, the wafer carriers are rotated through 90°.

Chemical methods of separating wafers into chips using photolithography techniques proved effective in some cases. These are especially applicable in those cases where projections extend out beyond the chip, such as, for example, in some integrated circuits with beam leads. In this case, the following technology is employed to place the chips in an oriented manner on a flat disk. The front side of the wafer is coated with wax, and the wafer is secured to a flat disk about 0.9 mm thick. The back of the wafer is polished down to a thickness of 50 μm and coated with photoresist. Then, the photoresist is removed at those points where necessary by means of masking. Infrared illumination is used to provide for matching during the masking. The region from which the protective layer is removed has the form of a grid, positioned just underneath the beam leads. Following photolithographic processing, the wafer is etched through at the points unprotected by the photoresist.

CHAPTER SEVEN EQUIPMENT FOR ASSEMBLING SEMICONDUCTOR DEVICES

7.1. Methods of Assembling the Major Types of Devices. Requirements Placed On the Equipment

The major assembly operations in planar technology are the mounting of the chips in a package and the connection of the leads. The chip mounting operation consists in seating it in a specified position and securing the chip in the package.

The operation of connecting the leads, or the making of the connections between elements consists in creating an electrical path between the contact pads on the chip and the external leads.

The requirements placed on the equipment are governed by the technical requirements placed on the installation of the chips [42]:

--The stability of the electrical and thermal characteristics of the device at the maximum operating temperatures;

--The adherence to conditions which assure the permissible limits for mechanical and electrical stresses at specified current and voltage levels, as well as installation methods, temperature ranges for storage and operation and the vibration and shock ranges.

At the present time, two methods of chip installation are widespread [43]:

--The connection of the plane of the chip to a contact pad of the substrate or frame;

--Connection using the inverted chip technique.

The connection can be realized in the following ways:

--Eutectic joining with the formation of an alloy of the two metals;

--Soldering, where a third component is used to join the two metals;

--Gluing;

--Ultrasonic welding [40].

Eutectic joining is widely used when installing silicon chips on a gold plated bonding pad.

The successful use of soldering depends on the capability of the solder to wet the metals being joined together and to create strong joints with them. Drawbacks to the soldering method are the necessity of fluxing the surfaces being joined, and since fluxes car cause corrosion, careful removal of the flux following the completion of the soldering.

Gluing of semiconductor chips is used to mount them on nonmetal surfaces (ceramic, plastic, etc.). Current conducting materials are sometimes used for the adhesive. The eutectic fastening, soldering and gluing processes can be intensified by the application of oscillations at various frequencies, all the way up to the ultrasonic. The major methods of fastening chips are given in Table 7.1.

The use of ultrasonics to speed up the process is most widely employed when connecting a chip using the inverted chip or "flip chip" method, the essence of which consists in joining the bonding pads of the inverted chip to the bonding pads of the base (substrate, package, contact frame) with the repeated melting of the solder from which these pads are made [44]. The flip chip techniques combine the operations of fastening the chips and connecting the leads. To make contacts on specified pads, their height is raised up on the chip or package. The height of such projections is about 25 µm. It is possible to connect several leads simultaneously to a single chip in one batch processing pass by means of bead and beam projections.

Besides the methods enumerated above for batch assembly of IC's without wires using beam and bead leads, there are two more to be singled out: the combination flip-chip and beam lead method and the strip technique, or the contact frame method. The latter is quite promising, since it makes it possible to use strip automation technology for the assembly process. Spiderwed leads which are stamped out or etched out from aluminum foil make the connections between elements when making batch connections in ultrasonic welding installations.

The most widespread method of connecting silicon IC chips to package leads is the welding of wire jumpers. The advantage of the technique consists in the fact that it does not place stringent requirements on the geometric dimensions; a drawback is the difficulty of automation and the high cost. Moreover, wire jumpers are at times a reason for IC failure, since the lead often breaks at the base where with the action of the welding head there is the strengthening of the wire by work hardening, which is accompanied by the formation of microcracks. Wire leads are fabricated primarily from aluminum and gold.

Thermal compression is the major method of connection, which provides for joining two parts by means of heating and pressure. Thermal compression overlap welding provides for a strong connection of semiconductor materials to leads made of gold, aluminum, silver and other malleable metals; butt joint welding can be done only with gold. The combination of plastic deformation and diffusion leads to a close interaction of the molecules of the parts being joined, as a result of which there is adhesion, although the joining of the parts is accomplished with heating up to a temperature below the melting point of the metals being joined.

Ultrasonic microwelding is used both for batch connection of leads and for making wire connections. It must be noted that it is necessary in mass production to very carefully select the ultrasonic welding conditions to assure stability of the quality indicators for the execution of the process. There is information that ultrasonic welding causes diffusion and recrystallization of the metals without their melting or with local melting in the contact zone. The formation of compounds is also ascribed to processes similar to friction welding. The majority of specialists feel that ultrasonic oscillations of the tool in the initial welding period destroy oxide films and provide for contact of the

TABLE 7.1. The Major Methods of Securing Chips

Method of Fastening	Material of the Bonding Pad of the Substrate	Back Side of the Chip	Working Temperature, °C	Advantages	Drawbacks	Remarks
Eutectic alloy	Gold coating 3 μm thick; gold type film conductor	Clean surface or with a deposited layer of gold	350 - 450	The capability of the thermal compression connection of wire leads. Good contacts.	Aging of the elements and parts due to the high temperature	The method is widely used.
Solder	A conductor to which it is possible to make a connection with solder	Metal coating or deposited layer	200 - 250	The capability of connecting large chips. High productivity.	The necessity of using flux and cleaning the flux away	It is used for high power elements
Conducting resin (glue)	A conductor with a low contact resistance	Metal coating or deposited layer	200 (hardening)	Ease of processing; low temperature process	Poor heat immunity; large thermal resistance	Most suitable for hybrid integrated circuits
Glass	Ceramic	The surface of the semiconductor material	400 - 600	The capability of simultaneously making connections to loop leads	High temperature; lack of conductivity from the fastening side	It is used for ceramic packages with dual in-line leads and flat packages

"juvenile" surfaces. Soldering is used when fabricating high power planar transistors and alloy devices, while electron beam and laser welding have a small area of applications at the present time.

The equipment for mounting chips on a bonding pad and for connecting the leads has many similar structural and design elements, especially in the loading, unloading and transport devices for the products during the process of executing the operations, visual observation, etc.

The assembly operations when manufacturing mass produced alloy semiconductor devices can be broken down into the following types: the assembly of the device components in multiple cell cassette holders; the attachment of the chip holder to the transition connection; the assembly of the transition connection and its installation in the device package; the hermetic sealing of the device.

The assembly of the elements of a device in multiple cell holders is used to improve the productivity of the operations performed by the batch method, for example, such as melting, group soldering, etc. The connection of the chip holder to the transition connection and the mounting of the transition connection and its installation in the device package are the most labor production process operations, which require high skill on the part of the operators and high precision actuating mechanisms.

Thermal compression and ultrasonic welding are widely used in the production of alloy semiconductor devices to join the fine wire leads to the interconnection electrodes and external leads, as well as in the production of planar devices [45]. The heat is delivered to the weld region in the following ways: by heating the mounting base of the device; direct heating of a needle or punch; indirect heating of the weld region, by passing current through the tool; heating a needle with simultaneous heating of the mounting base.

7.2. Equipment for Mounting the Chips of Planar Devices

With respect to the kind of product loading and unloading during mounting, a distinction is drawn between equipment with manual piece by piece loading and unloading and with automated loading and unloading mechanisms.

With respect to the type of feed of the chips for fastening, a distinction is drawn between various equipment designs: with cassette holder feed of chips put in them beforehand; with combined selection of chips suitable for attachment; and when they are fed in as wafers, separated into chips while preserving their orientation.

With respect to the type of feed for the solder tablets or gold liners (in the case of eutectic joining), a distinction is drawn between automated equipment and equipment with manual loading. The semiautomatic PUN-700 unit for soldering chips to the mounting base, which automatically sequentially joins the gold liner and the chips has the following technical specifications:

Productivity (depending on the chip size), pieces/hr	≤ 700
Size of chips which can be joined, mm	0.5 x 0.5 + 1.5 x 1.5
Connection temperature, °C	≤ 460
Precision in connecting the chips relative to the center of the gold plated pad, mm	± 0.2
Range of connection making times, sec	0.4 + 3.9
Range of working frequencies of the ultrasonic generator, KHz	≤ 60 ± 5
Output power of the ultrasonic generator, watts	16 ± 1
Control range for the tool pressure on the elements being welded, Newtons	0.2 - 2

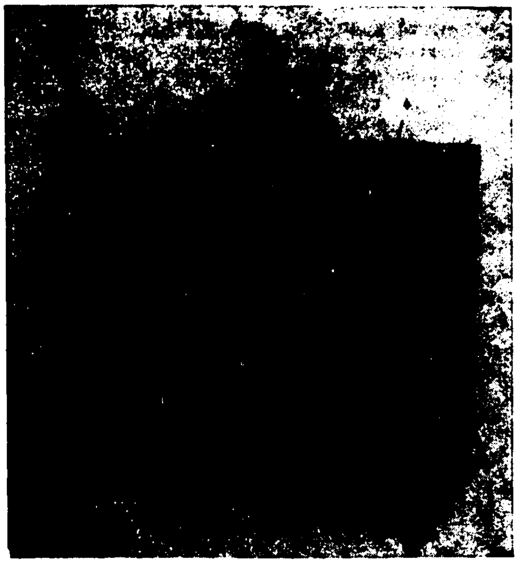


Figure 7.1. The PUN-700 semiautomated unit for sealing chips to mounting bases.

The soldering of the chips of transistors with a metal-glass package and flexible leads can be accomplished on the PUN-700 unit. The functions of the operator when working with the semi-automatic unit reduce to periodically changing the cylindrical cases with the belt carriers. In structural terms, the semi-automatic unit consists of the following structural parts (Figure 7.1): the machine tool bed 5; the grab type feeder for the products 1; the chip joiner and feed device 3; the foil feed mechanism 2 and the control unit 4.

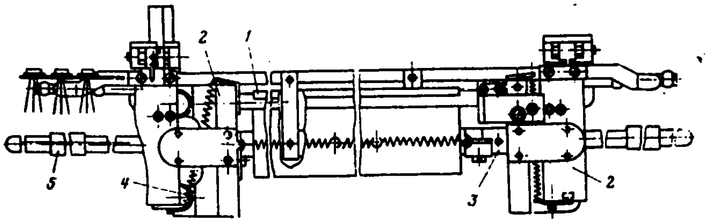


Figure 7.2. The grab type feed device for the products.

The bed takes the form of a welded structure. A plate is fastened on top of the bed, on which the major assemblies of the semiautomatic unit are mounted.

The grab type feed device for the products (Figure 7.2) serves for the step feed of the belt carrier with the mounting bases of the devices placed on it. The device consists of the guides 1, which are fastened to two bases 2, the drawbar 3, which joins the base and which imparts rigidity to the system; rods 5, which hold the magazine. The entire system is suspended freely on the springs 4 from the frame and is driven by a lever device.

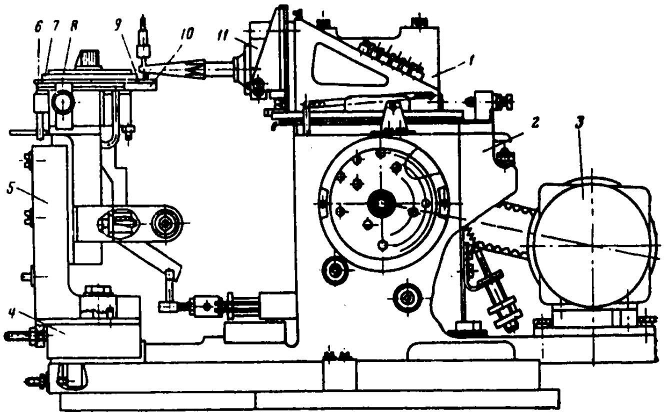


Figure 7.3. The feed and attachment mechanism for the chips.

The chip feed and attachment mechanism (Figure 7.3) consists of two assemblies in structural terms: the feed mechanism and the mechanism for attaching the chips.

The transport mechanism 4 serves to transport the cassette holders with the chips oriented on them to the position for grasping the chip by the working tool. The mechanism consists of the following components: the bracket 5, platform 6, which is rigidly fastened to the platforms; the cassette holders with the chips 7, which lies freely on the platform and takes the form of a ring with teeth about the periphery, where the chips are placed in nests in an oriented manner, where the number of nests corresponds to the number of teeth; disk 8, which presses against the cassette holder and can move in the ball guides along the platform. The step motion of a cassette holder is produced by a rocking lever, moving clamp 9 and finger 10. The mechanism for feeding and attaching the chips 11 consists of the carriage 1, which moves in the ball guides on the base with the magnetostrictive transducer secured to it, where this transducer has a vacuum holder. Both mechanisms are mounted on the common base 2 and are driven by a single drive 3.

The foil feed mechanism provides for feeding, cutting off and placing the gold tablet on the mounting base and consists of two assemblies: the foil feed and cut off assembly; the gold liner placement and connection assembly.

The latter assembly has a structural design and performs functions similar to the chip feed and attachment mechanism (Figure 7.3). The foil feed and cut off assembly has a spool with the gold foil wound on it, the feed of which is accomplished by two small rollers and the cutting is accomplished by a rocking knife. The intermittent rotation of the rollers is realized by a ratchet mechanism. The motion of the knife and the ratchet mechanism is accomplished from the cams of the common drive for the mechanisms. The chip feed and attachment mechanism is coupled by means of an elastic sleeve to the mechanism for placing and cutting off the foil.

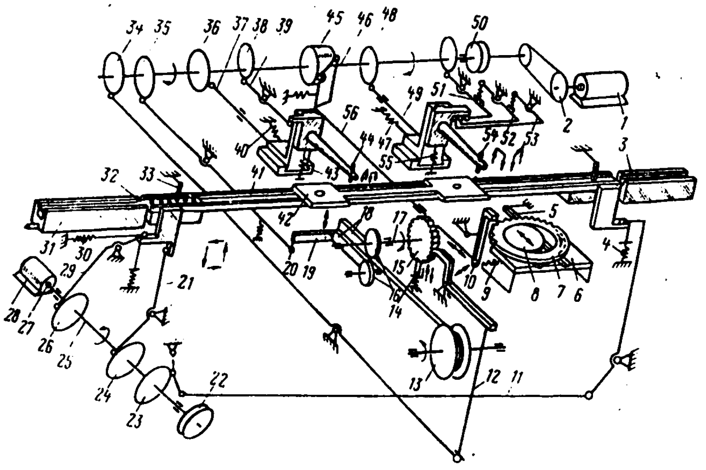


Figure 7.4. Kinematic schematic of the ultrasonic attachment automat.

The mounting bases of a device are heated by tunnel heaters with built-in heating elements.

In accordance with the kinematic schematic (Figure 7.4), the operation is realized as follows: electric motor 28 rotates the camshaft 25 through the elastic coupling sleeve 27. The grab mechanism is moved in the vertical plane by cams 23 and 26, as well as by spring 4 through lever 29, the system of levers and connecting rod 11; the grab mechanism is moved in the horizontal direction by cam 24, spring 30 and lever 21.

The belt carrier 32, which is filled with the mounting bases of the devices, is moved by the grab mechanism in vertical and horizontal planes and clamped by catches 33. The carrier moves from the cylindrical case 31 along the plate 41 to the position for the attachment of the foil and chips, where heater 42 is located. Then the carrier goes into case 3, from which it can be transmitted to the next production process operation.

Toothed belt 2 transmits the rotation from electric motor 1 to camshaft 46. Cam 34 transmits an intermittent motion through the lever and connecting rod 12 to the ratchet 15, which is clamped by finger 14. The rotation is further communicated through shaft 17 to disk 16, which feeds the gold foil from roller 13 to the stationary guides 18. The foil is cut off by knife 19, which is driven by cam 35, the lever and connecting rod 20. The cut-off foil (the gold liner) is caught by vacuum suction attachment 44 and by means of cams 38 and 39 as well as springs 43 and 40, a combined oblique motion with the gold liner to the mounting base of the device is imparted through connecting pull rod 37 and lever 39 to the suction attachment. After making the connection, the operational cycle is repeated. Holder 7 with the chips is set on the stage 6 and is pressed by disk 8 and spring 9 against the stationary clamp 5. A stepped motion is imparted to the cassette holder by lever 10, which receives its reciprocating motion through the system of connecting pull rods 56 from cam 45 with both end face and radial working profiles. Lever 10 moves the cassette holder out from stationary clamp 5 and rotates it through one step. When the lever moves out to the initial position, the cassette holder is clamped. The capture and transfer of the oriented chips from the cassette holder are accomplished by vacuum attachment 54, to which a combined oblique motion is imparted by cams 38 and 48 as well as springs 47 and 55 through connecting pull rod 49 and lever 51. The pressure of the vacuum suction attachment on the chips during capture and when making the connection is regulated by spring loaded levers 52 and 53. Programming devices 50 and 22 are mounted on the camshafts to synchronize the operating cycle of the semiautomatic equipment.

A provision is made in the semiautomatic unit for local feed of an inert gas into the region of chip attachment.

The loading and unloading of the belt carriers in the cylindrical cases are accomplished without shutting down the semiautomatic unit; a stockpile of semi-finished products can be stored in special magazines, the dimensions of which make it possible to place them in the pedestals of the machine bed.

During operation of the semiautomatic unit, attention is to be given to the operation of the vacuum attachments, which can be fouled or wear. In the case of contamination of the mounting bases of the devices or the back side of the chips, a reduction in the connection quality is possible.

Depending on the combination of the material of bead leads of chips and the bonding pads of substrates for integrated circuits, the following methods can be used to make connections in the EM-431 installation:

--Thermal compression microwelding or soldering with the capability of constant heating of the substrate and chip (the working stage and tool), as well as pulsed heating of the chip (or the tool);

--Combination microwelding or soldering (ultrasound with pulsed heating).

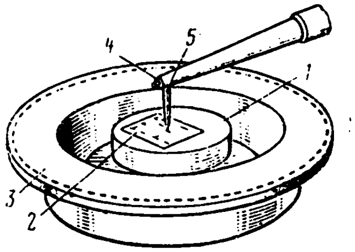
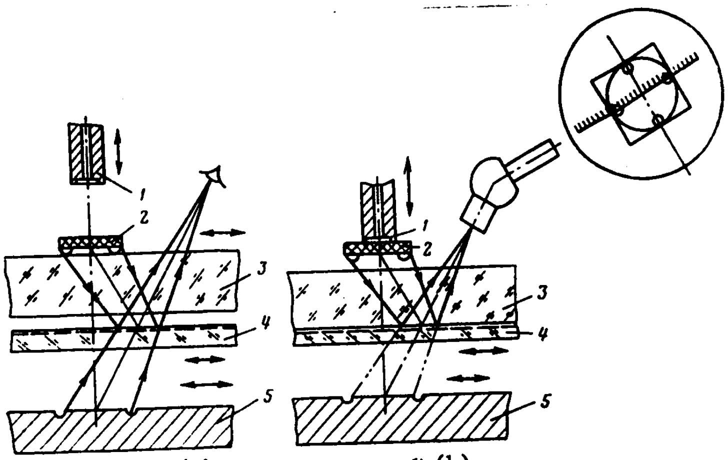


Figure 7.5. The assembly for the placement of chips in the EM-431 unit.

The assembly for placing chips of the EM-431 installation is depicted in Figure 7.5. An integrated circuit substrate 2 is placed on the working stage 1, which is equipped with a spring holder. The chips are fed into the unit in ring cassette holder 3 having a capacity of 180 chips. In contrast to the structural designs of the chip feed assembly described previously (see Figure 7.3), the ring cassette holder is mounted coaxially with the working stage. The spindle 4 with the tool 5 executes reciprocating motions from the center of the working stage to the periphery of the cassette holder and back.

The operator matches the chip up with the bonding pads of the substrates by means of a micromanipulator and an optical system, consisting of a microscope and semitransparent and reflecting mirrors. The installation can be put together with two types of interchangeable working stages: one is heated; batch installation of substrates is possible on the other.

The structural design of the MS-64P2-1 semiautomatic unit for the attachment of chips is of interest [46]. The semiautomatic unit is used in a set of equipment intended for assembling multiple chip hybrid integrated circuits. The attachment of chips with tinned leads-stubs on sitall and ceramic substrates is accomplished by means of pulsed heating of the working tool with additional heating of the working stage while applying ultrasonic vibrations. Crystals of a particular type (with dimensions of from 0.7 x 0.7 up to 1.8 x 1.8 mm) are placed in 6 vertical holders with a capacity of 350 to 400 chips each. Selective automated selection of the chips from any holder is possible in accordance with a program set on the control console. The specific features of the operation of the semiautomatic unit are the automatic orientation of the chip on the working tool and the matching of the bonding pads of the substrate to reference marks on the screen of the projector. The dimensional tolerance of a chip should be kept within ± 50 μm for high quality mounting. The fabrication of the cassette holders in the form of tubes, in the cavity of which the chips are stacked make it possible to create more compact feed assemblies than when using the cassette holders shown in Figure 7.5. The flip chip method of attachment requires the use of special devices for the observation of the matching of the contact projections of the chip and the substrate [38]. Several methods of matching are well known: using semitransparent and reflective mirrors (Figure 7.6).



а) (a) б) (b)

Figure 7.6. Schematic showing the matching of chips to the substrate.

When a semi-transparent mirror is used (Figure 7.6a), the welding tool, which is simultaneously the vacuum suction attachment, picks up the chip 2, which is matched to the figure on the substrate 5 by means of semi-transparent mirror 4. Then the transparent holder 3 is shifted in a horizontal direction, while tool 1 places the chip at the specified point on the substrate with a vertical motion. Such a method of matching requires that the chip always be located above the substrate.

When using a reflecting mirror (Figure, 7.6b), the matching of the chip 2 to the figure on the substrate is accomplished using the microscope crosshairs and using the imaginary image of the chip 5. The end face of the tool 1, which has a suction attachment for the chip, is aligned and guided in accordance with the same crosshair lines. The chip is arranged on the moving plate 3 of the reflective mirror 4 below the projections.

Following matching, the chip is held by suction, the plate 3 is removed, the welding tool moves it and the attachment is made.

A needle with a special geometry having a central opening to produce a vacuum over the chip can be used as the tool for catching and attaching the chips. The needle is made of a solid tungsten carbide alloy or special steels.

7.3. Equipment for the Attaching of Leads to Planar Devices

Two types of equipment exist in accordance with the technology for lead attachment: for wire mounting, and mounting without wire. The equipment for mounting without wire as a rule, uses the principle of batch attachment of the leads to the chip; some models of this equipment were described in the preceding section. The structural design of installations for wire mounting are treated in the following.

TABLE 7.2

	Method of Bonding		
The Characteristics of a Thermal Compression Bond	Butt with a "Bead"	Overlap with a "Wedge"	Overlap with a "Bird's Beak"
Wire material	Au	Au, Al	Au, Al
Wire diameter, μm	10 - 250	10 - 250	7.5 and more
Bonding area (gold lead with diameter of 25 μm), μm	Diameter 90	Diameter 40	50 x 100
Substrate temperature, °C	250 - 400	250 - 400	250 - 400
Method of cutting off the wire	Hydrogen flame	Moving the wedge; small knife	Moving the wedge; small knife
Output, welds/hr	≈ 2000	≤ 1000	≈ 2000

The types of thermal compression welding and the tool used in this case are given in Table 7.2. Thermal compression overlap welding provides for a strong joint between semiconductor materials and leads made of gold, aluminum, silver and other malleable metals; butt welding can only be done with gold. The heating temperature in the case of thermal compression welding should not exceed the temperature for the formation of eutectic alloys of the materials being welded and should not lead to the formation of dislocations. The heat is delivered to the weld region in the following ways:

--Heating the mounting base of the device;

--Direct heating of the needle or wedge;

--Indirect heating of the weld site, by passing current pulses through the tool;

--Heating the needle with simultaneous heating of the mounting base.

The characteristics of a few methods of thermal compression attachment are given in Table 7.3.

Besides the kinds of thermal compression welding indicated in Table 7.2, combination methods are being widely used of late [47]. The execution of the process using two methods is shown in the schematic (Figure 7.7): butt welding of gold wire to the bonding pad of a device and welding by bonding to the bonding pad of the substrate.

Ultrasonic bonding of wire leads is accomplished in two main ways at the present time: using a wedge with an obliquely positioned opening (Figure 7.8) and with a capillary. Steps in the process of bonding wire leads using a wedge tool are depicted in Figure 7.8:

--The lead wire 1 is fed to the point of its bonding to the chip 2 and clamped by clamp 4 (Figure 7.8a);

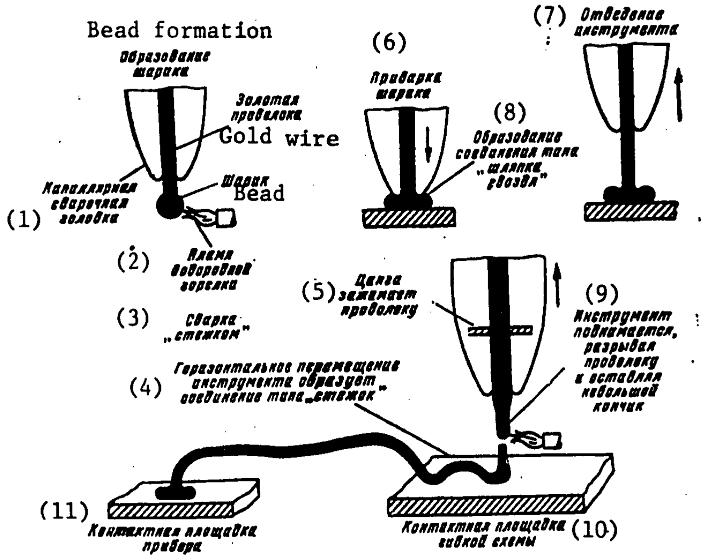


Figure 7.7. Schematic showing the combination weld bonding of leads.

Key:
1. Capillary welding head;
2. Flame from a hydrogen burner;
3. "Seam" welding;
4. Horizontal motion of the tool forms the "seam" type connection;
5. The collet chuck clamps the wire;
6. Welding of the bead;
7. Withdrawal of the tool;
8. Formation of a "nail head" type bond;
9. The tool is raised, breaking the wire and leaving a small end;
10. Bonding pad of a flexible circuit;
11. Bonding pad of the device.

--The lead is welded on (Figure 7.8b);

--The tool 3 is brought to the end face of the cross piece of the lead of the device 5, the second weld is made, the lead wire is clamped by clamp 4 and broken off (Figure 7.8c).

The following steps in the process of ultrasonic welding using a capillary are differentiated:

--The attachment of the lead to the chip;

--The attachment to the end face of the cross piece;

--Cutting the wire and simultaneously forming the "whisker".

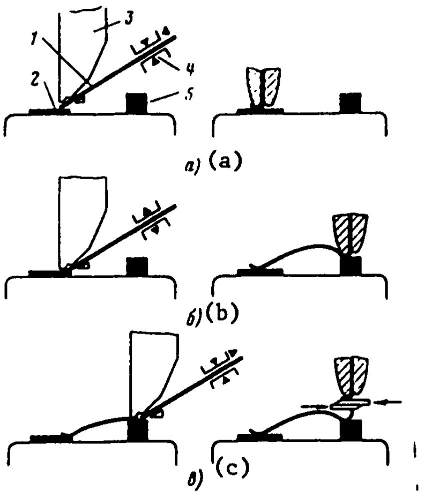


Figure 7.8. Steps in the process of bonding wire leads using a wedge tool.

The PUV-0.8 semiautomatic unit for the ultrasonic overlap bonding of leads to the components of devices assembled on TO-18, TO-5, etc. mounting bases uses the latter method. The semiautomatic unit has assemblies for loading, unloading and transporting the devices, similar to those used in the semiautomatic unit for attaching chips (see Figure 7.2). All of the operations with the exception of the loading and unloading of the strip carriers and the matching of the leads to the bonding pads are performed automatically.

The position where the bonds are made is shown in Figure 7.9. The wire is fed from spool 1 into the weld capillary 2, which is secured to the welding head 3. The strip carrier 4 with the products secured to it can be fed out in a stepped fashion. Following welding at the end faces of the cross piece, the wire lead is cut off by knives 5.

Figure 7.9. The lead bonding position of the PUV-0.8 semiautomatic unit.

Brief Technical Specifications for the PUV-0.8 Semiautomatic Unit

Output, welds/hr	1,000
Diameter of the wire leads, μm	25 - 125
Welding time, seconds	0.05 - 1
Tool pressure on the elements being welded, N	0.1 - 1.5

Travel of the manipulator in the horizontal plane, mm	8 x 8
Precision in setting the manipulator, μm	± 5
Travel of the tool in the vertical plane, mm	10

A provision is made for feeding an inert gas into the region of lead bonding.

The NPV unit for the ultrasonic bonding of leads makes the connection using a wedge, is of a desk top design, (Figure 7.10) and has the following technical specifications:

Kinematic productivity, cycles/hr	3,000
Materials which can be welded	gold, aluminum
Wire lead diameter, μm	24 - 60
Welding tool travel	automatic
Tool pressure on the elements being welded, N	0.1 - 0.15
Manipulator travel in the horizontal plane along the X and Y axes, mm	6 x 6
The forming of the jumpers	automatic
The strip carrier feed	stepwise, discrete

The structural design of the unit is executed as follows (Figure 7.10). The welding head 2 is secured with a screw in bracket fashion to base 3; a camshaft is mounted inside the head with a drive, a welding mechanism 8, a lever system, an electrical panel 4 and microscope 7. Ultrasonic generator 1 is mounted on the welding head. The manipulator 6 is installed inside the table. The working stage 5 is installed in the upper plate of the manipulator. The fastening of the camshaft and programming unit makes it possible to easily disassemble them for technical servicing.

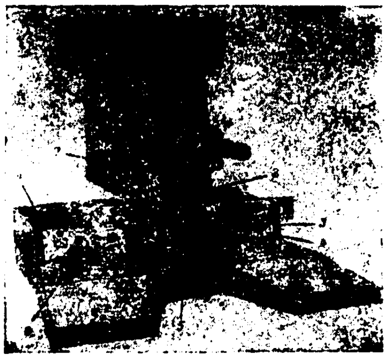


Figure 7.10. Overall view of the NPV-1 unit for the ultrasonic bonding of leads.

In accordance with the kinematic schematic (Figure 7.11), the unit operates as follows: by pressing the "start" button on control 24 of manipulator 23, electric motor 1 is started. The rotation is transmitted from the electric motor through the V-belt drive 46 to the shaft with cams 39, 40, 43 and 44. The tool which is fastened to chassis 9 is lowered to the first and second weld positions respectively by means of cams 32 and 40 through levers 41 and 42, plate 34 and rod 30. The tool lift is executed with the action of spring 29 and is limited by device 28. The tool executes a complex motion in conjunction with the chassis

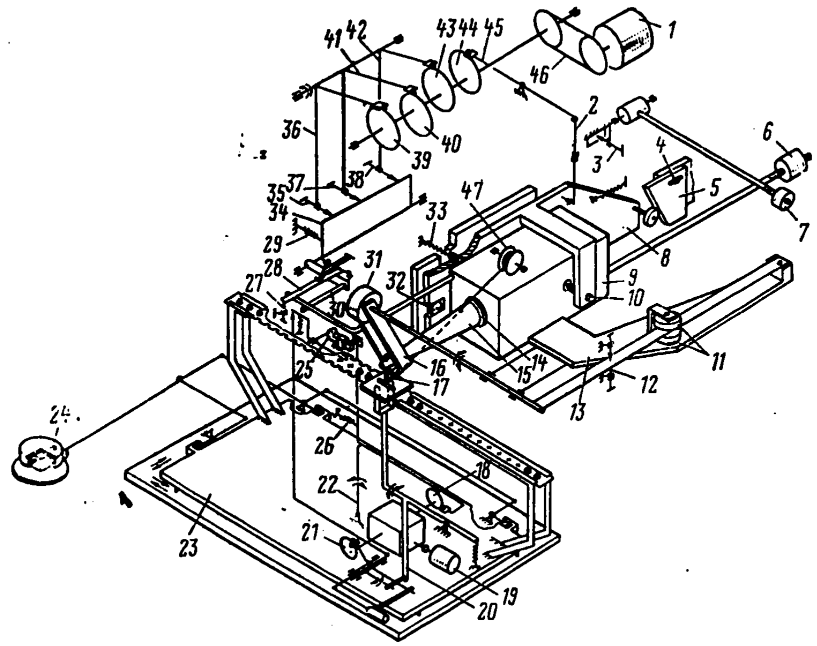


Figure 7.11. Kinematic schematic of the NPV-1 unit.

9 and bracket 8. The bracket 8, with the chassis 9 which is fastened in it in a hinged fashion, are drawn up to the stationary plate by spring 33 and have the capability of moving back and forth by means of former plate 5, which is secured with screw 4, and lever 45 and cam 44, rotating relative to roller 32. The wire being welded is fed and broken off by cramps 16, which are given the following motions: for tearing the wire, a feeding motion from electromagnets 11, mounted on the bracket, which moves together with the chassis 9; when clamping the wire, it is driven by electromagnet 31. The height of the wire lead when finishing a weld is limited by means of cam 39 through lever 36 with an adjusting screw. Screws 36 and 37 are used to adjust the height for the first and seconds welds, while screws 12 set the amount of travel of the cramps 16 when breaking and feeding the wire. The load on the elements being welded is set by weights 6 and 7, where weight 7 adjusts the pressing force only when welding on a chip. The strip carrier moves when the manipulator handle is inclined. In this case, the electric motor of drive 19 is turned on. Rod 25 with the dog which catches the strip carrier and moves it by one step is driven in motion by cam 18 through lever 22. The strip carrier is clamped in the welding position by levers 20 by means of cam 21, while the return travel of the rod with the dog is accomplished by spring 26; in this case, the dog slips freely along the strip. The adjusting devices 2, 3, 27 and 35 serve to align the corresponding assemblies.

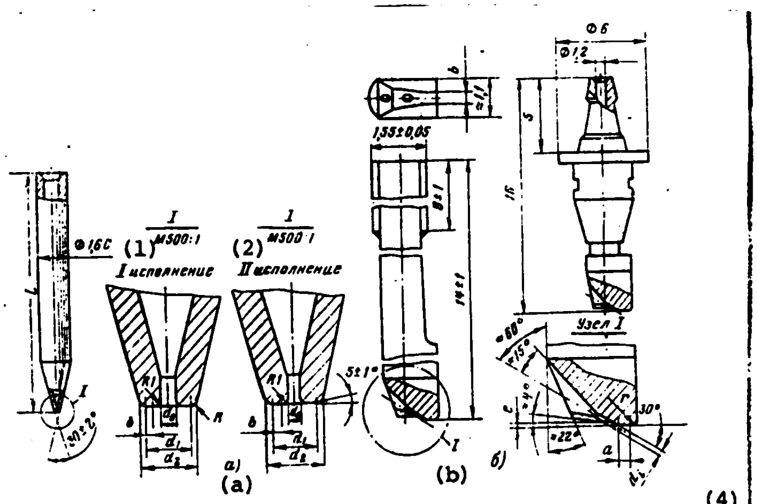
The welding mechanism consists of converter 15, which is mounted on chassis 9 by means of device 14; bracket 8; the wire feed and breaking device, which consists of bracket 13, the plate for the electromagnets 11, the U-shaped retainer 16, chassis 9 in which the spool with the wire 47 is placed as well as the shaft with the load 6.

The mechanism operates as follows: bracket 8 is kinematically coupled through master form plate 5 to the lever system and has the capability of rotating about the support stops 10, and moving in a vertical plane along with bracket 13. The lead wire is unreeled from spool 47, passes through the opening in U-shaped brace 16 and is fed under the tool of transducer 17. When a voltage is applied to the lower electromagnet 11, clamp 16 compresses and clamps the wire. Then the voltage is applied to the upper electromagnet 11, and the plates which are coupled to the U-shaped retainer 16 are pulled towards its core, the U-shaped holder rotates counter-clockwise and breaks the wire off. The stage for securing the strip carrier or product can be made as a driven unit: for assembling devices in metal-glass and plastic packages, or without a drive: for the direct fastening of a product package.

In the process of executing the operation, the stage can be manually rotated through an angle of up to 360°. When strip carriers are used, the unit can operate in a single production process line with semiautomatic units for bonding the chips.

Automated installations using minicomputers have been developed for the thermal compression bonding of leads [48, 49]. One of them is designed for the mounting of LSI circuits having a maximum of 42 leads. The LSI chips are mounted in a framework of leads, which are fed into the unit in the form of strips (tape segments). The receiving magazine holds 40 such strips and in step with their use, they are moved to another magazine. The frames for the leads are fixed precisely on pins in the guide racks. The operator corrects the shifting of the center of the chip and frame by means of an electrical device, where this shift runs up to 0.5 mm along the X and V axes with an angular shift of up to 5°. The operator views the chip being mounted on a television screen and by means of two controls orients the edges of perpendicular pairs of bonding pads with respect to the crossing lines on the screen. One control makes it possible to rotate the bracket with the frame for the leads fastened in it through a maximum of ± 5° to correct the angular shift, while the other changes the position of the thermal compression head by ± 0.5 mm in the direction of the X and Y axes to correct the shifts along these axes. The vidicon which serves for the determination of the chip position is attached to the thermal compression head. The controller generates signals proportional to the mechanical displacements and feeds them to the specialized computer of the system. Calculations are performed using the data on the position of the bonding pads, which are stored in a programmable read-only memory, to determine the corrections along the X and V coordinates. This makes it possible for the microcomputer to feed out the corrected X and V coordinates for the welding points to step motors as signals for the positioning of the thermal compression head with respect to the X and V coordinates in steps of 10 μm. No angular motions are required. Gold wires for the leads with diameters of 20 to 30 μm are bonded by the thermal compression head with a capillary using a butt joint at a rate of 2 leads per seconds; up to 3 chips with 42 leads are installed per minute.

A great advantage of programmable units for attaching wire leads, including those using computers, is the capability of setting up multiple machine tool servicing, where one operator works several production process machines simultaneously, something which achieves a reduction in the labor intensity of product manufacturing.



(3) Размеры, мкм					L, мм	Диаметр проволоки, мкм (4)
d_0	d_1	d_2	b	R		
28±3	88	118±5	20	20	7±0,3	20
38±4	113	150±5	25	25	(первый вариант)(5)	25
48±5	138	182±5	30	30	12±0,8	30
60±5	180	238±7	40	40	(второй вариант)	40
70±5	220	293±7	50	50	(6)	50

(3) Размеры, мкм				(4) Диаметр проволоки
di	a	b	e,r±10	
25±2,5	63±2	100±2	40	18
28±3,0	70±2	107±2	40	20
38±3,5	98±3	150±3	40	25
48±5,0	105±4	165±4	40	30
70±6,0	138±5	210±6	40	50
100±8,0	245±8	300±8	60	70
140±8,0	350±10	420±10	90	100
170±10,0	420±12	500±10	95	120
180±12,0	440±13	515±13	100	125

Figure 7.12. The main dimensions of hard alloy needles.

Key:
1. Design I;
2. Design II;
3. Dimensions, μm;
4. Wire diameter, μm;
5. First variant;
6. Second variant.

The series produced hard alloy microwelding tool has a complex microprofile for the contacting working surface, a capillary opening with a diameter of 0.02 to 0.1 mm and is usually fabricated from metal-ceramic hard alloys of the VK-8 tungsten group. The capillary holes are produced by using the techniques of sintering a hard powder alloy using a metal form into which a suspension of powder and filler is poured under a slight pressure.

The basic dimensional parameters of hard alloy needles used in lead bonding are shown in Figure 7.12: Figure 7.12a shows a cutting alloy capillary; Figure 7.12b shows a wedge with a lateral opening.

7.4. Equipment and Complexes for Mounting Semiconductor Devices and Integrated Circuits on a Strip Conveyor

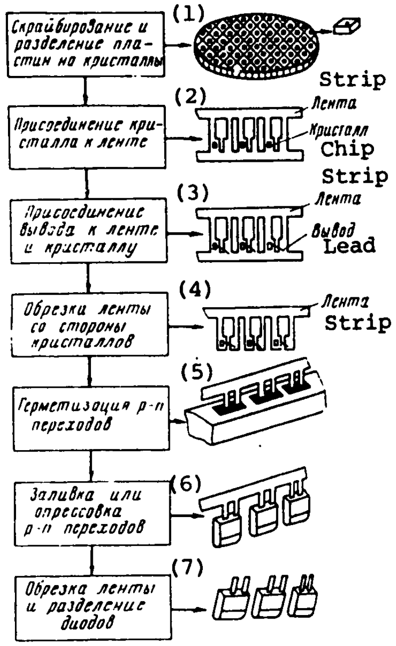


Figure 7.13. The typical sequence of operations to assemble diodes using a strip.

Key:
1. Scribing and separation of the wafers into chips;
2. Attachment of the chips to the strip;
3. Bonding of the lead to the strip and the chip;
4. Cutting the strip on the chip side;
5. Hermetic sealing of the p-n junctions;
6. Potting or compression molding the p-n junctions;
7. Cutting the strip and separating the diodes.

One of the ways of automating the assembly of semiconductor devices and IC's at the present time is the use of a strip conveyor. Equipment is described below for the installation of transistors and IC's on a continuous perforated strip.

A typical sequence for the performance of assembly operations for discrete devices (transistors, diodes) using a strip carrier is shown in Figure 7.13. The "Potok" comprehensively mechanized line [50] finds application in the production of a mass produced high frequency transistor for home entertainment electronics equipment (the KT-315 transistor). A continuous perforated strip which is simultaneously also the structural component of the transistor itself and the means of transporting it during assembly is used.

The use of a Fernico strip with partial local striped gold plating, accomplished by a continuous cladding technique, has made it possible to attach chips directly to the strip, without using additional solder tablets.

The metalized pads for the emitter and base leads of transistor structures are made in the form of two concentric circles, something which has made it possible to eliminate the orienting of the chips relative to the external leads during the assembly process and to make the bond (thermal compression) of the two leads simultaneously.

Figure 7.14. The KT315 mechanized flow line for the production of transistors.

The mechanized flow line consists of units, a portion of which are shown in Figure 7.14:

--The automated press for cutting out the perforations in the strip (Figure 7.14a). It has a nominal force of 104 Newtons, and a unit output of 6,000 transistors per hour. Several lines can be serviced;

--The unit for attaching the chips to the strip (Figure 7.14b). It has a machine output of 600 connections/hour. A vibrational hopper with a device for identifying and orienting the side of the chip by a probe head is used for the automated chip feed. The soldering of the chips is accomplished at a temperature of 400 to 420° C using ultrasonic generators with a power of 40 watts;

--The unit for attaching leads (Figure 7.14c). A double ruby capillary is used in it for the simultaneous connection of two leads (two units in a complete set). The thermal compression is realized using beads at a temperature of 300 to 360° C. The unit performs two operations. The first operation is thermal compression of two gold wires, which terminate in beads, to the metalized pads on a chip; in this case, all of the transitions in the operation are made automatically; only the precise matching is accomplished manually under a microscope. The second operation is the automatic connection to external current connectors; the operation is performed by means of resistance welding without the participation of the operator. The machine capacity is 300 to 350 devices per hour;

--The unit for preparing for hermetic sealing (Figure 7.14d). It has two working positions: for the unreeling of the strip with the transistor assemblies from a magnetic drum and loading into a satellite cassette holder for subsequent hermetic sealing; and for cutting off one of the jumpers on the strip. The capacity of one satellite holder is 20 devices. The output of the unit is 700 devices per hour;

--The hermetic sealing unit. It takes the form of a piston metering dispenser for epoxy compound, which is apportioned by 20 nozzles simultaneously. The working stage of the unit has a mechanism for automatically moving the potting forms by one regular step; the shifting is accomplished after each dosage;

--The KT-2-12 semiautomatic classifier. It is used for classifying the transistors; its feed and connection devices have been modernized for the flat plastic transistor package;

--The automatic marking unit. It is equipped with a vibrating feed hopper and a spiral volute chamber type drying chamber. The machine output of the automatic unit is 3,000 devices per hour;

--The devices are packaged in a polyethylene strip in two parallel rows. There is a vibrating feed hopper. The output of this automatic unit is 3,000 devices per hour;

--The magnetic storage drum is intended for accumulating the tape in the individual assembly operations and the subsequent transfer of the assemblies on the strip tape to the next production process operation. The drum is made of Fernico and bar magnets, which make it possible to heat treat the devices in an oxygen atmosphere.

For the batch assembly of IC's without wires using the contact frame technique, a set of equipment is employed in which the method of preliminary embossing of aluminum foil to produce the outline of the leads with subsequent etching out of the jumpers is used to produce the contact frames.

Some of the technical questions related to the use of strip carriers, in particular, additional information on the use of strip technology, known under the name "Mi-ni-Mod" are described in [51]. This technique, just as the variants of it, is based on the use of a plastic tape, reminiscent of a motion picture film, over the entire surface of which frames with leads produced by photolithography are arranged. A polyimide tape cladded with copper foil is most widely used for this purpose. The assembly of the IC's consists in the batch attachment of the chips, made with bead or beam leads, to the external leads of the frame. The chip is held above a small window in the plate by means of the internal leads, bonded by a thermal compression head to the bonding pads of the chip. Two narrow rectangular gaps make it possible to stamp out the exterior leads, removing the unnecessary edges of the film in this case. Then, these leads can be connected by the batch method to the housing or to the printed circuit board. The perforated holes at the edges of the films serve to move the film following the bonding of the chip and for the precise setting of the frame with the leads underneath the chip.

The typical process sequence for the group bonding of leads is shown in Figure 7.15. Prior to the start of the welding, the strip is lowered so that the internal leads formed beforehand match up with the bonding pads of the chip,

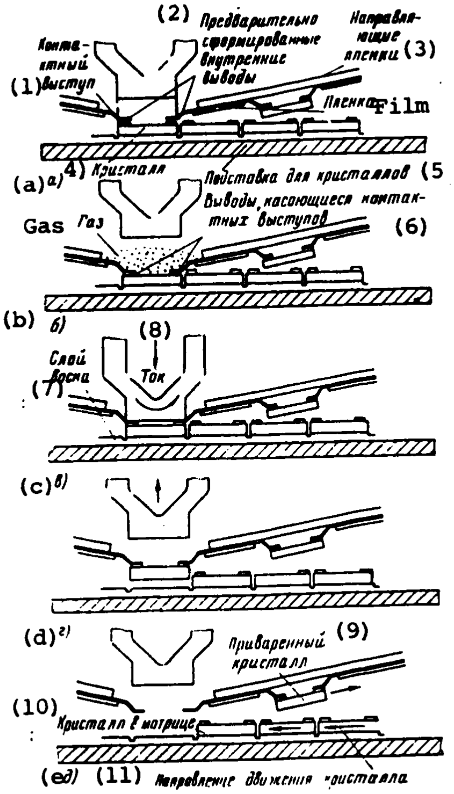


Figure 7.15. A typical process for bond-leads by the group method.

Key:
1. Contact projection;
2. Preformed internal leads;
3. Guide films;
4. Chip;
5. Support for the chips;
6. Leads which touch the contact projections;
7. Layer of wax;
8. Current;
9. Bonded chip;
10. Chip in the matrix;
11. Direction of chip motion.

which is glued with wax to the substrate (Figure 7.15a). The chip, which is observed in a microscope, is set in the requisite position either manually or automatically. Then the strip is lowered, bringing the internal leads in contact with the contact projections of the chip (Figure 7.15b). A stream of inert gas protects the weld site. The welding head is lowered, pressing the internal leads against the pads (7.15c). A pulsed electrical current heats the head, creating the bond. The liberated heat melts the wax and frees the chip. Following welding, the strip is lifted along with the bonded chip (Figure 7.15d), and then shifted to the left, transporting the next batch of leads into the working position (Figure 7.15e). The coordinate stage is shifted to the left, feeding the next chip for welding. Assembly machines have been designed having a tape winding unit. The machines are intended for soldering by means of melting a dosed amount of solder; the film is moved in steps of up to 127 μm at a speed of 38 mm/sec. Each chip is manually placed under a microscope. The requisite film tension is assured by an induction motor. The welding head of the machine has an electric drive. It is moved into the working position for 375 msec. The productivity of the machine is about 1,000 chips per hour.

A drawback to the technique consists in the fact that the polyimide strip, after the bonding of the leads, proves to be practically unnecessary, something which is not efficient from the viewpoint of material consumption, and moreover, the plastic tape yields a shrinkage on the order of 25 μm, which makes it difficult for automated equipment for connecting leads to operate reliably. Proposed as a promising system is the assembly of integrated circuits on a plastic film in rollers [42]. Using this method, instead of etching a polyimide film cladded

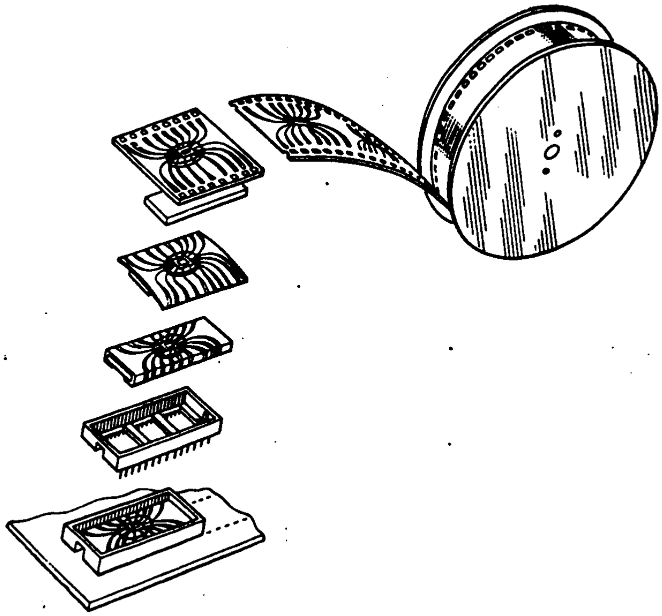


Figure 7.16. One of the fastening methods in an integrated circuit package in a film frame.

with copper, electrolytic and chemical deposition of copper or nickel is used, as a result of which, high precision is obtained in the figure for the lead layout. The minimal width of a conductor is equal to the minimum spacing between the conductors and amounts to 0.005 mm.

The walls of the conductors are vertical, while in circuits fabricated using foil etching, they are inclined as a result of undercut etching. The new technique is also favorably distinguished from earlier methods in that it does not require the use of an adhesive material to join the plastic film to the metal. This makes it possible to fully utilize the high thermal resistance of polyimide film: it is capable of sustaining a temperature of 400° C for 15 seconds, which is more than sufficient for the mounting of integrated circuits using electrical contact heating or thermal compression welding. Gold beads or beads of solder can also be deposited on the original film. The film, which is 16, 35 or 70 mm wide, with the integrated circuits attached is protected by a special coating.

The packages within which the film frames are hermetically sealed have inspection windows, and for this reason, when mounting IC's on a transparent polyimide film using the flip chip technique, the resulting contacts are partially visible through the package.

Frames of film with integrated circuits can be mounted in packages in various ways. One of them is shown in the figure (Figure 7.16). The edges of the film are bent around a rigid dielectric plate, and the resulting semi-finished piece is inserted in the package so that the conductors on the film make a reliable electrical contact with the package leads. The gluing of the frame to a dielectric plate or aluminum heat sink is also practiced. The most widespread method does not require hermetic sealing of the film and provides the capability of automating the assembly process. A special machine cuts out the frames with the IC's from a roller, sets them with their front side down on the printed circuit board and completes the assembly by means of electrical contact heating.

7.5. Equipment for the Assembly of Point Contact Diodes

The most widespread type of point diode is the D9 device. The attachment of the wire by means of welding to the needle holder of the D9 device, the cutting off of the wire, the forming of the needle, the quality control rejection as well as the placement of the needle holders with the weld attached needle in a cassette holder are accomplished on the automatic unit described below (Figure 7.17). When operated by a single operator, the automatic unit provides for the assembly of 3,600 to 4,500 devices per hour. It consists of three major assemblies: the unit for the welding and shaping of the needle 3, the table 1 and the vibration hopper 2. A pulse counter and other instruments, the readings of which are used to choose the welding process mode, are arranged on the control panel 4. The vibration hopper feeds the needle holders to the transport mechanism.

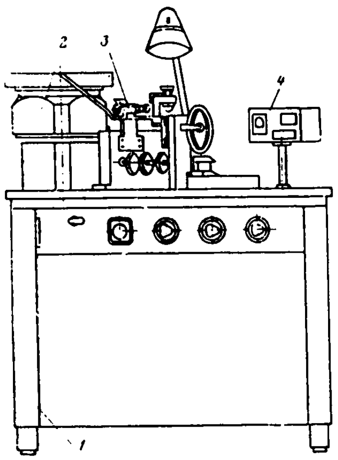


Figure 7.17. The automated needle welding and forming unit.

A kinematic schematic of the automatic unit is shown in Figure 7.18, from which one can trace the operation of the assemblies and mechanisms. The mechanisms are driven by drive 1, which provides for the motion and rotation of all the mechanisms. The needle holders which are loaded manually into vibration hopper 2 are fed via guides 3 and 5 to the transport mechanism, which moves a needle holder from one position to another and consists of a reducer, stationary rack 9 and moving rack 8. The piecewise feed mechanism 4 is mounted on the reducer, where this mechanism executes the individual feed of the needle holders to the transport mechanism by means of four levers, which are driven by a cam of the transport mechanism. The transporting element of the transport mechanism is rack 8, which executes a reciprocating motion and feeds the needle holders from one position to the next. The needle holders are moved via the rack to the region where the end of a needle holder is cut off. The cut-off mechanism 13 consists of a guide, and a slide to which the upper knife is fastened. The slide is driven by a cam, located on the reducer of the transport mechanism by means of a bearing. The bottom knife is mounted in the stationary rack of the transport mechanism. The needle holder is clamped in a definite position by means of a special device which is fastened to the slide.

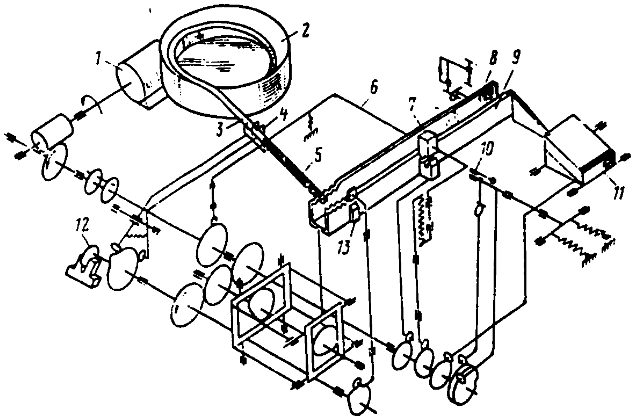


Figure 7.18. Kinematic schematic of the automated needle welding and forming unit.

The needle holders then move to the next position, where the needle holder is clamped., the wire is fed in and bonded and the needle is cut off and shaped. The clamping mechanism 6 consists of a slide, which is moved in the guide by means of a cam and a tilting bearing. A clamp is fastened to the slide by means of the chassis and a spring, where this clamps presses the needle holder against the rack prior to the welding operation. A contact is located on the chassis, which is used to check for the presence of the product and turn on the electrical power when performing the welding. The mechanism for feeding and bonding the wire 10 is located on a post. Two guides are secured to the post; the vertical up and down travel of the slide is accomplished via these guides using a screw. Two horizontally running guides are fastened to this slide; the rack is moved along these guides by means of a screw. A bracket is rigidly fastened to the frame, which also has two guides, along which the slide travels with the feed and welding heads positioned on the slide. The feeding of the wire is accomplished by means of a lever, which is driven by a cam of the transport and clamping mechanism.

The cutting and forming mechanism 7 consists of a bracket, guides and two slides. The lower knife is secured to one of them, while the upper knife is fastened to the other. The knives perform the operations of cutting off and shaping the wire. The motion of the guides is realized by means of a spring and cams of the transport mechanism through bearings. By virtue of grooves which exist in the bracket, on which the cutting and forming mechanism is mounted, it can be moved in a horizontal plane.

The welding process is accomplished by means of sector 12, which controls the limit switch. The finished products are fed to the cassette holder loading position. The final operation is carried out by means of the loading mechanism 11, which consists of a stationary housing and a moving carriage, on which the cassette holder is placed. The carriage moves along the guides by virtue of the motion of a stem and lug, which meshes with the toothed rack, fastened to the carriage. When one cell of the cassette holder is filled, the pulse counter feeds a signal to the electromagnet, which when turned on, the stem touching the cam moves the cassette holder by one step. When the cassette holder is completely full, the carriage moves to the microswitch, and the automatic unit is cut off. The operator changes the cassette, returns the carriage to the initial position and the cycle is repeated from the beginning.

7.6. Equipment for the Automated Assembly of Alloy Diodes

The assembly of D226 silicon alloy diodes is accomplished on an assembly unit with a continuous nickel belt. The belt transport mechanism is fed to a press from the unreeling assembly; the forming of the chip holder and the cutting out of the preparations are done automatically in the press. Oil residues are removed from the strip in a degreasing bath with trichloroethylene. The degreased strip is fed into the automatic unit for the weld attachment of the lower lead. A moving electrode is brought from above against the strip, while from below, a feed carriage feeds a nickel plated copper wire and presses it against the strip and welds it, after which a knife cuts off the lead. Then the strip moves on, going to a tinning mechanism, a washing bath and drying furnace.

The washed dry strip is transported in this way to a furnace for bonding the junctions. The operator sets the cassette holder with the junctions on the strip. The junctions are wetted with solder, and after cooling form a reliable electrical contact with the chip holder. Then a capsule is manually placed on the junction lead. After this, the capsule is automatically ring welded to the chip holder. The operator seats the cassette holder with the intermediate leads on the capsules to center a capsule relative to the crystal holder. The clamping devices go in the perforation holes, thereby centering the capsules. After performing the operation, the operator removes the cassette holder with the bonded capsules and the strip is transported to the automat for tube swaging. A die, which in pressing the tube against a stationary support, deforms it by 3.5 + 0.5 mm is fastened to the rod of a pneumatic mechanism, which is operated by a valve controlled by a cam. The swaged portion of the tube is then welded at 3 + 0.5 mm by the welding mechanism. The operation of the tube welding mechanism is similar to the swaging mechanism, only electrodes are mounted in it instead of dies.

Following the welding of the tube, the electrodes are moved away and the sealed device is fed to the position for welding the upper lead. The automatic welding of the lead is accomplished in the following manner. A clamp of the mechanism catches the nickel wire and feeds it through an interception assembly and a knife draw die to the small tube of the capsule. A moving electrode is brought up by means of a pneumatic cylinder, where this electrode presses the lead from the tube against another electrode which can be moved. With the approach of the moving electrode to the tube of the device, a centering fork catches the tube with its lower cutout, while with the upper one, centers the lead relative to its axis. Following the welding, a knife cuts off the lead, while the intercepting assembly retains the wire until the clamp returns to the upper position. The moving electrode is returned to the initial position and the entire cycle is repeated.

The removal of the assembled device from the strip is accomplished in a press for cutting out the finished device. The press cuts out two devices for the purpose of improving the dynamic characteristics.

In structural terms, the assembly unit combines several sections, which are joined together in a line, which is described in Chapter Fifteen. The mechanisms of the unit operate from three separate drives. The ring welding mechanism and the mechanism for swaging and weld attachment of the tube, as well as the mechanisms for welding the lower leads and tinning the strip, and the strip transport and upper lead welding mechanisms are all driven by the main drive. The forming press for the chip holders and the press for cutting out the finished device operate from individual drives. The synchronization of the operation of all of the drives is electrical.

The major assemblies and mechanisms which assemble a device are described in the following.

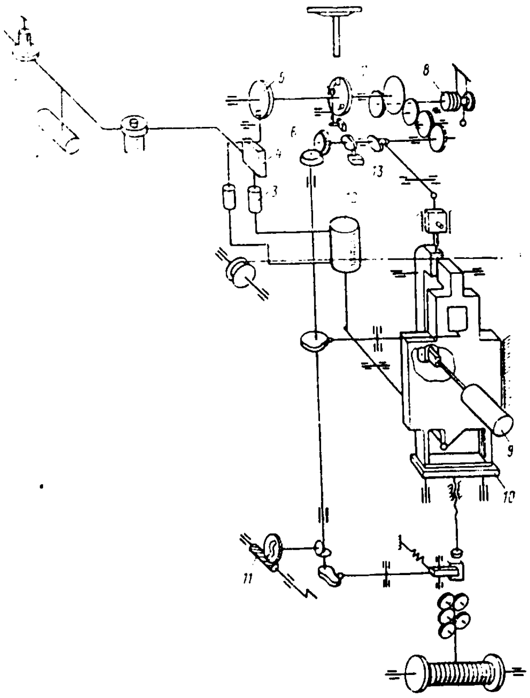


Figure 7.19. Kinematic schematic of the mechanism for welding the lower lead and the tinning mechanism.

The assemblies for clamping, feeding and cutting the wire, the upper electrode, the pneumatic cylinders and valves are located in the mechanism for welding the upper lead (Figure 7.19). The parts of the mechanism are driven by the main drive through clutch 8, cylindrical gear 7, the shaft for actuating the valves 5, cylindrical gears, shaft 13, the conical spur gear pair 6 and a vertical distribution shaft.

The lead is clamped by means of jaws which are driven by the rod of pneumatic cylinder 9, and moved by pneumatic cylinder 12. The pneumatic cylinders are controlled by valves 4. The pneumatic cylinder for feeding the lead provides for the requisite clamping force for the lead against the strip, which is regulated by varying the air pressure in the system by means of reducing valve 1 and is stabilized by receiver 2. The feed brake is adjusted by throttling valves 3. There is a moving stop 10, which limits the lowering of the feed assembly, for the regulation of the protrusion of the lead. During alignment and adjustment, the mechanism is disconnected from the main drive and the parts are moved by levers 11.

The drying furnace is made in a separate housing, in which spiral heaters are located. The working temperature for the drying is 100 ± 10° C. The time that the furnace is in the operating mode is no more than 30 minutes.

The furnace for attaching the junctions takes the form of a separate housing, in which there are four electric heaters. On the outside, the furnace is covered with a casing which is cooled by water flowing through it. The temperature in the furnace is adjusted in a range of from 50 to 600° C. The time that the furnace is in the maximum operating mode is no more than 30 minutes. It is powered from the AC mains at a voltage of 220 volts. The maximum power of the furnace is 2.4 KW.

A kinematic schematic of the ring welding, tube swaging and upper lead welding mechanism is shown in Figure 7.20. The main drive for the unit consists of electric motor 3, the V-belt drive, worm gear reducer 2, cylindrical spur gear transmission 4 and the distribution shaft 1.

The ring welding mechanism consists of the welding housing, the upper 5 and lower 11 pneumatic cylinders for moving the electrodes and the lower electrode clamping assembly 12. The overall travel of the upper electrode is 40 mm. The working travel of the upper electrode is 10 mm, and that of the lower electrode is 35 mm.

The tube swaging mechanism includes pneumatic cylinder 6, stationary stop 10 and the guides for holding the strip.

The mechanism for welding the upper lead has a welded frame, on which the distribution shaft 9 with the control cams and drive gears, as well as the wire bobbin 7 and electrode assembly 8 are mounted. The entire mechanism is secured on a separate plate, having four slots. The parts of the mechanism are rotated by the main shaft 1.

The entire process of assembling the devices is carried out in a controlled medium, which is assured by the protective suit existing in the unit. It consists of standardized sections of welded structures. Each section is installed and secured to the upper plate of the frame.

To control all of the mechanisms of the equipment, there is a control panel in it on which the requisite controls, switches and lights are located, by means of which the mechanism is turned on and the production process operations are monitored.

7.7. Equipment for the Assembly of Power Transistors

The sharp growth in the production of power transistors, the increase in the currents, voltages and power, and consequently, the increase in the dimensions of the chips, lead diameters, geometric dimensions as well as the materials of the package make it necessary to seek out new, more promising methods of assembly, which would make it possible to boost productivity and quality.

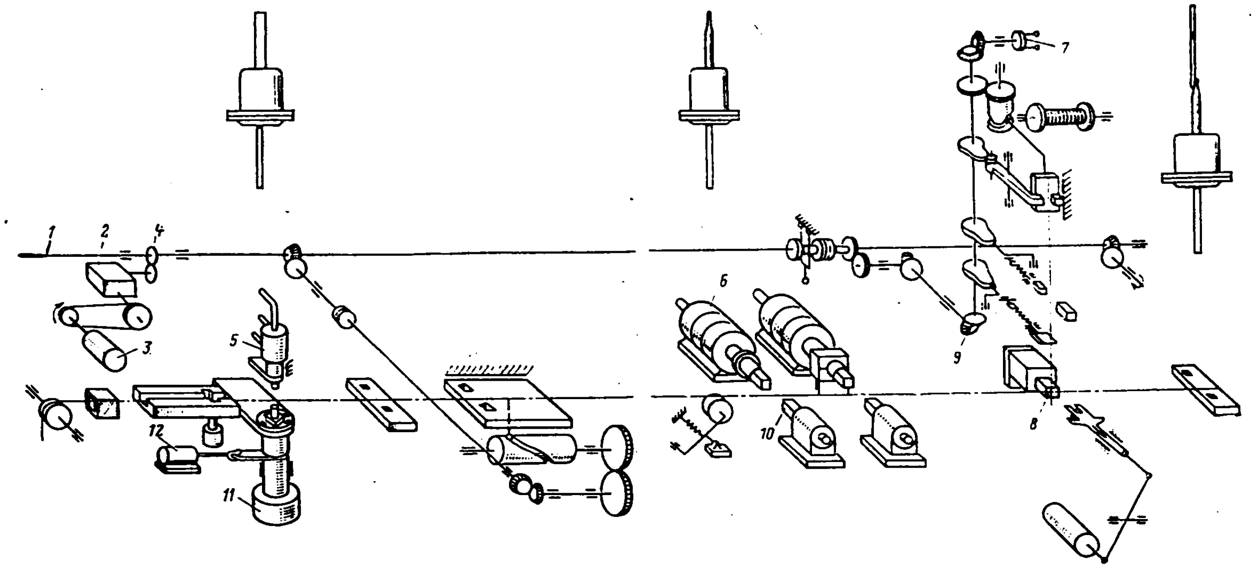


Figure 7.20. Kinematic schematic showing the operation of the ring welding, strip transport, tube swaging and welding as well as the upper lead welding mechanisms.

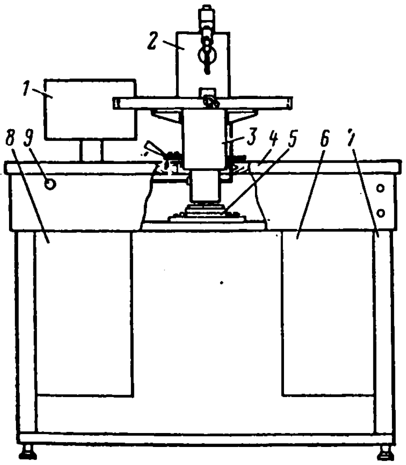


Figure 7.21. The unit for ultrasonic lead bonding.

The existing production of power transistors is characterized by a great diversity of the assembly methods, for example, the connection of the chips is accomplished by flux soldering, eutectic bonding, and bonding in a hydrogen furnace. In one case, here, the chip is joined directly to the mounting base, and in the other, to a gold plated molybdenum disk. The connection of the leads is also accomplished in different ways: flux soldering, bonding in a hydrogen furnace and ultrasonic welding. All of this requires the development of special equipment to perform the indicated operations.

The installation for the ultrasonic bonding of leads (Figure 7.21) to high power transistor chips is described below. It provides for the automatic bonding of two wire leads to the metalized pads of a chip by means of applying ultrasound and pressure with the subsequent forming of the leads to assure their orientation relative to the end faces of the transistor mounting bases. The installation is serviced by a single operator. The productivity of the installation is 1,200 welds/hr. The devices are fed in a cassette holder; the capacity of the cassette is 10 devices.

The installation consists of the following assemblies: the control panel 1, the welding head 2, the mechanism for clamping and feeding the devices 3, the plate 4, manipulator 5, the electrical equipment cabinet 6, table 7, ultrasonic generator 8 and the pneumatic assembly 9. The installation can operate in two modes. In the case of operation in mode I, the leads are welded to a chip in the unit; in the case of mode II operation, the leads are bonded ultrasonically to the cross-ties of the transistor mounting bases.

The bonding of a lead to a contact bonding track of a chip is accomplished by means of the tool which is mounted at the end of the waveguide of a magnetostrictive ultrasonic transducer. The bonding occurs by virtue of the joint action of pressure and ultrasonic oscillations on the parts being joined together.

The working cycle of the process takes place over one revolution of the distribution shafts A, B and C (Figure 7.22). The functional linkage of the operation of these shafts is accomplished electrically. The following mechanisms are operated by means of the cams arranged on distribution shaft A: the wire feed mechanism is driven by cam 14; the wire cutting mechanism is driven by cam 18 and the wire holder mechanism is rotated by cam 20. The shaft is rotated by electric motor 19. Distribution shaft B controls the operation of the mechanism for the step feed of the cassette holder by cam 29 and the mechanism for clamping the devices in the bonding position. The shaft is rotated by electric motor 26 through the toothed belt drive 27. The mechanism for lowering the acoustical system with the tool secured to the end of the concentrator is driven by cam 22, which is positioned on shaft C. The shaft is rotated by electric motor 21. The clamping of the wire feed jaws 12 is accomplished by an electromagnet, built into the stationary jaw 13. The wire, which is cut off by knives 11, is fed to holder 10 near the tool 25. The devices are brought into the working position in the cassette holder with each step of carriage 8. The final matching of the bonding pad on a chip to the tool is accomplished by manipulator 30. Shafts A and B, after being turned off, are braked by electromagnetic brakes 4, which are rotated through gear pairs 2 and 3, as well as brake 17.

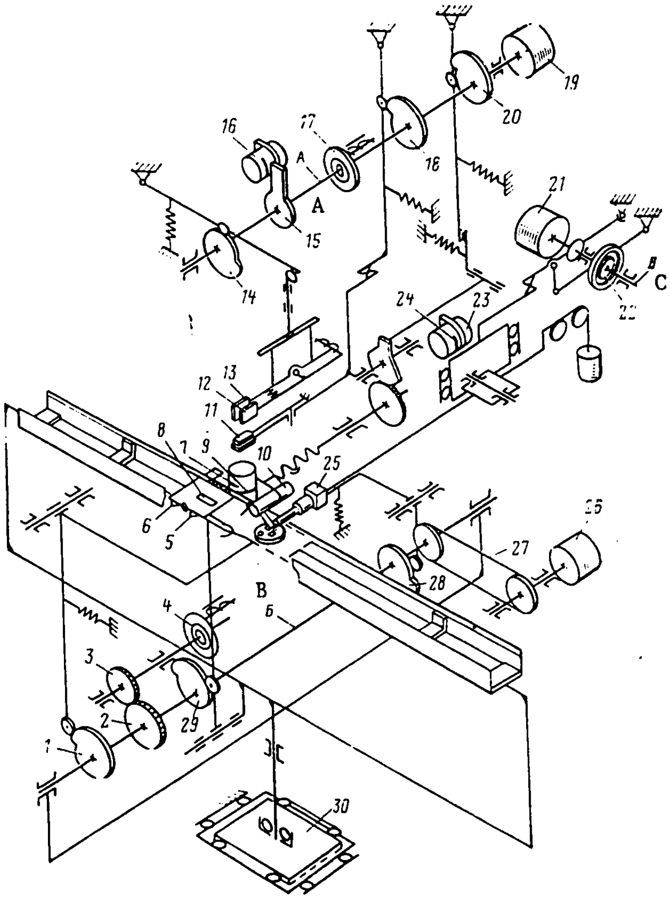


Figure 7.22. Kinematic schematic of the ultrasonic bonding unit.

The working controls of the installation are controlled by cams, contactless switches 9, 23 and 16, as well as clamping microswitches, by means of which the following are accomplished: the device is clamped (cams 1 and 28); the pneumatic valves for the lead bending and forming cylinders are actuated (microswitches 5 and 6); the device feed drive motor is turned on (lobes 7); the feeding of the wire to a specified length (cam 14); the turning-on of the drive motor for wire preparation (lobe 15); the cutting-off of the wire (cam 18); the rotation of the wire holder (cam 20); the lowering of the tool (cam 22); the turning on of the ultrasonic generator and the shutdown of the motors (lobe 24); and the moving of the cassette holder through one step (cam 29).

In structural terms, the major assemblies and mechanisms of the installation are made as follows. The welding head is the major actuating mechanism and consists of the following assemblies: the wire preparation drive, the wire feed and cut off mechanism, the mechanism for feeding the wire to the tool and the acoustical head and housing.

The wire preparation drive provides for the requisite motions of the mechanisms which prepare a wire segment for bonding. It consists of a distribution shaft with the cams seated on it, by means of which the clamped shutdown of the shaft is realized after the motor is turned off. In addition, there is an electromagnetic break.

The wire feed and cutting mechanism provides for feeding the wire from the spools by means of jaws into the nipple of the holder of the wire transport mechanism. The cutting of the wire is accomplished by a moving knife, which turns on its axis relative to the stationary knife. The mechanism has a stop plate, which is set up relative to the height of the guides, assuring that the requisite length of the wire is obtained.

The mechanism for feeding the wire to the tool feeds a section of wire, which is secured in the nipple by means of a spring, which actuates during the motion of the knife and clamps the wire at the tool. The wire feed is accomplished by virtue of a reciprocating motion of the lever.

The acoustic head is mounted in a carriage in ball guides on a cantilever bracket and is rigidly coupled to a shaft, which is supported on two bearings mounted in the bracket. Because of this coupling, it has the capability of rotating together with the axis through an angle of ± 5°. The horizontal position of the end face of the tool is set by adjusting screws. The rotation of the system about its axis depends on the height to which the head is lowered after the tool encounters an obstacle.

The mechanism for clamping and feeding the devices by means of the carriage and two lugs accomplishes the stepwise feeding of the cassette holder. The cassette holder moves in the guides on bearings, which extend above the slot. The clamping of the devices is accomplished on both sides by cams, mounted on a single shaft. There is an electromagnetic brake, which is coupled to the shaft through a gear coupling to clamp the shutdown of the shaft at the moment it is turned off.

The manipulator moves the cassette holder with the devices relative to the tool in a field of 25 x 25 mm. It is built using ball guides. There are two pushbuttons for turning it on and the feed of the devices in the drive control of the manipulator. The operator controls the operation of the installation from the control panel and both semiautomatic and adjustment modes are possible.

CHAPTER EIGHT EQUIPMENT FOR HERMETICALLY SEALING SEMICONDUCTOR DEVICES

One of the decisive factors which influences the stability of semiconductor device parameters is the composition of the ambient medium around the semiconductor chip with the electron and hole junctions, which are extremely sensitive to exposure to all possible kinds of dirt, moisture, various kinds of deformations, etc. A hermetically sealed package, inside which the junctions are placed, should reliably isolate them from the environment. Semiconductor device packages having a leakage of less than $5 \cdot 10^{-6}$ 1 · μm/sec are considered hermetically sealed.

The major requirements placed on hermetic sealing operations are: producing vacuum tight and mechanically strong joints of the package elements; precluding the possibility of dirt, gaseous emissions and splashes getting into the sealed volume of the device during assembly; the impermissibility of heating the junction during the hermetic sealing above 120° for germanium devices and 200° for silicon devices.

The diversity of existing semiconductor device and IC packages is explained by the simultaneous use of several methods of hermetic sealing in production and the types of equipment corresponding to them. The techniques of cold and resistance welding have become the most widespread for hermetically sealing metal-glass packages, while the methods of soldering with low temperature solders and roller contact welding are most widely used for sealing metal-ceramic packages. The sealing of semiconductor devices and IC's in monolithic plastic packages by means of transfer forming (casting under low pressure) has become widespread. A large group of semiconductor devices, diodes, is hermetically sealed in all-glass packages using special equipment; in this case, the alignment, electroforming and welding together of the packages is accomplished in the equipment. The parts being welded are heated by means of a plate or ring type direct incandescent heater. Equipment is known in which the heating is accomplished by radiofrequency currents. In a number of cases, equipment is used to hermetically seal complex products in multiple lead packages in which the heating of the parts of the package being joined together is accomplished by an electron beam, focused infrared rays, by a plasma or a laser.

8.1. Equipment for Cold Welding

Cold welding assures good quality of the weld seam: the process takes place without gas liberation and heating which have a harmful influence on the properties of an electron-hole junction. To be included among the drawbacks to this technique are the necessity of increasing the diameter of the package because of plastic deformation of the components being welded, the necessity of using ductile metals and the somewhat limited capabilities of welding thin wall parts.

Cold welding of a semiconductor device mounting base with a piston can be accomplished using one and two sided compression. In the case of compression on one side, an annular indentation is formed on one side (Figure 8.1a), and with two sided compression, it is formed on both sides (Figure 8.1b). The optimal variant is one sided deformation in a free volume. In this case, the deformation needed for seizure of the copper-Fernico pair is 67% as opposed to 72% in the case of double sided deformation [52].

The optimal degree of deformation of the package parts being welded is assured through the structural design of the working tool, which makes it possible to produce the specified thickness of the metals at the weld site.

The working tool is a punch (Figure 8.2) fabricated of the KhVG or Kh12M alloy steels and tempered to a hardness of H_{rc} = 52 to 60; the hard alloy VK20 is also used. The weld quality is governed by the condition of the surfaces being joined and the force applied to the working tool.

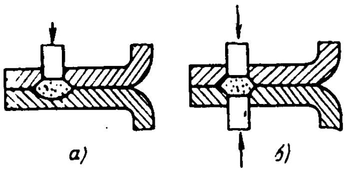


Figure 8.1. Kinds of cold welding.

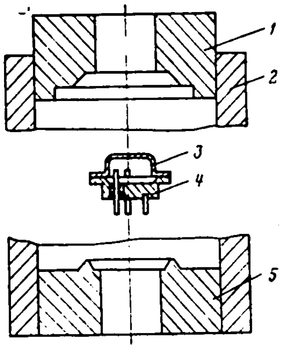


Figure 8.2. The working tool for cold welding.

Key:
1. Punch from the side of the part made of softer material;
2. Cup;
3. Cap;
4. Mounting base;
5. Punch from the side of the part made of harder material.

For hermetic sealing using cold welding in semiconductor production, special hydraulic or pneumatic presses are used having a force of from $5 \cdot 10^4$ up to $6 \cdot 10^5$ N. The parameters of the most widespread equipment are given below.

	Cold Welding Equipment				
Technical Specifications	020.0007	020.0011	2.221.006	2.220.003	5.333.00.000
Output, welds/hr	600-900	200-600	1,200	800	500
Working force, Newtons	10^5	$6 \cdot 10^4$ - $3 \cdot 10^5$	10^5	$5 \cdot 10^4$ - $2 \cdot 10^5$	$6 \cdot 10^5$
Working travel of the tool, mm	27	5	10	6	10
Number of carousel positions, pieces	12	2	8	6	6

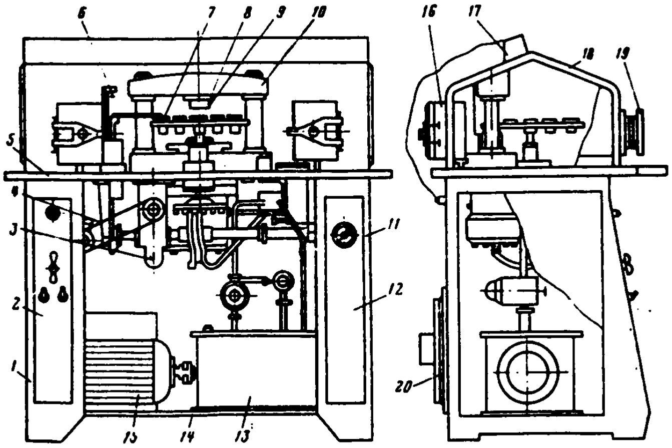


Figure 8.3. Semiautomatic unit for hermetically encapsulating semiconductor devices.

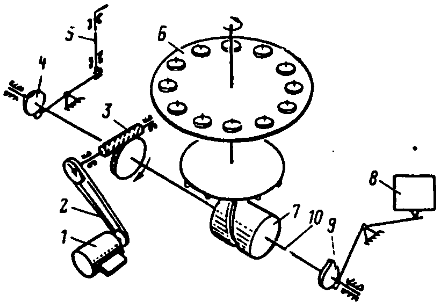


Figure 8.4. Kinematic schematic of the semiautomatic hermetic encapsulating unit.

The semiautomatic unit for hermetically sealing semiconductor devices using a force of 10^5 Newtons is shown in Figure 8.3. The semiautomated unit is a 12 position carousel type. All of the mechanisms, assemblies and parts are mounted on a machine tool bed, consisting of cast bases 1 and 11 and two plates: the upper 5 and the lower 14 plates. The carousel 7 with the seats 8 in which the assembly of the device package parts is accomplished prior to welding as well as the welding itself are mounted in the upper plate; the unloading mechanism 6 for the automatic unloading of the welded devices from the carousel nests; hydraulic press 10, which creates the requisite force and consists of a hydraulic cylinder with a piston, two columns and a cross-piece. The housing 9 with the upper punch is connected to the cross-piece; there are grabs on the piston to extract the nest with the lower punch. In case a device jams in the upper punch, a mechanical device for pushing it out is provided, which is coupled to the piston.

All of the assemblies which are located on the upper plate of the bed are isolated from the environment by protective cover 18. The interior volume of the protective cover is filled with an inert gas or clean dry air during the operation of the semiautomatic unit. There are two windows each in the front and rear walls of the protective cover in which locks 16 are inserted (for loading parts and unloading finished products) as well as seals 19 for the arms of the operator. A reducer 3, which is coupled to the electric motor by a V-belt drive 4 is

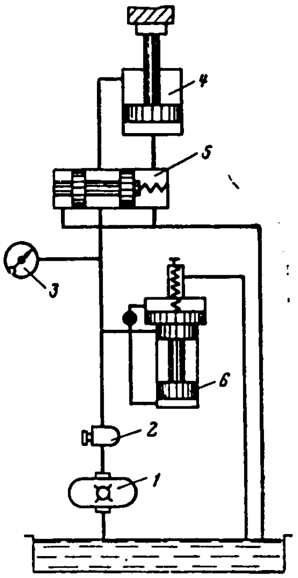


Figure 8.5. Hydraulic schematic of the semiautomatic hermetic sealing unit.

secured at the bottom of the top plate. Oil tank 13 with a hydraulic pump and electric motor 15 are mounted on the lower plate.

Panels 2 and 12 with the control elements, as well as the electrical and hydraulic equipment are mounted on cast bases. Cabinet 20 with the electrical equipment is built into the rear portion of the bed. To fill the lock chambers and working volume of the protective cover with the inert gas or cleaned dry air, a hose with a nipple, which is screwed into a through-hole in the upper plate. There are similar nipples in the lock chambers. A luminescent lamp 17 for local illumination is placed at the top in the protective cover.

The interaction of the actuating mechanisms can be traced using the kinematic schematic of Figure 8.4. The rotation from electric motor 1 is transmitted through V-belt drive 2 and the worm gear pair 3 to camshaft 10. The helical groove 7 as well as the cams 4 and 9 which are rigidly secured to the camshaft drive carousel 6, the unloading mechanism 5 and slide valve 8.

The hydraulic system (Figure 8.5) operates as follows. Industrial oil 20 (GOST 1707-54) is fed from vane pump 1 through the plate filter 2 into the four-way valve 5 to working cylinder 4. The oil pressure is monitored by manometer 3. When the projection of slide valve 5 is covered with oil, the oil fills the space beneath the piston under pressure and lifts the piston. The oil, which during this time is above the piston, drains off into the tank. When the valve is released, the oil executes the return trip and the piston returns to the initial position. Check valve 6 with the unloading valve provides for a constant specified pressure and protects the hydraulic system against overloads.

8.2. Equipment for Electrical Contact Resistance Welding

Resistance welding, in contrast to cold welding, makes it possible to weld finer parts, does not increase the dimensions of a package, and provides for a higher productivity. For the purpose of eliminating long term heating of the devices being sealed together, resistance welding is used which assures local and brief heat liberation at the weld site.

Parameters of capacitor machines for contact welding of semiconductor device packages are given below [53]:

	Type of Capacitor Machine			
Technical Parameters	MRK-4001	MRK-10001	MTK-8002	MTK-5-3
Perimeter of the package being welded (the welded seam), mm	22-55	55-100	30-80	3-12
Output, welds/hr	1,200	1,200	900	1,200
Force on the electrodes, Newtons	$1 \cdot 10^3$ - $5 \cdot 10^3$	$2 \cdot 10^3$ - $1.23 \cdot 10^4$	$1.5 \cdot 10^3$ - $1.23 \cdot 10^4$	$3 \cdot 10^2$ - $3 \cdot 10^3$
Nominal welding current (Amplitude value), amperes	40,000	100,000	80,000	32,000
Maximum stored energy, $J \cdot 10^3$	3.6	16.1	14.8	2.7

The formation of the welded seam in the case of electrical contact resistance welding occurs by virtue of the heating of the parts being welded by the current and their plastic deformation with the action of the applied compression force. The electrical energy is stored in a capacitor bank where the capacitors are charged from a DC power supply.

The quantity of energy stored is regulated by changing the working voltage and capacitance of the bank. Changing the working voltage is accomplished by changing the master voltage, while the capacitance of a bank is changed by means of switching three sections of a capacitor bank in different combinations by means of a step switch for the capacitance, P_{st}.

The battery is discharged through the primary winding of the welding transformer at the moment the discharge circuit is closed by one of the discharge contactors, which operate in sequence, changing the direction of current in the transformer windings in each cycle for the purpose of preventing the magnetization of the transformer.

The discharge current pulse, and consequently, the welding current pulse are governed by the parameters of the electrical power section: the working voltage, the capacitance of the bank of capacitors, and the transformation ratio of the welding transformer.

An overall view of a capacitive welding machine is shown in Figure 8.6.

The major assemblies of the machine are: the frame 2 with the bracket 8, welding attachment 11, the pressure drive 10, the pneumatic system 9, protective enclosure 5, gas system 4 with the drier 3, welding transformer 1 with the switch for the taps 7 as well as choke 6 and the electrical equipment. The machine complement includes a power supply and control station (not shown in the figure).

In structural terms, the frame takes the form of a welded metal chassis, on the upper plate of which the bracket and protective enclosure are mounted. The pressure drive is installed on the bracket; the welding attachment is mounted inside the protective enclosure. Inside the frame housing are located various

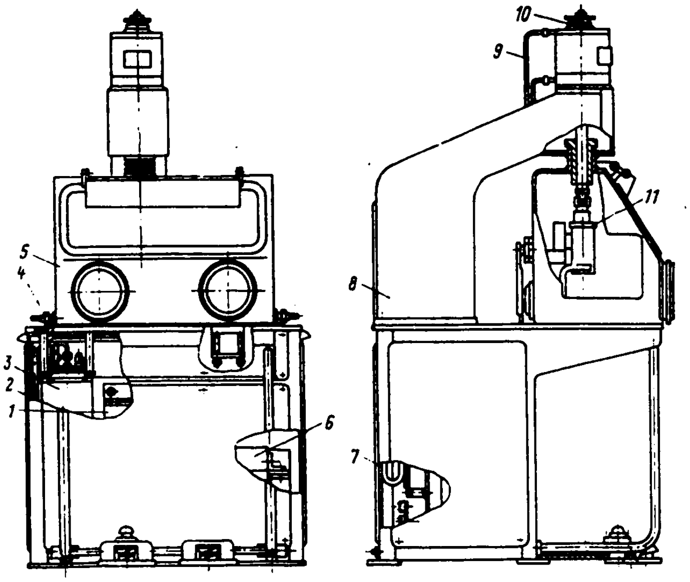


Figure 8.6. General view of the capacitive welding machine.

devices and machine systems; access to the adjustable elements of which is accomplished through two doors in the rear wall of the housing. The welding attachment provides for moving the upper electrode during welding and maintaining the working surfaces of the electrodes parallel, something which is important in obtaining a high quality seam. The welding attachment housing is fastened to the base of the protective enclosure.

A slide, with the upper electrode mounted in it, which is connected through the upper current conductor and flexible buses to the secondary winding of the welding transformer, travels inside the framework on ball bearings. The lower current conductor is brought in through a hole in the base of the chassis, where this conductor connects the lower electrode to the secondary winding of the welding transformer.

The force is transmitted from the pressure drive to the slide through a set of disk springs, placed between the slide and a U-shape bracket, which when engaged with the slide goes into the tailpiece of the pressure drive.

The pressure drive (Figure 8.7), which is intended for producing the force on the electrodes during welding, consists of pneumatic cylinder 7, piston 6 with the rod 5, spring 4, adjusting nut 3, push rod 1 and the pressure indicator 2. The force on the electrodes is produced as a result of the spring compression and the transmission of this force through the push rod to the slide of the welding attachment with the upper electrode secured to it. The structural design of the pressure drive provides for a stable specified force on the electrodes with considerable fluctuations in the pressure in the compressed air mains and in the pneumatic cylinder.

The air rate of flow through the system is regulated by means of valves, which in turn make it possible to regulate the rate of travel of the pistons of the pneumatic cylinders.

The constancy of the gas medium in the welding region is assured by the gas system and the protective enclosure. The quantity fed into the protective enclosure is monitored by a direct reading flow meter. The admission of gas into the lock chamber and its extraction from the protective enclosure and the chamber are accomplished by means of vacuum valves.

The welding transformer is mounted in the central portion of the machine frame housing. The primary winding of the transformer is made from two cylindrical type coils, while the secondary is made from two copper foil packets connected in parallel. A choke is used to shape the leading edge of the welding pulse, where the choke winding is inserted in series with the primary winding of the welding transformer. The core of the choke has a variable air gap.

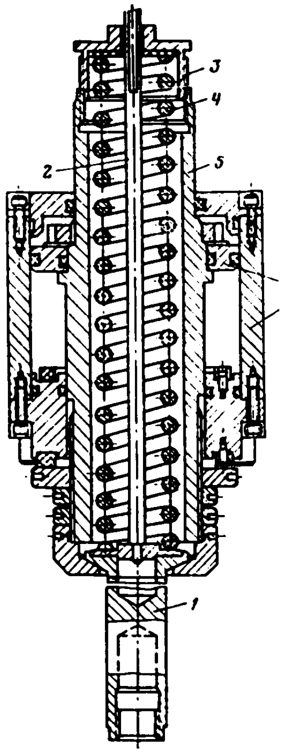


Figure 8.7. Structural design of the pressure drive.

The electrical equipment of the machine consists of the electrical power section and the control circuits. The power section stores the energy from the mains in the bank of capacitors and feeds it to the weld site. The control circuits provide for the sequence and duration of actuation of the power section components and the other elements of the machine during cyclical operation.

The machine has a broad control range for the amplitude and width of the welding pulse as well as the electrode force, because of which, one can weld devices with diameters of from 3 to 12 mm. The welding pulse is adjusted in seven capacitance steps of the bank of capacitors with the voltage varying from 150 to 400 volts, using eight steps for switching the welding transformer. The force on the electrodes is adjusted in a range of $3 \cdot 10^2 - 3 \cdot 10^3$ N.

8.3. Equipment for Hermetic Encapsulation With Plastics

Encapsulation using plastics finds wide scale applications for devices used in consumer electronics equipment. Various plastic materials are employed: epoxy resins with various hardeners and synthetic elastomers. The most widespread methods of hermetic encapsulation are the techniques of free potting of the forms and casting at low pressure - transfer forming.

The UGP-50 installation (Figure 8.8) for hermetic sealing of semiconductor devices with plastic takes the form of a column type hydraulic press with the compression plate located at the bottom and the casting cylinder 4 placed at the top. Control panel 1, cleaner 2, the press 3 and table 6 with the control unit 5 located on it are mounted on the welded frame. The frame is enclosed with sheathing, and the hydraulic equipment is located inside the frame. The servicing of the installation is accomplished from the instrument side of the panel on which the control buttons are brought out.

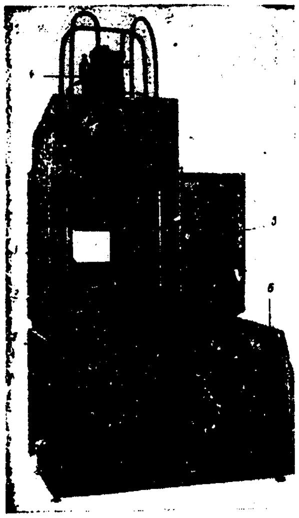


Figure 8.8. The installation for plastic encapsulation.

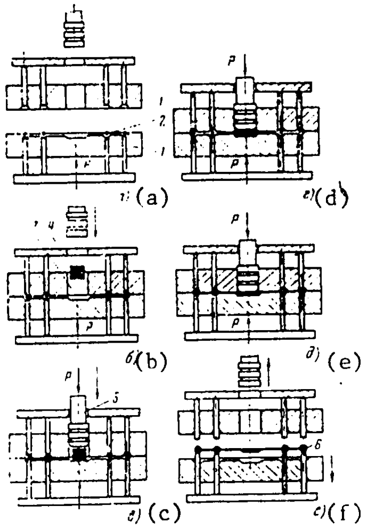


Figure 8.9. Functional schematic showing the hermetic encapsulation process.

The operation of the unit is based on the principle of batch encapsulation in a stationary compression mold. The sequence for the execution of the hermetic encapsulation operations is shown in Figure 8.9. A section of the strip carrier 2 is loaded into open compression mold 1 with the chips bonded to the strip (Figure 8.9a). When the pump is turned on, there is at first an accelerated closing of the compression mold, and then a slow closing. The maximum compression force in the UGP-50 installation is 0.5 MN. A tablet of the compression molding material 4 is loaded into casting chamber 3 of the compression mold (Figure 8.9b), then the lowering is speeded up, and thereafter the working stroke of rod 5 of the cylinder (Figure 8.9c). The speed of the working stroke is adjusted by means of the feed mechanism, while the force is adjusted by means of the stop valves using the manometers until the requisite pressure is reached in the upper and lower cavities of the cylinder. During the working travel of the rod, the material is injected at high pressure (Figure 8.9d). To improve the fluidity, the tablet of compression molding material is heated beforehand by high frequency currents. To obtain a high density in the package, it is exposed to the nominal pressure for some time (Figure 8.9e) (the exposure time depends on the compression molding material and is specified by a time delay relay). Then the rod 5 is lifted, the compression mold is released, the hermetically sealed devices 6 are removed and the compression mold is cleaned (Figure 8.9f). The installation is ready for a new cycle. Installations with compression forces of 1.0, 1.5 MN and more, as well as so-called shuttle presses, which provide for an increase in output by combining the main and auxiliary process times.

8.4. Equipment for Hermetic Sealing by Means of Soldering

Flat metal-glass and metal-ceramic packages are hermetically sealed in a batch sealing installation by means of soldering using a heated inert gas (Figure 8.10). One can run the soldering process in the unit both with flux and without it [54]. The devices being sealed in a ten place cassette holder with the assembled bases and caps are manually placed on the moving carriage of the installation, and then the entire soldering cycle is accomplished automatically upon instructions from the programmer. The devices are introduced into the effective zone of a jet of heated inert gas; there is a separate heater for each package, something which provides for better observance of the soldering conditions, as well as the possibility of more precisely maintaining the temperature. A provision is made for an individual direct reading flow meter to regulate the gas rate of flow for each heater. The heat flow is on the cap side, and therefore the temperature of the package base where the semiconductor structure is located is always lower than the soldering temperature. During the entire soldering cycle, including cooling, the cap of the device is clamped with a special device and pressed against the base with a specified force. Excessive force leads to splashes, and weak force promotes the shifting of the cap and the appearance of defective seals. Following soldering, the hermetically sealed packages are flushed with a cold inert gas, which promotes the rate of crystallization and prevents the infiltration of solder inside the integrated circuit package. Upon completion of the cooling, the carriage with the cassette holder is automatically returned to the initial position.

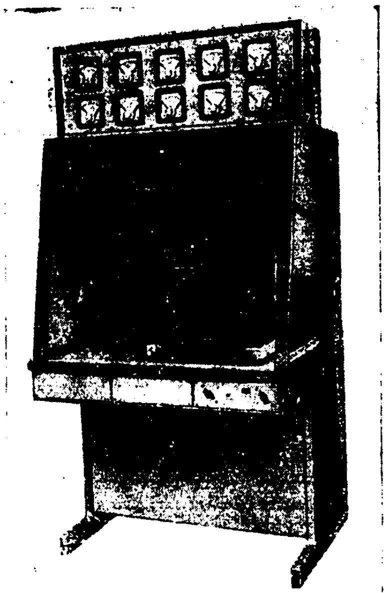


Figure 8.10. Installation for batch hermetic sealing by means of soldering.

8.5. Equipment for Checking the Hermetic Seal of Semiconductor Devices

The degree of the hermetic seal of the package of any semiconductor device or IC is one of the most important parameters which influence their operability and reliability. The criteria for a hermetic seal differ depending on the area of application of a semiconductor device and IC, as well as the interior volume of the package: thus, for consumer electronics devices, the leakage should not exceed 10^{-5} 1 · μm/sec, and for especially reliable devices, the permissible leaks do not exceed 10^{-8} 1 · μm/sec. This means that over a period of 10 years, the package will not admit more than 1 cm^3 of air with a pressure difference of 1 atmosphere.

Several techniques exist for checking the hermetic seal of devices:

a) Bubble methods, based on the observation of gas bubbles exiting a device placed in a liquid. These include the following:

--Fluid method, in which the check of the hermetic seal is accomplished by visual observation of air bubbles exiting the device package where the device is placed in silicon oil heated up to a temperature of 200° C;

--The vacuum-liquid method, which is based on observing gas bubbles exiting a device placed in a liquid, over which a rarefaction is created.

The vacuum-liquid technique has a poor sensitivity of 10^{-2} 1 · μm/sec (the liquid method has a sensitivity of 10 1 · μm/sec), but it can be increased up to 10^{-3} to 10^{-4} 1 · μm/sec, by varying the composition of the liquid, the pressure, the temperature and the depth of immersion of the device.

b) The mass spectrometry method, which is based on reading the amount of helium exiting through leaks existing in the device package. This is the most widespread and sensitive method: 10^{-12} 1 · μm/sec.

c) The halide technique, which is based on reading the concentration of halogens in the space surrounding the sensor (the sensitivity runs down to 10^{-6} 1 · μm/sec).

d) The radioactive method, which is based on reading the gamma radiation of a radioactive gas which penetrates inside the package during preliminary pressurization of the product being tested (a sensitivity of down to 10^{-9} 1 · μm/sec).

e) Indirect methods of testing for a hermetic seal, which are based on the change in the electrical parameters of the product being tested by virtue of the intrusion of a liquid inside the package (pressurization of the devices in water or acetone, exposure for several days in a heat and moisture chamber at a temperature of 40 ± 5° C and a relative humidity of 95 to 98%).

The use of a particular hermetic seal testing technique is determined based on the specific structural design and production process features of the products being tested so as to assure a reliable estimate of product quality. For example, the utilization of the mass spectrometry method does not preclude the necessity of checking for the presence of medium and large leaks, since where they are present, the helium which was introduced into the device beforehand during hermetic sealing or pressurization can escape prior to its testing. A significant complicating factor when testing with mass spectrometry can also be the presence of the flow of helium desorbed by the product package. In certain cases (polymer and ceramic packages), the desorption is so great that it is commensurate with a leak in the package. Mass spectrometry testing does not yield an objective estimate in this case.

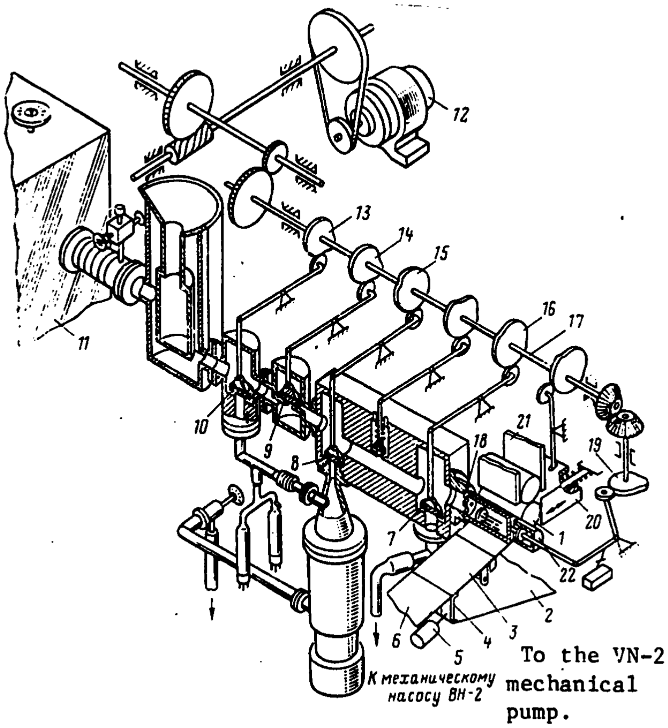


Figure 8.11. Basic schematic of the automatic unit for checking a hermetic seal.

The utilization of the vacuum-liquid method of testing products, in which polymer materials are present, can lead to a loss of seal because of the dissolution of the compound.

When selecting a method, it is also necessary to take into account technical and economic indicators, which govern the cost, production process suitability and equipment productivity for hermetic seal testing.

The most widely used equipment is based on the utilization of bubble (vacuum-liquid) and mass spectrometry methods.

A schematic is shown in Figure 8.11 which illustrates the operational principle of an automatic unit for testing for hermetic sealing and the interaction of its mechanisms. The automatic unit consists of a vacuum system and the standard PTI-6 helium leak detector. After starting the leak detector 11 and obtaining the requisite vacuum, cases 1 with the devices being tested are loaded into magazine 21, from which they roll down to feed mechanism 20 via the troughs. When the slide of the feed mechanism goes to the extreme rear position, the case which is located on its upper surface falls down and appears in front of the slide. When the slide moves forward, it pushes the case, which is located in the working position, and takes it place.

Mechanism 22, which is controlled by cam 19, presses the case against the seal 18. Cam 16 opens valve 7, and the preliminary vacuum exhaustion of the casing is accomplished. Then valve 7 is closed and valve 8 is opened, which is driven by cam 15. The high vacuum exhaustion of the case takes place. The further rotation of the distribution shaft 17 leads to the closing of valve 8 and the opening of valve 9 by means of cam 14, where valve 9 connects the vacuum volume of the automated unit, which is located to the right of valve 9, to the vacuum system of the leak detector. All the other valves of the automatic unit are closed at this time. In the case of a seal failure of the device being tested, the helium partial pressure increases in the mass spectrometer analyzer of the leak detector and a signal appears which is amplified by an electrical circuit in the automated unit and causes the actuation of relay 5, which plays the part of an electromagnet, and lock 4 and barrier 3 are opened in this case.

In order that the relay does not actuate before the case with the device which caused the increase in the mass spectrometer current is dumped, there is a time delay relay in the electrical circuitry which delays the signal to relay 5 by a few seconds, i.e., by the amount of time from the appearance of the leak detector signal to the contacting of the case. The case with the unsealed device is rolled through the open barrier 3 into the collection holder 2 for rejected devices. If the device is hermetically sealed, lock 4 remains closed and the case rolls via barrier 3 into collection holder 6 for good devices. Valve 10, which is actuated by cam 13, opens immediately after valve 9 closes, and remains open until valve 8 opens.

Valve 10 serves for additional pumping out of the vacuum system of the automatic unit, located to the left of valve 9, as well as the vacuum system of the leak detector. In the case a large quantity of helium from a heavily leaking device gets into the vacuum portion of the automatic unit and leak detector, this exhaust line helps to speed up the preparation of the automatic unit for the execution of the next testing cycle. If it turns out that such a quantity of helium has gotten into the leak detector that it cannot removed over one preparation cycle, the large leak blocking circuitry actuates and motor 12 of the automatic unit is cut off. The motor is turned on again only after the system is completely ready.

The PTI-6 standard mass spectrometric helium leak detector operates in the following manner. The molecules of helium which enter the vacuum system of the mass spectrometric analyzer along with the molecules of other gases and vapors are ionized by electrons, emitted by an incandescent cathode. The ion beam, which is subjected to an accelerating voltage, exits through the slot of a diaphragm stop into the mass spectrometer chamber, where the ions are segregated with respect to mass in a homogeneous magnetic field. By choosing the accelerating voltage, the mass spectrometer is set up in such a fashion that only helium ions impinge on the ion collector (receiver), which is positioned in the chamber at an angle of 120° to the source.

Following amplification, the ion current is registered by a voltmeter on a remote control panel. A change in the voltmeter readings is evidence of the presence of a leak and of its size. An electronic autorecording potentiometer or other instrument can be connected to the control console.

CHAPTER NINE EQUIPMENT FOR TESTING THE ELECTRICAL PARAMETERS OF SEMICONDUCTOR DEVICES

The electrical parameters of semiconductor devices are measured in practically all stages of their manufacture, beginning with the processes for producing the structures right up to reliability tests. The major task of testing parameters in the initial manufacturing stages is not to pass on to subsequent production process operations those devices whose parameters are worse than the values established beforehand. The parameters of semiconductor devices are measured at the conclusion of a production process primarily for the purpose of distributing them in groups in accordance with the limiting values of the parameters established for each group by the technical specifications. The third major function of parameter testing of semiconductor devices is the checking of the capability of the devices of maintaining their properties when exposed to various media: temperature, humidity, pressure, vibration, shock, etc. In this case, the electrical parameters serve as the criterion of immunity of the semiconductor devices when exposed to the perturbations enumerated above.

Depending on the level of mechanization and automation of the major and auxiliary operations, the quality control and measurement equipment can be broken down into manual, semiautomatic and automated. Included in the manual group is equipment for which the loading and unloading operations of the products being measured, as well as the reading of the measurement results, are accomplished by an operator. In automated testing and metering equipment, the loading, contacting, oriented unloading and sorting of the measured products in accordance with the measured parameters are realized automatically. Semiautomatic equipment occupies an intermediate position. In it, only the loading of the products being measured is accomplished manually by an operator, while the remaining operations are realized automatically.

In terms of the information obtained from quality control and measurement equipment, it is broken down into equipment for parameter measurement, which makes it possible to measure the true value of parameters, and classification equipment, which sorts the devices being measured into groups depending on the aggregate of measured parameters. For classification equipment, the sequence for parameter measurement, the comparison of the measurement results with the specified reference value and the logic processing of the measurement results of all of the parameters for the purpose of determining the group are all carried out automatically. The equipment breakdown given here into measurement and classification equipment is conditional to a considerable extent, since at times the same devic can perform both measurement and classification tests.

9.1. Measurement Equipment

Measurement equipment is used when tests are made by the quality control department services as well as during various tests, in laboratories during developmental work, in trial production when placing new devices in production, during input quality control by consumers of the devices, etc. As a rule, equipment of this type is designed for testing one or more parameters of the same type and has a comparatively simple design. Meter type measurement instruments are most frequently used as the indicators in it. Digital meters for semiconductor device parameters have started to become more widespread of late.

A significant quantity of specialized parameter meters intended for measuring one or more parameters of a certain type of semiconductor devices is in operation at enterprises fabricating semiconductor devices. As a rule, the measurement conditions are established automatically after the product being measured is connected, the range of measured values is small, the switching from one parameter to another is accomplished manually and the measured value is read out visually from the scale of a meter or a digital display. Such parameter meters are used in the case of a small production volume, during trial production or in other cases where the application of complex automated equipment is absent or ineffective.

Moreover, there are universal meters, which are distinguished by large ranges of operating mode settings and measurable values. This equipment is used in research laboratories for the incoming testing of semiconductor devices and for the measurement of their parameters when repairing various radioelectronic systems. Several types of such all purpose parameter meters are being produced by domestic industry.

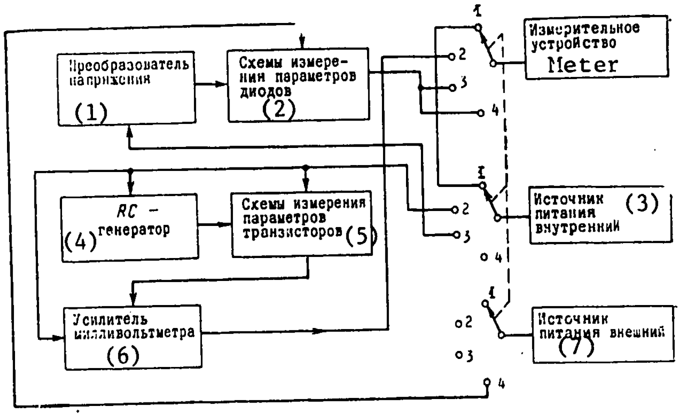


Figure 9.1. Block diagram of the L2-23 meter for semiconductor device parameters.

Key:
1. Voltage converter;
2. Circuits for measuring diode parameters;
3. Internal power supply;
4. RC oscillator;
5. Circuits for measuring transistor parameters;
6. Millivoltmeter amplifier;
7. External power supply.

The L2-23 parameter meter for semiconductor devices is intended for measuring the major parameters of p-n-p and n-p-n transistors as well as semiconductor diodes.

A block diagram of the meter is shown in Figure 9.1. The meter is powered from an internal power supply consisting of two "373" batteries; moreover, the meter can also operate from an external power source. The high voltage needed for the measurement of the inverse current of semiconductor diodes is obtained by means of converting the DC voltage from the internal source to an AC voltage and subsequently rectifying it. The 760 Hz alternating current signal needed to measure h_{21b} and h_{22b} is generating by an RC oscillator. The amplifier of the millivoltmeter amplifies the AC signal which carries information on the parameter being measured up to a level sufficient for the deflection of the meter needle. The parameter measurement circuits for semiconductor diodes and transistors provide for the connection of the devices being measured and the switching of the measurement resistors and power supplies. We shall analyze the measurement of one of the most important parameters of transistors: the common base current gain, h_{21b}, which is accomplished using the circuit depicted in Figure 9.2. The parameter h_{21b} is defined as the ratio of the change in the output current of the transistor to the change in the input current where the output circuit is short circuited for the alternating current. The short circuit mode is realized by inserting a capacitor C_4 in the collector circuit of the transistor. The alternating current input signal is generated by the RC oscillator, which is the current generator; this is assured through the insertion of resistor R_2, which considerably exceeds the input impedance of the transistor. In this case, the alternating current of the emitter-base junction of the transistor being measured is governed by the voltage U_{gen} and the resistance of R_2, and in the case of constant values of U_{gen} and R_2, the input current will be the same for all of the transistors being measured. Thus, the measurement of h_{21b} reduces to the measurement of the transistor output current. Since the value of h_{21b} is close to unity, the ratio of the base current to the emitter current is usually measured to improve the measurement accuracy:

$$\frac{i_{\text{б}}}{i_{\text{э}}}=\frac{i_{\text{э}}-i_{\text{к}}}{i_{\text{э}}}=1-\frac{i_{\text{к}}}{i_{\text{э}}}=1-|h_{21\text{б}}|. \qquad (9.1)$$

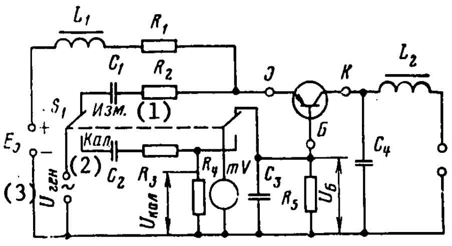


Figure 9.2. Circuit for measuring the current gain, h_{21b}, in a common base configuration.

Key:
1. Measure;
2. Calibrate;
3. $U_{generator}$.

The value of the input current i_e is measured as the voltage drop across the calibrated precision resistor R_4, while the base current is measured as the voltage drop across resistor R_5, which should also be a precision resistor. Resistors R_3 and R_2 should either be equal or differ from each other by a ratio specified beforehand. The gain is thus:

$$1-|h_{21\text{б}}|=\frac{U_{\text{б}}R_4}{U_{\text{кал}}R_5}. \qquad (9.2)$$

Since U_{cal}, R_4 and R_5 are constant quantities, the scale of the meter measuring U_b is graduated directly in the values of h_{21b}.

One can test the following parameters by means of the L2-18 digital low power transistor parameter meter: the quantity $1/(B_{st} + 1)$ (B_{st} is the static gain); the collector voltage $U_{CEO\ lim}$, at which the onset of the change in the phase of the base current begins; the voltage between the collector and the emitter in the saturation mode $U_{CE\ sat}$; the voltage between the base and the emitter in the saturation mode $U_{BE\ sat}$; the inverse collector current I_{CBO}; the inverse emitter current I_{EBO}; and the floating emitter potential $U_{EB\ fl}$.

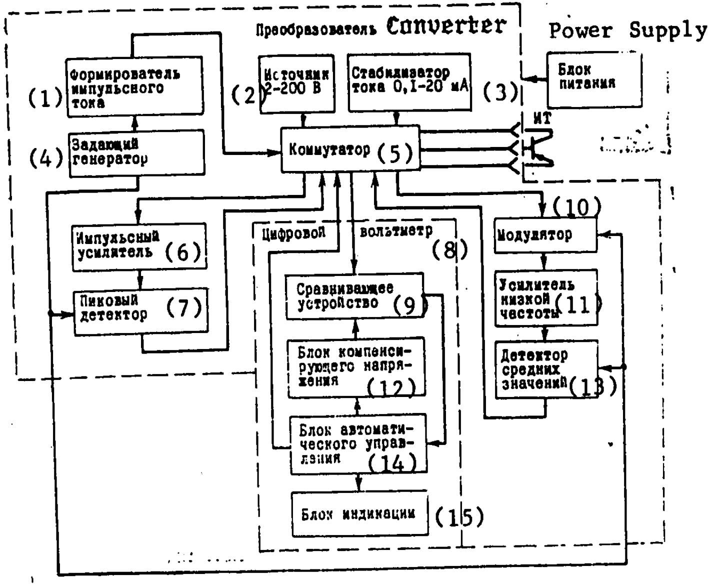


Figure 9.3. Block diagram of the L2-18 digital meter for low power transistor parameters.

Key:
1. Pulse current driver;
2. 2 to 200 volt supply;
3. 0.1 to 20 mA current regulator;
4. Master oscillator;
5. Switcher;
6. Pulse amplifier;
7. Peak detector;
8. Digital voltmeter;
9. Comparator;
10. Modulator;
11. Low frequency amplifier;
12. Compensating voltage unit;
13. Mean value detector;
14. Automatic control unit;
15. Display unit.

The procedures for measuring some of these parameters will be treated below.

The meter consists of three units: the converter, a digital voltmeter and a power supply (Figure 9.3).

The converter and the automatic range selector provide for feeding a DC voltage to the digital voltmeter input in a range of 0.1 to 1 volt, regardless of the parameter being measured and its value. The conversion factors for each parameter and the units of measurement are indicated on the front panel of the meter.

The transistors being tested are connected to the measurement circuits through a switcher. Various connections are made in this case, depending on the parameter being measured.

The Measurement of $1/(B_{st} + 1)$. The base of the transistor being tested is connected through the measurement resistance to the common bus. A voltage of 2 to 200 volts is fed to the collector from the supply. The emitter is connected to the output of the pulse current driver, which converts the voltage pulses of the master oscillator (a push-pull multivibrator) to current pulses with an amplitude variable in a range of 1 to 200 mA. Voltage pulses are picked off of the measurement resistor, the amplitude of which are directly proportional to the quantity $1/(B_{st} + 1)$. These pulses are amplified by a two stage pulse amplifier and converted to a DC voltage by the peak detector. The output voltage of the peak detector is fed to the input of the digital voltmeter.

The Measurement of $U_{CEO\ lim}$. The transistor being tested is connected just as for the measurement of $1/(B_{st} + 1)$. The output voltage of the peak detector is not measured; only its polarity is analyzed, which is indicated on a light display panel in the form of a > sign when the phase changes and a < sign in the absence of a phase change. The measurement is performed as follows: the voltage of the 2 to 200 volt source is changed until the sign < changes to the sign > ; at this moment, the voltage at the collector of the tested transistor is measured with an external voltmeter, which yields the quantity $U_{CEO\ lim}$.

Current Measurement. The transistor is connected in the appropriate measurement configuration. The current being measured is converted to a voltage proportional to it, which is first fed to a modulator, and then to a low frequency amplifier, an average value detector, and finally, to a digital voltmeter.

The digital voltmeter is an automatic compensator with discrete equalization. It consists of the following assemblies: a comparator, a compensating voltage generator, an automatic control unit and a display block.

A voltage proportional to the parameter being measured is fed to one of the two inputs of the comparator in the digital voltmeter. The compensating voltage is fed to the other input, which is changed discretely in accordance with a program governed by the operation of the automatic control unit. There is a programmer in this unit which is triggered by a pulse from the automatic range selector following the completion of the selection. The program actuates the flip-flops of a storage register in a definite sequence, which in turn switch on the requisite compensating voltage. The flip-flops remain turned on if no pulse arrives from the output of the comparator, or turn off, if such a pulse arrives.

The presence of a pulse at the output of the comparator means that the compensating voltage is greater than the voltage at the input. Upon the completion of the measurement cycle, a tetradecimal code (4, 2, 2, 1) is registered in the flip-flops of the register memory, where this code corresponds to the state of equality of the compensating and measured voltages, i.e., the digital equivalent of the parameter being measured. The tetradecimal code is fed to the input of the display unit, where it is converted to a decimal code. The image of the decimal numbers is produced by means of IN-1 neon indicators.

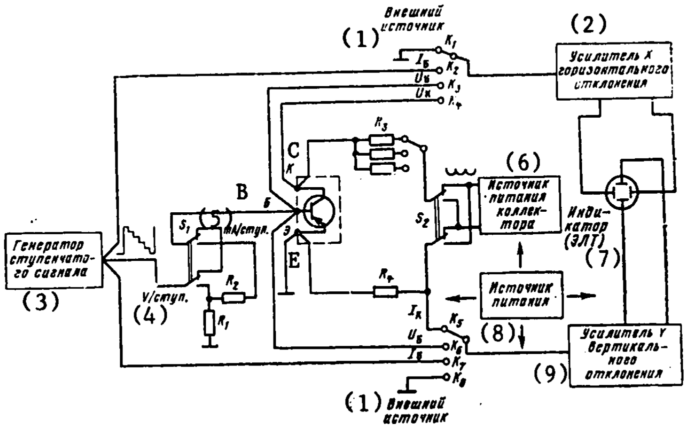


Figure 9.4. Block diagram of the PNKhT-1 instrument [transistor characteristic curve family tracer].

Key:
1. External supply;
2. Horizontal deflection X amplifier;
3. Step function generator;
4. Volts/step;
5. mA/step;
6. Collector supply;
7. Indicator (CRT);
8. Power supply;
9. Vertical sweep Y amplifier.

The comparator takes the form of a DC voltage amplifier with periodic drift correction. The amplifier consists of two vacuum-tube and six transistor stages.

The compensating voltage unit consists of a Y configuration potentiometer, designed for a tetradecimal code with weights of 4, 2, 2 and 1, and a group of relays, the contacts of which switch the potentiometer resistance. The relay coils are controlled by signals from the flip-flops of the memory register of the automatic control unit.

A provision is made for the capability of connecting a recorder (printer) to the meter; a voltage drop with an amplitude of 5 volts is used to trigger it. The information for the recording is fed out in the 4, 2, 2, 1 tetradecimal code.

Transistors can be rejection sorted with respect to one of the parameters by the meter. The meter takes the form of a desk top type instrument.

Important information on the electrical properties and quality of semiconductor devices is contained in their volt-ampere characteristics. A whole series of instruments exists for the visual observation of the volt-ampere characteristics of semiconductor devices. A block diagram of the PNKhT-1 instrument for observing transistor characteristics is shown in Figure 9.4, while an external view of this instrument is shown in Figure 9.5. The major assemblies of the PNKhT-1 instrument are:

--The collector power supply;

--The step function generator;

--The vertical sweep amplifier (the Y amplifier);

--The horizontal sweep amplifier (the X amplifier);

--The indicator;

--The power supply.

Figure 9.5. The PNKhT-1 scope for observing transistor characteristics.

The PNKhT-1 instrument makes it possible to observe both the families of transistor characteristics as well as the volt-ampere characteristics of p-n junctions. To obtain a family of transistor characteristics on the cathode ray tube screen, a pulsating voltage is fed to the collector which is obtained by rectifying a sine wave and which serves for the sweep. A step function changing voltage is fed to the input of the transistor being tested, where this voltage is used as the argument signal. The voltage across the junctions of the transistor being studied or the voltages proportional to the currents through these junctions (depending on which characteristics of a transistor must be observed) are fed to the X and Y amplifier inputs, and following amplification, are fed to the deflection plates of the CRT. By way of example, we shall consider the circuit configuration for a test transistor to observe the family of output characteristics of the type $I_C = f(U_C)$ for different values of the base currents in a common emitter circuit (Figure 9.6).

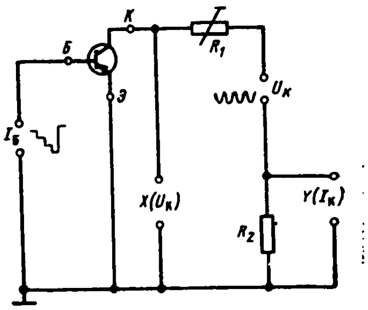


Figure 9.6. Common emitter circuit configuration for plotting characteristics of the type $I_c = f(V_c)$.

In this case, a step voltage is fed to the base of the transistor, while a half-wave of the sinusoidal voltage is fed to the collector. The signal picked off of resistor R_2, which is proportional to the collector current, is fed to the vertical sweep amplifier, while the signal from the collector-emitter junction if fed to the horizontal sweep amplifier. The pulsing and step voltages are synchronized so that during one half-wave, the current in the base of the transistor remains constant and one characteristic is traced during this time. During the time of the next half-wave of the collector voltage and the next step of the base current, yet another characteristic is traced on the indicator screen. During the action of the next half-wave of the collector voltage and the next base current step, the following characteristic is traced on the indicator screen: $I_C = f(U_C)$, etc.

The 13L06I cathode ray tube is used as the indicator; a transparent scale with a grid is placed in front of its screen. Structurally, the PNKhT-1 instrument is made in the form of a table top unit. A sloped panel with the contacts for the connection of the semiconductor devices to be studied is fastened to the lower portion of the front panel of the unit.

9.2. Classification Equipment

A typical representative of classification equipment is the all-purpose low power transistor classifier, the KT-2 (Figure 9.7a). This is a semiautomated classifier with a carousel transistor transporter 5, which is structurally separated from the support frames 1 with the measurement and operating control units, and the support frame 2 for the logic and computer units. The classifier has programming panels 3, test probes 4 and receiving hoppers 6. Universality is achieved through the capability of changing the classification program, test modes and limiting values in an operationally timely manner; the modular structural design makes it possible to rapidly change the composition of the parameters being tested by changing the instrumentation units.

A block diagram of the classifier is shown in Figure 9.7b. The transistors being tested, with the prestraightened leads are loaded by the operator in an oriented manner in the connecting heads 3. The latter are mounted on the carousel 10 and execute a start stop motion together with it, because of which each connecting head sequentially passes by all of the measurement posts. A measurement post consists of the test probe 2 as well as the measurement and test condition setting units 9.

The test probes are installed above the carousel. The transistor pins are connected directly to their contacts, which are located in the bottom end face

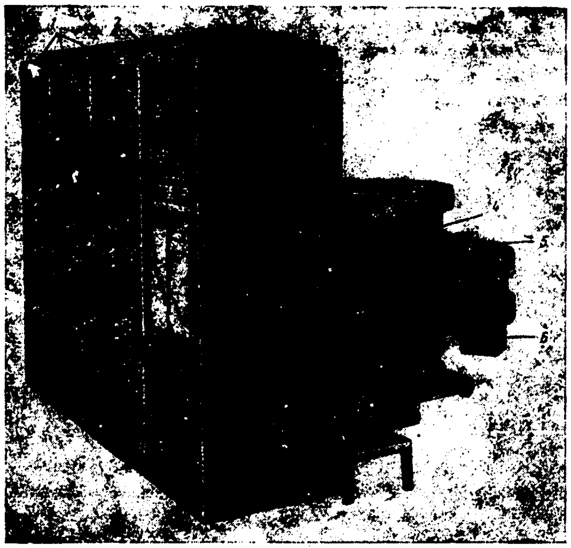
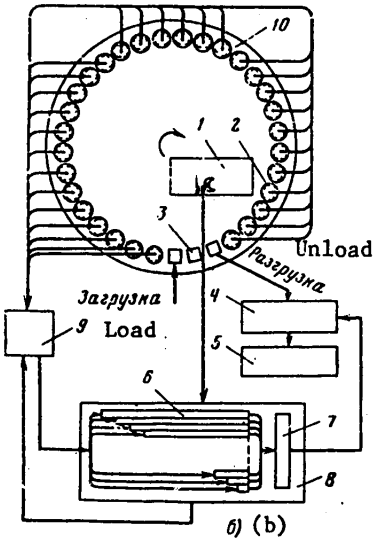


Figure 9.7. The KT-2 all-purpose classifier for low power transistors.

a. External view;
b. Structural schematic.



during the time the carousel is stopped. The input circuits and the measurement unit devices are placed inside the test probes, which should be brought close to the test object to assure noise immunity and reduce the influence of parasitic leakage and reactances.

The values of a particular parameter of the transistor being tested are compared in each measurement block with its limiting value which is established beforehand. The comparison results are transmitted in the form of a binary code (1 is a value measured greater than the limit; 0 is a value measured less than the limit) for storage to one of the shift registers 6 of the logic and computing unit (SLU) 8. The storage is needed because the rejection sorting is based on the measurement results for all of the parameters.

Corresponding to each measurement post is its own shift register. In step with the travel of the tested transistor from one to measurement post to another, the data on it is accumulated in the registers and is moved simultaneously in them from the input to the output. The capacity of the registers is not the same; it is numerically equal to the number of the measurement post to which the register belongs (the count starts with the unloading post, to which the number 0 is assigned). Such a configuration of the shift registers provides for the synchronous output of all data on the transistor being tested to the data processing unit 7 at the moment the transistor arrives at the unloading post. The shift registers are designed around ferrite-transistor memory cells. The data processing block, in accordance with the program entered in it and based on the information arriving at it, generates the instruction for the sorting rejection mechanism 4, which routes the transistor to receiving hopper 5.

The classification program is composed on the basis of the technical specifications and is entered on two program cards in the form of holes punched through at the requisite points. The cards are placed on the program panels of the SLU, and special electrical contacts are inserted in the receptacles for these panels, which match the holes in the cards.

The operation of all of the measurement blocks is synchronized through the SLU from the contacts which are closed by cams 1, which rotate synchronously with the carousel.

SE1-1 electromechanical counters are mounted in the classifier, which count the number of transistors in each group, the overall number of transistors which have been sorted, and the number of transistors having a negative test result at any of the six measurement posts.

In the majority of measurement units in the classifier, the compensation measurement method is employed, because of which, stringent requirements are not placed on the stability of the gain and the linearity of the amplifiers.

Voltage and current regulators, regulated pulse current generators as well as low and high frequency generators are used as the test condition setting units in the classifier. A provision is made in the test condition setting blocks for the capability of adjusting the output voltages and currents.

The device for transporting the transistors, a kinematic schematic of which is shown in Figure 9.8, operates as follows. All of the mechanisms are driven by the distribution shaft 24. Rotation is coupled to the distribution shaft from electric motor 1 through V-belt drive 42 and a worm gear reducer (worm 39 and worm gear wheel 23). A number of auxiliary elements are installed in the transmission from the electric motor to the distribution shaft: safety clutch 43, free-wheeling clutch 41, which permits only one-way rotation of the drive, and electromagnetic break 40, which is actuated when the electric motor is turned on. End cam 20, the Geneva mechanism carrier 21, the conical gear of reducer 37 and cams 38.

During the rotation of end cam 20, once every revolution of it the rack 11 is raised and lowered, which rotates two shaft-gears 10 (one directly, and the other

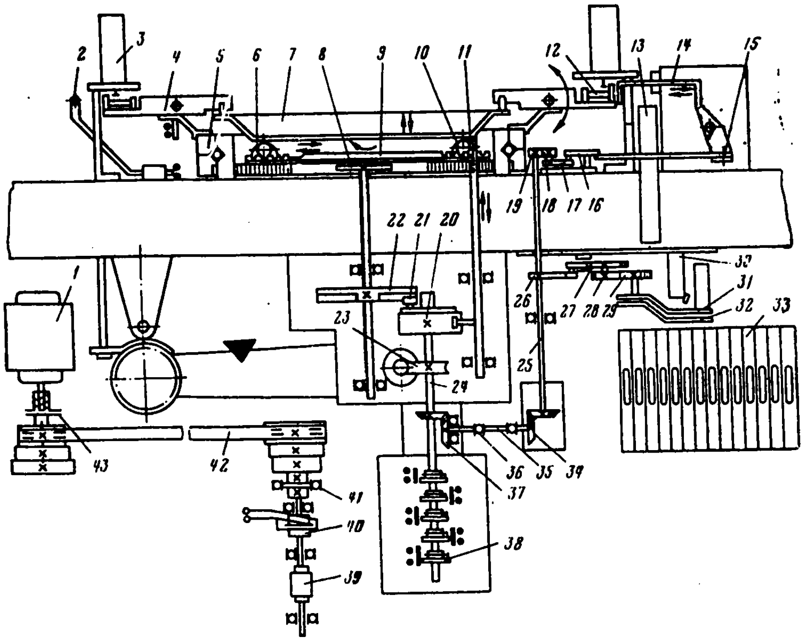


Figure 9.8. Kinematic schematic of the KT-2 all-purpose classifier.

through rack 9). Eccentrics 6 are mounted on the shaft-gears, which when rotating, raise and lower disk 7. When the disk is lowered, levers 4 take a position such that the leads of the transistors being tested, which are installed in the connecting heads 12, are pressed against the contacts of test probes 3. When disk 7 of lever 4 is raised, in rotating, the leads of the transistors are disconnected from the contacts of the test probes.

The levers 4 are installed on the carousel 5, which executes a start-stop rotating motion. The carousel rotates at that point in time when disk 7 is lifted. The start-stop motion of the carousel is realized by means of a Geneva mechanism, the carrier 21 of which rotates along with the distribution shaft 24 and rotates the Maltese cross 22. The backlash free gear 8, which is engaged to the carousel gear, is mounted on the same shaft as the cross.

The transistors are off loaded and sorted into groups at a special post. When lever 4 arrives at this post and its arm with the connecting head is lifted upward, the package of the transistor being tested enters into the fork of unloading lever 14. By this point in time, the cup on lever 31 is set under tray 13. Lever 14 is driven by shaft 25 through gears 19 and 18, cam 17, lever 16 and pull rod 15. With the rotation of lever 14, the transistor is removed from the connecting head and by virtue of the weight of the transistor itself, falls through tray 13 into the cup on lever 31. After this, levers 31 and 32, which are coupled through gears 29 and 28, rake-rod 27 and cam 27 to shaft 25, begin to move and run up to the turned on electromagnet 30; the lever 32 opens the bottom of the cup and the transistor falls into one of the hoppers 33.

The number of electromagnet and hoppers corresponds to the number of classification groups. The electromagnets are actuated by signals from the logic computer unit.

Shaft 25 is driven by distribution shaft 24 through reduction gear 37, articulated couplings 36, shaft 35 and reducer 34. With the rotation of distribution shaft 24, cams 38 periodically turn microswitches on and off, because of which electrical signals are generated which are used via the logic computer unit for the synchronization of the operation of all of the classifier devices. An emergency shutdown lever 22 is provided in the design of the semiautomatic unit.

Main Technical Specifications of the KT-2 Classifier

Output, pieces per hour	1,200
Number of classification groups	14
Number of limiting values for the parameters being tested	29
Frequency of the signal for the measurement of high frequency parameters, KHz	20
Power consumption, KW	3.5

While the KT-2 classifier contains the loading and unloading mechanism for the transistors being measured and a measurement section as indispensable parts, the operation of classifying the semiconductor devices into groups can be realized if any of the general purpose or specialized meters are used in conjunction with a separate sorter, intended for the loading, contacting and sorting of semiconductor device into groups.

By way of example, we shall consider the combined operation of the EM-630 parameter measurement instrument and the US-5002 sorter. The EM-630 unit is designed for testing the static parameters of digital integrated circuits having up to 24 pins based on the "reject - good" principle. The measurement of a sequence of parameters (tests) is accomplished automatically in accordance with a specified program. The programming is realized by a combination of special pins, inserted in the appropriate jacks of the programming matrix. The unit can run either an entire sequence of tests (up to 78 tests) or terminate the measurements following the first rejection. The parameter measurement process is based on the automatic comparison of measured and reference analog signals. A block diagram of the EM-630 unit is shown in Figure 9.9. We shall analyze the function of its major assemblies.

The instrument control circuitry 1 provides for the following: the generation of a pulse train at a frequency of 100 Hz for the counter and the test number indicating circuit 2; control of the 80 bit register for program indication and indicating the result of each test 5; triggering the modulator of the test circuit

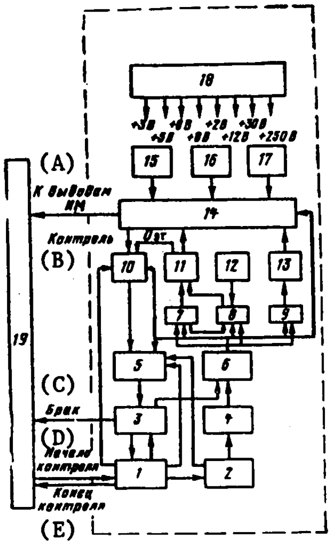


Figure 9.9. Block diagram of the EM-630 tester for checking the parameters of integrated circuits

Key:
A. To the integrated circuit leads;
B. Test;
C. Reject;
D. Start test;
E. End test.

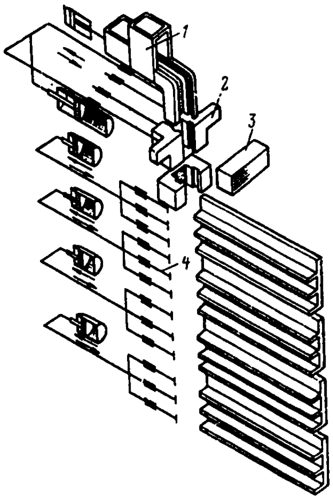


Figure 9.10. Kinematic schematic of the US-5002 sorter.

10 in each test; generating the "end of test" signal, which is fed to the external monitor 20. The test number indicating circuit and pulse counter 2 provide for counting the test pulses, indicating the number of the test and control the operation of the 80 bit register for indicating the results of each test 5; they also control the program setting circuit 4. The program setting circuit serves to specify the program for each test, and store the program for all tests and feed out the program for any test to the 80 bit program register 6. Program register 6 receives the program for each test from the program setting circuit 4, converts it to voltage signals, which then control the elements provided by the program of the given test. The integrated circuit lead and test signal circuit switcher 14 provides for connecting the supply voltages generated by block 17, the test signals incoming from block 16, and the loads located in load unit 15 as well as the reference registers for checking the currents, which are located in block 13, to the pins of the IC being tested in accordance with the program. Moreover, the switcher provides for the connection of the voltage being measured to test circuit 10, to which the reference standard signal is also fed from code to voltage converter 11, where the measured and reference standard voltages are compared, the polarity of the difference signal is determined and the signal that the IM is good in terms of the given test is fed out. Register 5 stores and indicates the test result of each test, feeds this result out to the test data processing circuitry 3, which in turn generates the "reject" signal, which is fed to the external monitor. Power supply 18 is intended for powering all of the units of the EM-630.

The Main Technical Specifications for the EM-630 Unit

Number of quality control tests	78
Duration of a quality control test, msec	10
Number of leads which can be switched	24
Range of voltages which can be checked, volts	0.01 to 9.99
Range of currents which can be checked, A	$0.1 \cdot 10^{-6}$ to $99.9 \cdot 10^{-3}$
Voltage test error, mV	± (1% + 0.5)
Current test error, nA	± (2% + 10)

The kinematic configuration of the US-5002 sorter (Figure 9.10) consists of three sections, which are coupled together pneumatically. The major section, the travel mechanism 2, receives a reciprocating motion from a pneumatic cylinder, the rod of which is rigidly coupled to the guides of the travel mechanism. The product loading mechanism 1 functions cyclically with the latter, where the operation of this mechanism is likewise based on the reciprocating motion of the rod of another pneumatic cylinder. The third section is composed of the unloading and sorting mechanisms 4 of a modular design with individual pneumatic cylinders. The pneumatic cylinder rod of each mechanism is rigidly coupled to the three other unloading rods. The drive for each unloading mechanism is pneumatically coupled to the main drive (the travel mechanism) in such a way that the unloading rods begin to move only after the travel mechanism is passed by the guides two-thirds of the way to the position of the elements. The return travel of the working elements of all three mechanisms is accomplished simultaneously. The cycle time can be adjusted by two factors: the standstill time of the travel mechanism in the measurement and unloading positions (electrical control); choking down the cross-sections of the internal bores (pneumatic control). The loading mechanism 1 pushes out one product each from the case (or other loading device) during each cycle, where this produce is the one whose parameters are to be measured. This product is moved by the travel mechanism to the contact position, where the product being measured is connected by means of the contacting device 3 to the power source setting the conditions as well as to the measurement circuits [through switcher 14 (see Figure 9.9), if we are speaking of the operation of the US-5002 sorter in conjunction with the EM-603 measurement instrument]. During the return motion of the travel mechanism, the product whose parameters have just been measured, enters the unloading and sorting mechanism, and depending on the measured parameters and signals from the measurement unit, goes into the appropriate case. The products being measured are housed in this case in special satellite carriers with standard dimensions, which makes it possible to standardize the transport assemblies, loading, unloading and contacting devices.

9.3. Automated Systems Using Computers for Parameter Testing

Quality control and measurement complexes which contain a measurement unit and computer (EVM) have become widespread recently, where the computer controls the feed of the mode setting currents and voltages to the product being measured, provides for switching the pins of this product in accordance with the measurement circuit for a particular parameter, as well as the measurement of the parameters and the processing of the measurement results. In this case, the entire sequence of parameters is measured automatically in accordance with the computer program. Following the completion of the measurement process, the computer makes the decision as to the conformity of the parameters of the measured product to their specified values. Information on the measurement results can be fed out in various forms: the true value of the parameters, printed out on paper by a numeric printer operating as part of the computer hardware; a "reject - good" light signal on the panel of the measurement unit; control signals to the sorter for the products being measured, by means of which the products are broken down into groups.

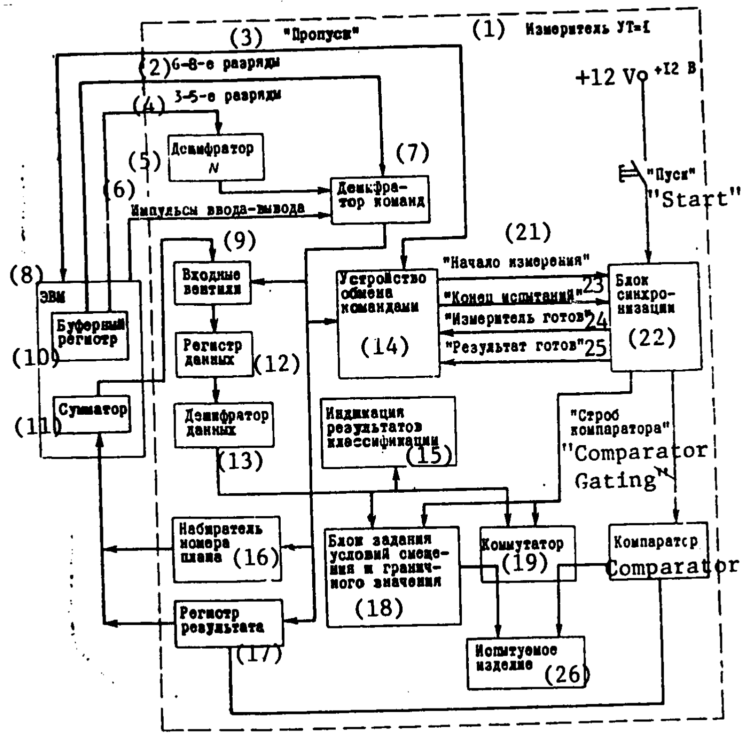


Figure 9.11. Block diagram of the UT-1 meter.

Key:
1. UT-1 meter;
2. Bits 6 to 8;
3. "Pass";
4. Bits 3 to 5;
5. Decoder N;
6. Input-output pulses;
7. Instruction decoder;
8. Computer;
9. Input gates;
10. Buffer register;
11. Adder;
12. Data register;
13. Data decoder;
14. Instruction exchange unit;
15. Classification result display;

Key to Figure 9.11 [cont.]:
16. Plan number selector;
17. Result register;
18. Unit for specifying the bias and limiting value conditions;
19. Switcher;
20. Comparator;
21. "Start measurement";
22. Synchronization unit;
23. "End of tests";
24. "Meter ready";
25. "Result ready";
26. Product being tested.

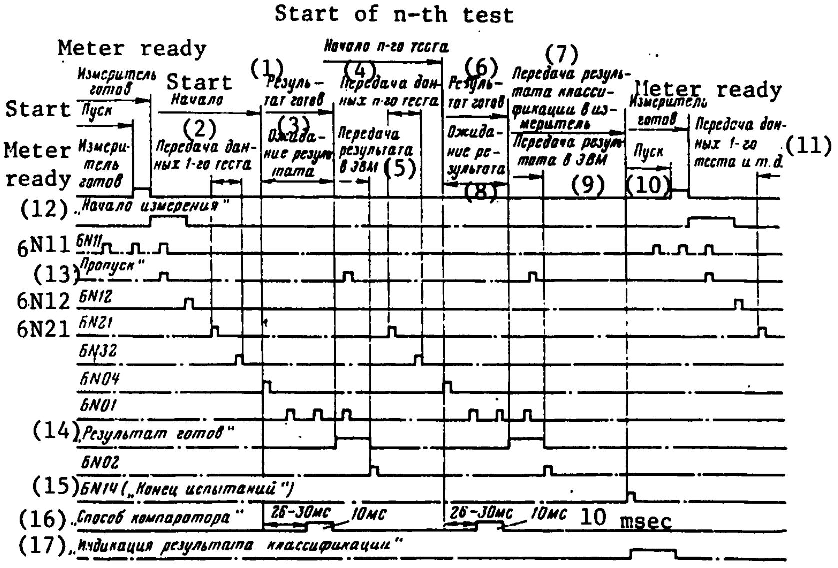


Figure 9.12. Time diagram showing the interaction of the UT-1 meter and the computer.

Key:
1. Result ready;
2. Transmission of the data of the first test;
3. Waiting for the result;
4. Transmission of the data of the n-th test;
5. Transmission of the result to the computer;
6. Result ready;
7. Transmission of the classification result to the meter;
8. Waiting for the result;
9. Transmission of the result to the computer;
10. Start;
11. Transmission of the data of the first test, etc.;
12. "Start measurement";
13. "Pass";
14. "Result ready";
15. 6N14 ("end of tests");
16. "Comparator mode";
17. "Classification result display".

The measurement time for a single parameter usually amounts to a few milliseconds, and thus it is possible by means of a computer to carry out the testing operations for several tens of parameters of a semiconductor device, for example, an integrated circuit, in fractions of a second. The high productivity of parameter testing is the major distinctive feature of computer controlled monitor and measurement equipment. The second feature is the measurement precision, which is due to the use of the "weighting" measurement procedure and the comparison of the quantity being measured with a reference value. A characteristic representative of the family of computer controlled measurement and classification equipment is the all-purpose UT-1 meter, which is intended for checking the static parameters of low and medium power transistors and diodes. The operational principle of the meter will be clear following an analysis of its structural configuration (Figure 9.11) and the time diagram showing the interaction of the meter and the computer (Figure 9.12).

After the system is started, the computer operates by periodically interrogating the meter readiness starting with the initial program address, by sending the 6N11 instruction to the meter with a period equal to the execution time for two instructions in the computer. After the arrival of the "Start" signal at the meter synchronization unit (from the pushbutton on the control panel with manual loading or from the automatic sorter), the synchronization unit feeds out the "Meter Ready" signal to the instruction exchange unit, which with the arrival of the next 6N11 instruction will feed a "Pass" signal to the computer. After receiving this signal, the computer leaves the periodic interrogation mode, feeds out the 6N12 instruction, upon which the meter readiness flip-flop is reset and the number of the classification plan is transmitted to the computer. Following this, the initial data for the performance of the first test are transmitted (1 to 5 words for the 6N21, 6N22, 6N24, 6N31 and 6N32 instructions each) and at the end, the 6N04 instruction, "Start Test", is fed out. The 1 to 5 words are written into the data register and are decoded by the data decoder, the signals from which are fed to the unit for specifying the bias and limit value conditions, as well as to the switcher. As a result, the requisite circuits are switched for testing the requisite parameter and the specified currents and voltages are applied to the pins of the product being tested.

The instruction "Start Test" is converted in the instruction exchange unit to the "Start Measurement" signal, which when received by the synchronization unit, the latter generates the "Comparator Gating" signal 26 to 30 msec following the "Start Test" instruction. This delay is necessary so that the transient processes from the switching are finished before the comparator begins to compare the actual value of the parameter with the specified ultimate value.

After putting out the "Start Test" instruction, the computer changes over to the periodic interrogation of the readiness of the measurement result. The interrogation is accomplished by means of periodically sending the 6N01 instruction to the meter. When the test is completed, the synchronization unit will feed out the "Result Ready" signal to the instruction exchange unit, which upon the arrival of the next 6N01 instruction, will feed out the "Pass" signal to the computer. The computer then quits the periodic interrogation mode and feeds out the 6N02 instruction, upon which the result readiness flip-flop is reset and the result is transmitted to the computer. The computer compares the result obtained with the specified limiting value, and then transmits the initial data for the performance of the next test. Following the measurement of all of the parameters, specified by the classification plan, the computer determines the classification group of the product being tested and feeds out the instruction 6N14, in accordance with which the classification result (the group number code) is transmitted to the data register, and after it, to the classification result display. In accordance with the 6N14 instruction, the "End of Tests" signal is fed to the synchronization unit, because of which, the generation of the "Comparator Gating" signal is inhibited and the "End of Tests" light lights up on the front panel of the meter.

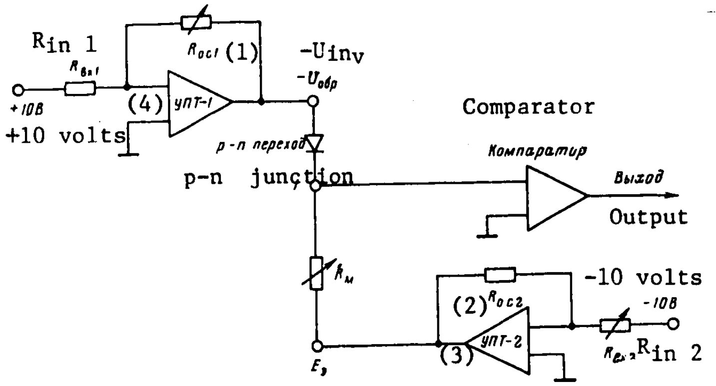


Figure 9.13. Circuit for measuring the inverse current of a p-n junction.

Key:
1. Feedback resistor 1;
2. Feedback resistor 2;
3. DC amplifier 2;
4. DC amplifier 1.

Following the transmission of the classification result, the computer shifts over to the mode for interrogating the readiness of the meter using the 6N11 instruction, which continues until the next "Start" signal is transmitted. One computer can control several meters. In this case, each meter is assigned its own ordinal number and the N decoder in each meter is correspondingly aligned. The computer periodically interrogates the readiness of the meters and the measurement results. When any meter feeds out a reply signal to the computer, it transmits the corresponding data to it and continues to interrogate the other meters.

By way of example, we shall consider the measurement of the inverse current of a p-n junction using the UT-1 meter, which is based on the principle of comparing the measured and reference values. A resistor R_m (Figure 9.13) is connected in series with the p-n junction being tested. Two voltages are applied to the network consisting of the p-n junction and the resistance R_m: a voltage U_{inv} is applied from the tested junction side, while a reference voltage of opposite polarity E_e is applied on the side of resistor R_m. When the two currents flowing through the p-n junction and resistor R_m are equal, the voltage at point 1 is $U_1 = 0$. If the currents are not equal though, the voltage U_1 will be positive or negative. Thus, the polarity of the voltage at point 1 is an indicator of the equality of the measured and ultimate values of the currents.

The following can be written for the limiting value of the current:

$$I_{lim} = E_e/R_m \tag{9.3}$$

The quantity I_{lim} is specified by setting definite values of E_e and R_m. The voltage E_e is produced by an operational amplifier which takes the form of direct current amplifier UPT-2 which has feedback. A reference voltage of 10 volts is fed to the input of UPT-2. The setting of E_e is accomplished by changing the input resistance of UPT-2, R_{in2}, since the following equality is justified for UPT-2:

$$E_e = U_{in}(R_{fb2}/R_{in2}), \tag{9.4}$$

where U_{in} = 10 volts is the reference voltage and R_{fb2} = KOhm [feedback resistance 2].

Thus, by changing R_{in2} in accordance with the computer program, one can produce various values of the reference voltage E_e at the output of UPT-2. The inverse voltage U_{inv} is generated by operational amplifier UPT-1 and is set by changing the feedback resistance R_{fb1}.

The moment the limiting value of the current is equal to the measured value, i.e., the point in time when the voltage at point 1 becomes equal to zero, is registered by the comparator, which transmits the appropriate signal to the computer. In this case, it is not necessary to carry out the testing process until the point in time when the limiting current value is equal to that flowing through the p-n junction. It is sufficient in the classification mode to determing whether the current through the junction is greater or smaller than the specified limiting value, and to feed the appropriate signal to the computer.

9.4. Contacting Assemblies for Checking the Parameters of Semiconductor Devices

One of the most important mechanisms whose influence is felt on the mean time between failures, the service life, the productivity of measurement and test equipment as well as the confidence levels of the measured parameters is the contact making assembly. A contacting assembly (KU) is understood to be that device which makes it possible to repeatedly connect the devices being tested to the electrical circuitry, in this case assuring a minimum connection resistance, R_{con}, for the electrical current flowing through the plug connection between the contact and the lead to the product which is connected, as well as minimal induced currents in the measurement circuits and maximum insulation resistance between the contacts in a specified temperature range. It is apparent from the definition of a contact assembly that its major technical characteristics will be the following:

- --The permissible current, A;
- --The permissible voltage, V;
- --The capacitance between any contact pairs, pFd;
- --The contact inductance, nHy;
- --The connection resistance between the contact device contacts and the lead of the device being tested, ohms;
- --The insulation resistance between two contact pairs and between any contact and the device package, ohms;
- --The wear resistance, the number of contact making cycles;
- --The operating temperature range, °C.

The nominal values of the technical specifications of contact assemblies for various semiconductor products are stipulated by the corresponding standards [55-57].

Depending on the structural design, contact assemblies are broken down into two major classes: contact assemblies without a mechanical drive and mechanically driven contact assemblies.

Contact assemblies without a mechanical drive are intended for operation in manual quality control and measurement equipment as well as test stand equipment, where the operations of loading the products into the contact assemblies and removing them are accomplished manually. In this case, the leads of the products fall directly on the contacts of the contact assemblies. Loading is realized in the majority of cases with lead friction against the contacts, something which leads to the destruction of the coating on the semiconductor device leads and to rapid wear of the contacts of the contact assembly.

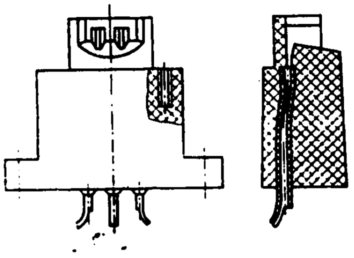


Figure 9.14. The contacting device for transistors with flexible leads.

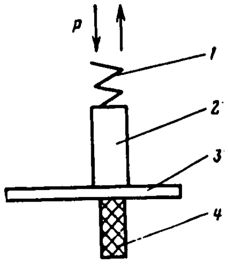


Figure 9.15. Schematic of the contacting device of measurement equipment which operates using the start-stop principle.

Various contact systems are used in contact assemblies without a mechanical drive depending on the type of semiconductor device packages. For diodes and transistors with rigid leads, these are usually push-in contacts, where the insertion and removal of the device are accomplished with friction, while the contact force is produced by means of the elastic properties of the contact material and additional springs.

There are several contact system designs for transistors with flexible leads: bent tubes made of nickel alloy, bronze tubes with a lobe shaped contact bent back inward, collet chuck type clamps, as well as guillotine type terminals. Contact assemblies having a collet chuck or guillotine type contact system make it possible to insert and remove the devices without friction, but are complex to manufacture and have a low productivity, and for this reason have not found wide scale applications in the production of semiconductor products.

Contact assemblies for transistors with flexible leads using contacts made of nickel tubes have become widespread. Such contact assemblies are shown in Figure 9.14. The contact force in the tubular contacts is created by virtue of the deformation of each lead of the transistor being tested, which duplicates the profile of the contact tube. Contact is made at several points in this case. Since the insertion and removal of the devices are accomplished by overcoming the frictional forces between the device lead and the contact tube, the protective coating of the device leads and nonuniform contact wear take place as a consequence of this. Especially severe wear is observed at points where the tube bends. A tubular contact provides for a resistance of $R_{con} \leqq 5 \cdot 10^{-2}$ ohms. The instability of the contact resistance, which is explained by the differing degree of curvature and differing cleanliness of the lead surfaces are to be numbered among the drawbacks of a tubular contact device. It is necessary that the contact assembly by mounted in a vertical position, while the lower end should not be clamped or sealed shut so as to spontaneously remove from the contact tubes any wear products caused by friction with the leads of the devices being measured.

Mechanically driven contact assemblies, which are schematically depicted in Figure 9.15, are used in automated and semiautomatic measurement and test equipment which operates using the start-stop principle. They operate in the following manner: the leads of the device 3 are automatically inserted in the receptacles of the support 4 and connected to the electrical circuit by the contacts 2. The requisite force is produced by elastic element 1. Contact assemblies with a mechanical drive should be distinguished by a high service life, since they are intended for operation in high output equipment.

Their serviceability depends on meeting four conditions:

--The simultaneous entry of the leads of a single product during the measurement time;

--A low resistance and stable contact between the product and the electrical circuitry during the measurement time;

--Connection without deformation of the product;

--Spontaneous removal of inadvertent objects from the contact region.

Difficulties arise in meeting the first condition which are due to the ambiguous arrangement of the leads of the majority of products (diodes and transistors with flexible leads, all types of series produced IC's). For this reason, it is necessary to begin meeting the condition with an analysis of the structural design of the semiconductor product, the quality of the leads and possible deviations from the geometrical shape.

The condition for a low resistance stable contact between the product and the electrical circuitry will be met if R_{con} between the contact and the product lead is no greater than the permissible maximum value for the entire operational time of the equipment. Greater contact compression forces lead to rapid wear of the contact and support surfaces. For this reason, in developing contact assemblies it is necessary to determine the optimal contact pressure depending on the structural design of the contact, its material and coating as well as the specific nature of the lead of the product being tested (diameter, coating, etc.).

The most characteristic type of semiconductor devices with an indeterminate arrangement of the leads are transistors with flexible leads. The transistor leads having a diameter of 0.2 to 0.3 mm are at times deformed and tangled together. For this reason, it becomes necessary to straighten the leads of the transistors prior to measuring the electrical parameters. Special lead straightening machines have been designed for this purpose. At times, the lead straightening operation is performed by the contact assembly. One of the structural designs for a contact assembly with a comb for straightening out transistor leads prior to measurement is depicted in Figure 9.16. In this case, the leads of the transistors being tested 2, which are fed to the measurement position by means of shuttle 8, pass through the teeth of the comb 7 prior to coming in contact with the contacts 1, where the comb teeth fan the transistor leads out in a definite manner and the probability of the leads making contact with the contact areas 1 will be significantly higher than in the case of unstraightened leads. The comb 7 and the shuttle 8 are not shown in Figure 9.16 (at the left). After the transistor gets into the contact position, contacts 1 are pressed against the transistor leads by a clamping force P, which is applied to plates 3, which are spring loaded and secured together with the current conducting flexible elements 4 on base 5. The conducting elements 4 and the springs of the plates 3 are separated by insulating washers 6.

The vertical impinging of the leads on the contacts is assured by the width of the contacts, which must always be chosen greater than the possible deviations of the transistor leads. The task of horizontal alignment of the leads on the contacts reduces to the condition for the teeth of the comb getting between the transistor leads (see drawing section B-B).

The design of contact assemblies for integrated circuits (IC's) presents considerable difficulty, since IC's have a larger number of leads (usually from 8 to 64) with relatively small package dimensions. In this case, the leads of

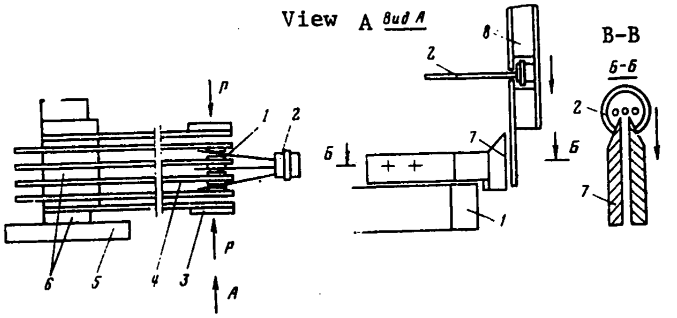


Figure 9.16. A contacting device with a comb for splaying out the leads of transistors.

IC's housed in flat packages with a planar arrangement of the leads, are as a rule made of inelastic strip materials and are readily deformed. The use of push-in contacts, similar to the contacts treated earlier for other types of semiconductor devices, is characteristic of IC's in the 201.12, 301.8, 301.10 and 301.12 packages. For flat pack IC's, the elastic properties of the contact material are utilized to compensate for dimensional deviations and produce the contact force.

Contact assemblies without a mechanical drive for integrated circuits in the 401.14, 301.12 and 201.14 packages are shown in Figure 9.17. Their operational principle is clear.

To automate the measurements of the electrical parameters of integrated circuits, it is expedient to place the latter in special satellite carriers, which make it possible to use automated vibration load equipment and automatically sort the measured IC's into groups. The use of satellite carriers with standard dimensions has made it possible to standardize the design of contact assemblies for integrated circuits in various packages. A series of standardized contact assemblies is being produced by domestic industry for integrated circuits with a low level of integration; the technical specifications for these assemblies are given in Table 9.1, while the structural design of two types is shown in Figure 9.18. In the KUU-1 and KUU-2 contact assemblies (Figure 9.18a), the satellite 4 with the integrated circuit in a circular package which is placed in the satellite, where the IC rests on the support surface 5, causes the contacts 3 which are arranged in a circle to move towards the center of the circle. In this case, the contacts go into the corresponding grooves in the satellite, where the IC pins are positioned, connecting them to the electrical circuits of the measurement instrument through contacts 1, and electrical connector 2, which serves to disconnect the contact assembly during the replacement and repair of the latter.

The KUU-6 contact assembly (Figure 9.18b) for integrated circuits in flat packages also functions in a manner similar to that described above. The difference consists in the fact that the contacts in this case are arranged in

Figure 9.17. Contact assemblies for integrated circuits.

four rows so that their ends are in one plane. The IC being tested is clamped in the KUU-6 by means of special pins, which are located in the assembly, and holes in the satellite 4. In this case, the IC leads make contact with the contacts 3 of the contacting assembly. With the further squeezing of the satellite, by virtue of the elastic properties of the contact material a reliable contact is made between the IC leads and the electrical circuits of the measurement instrument through electrical connector 2. In all of the standardized assemblies treated above, contact is made with the IC's being tested using a two wire Kelvin system, something which makes it possible to segregate the voltage and measurement circuits.

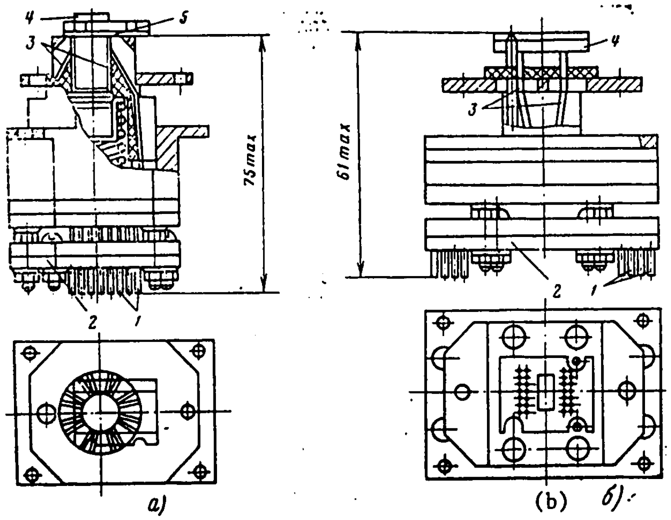


Figure 9.18. Mechanically driven contact assemblies for integrated circuits.

a. In the 301.8 and 301.12 packages (KUU-1 and KUU-2);
b. In the 401.14 package (KUU-6).

TABLE 9.1. The Main Technical Specification of Contact Assemblies for Integrated Circuits

Type of Assembly	Type of Package of the Tested Device	Number of Contacts	Current, A	Permissible Voltage, V	Contact Inductance, nHy	Contact to Lead Connection Resistance, ohms	Capacitance Between Any Contact Pairs, pFd	Immunity to Wear (Number of Contacting Cycles).	Force Needed to Assure the Travel of the Support Surface, N	Weight, g
KUU-1	301.8	16	10^{-10}–0.5	500	70	0.05	$\geqq 2$	$\leqq 5 \cdot 10^5$	40	185
KUU-2	301.12	24								
KUU-4	201.14	28								
KUU-5	201.16	32								
KUU-6	101ST14-1, 101MS14-1, 401.14	28					$\geqq 1.5$	$\leqq 1 \cdot 10^6$	15	153

CHAPTER TEN TEST EQUIPMENT

Semiconductor devices which are used in different equipment function under complex and diverse conditions of exposure to the environment and mechanical loads. The structural design of semiconductor devices and the observance of the technological processes for their manufacture should guarantee their normal operation under the conditions stipulated in the technical specifications. However, in practice because of the degradation of the quality of the raw materials, deviations from the fabrication technology, worker errors, equipment failure and a number of other reasons, not all of the manufactured semiconductor devices can maintain their parameters under difficult conditions of exposure to the factors indicated above. Because of this, all semiconductor devices or sample batches are subjected to various kinds of tests during their manufacture so as to confirm the capability of the semiconductor devices of functioning under the stipulated conditions while retaining the electrical parameters within the stipulated range.

As a rule, devices are subjected to tests in the concluding stages of the production process for their manufacture.

The major kinds of tests of semiconductor devices are:

--Mechanical;

--Climatic;

--For immunity to special effects;

--Aging;

--Reliability and service life.

The requirements placed on the immunity of semiconductor devices to various effects, the immunity principle, the testing procedure and the circuit configuration for the devices being tested are stipulated in the overall technical specifications (OTU) for the semiconductor device, by the special technical specifications (ChTU) for each particular series or type of semiconductor device as well as by the state (GOST) or sectoral (OST) standards.

10.1. Equipment for Mechanical Tests

The major kinds of mechanical tests of semiconductor devices are the following [58]:

--Tests for the absence of freely moving particles inside a package which are capable of disrupting device operation;

--Tests for the absence of short term short circuits and breaks in the circuits of the semiconductor device leads;

--Tests for resistance to shock and vibration loads;

--Tests for resistance to exposure to linear acceleration.

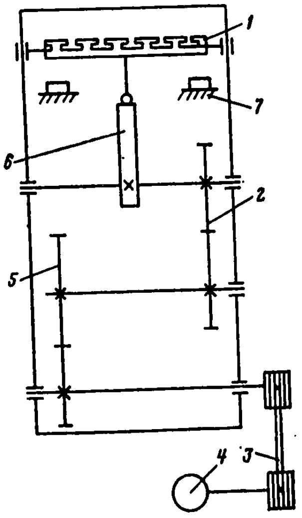


Figure 10.1. Kinematic schematic of the SU-1 shock test stand.

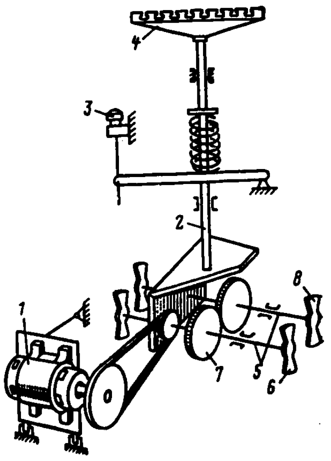


Figure 10.2. Kinematic schematic of the VS-68 vibration test stand.

Metallic particles which are capable of causing short circuits of the leads of semiconductor devices may remain inside a package in the fabrication of such devices. One of the most widespread reasons for the appearance of metal particles is the sparging of the metal during the hermetic sealing of the packages. Poor quality execution of the operation of lead bonding can be the cause of an unreliable contact between a chip and the external leads of the semiconductor device.

Permanent breaks and short circuits in the leads of semiconductor devices are easily detected when measuring the electrical parameters. To ascertain short term disruptions of this type, the devices being tested should be subjected to shock and vibration loads, and the presence of short term short circuits and breaks is registered by special equipment.

Equipment for mechanical tests should incorporate the following devices:

--For generating mechanical loads (vibration, shock or linear loads) with the requisite parameters;

--For securing the devices being tested;

--For setting the electrical operating conditions (where necessary, stipulated in the sectoral or special technical specifications).

Moreover, equipment intended for testing for the absence of short term breaks and short circuits in lead circuits should also contain devices capable of registering these defects.

Primarily mechanical and electrodynamic shock test stands are used to produce shock loads. Mechanical stands have found the greatest application because of the comparative simplicity of their structural design as well as the absence of electrical interference arising during their operation.

A kinematic schematic of the mechanical SU-1 shock test stand is shown in Figure 10.1, which provides for the free fall and sharp deceleration on its platform of the products being tested.

The products being tested, which are placed in special cassette holders, which provide for reliable fastening and supply the proper electrical conditions where necessary, are secured to platform 1, which is coupled by means of cam 6 to the drive mechanism, consisting of electric motor 4, V-belt drive 3, and a reducer containing two pairs of cylindrical gears 2 and 5. With the rotation of cam 6, platform 1 first lifts up, and then falls sharply on the supports 7, and a shock load is thereby imparted to the products being tested. The number of shocks per unit time is adjusted by varying the r.p.m. of direct current motor 4, while the size of the shock load is adjusted by changing the adjusting washers on supports 7. The number of platform impacts is counted by a counter.

The Main Technical Specifications of the SU-1 Test Stand

Number of impacts per minute	10 to 100
Acceleration, g	10 to 150
Maximum weight of testable products, kg	50
Platform dimensions, mm	285 x 452
Overall test stand dimensions, mm	620 x 540 x 750
Overall control console dimensions, mm	632 x 640 x 854

The vibration test stand, a kinematic schematic of which is shown in Figure 10.2, imparts vibration loads to the products being tested. The tested products are placed on table 4. A rotation is transmitted from electric motor 1 through V-belt drive and gears 7 to shafts 5. Gear sectors are fastened at the ends of these shafts: stationary 6 and moving 8 sectors. With the rotation of the shafts 5 at the same angular speed in opposite directions, the horizontal components of the unbalanced forces mutually cancel out, while the vertical forces are summed and cause the vertical motion of table 4, which is rigidly fastened to shaft 2. The amplitude of the oscillations is adjusted by moving the moving gear sectors relative to the stationary ones, while to adjust the amplitude, there is adjusting screw 3. The frequency of the vibrations is regulated by changing the rotational speed of electric motor 1.

Electrodynamic vibration test stands are used to test semiconductor devices and IC's for vibration resistance at frequencies above 500 to 1000 Hz; in these test stands, the vibration of the table with the products being tested fastened to it, is accomplished by means of the motion of a metal core in an alternating magnetic field, produced by a sine wave or pulsed voltage. The UVE-5/1000 electrodynamic vibration test stand, consisting of the VE-5/1000 vibration test stand, the

UUS-3 amplifier and the control console for the unit are pictured in Figure 10.3.

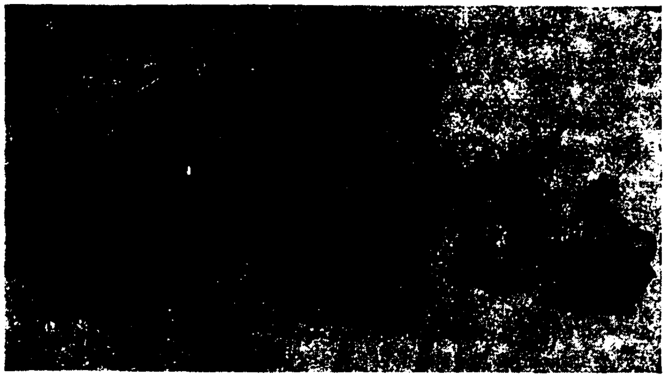


Figure 10.3. The UVE-5/1000 electrodynamic vibration test stand.

a. Control console;
b. Amplifier;
c. Vibration test stand.

The Major Technical Specifications for the UVE-5/1000 Vibration Test Stand

Nominal load capacity of the vibration test stand, kg	5
Frequency range, Hz	5 to 10,000
Maximum acceleration for a load weighing 5 kg, g	30
Maximum travel amplitude, mm	7.5
Magnetic field intensity at the level of the vibration test stand table, no more than, A/m	400

When testing for the absence of short term breaks, shock loads with a specified acceleration and frequency are imparted to the semiconductor devices. In this case, the appropriate electrical conditions are created for the devices being tested and meters which register the appearance of a pulse from a short term break should be connected to each tested product during the entire testing time.

Tests for the absence of short circuits in the leads and for freely moving particles in the package of semiconductor devices are performed under the same conditions, with the exception of the fact that the tested products are placed on the platform of the vibration test stand. Additionally, the electrical conditions during the tests for the absence of breaks and short circuits are different, about which something will be said below.

Devices for which no disruptions of the contacts, short circuits and breaks in the leads were detected are considered to have passed the tests. A short circuit in the lead circuitry of a semiconductor device is characterized by a resistance $R_{s.c.}$ which is inserted in parallel with this circuit, and by the short circuit time. A break can correspondingly be characterized by a resistance R_{break}, inserted in series with the lead circuit, and by the duration of the break process. Values of the resistances $R_{s.c.}$ and R_{break} can vary in a range of from 0 to ∞, depending on the factors which caused the short circuit or break. In line with this, the signal which appears in the circuits of the product being tested and which characterizes the occurrence of a short circuit or break can have different values under identical test conditions.

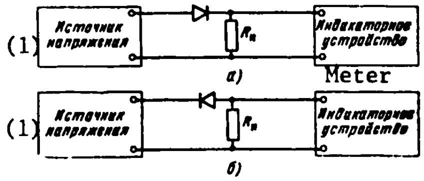


Figure 10.4. Block diagram showing the testing of diodes for the absence of breaks (a) and short circuits (b).

Key: 1. Voltage source;
R_H = load resistance.

Circuit configurations for diodes are shown in Figure 10.4a and b, while circuits for transistors when testing them for the absence of short circuits and breaks are shown in Figure 10.5.

Voltage sources are necessary to set the electrical test conditions, while the metering devices register the pulses which appear across the load resistance R_H in the case of the appearance of short term short circuits or breaks. In this case, the polarity of the recorded pulses differs when testing for a break and for short circuits. The sensitivity of the metering devices should be such as to be able to determine the values of the resistance $R_{s.c.}$ and R_{break} for a definite value of the voltages at the leads of the devices being tested.

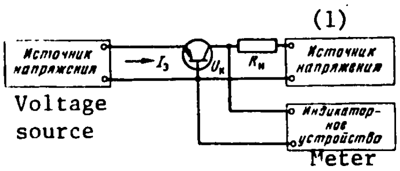


Figure 10.5. Block diagram showing the testing of transistors for the absence of short circuits and breaks.

Key: 1. Voltage source.

Transistors which operate at low and medium frequencies (up to 300 to 500 MHz) are tested for the absence of short circuits and breaks in the active mode, i.e., when an inverse voltage is applied to the collector and a forward voltage is applied to the emitter. The values of the voltage at the collector U_K [V_{cc}] and the emitter current I_E are stipulated in the special techical specifications for the specific semiconductor devices. Testing high frequency transistors in such a mode can lead to the appearance of self-excitation phenomena in the devices being tested, which in turn leads to false actuation of the metering units. To combat these phenomena, blocking chokes, capacitors, etc. are usually placed close to the products being tested. In a number of cases, it is expedient to test high frequency transistors with the junctions blocked, i.e., it is necessary to apply inverse voltages to the emitter-base and collector-base junctions.

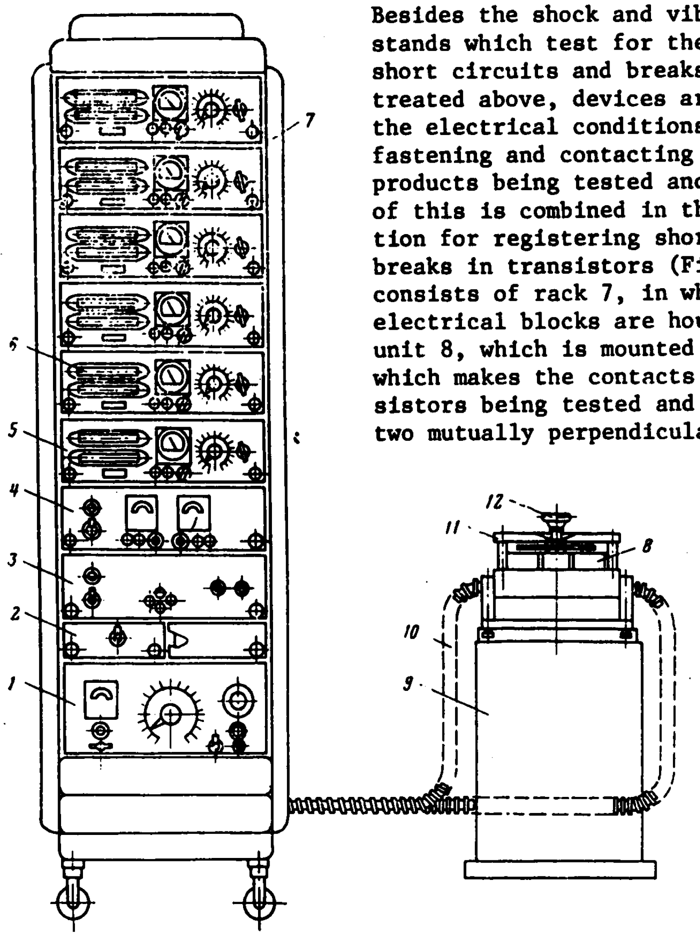


Figure 10.6. The RT-120 tester for registering short circuits and breaks in transistors.

Besides the shock and vibration test stands which test for the absence of short circuits and breaks, which were treated above, devices are needed to create the electrical conditions as well as fastening and contacting devices for the products being tested and indicators. All of this is combined in the RT-120 installation for registering short circuits and breaks in transistors (Figure 10.6). It consists of rack 7, in which all of the electrical blocks are housed, and rotating unit 8, which is mounted on stand 9 and which makes the contacts with the transistors being tested and rotates them in two mutually perpendicular planes. Some six indicator units 5 are housed in rack 7, in each of which there are 20 indicator cells. Each cell is connected by its own input circuits to one transistor under test, while the output circuits are connected to a small light mounted on the front panel of the metering unit. The lights from the 20 meter indicator cells are combined together in signaling display 6. The power supply for the transistors being tested 3, the power supply for the indicator cells 4, a block of filters 2 and the control unit for the vibration and impact test stand 1 are located in the lower portion of rack 7. The rotating device 8, which is connected to the rack by cable 10, is made in the form of a rigid platform, which rotates through 90° on its own axis. The cassette holders with the transistors being tested (20 transistors in each cassette) are clamped in the rotating device by means of plate 11 and flywheel 12. The transistors are connected to the metering and mode setting units through special contacts, which provide for reliable contacts during the impact and vibration testing time.

The RD-120 unit for registering short circuits and breaks in diodes is structurally similar to the RT-120 unit treated above.

The resistance of semiconductor devices to linear acceleration is tested in a centrifuge. The goal of these tests is to check the strength of the bonding of the chip to the device package, the strength of the bonding of the leads to the bonding pads of the chip, the hermetic seal quality and the quality of the metal to glass seals at the sites of leads in the device and to generally check the capability of the device of performing its functions during the process of exposure to linear loads. The criterion for a device being good following the tests is the maintenance of the electrical parameters within the specified range or the satisfying of other requirements indicated in the special technical specifications.

10.2. Equipment for Climatic Tests

The main function of climatic testing equipment is to check the operability of semiconductor devices and IC's when exposed to various climatic factors [58]. The operability criterion for tested products is the preservation of their structure, external appearance and electrical parameters, which are checked either during the tests or after exposure to the climatic factors.

The following categories of climatic tests have been established by existing standard setting documents:

--For heat resistance;

--For cold resistance;

--For moisture resistance with both short term and long term exposures;

--For resistance to exposure to a cyclical change in temperature;

--For resistance to exposure to reduced and elevated pressures;

--For resistance to exposure to a sea fog;

--For fungal resistance.

Semiconductor devices are tested for thermal and cold immunity in heat and cold chambers respectively, where they are exposed for a definite time, most often 30 minutes, with the electrical conditions maintained. Upon the expiration of this time, the electrical conditions are removed from the devices under test and the parameters of the devices being tested are measured until they are removed from the chamber. Cold immunity is tested at a temperature of -60° C, while heat immunity is tested at a temperature of +70° C for germanium devices and +125° C for silicon semiconductor devices. Other values of the test temperatures are also possible, which are indicated in the special technical specifications for the device being tested.

For moisture resistance testing, the devices being tested are placed in a moisture chamber without any electrical power being applied to them and kept there for 4 to 30 days. In this case, a definite temperature is established in the chamber in a range of +40 to +60° C at a relative humidity of 98%. At the end of the tests, the electrical conditions are supplied for 5 minutes for the devices.

Testing for resistance to a cyclical temperature change, which has the purpose of checking the quality of the seals of the device leads to either glass or ceramic material as well as the quality of the connection of the chip to the mounting base of the device, is carried out by means of placing the products being tested in the heat and cold chambers by turns, the temperatures in which are previously brought to the ultimate values indicated in the particular technical specifications. The exposure time for products in the chambers is limited by the time it takes to reach temperature equilibrium or is established by some standard setting documents. The devices should be moved from chamber to chamber within the time specified in the particular technical specifications (no more than 1 to 5 minutes). In this case, the temperature in the chamber after inserting the products in it should change by no more than 10° C and be restored after a time of no more than 5 minutes, if other values are not indicated in the particular technical specifications. The time, which includes the exposure of the products in heat and cold chambers taking into account the movement of the products from chamber to chamber, is called the cycle time. The number of test cycles is specified by the particular technical specifications. The devices are as a rule tested without electrical power applied.

The immunity of semiconductor devices to reduced and elevated pressure is checked in a pressure testing chamber. The level of the pressure, the testing time and the necessity of applying electrical power and the electrical parameters are stipulated by the relevant standard setting documents.

To test for sea fog exposure, which is carried out for the purpose of determining the corrosion resistance of semiconductor devices in an atmosphere saturated with viscous salt solutions, the devices are placed in a chamber in which a fog is produced from sea water by means of an aerosol device, pulverizer or in some other fashion, or from a salt solution obtained by dissolving sodium chloride in distilled water. The fog should have a dispersion particle size of 1 to 10 μm (95% droplets), and an absolute moisture content of 2 to 3 g/m^3. During the testing, the devices being tested are placed in the chamber so that the solution spray and drops from the ceiling, walls and system of supports do not fall on the products.

When testing for immunity to fungi, the semiconductor devices are placed in a special fungi formation chamber, where they are sprayed with a water suspension of a mixture of fungi spores, prepared in accordance with special instructions. The testing is carried out at a temperature of about +30° C and a relative humidity of 95% in the absence of air circulation.

There is a large products list of specialized and general purpose test equipment to test semiconductor devices for resistance to exposure to climatic factors.

TABLE 10.1. The Major Parameters of Climatic Test Equipment

	Наименование Designation	Тип Type	Parameters Параметры					
			Диапазон температур, °C Temperature Range, °C	Рабочий объем камеры, м³ (1)	Относительная влажность, % (2)	Максимальное разрежение, Па (3)	Предельное повышенное давление, Па (4)	Конструктивное исполнение Structural Design
	Камера тепла Heat Chamber	КТ-0,01—350	+(80—350)	0,01	—	—	$3\cdot10^5$	Настольная Desk Top
	Камера тепла	КТ-0,025 350	+(80—350)	0,025	—	—		Консольная Console
	Камера тепла Heat Chamber	КТ-0,4 - 350	+(80—350)	0,4	—	—		То же The same
(5)	Камера тепла и холода	КТХ-0,015	(−65)−(+155)	0,015	—	—		Настольная Desk Top
(5)	Камера тепла и холода	КТХ-0,063—007	(−55)−(+155)	0,063	—	—		То же The same
(6)	Бароустановка	КБ-1	−	1,0	—	$1{,}3\cdot10^2$		Консольная Console
(7)	Термобарокамера	КТХБ-0,025	(−65)−(+155)	0,025	—	$0{,}6\cdot10^2$		То же The same
(7)	Термобарокамера	КХБ-0,4—65	−65	0,4	—	$0{,}6\cdot10^2$		» »
	Термобарокамера	КТБ-0,4—300	+(80—300)	0,4	—	$0{,}6\cdot10^2$		» »
(8)	Камера влаги	КВ-0,01	+(40—55)	0,01	95—100	—		Настольная Desk Top
	Камера влаги	КВ-0,4	+(20—70)	0,4	85—98	—		Консольная Console
(9)	Термовлагокамера	КТХВ-0,25	(−25)—(+90)	0,25	85—98	—		То же
	Термовлагокамера	КТВ-0,025	+(40—155)	0,025	85—98	—		» »

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Key:
1. Working volume of the chamber, m^3;
2. Relative humidity, %;
3. Maximum rarefaction, Pa;
4. Ultimate elevated pressure, Pa;
5. Heat and cold chamber;
6. Pressure test chamber;
7. Temperature and pressure testing chamber;
8. Moisture testing chamber;
9. Temperature and moisture testing chamber.

Climatic testing equipment can be broken down into manually controlled equipment and automated equipment with respect to the manner of loading the products being tested into the medium and their removal from it, as well as with respect to the manner of recording and processing the test data. Manually controlled equipment, as a rule, is utilized in sample tests, where not all of the semiconductor devices being manufactured are subjected to testing, but only a portion of them. The productivity of this equipment is determined by the capabilities and skills of the operator. The test results are recorded manually by the operator. The major technical specifications of manually controlled climatic equipment are given in Table 10.1.

In automated test equipment which is used in the mass testing of semiconductor devices, the loading of the products into the chambers, their removal following the tests and sorting into groups are accomplished automatically.

Chambers with manual control of the heat, cold, moisture, sea fog, fungal growth as well as pressure test chambers consist of the chamber itself where any of the climatic conditions are created and the products being tested are placed, the climatic support system, as well as the devices for regulating the climatic parameters of the chamber within the range permissible for the testing and an instrument for recording the values of the climatic parameters. Depending on the external dimensions and useful volume, the equipment can either be of a desk top or console type design. As a rule, such equipment is all-purpose and can be used for testing various electronic hardware. In this case, the enterprises performing the tests of, for example, semiconductor products, should themselves design the devices for making the contacts with and switching the products under test, which are placed in the chambers, as well as the devices which assure the proper electrical conditions for the tests.

An elevated temperature is produced in heat chambers by means of electrical heating, and either the vaporization of compressed gases or compressor cooling is used to produce a below freezing temperature in cold chambers. We shall consider the structural design of a console type heat and cold chamber (Figure 10.7). A two stage compressor 1 is used to obtain a below freezing temperature in the working volume of the chamber. A positive temperature is produced in the chamber by means of electric heaters 5. The fans 4 are used to mix the air in the chamber to obtain a uniform distribution of the temperature field over its entire working volume. The setting and regulation of the temperature are accomplished by thermal regulator 2; the current value of the temperature in the chamber is registered by instrument 3, which can either be a meter, a digital meter or an autorecorder. Moreover, there should either be holes in the chamber for the electrical cables, or special sealed entrances for supplying voltages from the external supplies to the products being tested, as well as for the measurement of the parameters of the tested products.

Moisture chambers differ from heat and cold chambers to a minor degree: special devices are used to create environments with an elevated humidity instead of devices for heating and cooling. One can use a fan with a vaporizer as such a device. The vaporizer, which takes the form of a reservoir with water and a water heater, humidifies the ambient air by virtue of heating and evaporating the water. The fan circulates the air in the chamber. Semiconductor devices are usually tested for moisture resistance at a relative humidity of 85 to 98%. Tests for moisture resistance are usually performed at an elevated temperature. Because of this, moisture chambers are usually made together with heat chambers.

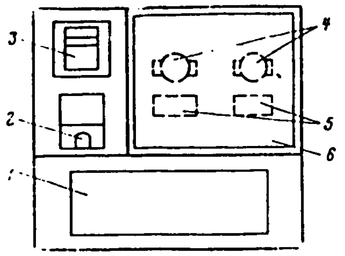

Figure 10.7. A heat and cold chamber.

Pressure testing chambers, which are intended for testing semiconductor devices for exposure to elevated and reduced atmospheric pressure, likewise differ little in structural terms from the heat and cold chamber treated here. A specific feature of them is the elevated requirements placed on the strength and hermetic seal integrity of the walls, seals as well as the electrical leads. Sometimes, the tests in a pressure testing chamber should be accompanied by heating or cooling of the tested products. Because of this, there exist combined chambers which combine tests at elevated and reduced temperatures as well as with elevated and reduced atmospheric pressures. A reduced atmospheric pressure is created by means of vacuum pumps. An elevated atmospheric pressure is produced by means of a compressor.

Figure 10.8. The set of equipment for testing the electrical parameters of transistors at temperatures of -60 and +120° C.

In contrast to the all-purpose climatic testing equipment treated above, the UKT-120 (position 1) and the UKT-60 (position 3) (Figure 10.8) installations for testing the electrical parameters of transistors take the form of specialized heat and cold chambers respectively and are designed for heat and cold resistance testing, as well as for measurements of the major parameters of transistors (inverse currents and the gain) at temperatures above and below freezing. Each of these installations is equipped with a switcher for the sequential connection of the transistors to the tester to measure the parameters and a device for setting the electrical operating mode of the transistor being tested. The switcher and the control point setter are housed inside the installations. The parameters are measured by an IKT-2 digital meter-classifier (position 2). There is a display in it on which the ordinal number of the transistor, the parameter being measured and its value are indicated. Moreover, all of these quantities are automatically recorded on a numeric printer.

Evaporating liquid nitrogen is used as the coolant in the UKT-60 installation. A Dewar flask with liquid nitrogen is located inside the installation. The exposure time of the tested transistors in the heat chamber or in the cold chamber is set by a timing relay located inside the unit.

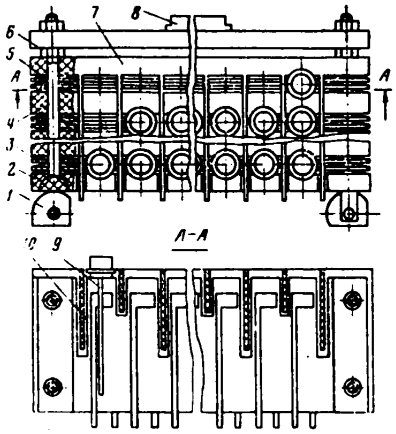

Figure 10.9. Cassette holder for testing transistors with flexible leads.

The heat chamber (in the UKT-120 unit), in which the temperature is maintained in a range of +100 to +130° C with a precision of ± 2° C, and the cold chamber (in the UKT-60 unit) having a temperature in the operating mode of -60 ± 2° C, are located in the upper left corner of the installations. There are two circular holes on the front side in the heat and cold chambers, in which the cassette holders with the transistors being tested are inserted. Similar openings, positioned symmetrically in the lower portion of the installations, serve for holding a spare set of cassette holders. Moreover, one can place in them the cassette holders with the transistors just extracted from the chambers to keep them at the ambient temperature.

The electrical connectors are fastened to the external surface of the cassette holders, and it is through these electrical contacts that the emitter, base and collector leads of the transistors being tested are connected to the switcher. The holders are interchangeable for various types of transistors.

A cassette holder for low power transistors with flexible leads is depicted in Figure 10.9 [59]. It is distinguished from similar devices by its increased contact reliability and simple structural design. This is achieved in that the contact system of the holder is made in the form of moving flat insulating plates with contact elements placed them, along one of the edges of which there are grooves for the positioning of the teeth of the insulating comb. The insulating plates 3 are put together in packets on cylinderical guides 4 with the flat contacts 9 secured to the packets. The requisite gap between the plates is achieved by springs 5 and adjusted by nuts 6. To prevent the transistors touching each other, they are separated by isolating frame 7, the ribs of which move freely in grooves 10 of plates 3. The contacting force is produced by the rotation of eccentrics 1. There are plug connectors 8 to which the cassette holder contacts are connected for the connection of the cassettes to the measurement equipment and to the electrical power supplies and instrumentation.

The force produced by the rotation of eccentrics 1 is uniformly transmitted by stiff plate 2 through the springs to plates 3, which in moving along guides 4, produce the requisite contact force on each transistor lead.

The automation of the measurement of semiconductor device parameters in a range of temperatures from below freezing to above freezing has a considerable economic impact, since the measurement of the parameters takes only fractions of a second itself in the overall operational cycle, while the insertion, exposure to the medium at a specific temperature, as well as the removal and recording of the measurement results is more or less easily automated. In this case, automated testers are used as the measurement equipment, which was the topic in the preceding chapter, while run-through chambers are usually called climatic equipment, having in mind the fact that the products being tested in an automated cycle sequentially pass through all stages from the loading to the sorting into the appropriate containers following the completion of the tests [60].

Semiconductor devices are usually tested in run-through chambers while placed in group or individual carriers. The use of satellite carriers in automated equipment is covered in more detail in Chapter 15.

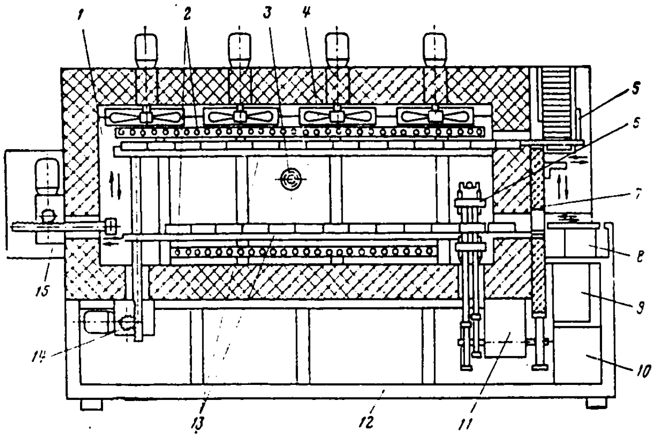

Figure 10.10. The PPS-130 semiautomated unit for diode instability testing.

We shall consider the structural design and operational principle of the PPS-130 and PPS-60 semiautomatic units, which are intended for checking the drift in the parameters of alloy diodes at temperatures of +130° C (PPS-130) and -60° C (PPS-60). In the units, the diodes being tested are placed in a group carrier cassette, which is loaded either manually or automatically on an independent piece of equipment, while the diodes are removed from the cassette upon the completion of the tests automatically, being allocated to individual hoppers in accordance with the value of the parameters measured.

The structural design of the units is quite similar, and their difference consists in the system for producing the appropriate temperatures.

In the PPS-130, this is a coil heater, and in the PPS-60 unit, it is a valve for delivering liquid nitrogen and a tubular coil.

The unit (Figure 10.10) consists of the following major assemblies: the frame 12, in which the chamber 1 is mounted and all of the remaining assemblies and mechanisms. There are two rectangular openings in the front wall of the chamber for the cassette holders to enter and leave it. Two-level guides 13 are installed inside the chamber, along which the holders move, one pushing the other. The coil heaters 2 (or the tubular coil with the coolant in the PPS-60 unit) are secured on special brackets to these same guides.

Four axial fans 4 are installed for the purpose of assuring uniform temperature distribution in the upper portion of the chamber. The mechanism 8 which feeds the cassette holders into the chamber 1 is mounted on the front of the chamber. The mechanism 15 which removes the cassettes from the chamber 1 is mounted on the back of the chamber opposite the lower level of guides. The cassette holders are transferred from the upper level to the lower by means of mechanism 14.

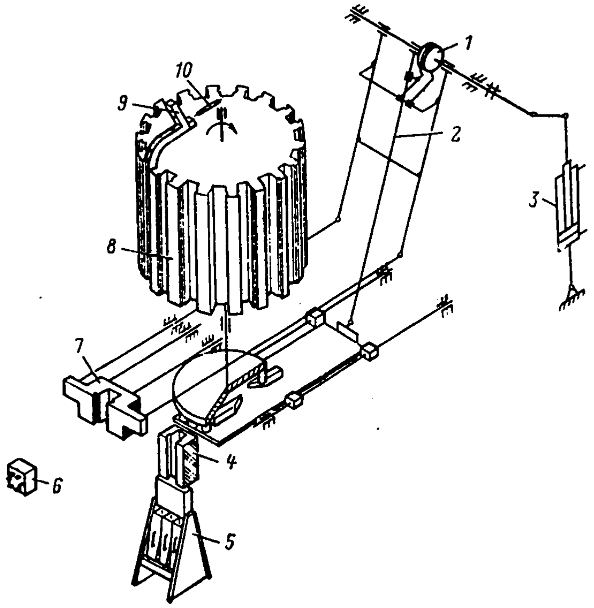

Figure 10.11. Kinematic schematic of the PK-5005 run-through chamber.

The contacting device 6 is positioned in the immediate vicinity of the output opening of the chamber, where this device is used to connect the diodes being tested to the instrumentation. Mechanism 11 moves the contact sockets, and also opens and closes door 7. Mechanism 9 unloads the cassette holder from the chamber, while mechanism 10 sorts the tested diodes into groups. All of the mechanisms operate in a definite sequence, which is assured by the electrical circuitry. The temperature is automatically maintained at the specified level by means of an automatic control system, the sensor 3 of which is located in the center of the chamber volume. There is a reference graphic control chart 5 on the front panel for operational convenience, which depicts the operating sequence of the mechanisms in the unit.

The PK-5005 run-through chamber is an automated unit for measuring the parameters of transistors and integrated circuits in a temperature range of from -65 to +150° C. In this case, the products being tested can be exposed in the chamber automatically for from 6 to 30 seconds. The parameters are measured by an external measurement instrument [60]. The operating principle of the PK-5005 run-through chamber is illustrated by the kinematic schematic shown in Figure 10.11.

The products being tested, which are placed in a special satellite (Figure 10.12), are fed into the loading magazine 9 (Figure 10.11) from which they are pushed out one at a time by pneumatic cylinder 10 into the drum type transport magazine. The slots in carousel 8 of this mechanism are thus gradually filled with the products being tested in the satellites. Carousel 8 has 31 slots, arranged uniformly about the perimeter. Each of the slots holds 7 satellites, which feed under their own weight from the loading magazine and are arranged one on top of the other. Following the loading of seven satellites in one slot, the carousel rotates clockwise through an angle of 11.6° and the next slot comes up to the loading magazine, where this slot had been in the measurement and unloading position. Each subsequent rotation of the carousel occurs after feeding seven satellites sequentially into the measurement position and correspondingly loading seven satellites into the slots of the carousel in the loading position, which is realized by means of transport mechanism 7. The loading of the products being tested into the chamber and the rotation of the carousel coupled to it take place in a definite cycle, set by the control unit, which is not indicated in the schematic. The exposure time of the products in the chamber prior to the measurement of their electrical parameters depends on this cycle, as well as the capacity of the carousel.

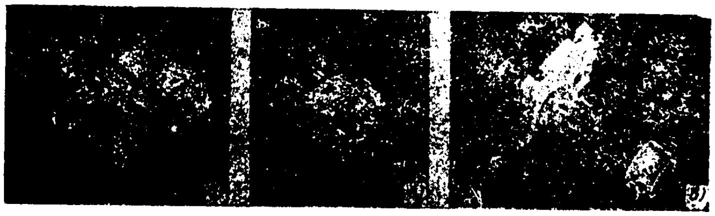

Figure 10.12. Satellite carriers: for unencapsulated transistors (a), integrated circuits in the 101ST14-1 package (b) and transistors with flexible leads (c).

The motion of the carousel 8 and the travel mechanism 7 is accomplished by means of pneumatic drive 3, which is driven by compressed air at a pressure of 2 to 5 atm. The carousel is rotated through each seven operational cycles of the travel mechanism 7 by means of the ratchet wheel 1 and lever 2, which are located on the shaft of the travel mechanism 7.

After the travel mechanism has brought carousel 8 to the new position 30 times, the products being tested which were first placed in the carousel slots come to the measurement and unloading position. The transport mechanism 7 engages the satellite with the product and brings it to contacting device 6, where all of the leads of the tested product are connected to the circuits of the external measurement instrument. In this case, the control unit feeds the "Start Measurement" signal to the external meter for the parameters. Following the completion of the measurements, a "End Measurement" signal is fed to the control unit from the metering instrument. The control block generates the signal to turn on the electropneumatic valve of drive 3. In this case, transport mechanism 7 transports the satellite to the unloading position, where it falls into unloading magazine 4 by virtue of its own weight, and then into the corresponding hopper of the unloading device 5. Having stopped in the unloading position for about 200 msec, the transport mechanism 7 returns to the contacting position, extracting behind itself the next satellite with the product from the carousel slot, located in the measurement and unloading position. The connecting device is equipped with special catches, while the satellites have special holes for locking in the contacting position.

The high temperature is maintained in the chamber by means of the coil heater, while the environment with the below freezing temperature is produced by the evaporation of liquid nitrogen.

The Major Technical Specifications for the PK-5005 Run-Through Chamber

Output for a product exposure time in the chamber of, pieces per hour:	
3 minutes	4,200
6 minutes	2,100
Exposure time of the products in the chamber, minutes	6 to 30
Temperature range in the chamber, °C	(-65) to (+150)
Precision in setting the temperature, °C	± 1.5
Temperature fluctuations around the set point, °C	± 0.5
Temperature distribution nonuniformity in the product transport region, °C	4

Semiconductor devices can be tested for exposure to a cyclical temperature change in the simplest case by means of conventional heat and cold chambers, which were treated above. In this case, the transport of the products from one medium to the other, which is realized manually, should not take more than one minute in accordance with the requirements of the existing standard setting documents. The chamber temperature following the insertion of the products being tested into it from another medium should not change by more than 10° C. It is difficult to meet these and a number of other requirements in the case where heat and cold chambers are used which are not coupled to one another. Several types of specialized units exist for testing for exposure to cyclical temperature change (thermal cycling).

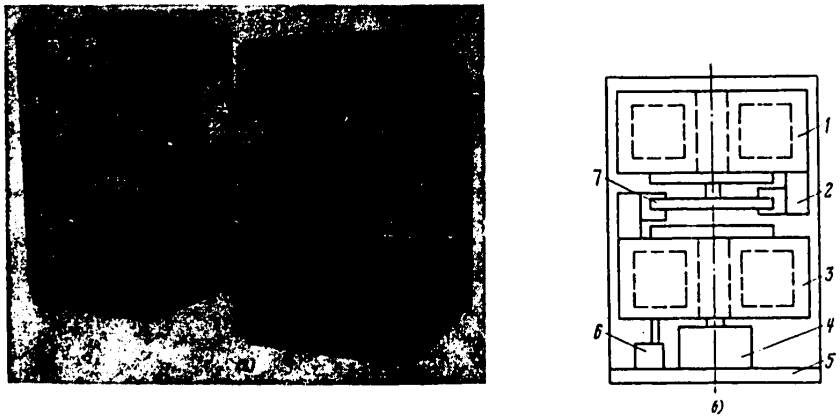

Figure 10.13. The UTTs-60/160 semiautomated temperature cycling unit.

a. General view;
b. Schematic drawing of the climatic testing unit.

The UTTs-60/160 semiautomatic temperature cycling unit (Figure 10.13a) consists of two parts: the control console (depicted on the left) and the climatic unit, a schematic drawing of which is shown in Figure 10.13b. The heat chamber 1 and cold chamber 2 are made in the form of hollow toroids, inside which there is an intense air flow circulation. Cassette holders with the products being tested are transported by means of carousel 7 and holder transport mechanism 2 clockwise about the periphery, and simultaneously upward and downward, alternately falling into each position in the heat and cold chambers. The carousel 7 and mechanisms 2 are driven by electric motor 4. All of the mechanisms and devices in the unit are mounted in the assembly frame 5. Liquid nitrogen is used as the coolant; the feed of the coolant is regulated through valve 6, which is controlled by a thermal regulating system located on the control panel. For repair and preventive maintenance of the unit, its upper section with the heat chamber can be lifted by means of an electric hoist, located in the lower portion of the installation. The UTTs-60/160 semiautomated unit makes it possible to perform thermal cycling operations in three and five cycle multiples. Upon completing the last half-cycle, the cassette holder with the products is pushed out into the unloading position.

An external view (Figure 10.14a) and an operational schematic (Figure 10.14b) of the single chamber TO-5081 semiautomated thermal cycling unit are shown in Figure 10.14. A distinctive feature of the unit is the absence of a mechanism to transfer the products being tested from one medium to another, since these products are fixed in a stationary position in the chamber, where an elevated and reduced temperature environment is alternately produced in the chamber [60].

The TO-5081 semiautomated unit consists of the chamber 12, which is connected to the branch pipes 2 and 15 and air ducts 5 and 11 by means of the channel switches 1 and 9, and along with these units, forms closed loops. There are guides for the placement of the cassette holders with the tested products in the walls of chamber 12. The holders for various types of semiconductor devices differ in their structural design, but the external dimensions of all types of cassette holders are the same. The products being tested can be placed in the cassette holders both chaotically and with an ordered row layout. A block of heating elements 4, consisting of five ESP-01 resistive elements and which serves as a sensor in the temperature regulating system, is placed in the center of chamber 12. The upper 1 and lower 9 switches for the channels serve to switch the air flows through the chamber 12. The drive for the channel switches is pneumatic. One sensor each 14 for the temperature regulation system, which takes the form of a resistance thermometer, is installed in branch pipes 2 and 15. A thermal relay 3 is additionally inserted in branch pipe 2 for the emergency disconnection of the semiautomated unit in the case where the temperature norm is exceeded in the "heat" channel.

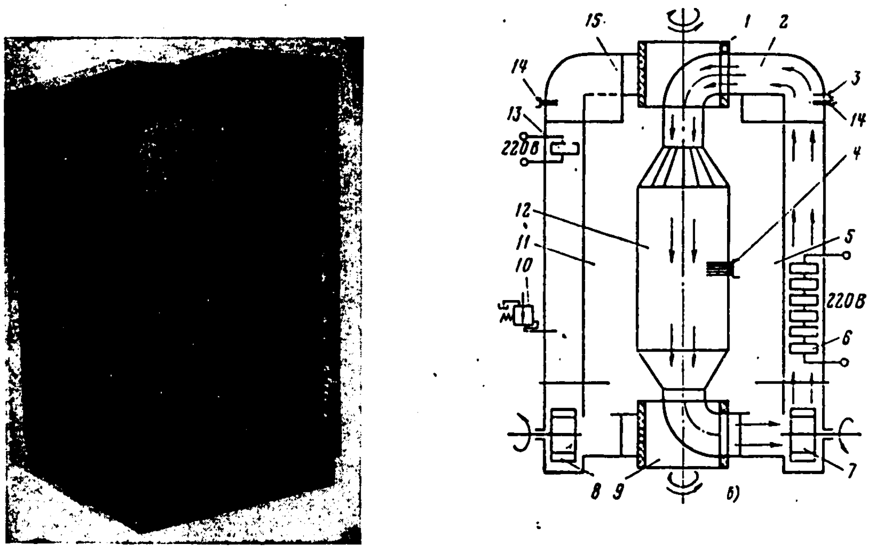

Figure 10.14. The single chamber TO-5081 semiautomated heat cycling unit.

a. External view;
b. Operational schematic.

A three-phase heater 6 is used to heat the air in the "heat" channel. The evaporation tube of liquid nitrogen feed valve 10 serves to cool the air in the "cold" channel. A heater 13 is inserted in the air duct 11 of the cold channel to dry the air duct when repairing the semiautomated unit and after the completion of operation.

Fans 7 and 8 serve to product an intense flow of heated and cooled air through chamber 12.

All of the major controls, the digital display for the number of half-cycles and meters which show the value of the temperature in the channels are placed on the panel of the control console located in the top left corner of the unit. Chamber 12 is covered with a door with a special device which reliably hermetically seals the joint between the door and the chamber.

In the case where an intense flow of hot air flows through the chamber with the devices being tested, as shown in Figure 10.14b, the cold air loop is closed into itself in the idle mode. The temperature in the working and cold loops is maintained in the specified range by a temperature regulation system. After the specified time for a half-cycle has elapsed, i.e., the time for the exposure of the products in one particular medium, the channel switches 1 and 9 automatically connect the cold air channel to chamber 12 with the products under test, while the hot air channel is switched to the idle mode. The number of cycles in the TO-5081 semiautomatic unit is specified beforehand by a special unit on the control panel, and after the time for all cycles has elapsed, the semiautomatic unit is cut off and signals the conclusion of the tests.

The Major Technical Specifications for the TO-5081 Semiautomatic Thermal Cycling Uni.

Useful chamber volume, liters	80
Specific mass rate of flow of the liquid nitrogen per kilogram of tested products, per hour, kg	4
Compressed air flow rate, mm^3/hr	0.5
Maximum weight of the products which can be tested, simultaneously loaded into the chamber, kg	43
Range of working temperatures, °C	from -65 to +200
Temperature fluctuations at the operating point, °C	2

10.3. Equipment for Aging and Reliability Testing

The reliability of semiconductor devices is characterized by the probability of their failure free operation for a specified period of time. The failure rate expressed as a function of their operating time is characterized by the greatest failure rate during the period immediately following the start of device testing. This is explained by the revealing of hidden manufacturing defects. Then the failure rate falls off and is practically constant over time. This is the main operating time of the devices.

Manufacturers of semiconductor devices, in striving to deliver products with a high reliability to consumers, subject the devices to conditioning, the duration of which corresponds to the burn-in time, i.e., the revealing of unreliable devices is accomplished in the manufacturing stage prior to the delivery of the products to consumers. The conditioning time falls in a range of from a few hours to several hundreds of hours and is primarily determined by the level of fabrication technology for the devices and the requirements placed on their reliability.

To determine a quantitative reliability indicator, the semiconductor devices are subjected to special tests, which reduce to exposing the tested products to definite electrical and temperature conditions, and monitoring the electrical parameters and recording the devices which fail. The test conditions and criteria for good products are defined by the special technical specifications.

In terms of its functional configuration, equipment for aging and reliability testing is identical. But a number of specific requirements placed on each of these types of tests leads to the necessity of designing specialized equipment for both conditioning semiconductor devices and reliability testing.

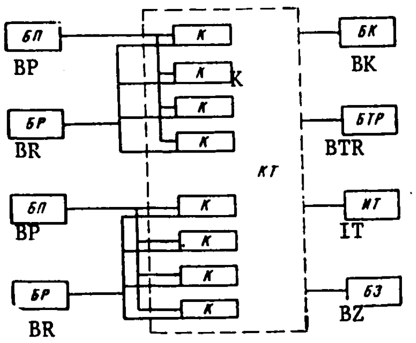

Figure 10.15. Block diagram of the STT-2000M test stand for the electrical and thermal conditioning of integrated circuits.

Key:
BP = Power supply;
BR = Mode setting units;
K = Cassette holders;
KT = Heating chamber;
BK = Monitor unit;
BTR = Thermal regulating unit;
IT = Measurement instrument;
BZ = Protection unit.

The conditioning of discrete semiconductor devices and IC's can be carried out both at room temperature (electrical aging) and at an elevated temperature (electrical and thermal aging), both in static and dynamic modes.

A block diagram of the STT-2000M test stand, which is designed for the electrical and thermal conditioning of integrated circuits, is shown in Figure 10.15. The electrical conditions are set by the power supplies BP, while the dynamic mode for switching the IC's under test is provided by mode switching units BR. The electrical circuits being subjected to electrical and thermal conditioning are placed in special cassette holders K, made in the form of printed circuit boards and placed in the heat chamber KT, the temperature in which can be brought up to +150° C. The monitor unit BK serves to monitor the test conditions, while the thermal control unit BTR sets and maintains the temperature in the heat chamber KT at the specified level. The measurement instrument

Figure 10.16. The STT-2000M test stand for the electrical and thermal conditioning of integrated circuits.

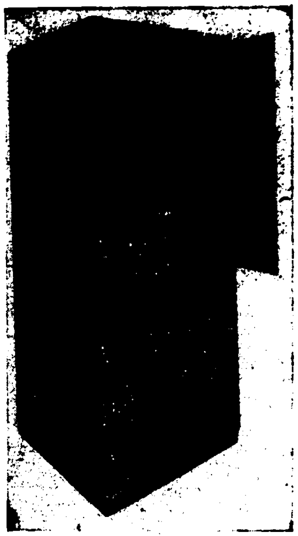

Figure 10.17. The UETT-T test stand for electrical and thermal conditioning of transistors.

IT registers the value of the temperature in the chamber, while the protective unit BZ protects a number of assemblies of the test stand against overloads, such as the fan motors and the heaters. The STT-2000M test stand is structurally made of two sections: the rack with the power supplies and mode control units and the table with two chambers, mounted one on the other (Figure 10.16). A spare set of cassette holders with contacting devices for the tested integrated circuits is placed on the table.

The Major Technical Specifications for the STT-2000M Test Stand

Test stand capacity, pieces	2000
Triggering pulse repetition rate, Hz	50
Pulse amplitude, volts	5 to 6
Temperature in the heating chamber, °C	40 to 150

The UETT-T test stand for the electrical and thermal conditioning of transistors (Figure 10.17) consists of a single rack, in the lower portion of which the power supplies to produce the collector and emitter voltages are placed, while the heat chamber is placed in the upper section, where five loading units with contacting devices for the connection of the transistors under test are inserted in this chamber. The test stand is intended for static electrical and thermal aging of low and medium power transistors with flexible leads, connected in a common base configuration. The conditioning of the transistors is carried out with the application of inverse bias to the collector and emitter junctions.

The Major Technical Specifications of the UETT-T Test Stand

Test stand capacity, pieces	5,400
Temperature range, °C	40 to 200
Power supply voltage for the transistors being tested, volts	3 to 100

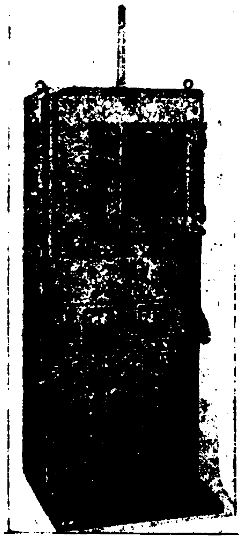

Figure 10.18. The UNTM/T-2 unit for reliability testing of low and medium power transistors.

In contrast to equipment for conditioning, test stands for testing semiconductor devices for service life and reliability should make it possible to monitor the operating conditions and measure the electrical parameters for each product under test during the testing time. Moreover, the products being tested should not fail because of defects in the test stand equipment. All of this does not allow the design of equipment for reliability testing for a large number of products to be tested simultaneously and requires the incorporation of all possible protective, warning and automatic recording devices.

The UNTM/T-2 unit for the reliability testing of low power transistors is shown in Figure 10.18. The heat chamber is located in the upper portion of the rack in this installation. The checking of the operating conditions and electrical parameters in each product under test is accomplished through special electrical connectors.

A temperature regulating unit is located below the heat chamber, where this unit has a device for signaling when the set temperature conditions are disrupted.

An electrical operating mode monitor unit and the power supplies which provide for the maintenance of the specified electrical test conditions stipulated in the special technical specifications for the specific type of device are installed in the lower portion of the rack. The products being tested are secured either by means of special terminals, or by means of soldering to provide a reliable contact during the tests.

The Major Technical Specifications for the UNTM/T-2 Unit.

The capacity for three sections having different independent electrical conditions, units	150

Range of temperatures, °C	40 - 155
Temperature maintenance precision, °C	± 1
Setting range for the collector-base voltage, volts	1 - 60
Setting range for the collector current, mA	3 - 50

CHAPTER ELEVEN PRODUCTION PROCESS EQUIPMENT FOR THE FINAL OPERATIONS

The final operations in the production of semiconductor devices and integrated circuits include the application of protective coatings to the finished devices, their marking and packaging.

For the purpose of protecting semiconductor device packages and IC's against external effects during operation, thin films of varnish and paint materials or metals are applied to their surface.

Degreasing and drying, priming and drying as well as painting and drying can be numbered among the operations of the production process of painting semiconductor device packages. The painted devices undergo a 100% examination for external appearance and selective quality control.

The semiconductor devices are marked for the purpose of designating the type of device, the trademark of the manufacturing plant, the date of manufacture and the mark of the quality control department which confirms the good condition of the device, and where necessary, polarity marks. The devices are marked with fast drying marking paints or nitrocellulose enamels of various colors. The marking label is applied to integrated circuit and semiconductor device packages primarily using the so-called offset method.

Packaging is the final operation in the process of manufacturing semiconductor devices and protects the devices against mechanical damage and other effects during transportation and storage. There are several methods of packaging:

--In cardboard or plastic boxes, where each device is placed in a separate nest to prevent its moving;

--In polyethylene packets;

--In polyethylene material in which cells are produced underneath the devices by means of vacuum forming [61].

11.1. Equipment for the Protective Coating of Finished Devices

Depending on the type of semiconductor device, various techniques are used to apply protective coatings: painting, nickel plating and tinning. The most widespread methods of painting are dipping, flushing with a continuous stream and spray painting.

The structural design of an automatic painting unit for semiconductor devices in metal-glass packages, using preliminary straightening of the leads, drying and feeding of the finished devices to the next operation, is shown in Figure 11.1. The automatic unit is attended by a single operator and paints from 8,000 to 10,000 devices per hour.

The production process is realized in the following sequence. The devices which are degreased beforehand are loaded into vibrating hopper 7, from which they

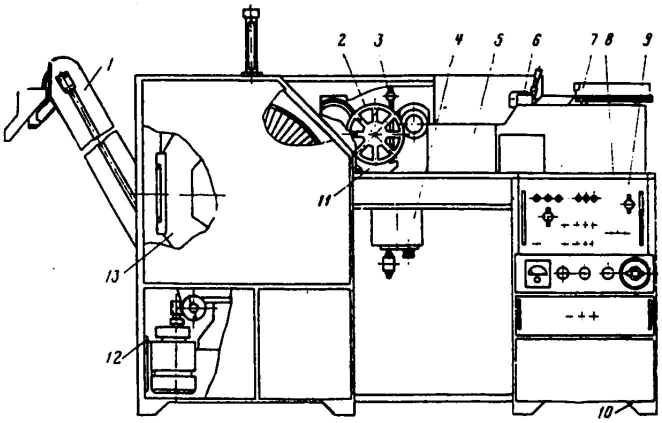

Figure 11.1. Automatic unit for painting and drying [semiconductor] devices.

are fed piece by piece to the lead straightener 6. The uniform feed is accomplished by means of setting the requisite gap in an electromagnet. Having fallen into the electromagnetic scoop of the lead straightener, the devices are oriented by an electromagnetic field and are transported to a drum, which in rotating continuously, catches and feeds them into a slot between upper and lower cams, where the leads are straightened. (The leads of the devices may not be straightened. This occurs because the devices are not rolled out and untwisted. To eliminate this defect, it is necessary to adjust the pressure of the rubber surface of the cams against the device. In that case where the rubber is worn out, it must be replaced.) The straightened leads are rolled down into the magnetic holding tray 5, where they are uniformly distributed over the entire length and are fed into the loading drum by means of a magnetic field, where this drum in rotating continously catches and feeds them to transfer loading drum 2, between the disks of which the tube of the painting assembly 3 is located. In passing through under the tube, the devices are painted and fall onto a comb where the excess paint is removed, which drains off into a funnel and goes through an opening into the pump tank. The width of the jet is regulated by a lever located on the upper part of the painting assembly. The painted devices fall from tray 11 into the radiative heat chamber for drying them, where they are dried in an ultraviolet spectrum for 7 to 9 minutes at a temperature of 130 ± 10° C. The temperature in the chamber is regulated by a slide valve which is located in the air duct. When leaving the drying chamber, the devices fall into the unloading transporter 1, by means of which the devices are loaded into the corresponding packing case and forwarded to the next operation.

The major assemblies and mechanisms of the automated unit are: the vibrating hopper, the lead straightener, the magnetic holding tray, pump 4, the painting assembly, drying chamber 13, the unloading transporter, control panel 9 and drive 12. Small table 8, the vibration hopper, lead straightener, magnetic holding tray with the delay unit for devices with unstraightened leads and the device for stopping the feed of the devices to the loading drum as well as the panel with the transfer drums and painting assembly are mounted in frame 10. A pump is mounted underneath the small table which feeds the paint into the painting assembly. It is equipped with a coarse cleaning filter, a drain valve and a housing with an exhaust unit. The vibrating hopper orients the device and feeds them into the lead straightener. The drying chamber which is shown in Figure 11.2 is located in the left side of the frame and takes the form of a thermally insulated enclosure 2 with double doors. The inside door is made in the form of panel 3 on which the PRK-2M lamps are mounted with reflectors. Inside the chamber, the coil heater 1 is secured to a textolite plate. It consists of a stationary brass coil and a brass rotating disk with cutouts in which the devices are loaded. The internal elements of the chamber have a light reflecting surface. The panel of magnets 4, by means of which the devices are held and moved along the groove of the coil from the periphery to the center is located behind the coil heater.

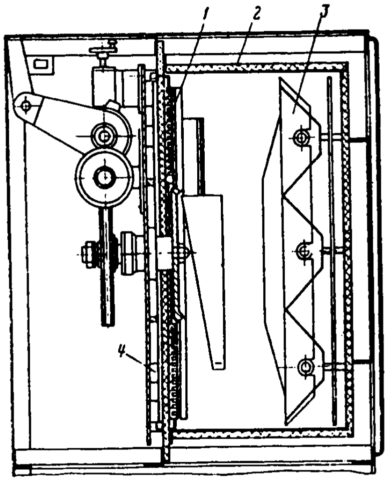

Figure 11.2. Thermal radiation drying chamber (section through A-A).

The rotation of the transfer drums and the coil heater is accomplished by drive 12 (see Figure 11.1), which consists of an AOL-12-4 electric motor, a worm gear pair and a number of intermediate gears. A three step pulley is mounted on the electric motor shaft to change the r.p.m. of the disks, the transfer and loading disks, and correspondingly, the drying time. The electric motor is secured in one of three positions. The drum 2 is turned by two RD-09 motors.

11.2. Labeling Equipment

The offset method of applying the marking label has become the most widespread technique in semiconductor device and IC production. Additionally, coded markings are used in the fabrication of microminiature devices. There are more than 20 ways of applying a marking brand, including direct, flat application, stenciling, etc.

Depending on the structure of the device package, the marking is applied either on the end face of the package, its side surface, and so on (Figure 11.3) [4].

An automated unit for marking and drying devices is shown in Figure 11.4. It consists of the following major assemblies and units: the marking unit I, the infrared drying conveyor furnace II and the combination unit III. When attended by a single operator, the automated unit provides for a kinematic productivity of 5,600 devices per hour.

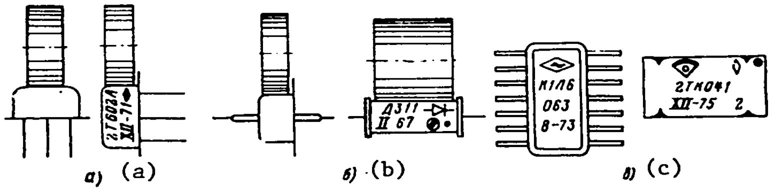

Figure 11.3. The application of the marking label to the surface of a device.

a. Transistor; b. Diode; c. Integrated circuit.

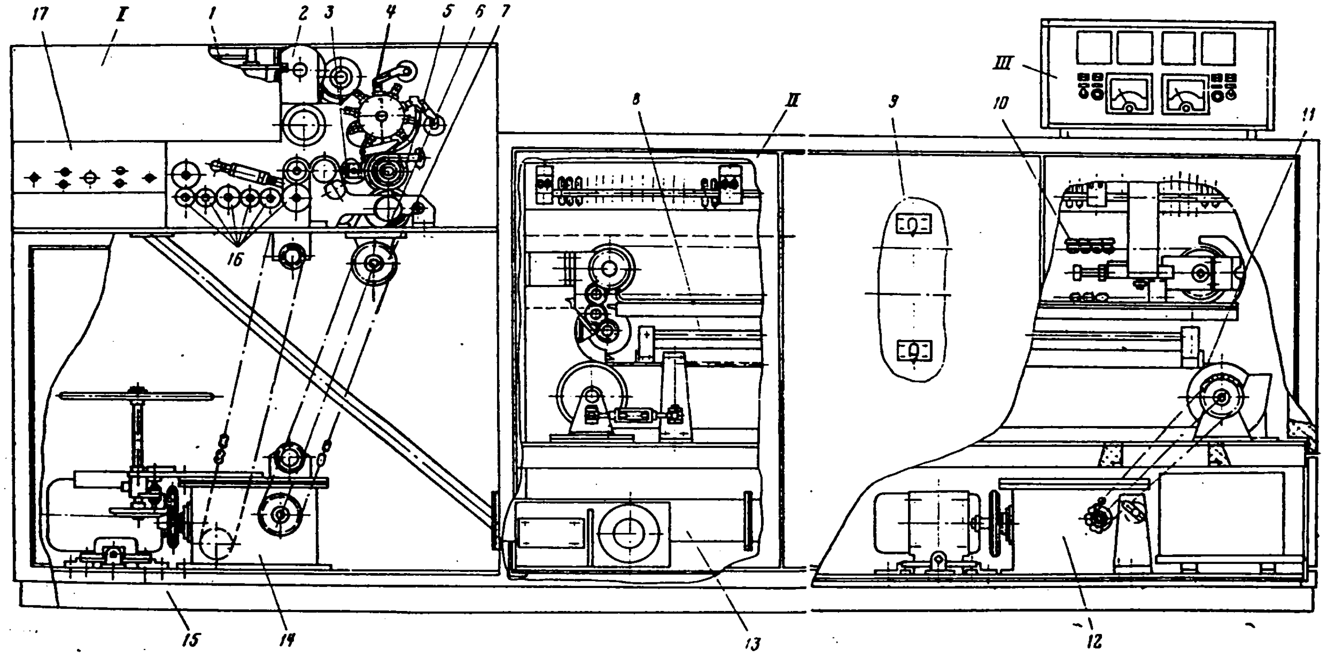

Figure 11.4. Automatic unit for marking and drying [semiconductor] devices.

The operational principle of the automated unit consists in the following: the devices which are degreased beforehand and have straightened leads are loaded into vibration hopper 1 in batches of no more than 700 pieces each. The devices are fed from the vibration hopper by means of a directed magnetic field into each of the forks of carousel 4 by means of the transfer drum, which takes them from the loading drum 2, rotating synchronously in this case with both them and the carousel. The polarity of the device is determined on the forks of the carousel. In the case of improper orientation of the device relative to the marker, the device is rotated through 180°. This is accomplished through a belt drive, which is engaged by means of an electromagnetic assembly. A pair of blocking contacts which gives the instruction to shut the automated unit down is provided to prevent improperly oriented devices falling onto the marking drum. The correctly oriented device goes onto the marking drum 5, where the marking sign is applied to the cylindrical surface of the device package by means of rolling using a rubber roller, on which there is the corresponding protruding marker. The rotation of the device about its axis is accomplished by virtue of friction between the device package and the rubber insert of the printer mechanism.

The marked devices are transloaded into the carriage of the distribution mechanism 6 and layed out on the chain conveyor 10, on which they are fed into the furnace chamber for preliminary drying. The final drying of the marking label is accomplished on the grid of a strip conveyor 11, located in the lower portion of the chamber, to which the devices are transferred by the transloading drum from the chain conveyor. The dried devices are unloaded from the strip conveyor to the receiving hopper. In step with the accumulation of finished devices, they are periodically unloaded and forwarded to the subsequent operations.

The marking unit I consists of the following major assemblies and components: the vibration hopper, the marking mechanism, the drive sprocket wheels 7, the rubbing rollers 16 which uniformly apply the paint to the printing plate of roller 3, drive 14 and control panel 17. The unit is driven by an electric motor through a V-belt drive, a conical worm gear reducer, having two output shafts for driving the marking mechanism and the master block of sprocket wheels for the chain conveyor drive. Manual drive is used when aligning the unit for the drives of the chain conveyor and marking mechanism assemblies.

The marking mechanism is structured from the following major assemblies and components: the loading drum, the collecting drum, two bushings with built-in permanent magnets, a carousel, consisting of a chassis on which 10 toothed small shafts are uniformly mounted in a circle where the shafts have fork brackets fastened to the square tail stems. The forks are clamped by means of flat springs in a definite position, because of which they are always set in a plane parallel to the axis of rotation of the carousel. The permanent magnets built into the forks hold the devices and keep them from falling out during the rotation of the carousel. The marking drum is made in the form of a disk with two rim flanges, about the outer diameter of which the grooves for the placement of the devices are uniformly arranged. The printer mechanism consists of the frame, cover, nut and holder with the rubber insert. The marking paint for the outer surface of the cylindrical rubber insert is transferred from the marking pattern to the package of the device, making the necessary marking in this case. Then the devices are fed by means of a similar drum into slots in the carriage, which executes a reciprocating and cyclical motion along the axis of the shaft, placing the devices in two rows in the indentations in the combs of the chain conveyor. The reciprocating motion of the carriage is realized by means of a cam working through levers and stems with a stationary fastened fork and tray, which hold the devices in the slots of the carriage during its motions.

The stereotype block mechanism consists of a disk with two carriages which are fastened in a stationary manner to a shaft; the templates are fastened to these carriages; a bracket with rollers and slide blocks, by means of which the periodic reciprocating motion of the carriages along the slotted shaft of the stereotype block is realized; an electromagnetic assembly, which engages the belt drive for orienting the devices by means of an electromagnet; an armature and brackets; a Geneva mechanism, by means of which the carousel and the printing drum are rotated cyclically; as well as a brake which suppresses the inertia of the rotating parts of the marking mechanism.

The infrared conveyor drying furnace consists of the chain conveyor 10, the strip conveyor 11, the sprocket drive wheels 7, the upper and lower heaters 8 (the KI-220-1000 infrared lamps), thermocouple 9, strip conveyor drive 12, air duct 13 and frame 15.

The control panel 17 consists of the panel on which the toggle switches for controlling the following are mounted: the marking mechanism, the plate and strip conveyors and the vibration hopper. The corresponding signaling lights are also placed here.

The setting and monitoring of the thermal modes of the drying chamber, as well the adjustment and automatic maintenance of the specified temperature (± 15° C in the drying region) are accomplished by means of the regulating devices and instruments.

11.3. Packing Equipment

Figure 11.5. The mounting of devices on a cardboard card.

With mass production, the packaging of semiconductor devices, especially miniature ones, is extremely labor intensive. The presence of external leads creates certain difficulties when packing the devices. Finished devices are frequently packed in cardboard boxes, shaped sheets of polyethylene or polyethylene packets. A general view of devices mounted on a cardboard card is shown in Figure 11.5a.

Holes are punched in the cardboard card prior to mounting for the installation of the devices. The cardboard cards and the finished devices (classified into groups) are delivered to the work positions, where workers install a device in a hole and fasten it with a nut, placed on the heat sink (Figure 11.5b). After this, the devices, along with the accompanying sheets, are placed in cardboard boxes and dispatched to the finished product warehouse.

Yet another method is that of packing finished devices in shaped cells. Polyethylene with a thickness of 2 to 2.5 mm is used in this case. The cells are produced at a temperature of 160° to 250° C corresponding to the configuration and overall dimensions of the devices. A formed polyethylene sheet for packing integrated circuits is shown in Figure 11.6. Such sheets are fed to the work positions, where the devices are loaded into the cells. After this a second sheet is placed on top and they are sealed together. Devices packaged in this way are then forwarded for delivery to consumers.

Figure 11.6. The packing of devices in polyethylene cells.

In the structural design of the installation described below (Figure 11.7), the semiconductor devices are packaged in polyethylene and cellophane packets. The unit is attended by a single operator and its output is 2,000 devices per hour. 100 devices are packaged in a single packet. The automatic fabrication of packets with dimensions of 84 x 60 mm is carried out in the unit as well as the counting of the devices loaded into the packages. The batch loading of devices into ready packets is done manually by the operator. A packet is fabricated from a doubled polymer polyethylene-cellophane film.

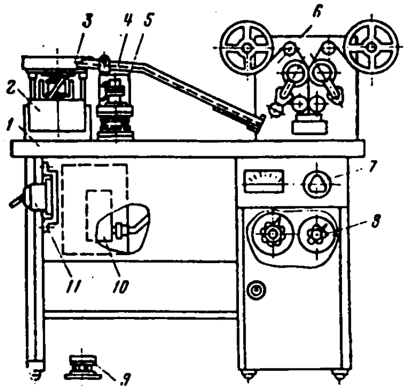

Figure 11.7. A unit for packing semiconductor devices.

The following operations are performed in the unit:

--The fabrication of the packet;

--The automatic counting out of the requisite number of devices (50 pieces);

--The loading of the devices into the packet;

--The sealing of the loaded packet.

The operational principle of the packaging unit consists in the following. The packet is fabricated from polyethylene-cellophane film in the sealing unit 6, where this film is unreeled from two bobbins and fed through an upper pair of guide rollers to the sealing rollers, which are driven. The bobbins with the stock of tape are mounted on brackets, which are fastened to the chassis of the sleeve sealing assembly. There are flat springs for clamping the end of a strip prior to winding a bobbin. The rollers are heated up to a temperature in a range of 160 to 250° C, necessary to sealing the film. When the strips move between the rollers, they are sealed along the edges. Here, the cross welding is accomplished at definite spacings. In continuing their motion, the sealed strips (sleeves) are fed into the lower pair of rollers, which move it into the knife assembly where the sleeve is cut into packets.

The rotational speed of the sealing rollers is regulated by an r.p.m. controller 8, which is located in the table pedestal. The devices are loaded into the packets from guide 4, which is a unique kind of holder to which the devices are fed in an oriented position from vibrating hopper 3. With the accumulation in the guide of a definite number of devices (units of 50 pieces each), the ready and open packet is brought up to the lower section. After this, by pressing on a lever, the upper support is opened and the lower one is closed. In this case, the upper support cuts out the 51st device from the series of devices appearing one after the other. The lower 50 devices fall from the guide into the packet. The lever returns the supports to the initial position (the top one is open and the lower one is closed), while the guide is filled with a new batch of devices from the vibrating hopper. The devices are loaded twice in groups of 50 pieces each time into a packet. Upon completing the loading into the packet, an accompanying sheet is inserted and the loaded packet is sealed shut. This is accomplished in sealing unit 5. For this, the edges of the packet which are to be sealed are placed in the lower heater of the assembly and the actuating foot pedal 9 is pressed. After the upper heater is lowered until it makes contact with the bottom one, the foot is taken off of the pedal. After a few seconds have elapsed (the duration of the pulse is adjusted in a range of from 1 to 6 seconds), the upper heater automatically returns to the initial position. The devices which are packaged in the packets are fed to the finished product warehouse.

The unit has a table 1, on the plate of which all of the major assemblies of the unit are secured, including the unit control panel 2. The table has a pedestal, in which the power panel is located as well as the electrical equipment. Located on the front side of the pedestal are the handle of the RNO-250-0.5 regulator, by means of which the r.p.m. of the sealing rollers of the sleeve sealing assembly is changed, as well as the handle for adjusting the voltage of the pulsed heater of the sleeve sealing assembly and the handle of regulator 7 (a RNO-250-0.5), by means of which the voltage fed to the electromagnets of the vibrating hopper is adjusted. Handle 11 of the automatic unit AST-2 is placed in the left portion of the table, where this unit is intended for turning the mains voltage on and off. There is a recess in the rear part of the table in which the pneumatic control panel 10 is located. The recess is covered with a small removable door.

PART III LINES AND SYSTEMS FOR THE MASS PRODUCTION OF SEMICONDUCTOR DEVICES AND INTEGRATED CIRCUITS

CHAPTER TWELVE THE THEORETICAL PRINCIPLES OF THE COMPREHENSIVE MECHANIZATION AND AUTOMATION OF SEMICONDUCTOR PRODUCTION

12.1. Problems of Comprehensive Automation and Specific Features of Semiconductor Production

Semiconductor production differs substantially from machine construction in a number of specific features. The major feature consists in the fact that the process of producing the major element of the device, which determines all of its functional capabilities - the chip with the p-n structure - is the result of a series of successive operations inside the volume of the chip. In contrast to machine structures which can be taken apart, a chip is practically a single component, and a rejection in only one operation leads to the rejection of the device as a whole. A second feature is the microscopically small dimensions of a device and the exceptionally high requirements placed on the overall technical level for the production, the purity of the materials used and the conditions under which the process is performed. The third feature is the large number of different products in the products list with a relatively unstable market situation as well as the presence of such production process operations as classification or sorting according to the types of devices with different parameters following their final fabrication (Figure 12.1). The specific features enumerated here bring about a high level of production process losses. The level of production process losses depends in the final analysis on the technical level of the technology and production which is achieved in the industry. It is rather high, something which leads to the necessity of planning it for each product, in contrast to machine building production, where production process losses are the result of rejects in the fabrication of individual parts, are insignificant and are not planned for, with the exception of certain products in special instrument making, the production technology of which has a number of general features in common with electronic instrument making.

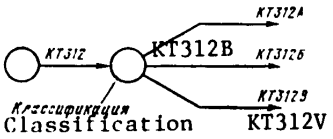

Figure 12.1. Schematic showing the separation of finished KT312 devices into groups in the classification operation.

Because of this, all of the design calculations for lines to be developed, including the determination of the quantity of necessary production process equipment, the arrangement of the monitor equipment, etc., must be carried out taking into account the average static plan norms for production process losses (the percentage yield). Correspondingly, the problem of reducing losses through reducing the level of production process losses takes up first place in semiconductor production. The major ways of solving it are improving the quality of the materials used, creating special product [illegible] conditions, stabilizing the parameters of the production process, etc. When creating comprehensively mechanized production, decisive factors are also the choice of the production process, which assures minimal losses, as well as the development and introduction of equipment which assures stability and reproducibility of the parameters of the production process.

The most objective criterion for evaluating the work of any sector of the national economy is the growth in the productivity of the labor force. This indicator can be utilized to analyze and substantiate objective laws which govern technical progress, quantitatively estimate them and forecast the developmental paths of new hardware, since in the final analysis, this indicator is related to the production cost and the qualitative level of production. The theory of machine and labor productivity developed by Professor G.A. Shaumyan, in figuring the final parameters of new hardware and determining its efficiency, works from the condition of attaining a maximum growth in labor productivity [62, 63]. The starting postulate of this theory is the concept of an ideal continuous service machine with an infinite service life and absolute reliability, the productivity of which is governed only by the production process (the technological productivity):

$$\theta_{ideal} = k$$

Of course, the general trend in automation is towards increasing the production process productivity, i.e., developing progressive technological processes and methods, and creating highly productive tools for production based on them. However, this approach is a far from adequate tool for the creation of high efficiency production, since the degree of utilization of the capabilities of a production process in an actual machine or line can differ substantially, but is always less than the ideal. From the viewpoint of machine and labor productivity theory, any time during which the production process is not under way is lost. For this reason, both cyclical losses (idling time for machines or an automated line) and non-cyclical losses, despite their different nature, are treated as losses. The actual productivity is:

$$\theta = k\eta\eta_{tech}\eta_{org}$$

where η is the productivity coefficient which takes into account the cyclical losses; η_{tech} is a coefficient which takes into account the losses due to technical factors; η_{org} is a coefficient which takes into account the losses due to organizational factors.

Losses are broken down into the following six kinds, each of which determines the corresponding problem of the comprehensive automation of production processes.

Losses of kind I are cyclical, and define the problem of automating the working cycle, and creating continuous service machines and lines; problems of kind II are related to the tool (changing, adjusting, truing, etc.), and define the problem of automating the changing and adjusting of a tool; losses of the III kind are the adjusting and repair of machine mechanisms and define the problem of service life and reliability of automated systems; losses of the IV kind pertain to organizational factors (receiving the material, turnover of the finished parts and the collection of waste, the absence of semi-finished products, etc.), and define the problem of automating production control; problems of the V kind are those of product rejection and define the problem of product quality; losses of the VI kind relate to setting up equipment again because of the transition to the fabrication of another product and define the problem of automated production flexibility.

Formulated in general form, these problems are fully applicable to semiconductor production, however, because of its specific features, the significance of the individual problems is substantially and qualitatively redistributed as compared to those of machine building production, and the tasks in the field of comprehensive mechanization are made more precise and specific [64].

The Problem of Automating a Working Cycle and Designing Continuous Operation Machines and Lines

The following approaches to the solution of this problem as applied to semiconductor production can be noted:

1. The wide scale application of the batch processing technique is here one of major ways of curtailing losses of the first kind. The features of semiconductor production noted above provide for a considerably higher efficiency in the application of the group method than in the case of other types of production. The group coefficient, i.e., the number of elements subjected to simultaneous processing, amounts to more than 1,000 in semiconductor production in the operations of producing junctions on a wafer, and with an increase in wafer diameter up to 100 to 150 mm, the number of elements of a device which can be processed simultaneously on a single wafer reaches 4,000 and more. If one considers that in a number of chemical treatment operations, a special batch package is employed which makes it possible to load up to 100 or more wafers, then it can be asserted that the difference in the batch methods in semiconductor production is of a qualitative nature and has a substantial influence on the organization of this production and the techniques for automating it.

2. The use of through-going production process satellites and group interoperation containers. In the overwhelming majority of fabrication stages in semiconductor production, as a rule, the product is not put in hoppers or mechanically transloaded, and its transportation at times results in additional rejects. For this reason, a universal technical solution in the creation of a continuous automated flow is the use of new principles for transfer between operations based on the utilization of through-going production process satellites to assure the maintenance of product reliability, where such satellites are frequently inseparably coupled to the structure of the device, as well as principles based on the use of strip carriers and special cassette holders.

3. The design of specialized transloading and collecting holders. Those specific features of the production process such as the necessity of performing operations in a controlled gas environment, in a vacuum, or in a dust free volume, as well as the limitation on the storage time of the process stock require the design of special loading and unloading as well as collecting devices to meet these

conditions. Specialized transloading devices are also being designed for brittle or easily deformed elements of a product. In the initial production stages, where wafers are manipulated, the automation of their transloading is most efficiently realized by means of using individual production process transport cassette collecting holders.

One of the ways of automating the auxiliary transport and loading-unloading operations is the utilization of industrial robots and automated manipulators, which are computer controlled [65]. The introduction of such robots is of exceptionally great importance in the stage of the complete automation of semiconductor production for a large products list.

Losses of the second and third kinds and the problem of automating the replacement and adjustment of a tool which are related to them, as well as the problem of the service life and reliability of automated machines and lines in semiconductor production are also of no less importance than in other sectors of precision instrument making. There are no substantial specific differences between the problems in precision instrument making and those in semiconductor production, and for this reason, they are not treated here.

The Problem of Control Automation

The problem of automating production control with an elevated level of automation for the major production processes, and correspondingly, with an increase in the specific share of organizational losses is taking on ever increasing importance. The introduction of elements for the scientific organization of labor based on the simplest organizational equipment, standard collecting holders and transloading devices frequently has a great impact. Of course, the task in the creation of comprehensively mechanized production is the introduction of an automated production control system (ASUP) based on computers.

The Problem of Product Quality

Reducing production process losses leads to a direct decrease in the labor expenditures in the same production where the losses were reduced, something which can be seen from Table 12.1, where two production variants are cited with an arbitrary output of 1,000 pieces of finished devices. The overall percentage

TABLE 12.1. The Influence of an Increase in the Percentage Yield in Individual Production Stages on the Overall Reduction in the Labor Input Requirements for a Device

Production Indicators for the Various Stages	Stage I		Stage II		Total	
	Variant 1	Variant 2	Variant 1	Variant 2	Variant 1	Variant 2
Percentage yield, %	50	75	40	80	20	60
Production volume, pieces	5,000	1,670	2,500	1,250	1,000	1,000
Labor input requirement	450	150	250	125	700	275

yield in the second case is three times greater than in the first, the labor intensity in the first step is three times lower, and two times lower in the second. The overall labor intensity is reduced by a factor of more than 2.5 times. For this reason, the design of a unit which produces a drop in the production process losses for semiconductor devices can frequently lead to a more substantial result as regards the reduction of labor intensity than the mechanization of any manual operation, without increasing the yield percentage. And even a significant increase in labor productivity in an individual mechanized operation leads to a reduction in the overall labor productivity in the production complex given the condition that this mechanization is accompanied by even a slight reduction in the percentage yield. For this reason, any engineering decision concerning the introduction of new processes and the creation of tools for comprehensive mechanization should be made as a result of a technical and economic analysis, based primarily on an evaluation of the change in the level of production process losses.

Because of the special importance of the problem of quality in semiconductor production, one of the most important tasks is the design of automated quality control and measurement equipment for the monitoring and classification of both the finished products with respect to their parameters, as well as the technology and components of a device during the fabrication process, the design of automated production process equipment, equipped with sensors, monitor instruments, and built-in microprocessors for monitoring, controlling and optimizing the production process modes. The final task is the creation of automated control systems for the production process (ATU TP) based on computers. The production process losses should be reduced to a minimum, and the possibility of producing the requisite, previously specified group of devices during the production process should be realized by means of these systems.

The Problem of Production Flexibility

The problem of flexibility of highly mechanized production is also particularly acute for semiconductor production. The group method yields almost unlimited possibilities for increasing productivity in the first production stages. The same possibilities have been obtained recently in the stage of quality control and classification operations because of the use of universal testers as part of a computerized complex. The high productivity and universality of these installations comes into contradiction with the relatively poor productivity of assembly lines and the sometimes limited demand for specific types and groups of devices. This problem can be resolved through the creation of high productivity production systems for products lists with many products, including high productivity all-purpose production of chips and specialized assembly operations.

12.2. The Systems Approach to the Planning of Automated Production

The considerations set forth above make it possible to define the production of semiconductor devices as a complex probabilistic system, in which the production processes are structured based on the conditions of the combined work of man and machine. This means, first of all, that in all stages of the design and development of automated production, it must be treated as a complex system which converts expenditures to product as a result of the mutual interaction of all of its components (people, equipment, the technical conditions for production, production stocks of materials, etc.); secondly, production control must also be treated as a complex system, which performs the functions of resource distribution, analysis and quality control for the final purpose of decision making; thirdly, the two systems - production and control - must also be studied in their interaction, since each production component is tied to each control function [66, 68, 69].

The relatively small amount of research in the field of comprehensive automated production system design was one of the reasons for the fact that in the technical literature devoted to this topic there is as yet no standard terminology.

At the present time, production, which incorporates several comprehensively mechanized lines, is called comprehensively mechanized production or a comprehensively mechanized shop, if it is enclosed within the framework of a single shop. However, it is expedient to use these terms only as applied to a specific production structure, while in the developmental stage for a universal project plan, their application is not convenient. For this reason, the term "line" is frequently applied without substantiation to several lines, arranged sequentially in different production stages. The terms "complex" and "set" which are frequently used also lead to an ambiguous interpretation, since they are introduced in GOST 2.101-68 [State Standard 2.101-68] as a broad concept of specified products, the main difference between which and the assembly unit is the fact that they are not put together at the manufacturing enterprise in the assembly operations.

The term "system" is also a very broad and ambiguous concept. From the formal viewpoint, a system is an aggregate of functional components which interact with each other to achieve the set goal. A man working with a machine is already a system. A "man-machine" system is only a component of a flow line system, etc. In much system research, the concept of an "system" applies only to the process. However, it must be recalled that systems analysis and systems engineering were created primarily for working with objects in the physical world for the purpose of creating technical systems. It is expedient to use the term "production system", which most precisely reflects the existence of a facility, which basically takes the form of an aggregate of technical hardware, lines and sections, in contrast to a "system of production", which takes the form of a process for a specific purpose, because of which the individual components are transformed into a useful product. The major terms and definitions adopted by the authors are given below.

A complex is two or more specific products which are not put together at the manufacturing enterprise in the assembly operations, but which are intended for the performance of mutually related operational functions. Each of these specific products, which is incorporated in the complex, serves to perform one or more main functions, established for the entire complex (for example, a flow line, an automatic telephone exchange, etc.).

A set is two or more products which are not put together at the manufacturing in the assembly operations and which take the form of a set of products having a general operational function of an auxiliary nature (for example: a set of spare parts, a set of tools and accessories, etc.).

A flow line is a set of main, auxiliary or lifting and transport production process equipment, machines and mechanisms (consisting of a minimum of two units of the main equipment which perform various operations), in which the operations of reprocessing or assembly, which are carried out with human participation, and these operations are assigned to definite equipment or definite work positions. In this case, the sequence for the equipment configuration or the working positions conforms, as a rule, to the sequence for the performance of the operations.

A comprehensive mechanized flow line (KML) is a line in which all of the main operations of the production process for the fabrication of a product are performed by mechanisms, machines or other kinds of equipment with a mutually linked productivity, and additionally, the processes for transporting the products from one working position to another are mechanized.

An automated flow line (APL) is a set of main, auxiliary, lift and transport production process equipment, machines and mechanisms (consisting of a minimum of two units of main equipment which carry out different operations), which execute the operations of a portion of the production process for the fabrication of a product without direct human participation and in a definite production process sequence at a definite pace. In this case, there are both overall control and automated transport devices to move the products from one type of equipment to another, while man performs only the functions of set-up, observation and control. The initial loading and final loading operations (or one of them) may be performed manually in individual cases.

A comprehensively mechanized (automated) production system (KMPS) is a complex having an overall production program for a specific purpose and which takes the form of an aggregate of a minimum of two comprehensively mechanized (automated) lines, coupled by material transport flows and joined together by a common (automated) technology and production control system.

The planning of large systems such as production systems for semiconductor production is impossible without a preliminary engineering and economic analysis of the production process, without preliminary work to optimize the structure and parameters of the system being planned, as well as to tie together and match up the main indicators for the lines incorporated in the system.

An effective tool for analyzing a system and optimizing its parameters is modeling: the main tool for checking the theories and design methods being created, as well as the main tool of the optimal design theory. The model, in being a copy or abstract representation of the major characteristics of any process, shows the links which exist between the cause and effect, between the tasks and the capabilities. The creation of a mathematical model for a production process is a necessary condition and the first step in the work on its automation. However, the study of production systems using mathematical models would be impossible without computers. The utilization of mathematical optimization techniques using computers in the design of production systems opens up further possibilities to improve the efficiency of production, and along with this, is the basis for the development of the principles of computer aided design for automated lines and production systems.

An important problem for the developers of comprehensively mechanized production systems in the initial stage of planning is becoming the determination of the optimal parameters of the system and the lines incorporated in it, as well as the determination of an efficient structure for it, the optimum production volume and the choice of the quality control system (Figure 12.2). The sequence for the determination of optimal system parameters shown in the schematic is of a conditional nature, since it is necessary to take into account their unavoidable interrelationship during the project planning process.

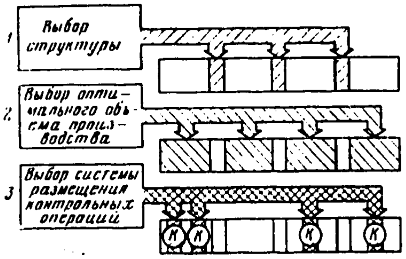

Figure 12.2. The sequence for the selection of the major parameters of a production system.

Key:
1. The selection of the structure;
2. The choice of the optimum production volume;
3. The choice of the system for positioning the quality control operations.

The task of reliably determining the final parameters of the hardware being designed, including the production engineering parameters of enterprises is directly related to the problem of parameter optimization; production engineering parameter optimization is an important condition for reliable forecasts of scientific and technical progress. Having calculated reliable data on the final indicators of the production facilities being developed, it is as if we are obtaining information from the future. This source of information makes it possible to depart from traditional methods of extrapolation (although only within the limits of the period being examined) and increase the reliability of predictions of technical progress for this period. The economic interpretation of the indicators and the achievements of scientific and technical progress are of first rate importance in this case. It is specifically this moment that should become a connecting link between the general economic forecast of sector development and the particular technical results anticipated with the creation and introduction of the new hardware and technology into production. This is a complex and as yet not fully solved problem in terms of methodology.

The special position of the three following tasks follows from the definition of a production system itself: the creation of the system for assuring the appropriate production conditions; the creation of the quality control, production and technology control systems as well as the creation of organized material transport flows.

One of the most important factors which assure the technical level of production is the design of the system for providing production systems with water and gases of the appropriate degree of purity, as well as with dust-free environments. Although many devices intended for this purpose are developed for applications in individual installations and are even built into them, such a system should be designed as a whole as applied to comprehensively mechanized production.

The development of a quality control system is likewise necessary for the successful functioning of a production system. The basis on which quality is maintained and controlled, as well as quantitative monitoring - the feedback - in the final analysis develops a quality control system into a production and technology control system.

The performance of the functions which comprise the basis of the production process depend on the system of material flows. For this reason, the methods of moving materials and semi-finished products, related to the use of the latest equipment, should be developed simultaneously with the resolution of other production problems. A situation is more often encountered where the inclusion of a new piece of equipment in a flow line makes the existing procedure for the movement of semi-finished products inefficient. J. Riggs [67] underscores the fact that attention devoted only to one part of the overall flow line leads to the fact that the solution of one problem generates another, on the solution of which the existence of the entire flow line will depend. In this case, the author employs an analogy with a river, where the cleaning of the bottom on any section of the river does not increase the volume of water flowing through this section.

Chapters 13, 14 and §15.1 of this book are devoted to questions of designing systems for providing production with pure media, control systems for technology and production as well as material transport flows using comprehensively mechanized lines in semiconductor production.

12.3. The Engineering Economic Analysis of a Technological and Production Process

The engineering policy in all stages of the design of comprehensively mechanized flow lines and production systems should be based on an engineering economic analysis of the production process, for which this equipment is being developed. The following goals must be kept in mind in this case:

1) The engineering economic stage by stage production analysis should precede the formulation of the task and the advanced project plan, so as to determine the production steps and operations where the greatest labor outlays and materials are concentrated, and to determine the most "critical" production points as well as determine the stages and operations in which there is the potential possibility of obtaining the maximum effect, and thereby, establish the points for the necessary concentration of the efforts of system designers;

2) The technical and economic analysis of the processes in the individual stages should assist in determining in the preplanning stage through which components the desired effect may be obtained (savings of the main or auxiliary time, savings in materials, etc.), and thus, in choosing the direction for the solution of the problem;

3) And, finally, the analysis should assist in determining the most efficient path for solving the problem and choosing the optimal technical variant in the developmental stage.

Some techniques of technical and economic analysis of production as applied to problems which arise in project planning and design work on the automation of semiconductor production are presented below.

A Model of Material Flows of a Production System Based on Cost Indicators

When determining individual labor productivity at an individual enterprise or section, only the expenditures for human labor at the given enterprise (or section) are taken into account. Correspondingly, a savings in human labor, including savings due to reduction in the labor input requirement, means a growth in labor productivity.

The special position of the problem of quality in semiconductor device production is responsible for the fact that the balance sheet for labor productivity is governed in many respects here by the level of production process losses. This circumstance does not allow one in the comprehensive analysis of production systems to limit oneself to the labor input requirement indicator for an individual section, since the use of this indicator without taking production process losses into account can lead to erroneous conclusions in the choice of the approach to the design of new equipment. It is necessary to work from the overall labor productivity, which is defined by all of the work time expenditures per product unit, i.e., by the expenditures of current and past human labor, embodied in raw materials, working materials, fuel and labor tools. The total outlays of present and past human labor are characterized by the "economic input requirement for a product" indicator which has been developed in recent years. However, the practical utilization of this indicator involves a number of procedural and practical difficulties. Therefore, it is expedient in practical calculations to use an estimate of the optimality of a variant based on the "minimum production cost" criterion, since the production cost indicator sufficiently precisely accounts for the additional expenditures of materials and semi-finished products related to production process losses.

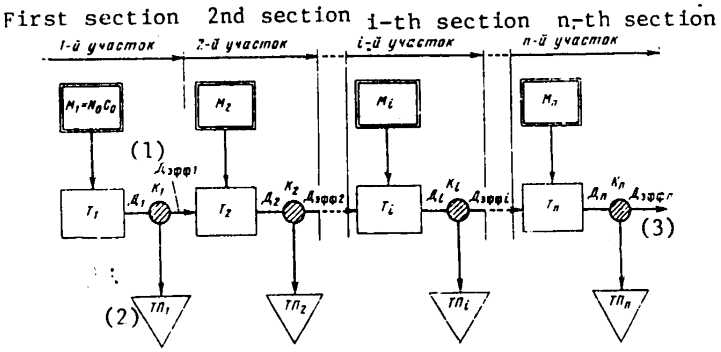

Figure 12.3. A model of the material flows for a production system.

Key:
1. $D_{eff\ 1}$ [section 1 cost];
2. TP_1 [section 1 production process losses];
3. $D_{eff\ n}$ [n-th section effective cost].

A model of material flows in a production system, which takes into account expenditures related to production process losses, can be represented in the following form (Figure 12.3). The system consists of n production process sections or lines;

at the end of each of these, the product quality is checked, which, as was noted above, is one of the conditions for singling out a section as a subsystem. As a result of the quality control in each section, the rejects and production process losses TP are ascertained. Since quality control operations can also be carried out within a section, we understand K_i in this model to be the entire quality control sum, which is realized in the section, including the final one, while TP_i is the sum of all of the losses ascertained in the section as a result of the quality control. The semi-finished products from the preceding section are fed to the i-th section, where these products are acknowledged as good following the K_{i-1} quality control with an overall cost of $D_{eff\ i-1}$, as well as the additional materials for the processing in the i-th section of the entire amount of semi-finished products which arrive at this point. The cost of these materials (or semi-finished products) is expressed by the M_i. The labor expenditures for production and quality control of the operations, carried out in the i-th section, comprise the quantity T_i.

To carry out an engineering economic analysis of a production system using the model proposed here, it is necessary to introduce an indicator which evaluates the cost level of the production process losses.

The Cost Coefficient of Production Process Efficiency

The generally accepted characteristic at the present time for the sifting out of defective products in semiconductor device production is the good product yield coefficient (or percentage), κ; let the quantities κ_i be the yield coefficient in the i-th operation (or section) and $\eta_{B\ i}$ is the overall yield coefficient in the i-th operation from the start of the process. This indicator is rather informative and convenient in estimating the technical level of production, for the operationally timely analysis of the course of a production process as well as the analysis of a local production process. It is needed in the calculation of a whole series of parameters for complex lines, including their effective productivity, the line pace, the quantity of process stock, etc.

However, the good product yield coefficient does not sufficiently completely reflect the cost level of losses in a comprehensive analysis of several production sections arranged in series, since it does not take into account the differing volume of losses in the indicated sections, including those related to the arrival of additional materials and semi-finished products at the given section. It is apparent that for production processes producing devices which differ in their structural design and production technology, where these devices have the same yield coefficient, the specific share of the production process losses differs in the cost expression. For this reason, in line with the model adopted here, we shall introduce a cost indicator along with the good product yield coefficient, where this cost indicator takes into account the production process losses [68], and we shall consider its relationship to the yield coefficient (Figure 12.4).

Let C_i be the cost of all of the outlays (for materials, processing, product measurements, etc.) to produce one product in the i-th production section (or step). Then one can write the total expenditures in the section, D_i, in the following form:

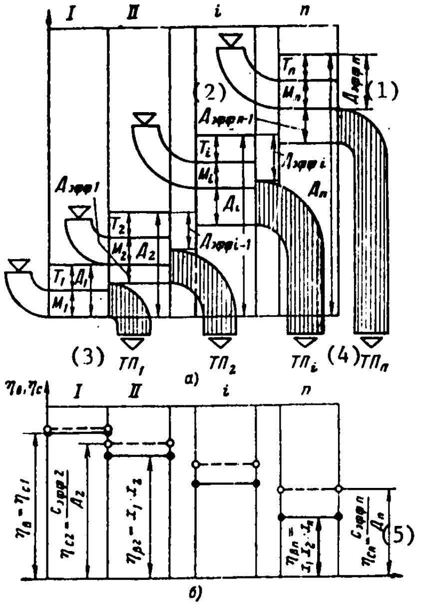

Figure 12.4. The cost coefficient of production process efficiency.

a. Material balance sheet for the production of semiconductor devices;
b. The relationship of the yield factor ξ_B and the cost coefficient of production process efficiency Z_C.

Key:
1. $D_{eff\ n}$ [effective cost of the n-th section];
2. Effective cost of the (n - 1)th section;
3. TP_1 [production process losses of section 1];
4. Production process losses of section n;
5. $\eta_{cn} = C_{eff\ n}/D_n$.

$$D_i = (M_1+T_1)+(M_2+T_2)+\ldots+(M_i+T_i) = \\ = N_0(C_0+C_1+\eta_{B1}C_2+\ldots+\eta_{B\,i-1}C_i),$$

where C_0 is the product cost at the start; N_0 is the number of products started in production.

The cost retained in production after the i-th section amounts to:

$$D_{эфф\,i} = \eta_{Bi}N_0C = \eta_{Bi}N_0\sum_{k=0}^{i} C_k,$$

where $C = \sum_{k=0}^{i} C_i$ is the aggregate of expenditures in the i sections for one product; $\eta_{Bi}N_0$ is the number of good products following the i sections.

The quantity:

$$\eta_{C,i} = \frac{D_{эфф\,i}}{D_i} = \frac{\eta_{B\,i}\sum_{k=0}^{i} C_k}{\sum_{k=0}^{i} \eta_{B\,k-1}\,C_k}$$

is the cost coefficient of technological production efficiency, which is introduced in a manner similar to the good product yield coefficient. It is not difficult to see from the latter relationship that the following inequality is observed:

$$\eta_{Bi} \leqslant \eta_{Ci} \leqslant 1.$$

This inequality makes it possible to immediately conclude that the specific share of production process losses in the cost expression is usually less than expressed by means of the product yield coefficient. It can be seen for the first, or separately treated section (i - 1) that:

$$\eta_{C1} = \eta_{B1} = \varkappa_1,$$

i.e., the use of the η_C coefficient is expedient only in the case of a comprehensive and simultaneous analysis of several sections or stages. The diagrams (see Figure 13.4) [sic] clearly show the specific features of the change in the cost coefficient of production process efficiency η_C during the production process and its relationship to the good product yield coefficient with respect to the start η_B.

Since the production cost for a good device can be represented by the expression:

$$C_0 = \frac{1}{\eta_{B\,n} N_0} S_n = \frac{1}{\eta_{B\,n}} \sum_{k=0}^{n} \eta_{B\,k-1} C_k,$$

while the aggregate expenditures for the fabrication of a single device are:

$$C = \sum_{k=0}^{n} C_k,$$

TO Then:

$$\eta_{C\,n} = \frac{\eta_{B\,n} \sum\limits_{k=0}^{n} C_k}{\sum\limits_{k=0}^{n} \eta_{B\,k} C_k} = \frac{C}{C_0}.$$

Thus, the coefficient η_{Cn}, calculated for the production process as a whole, reflects the fraction of the requisite expenditure for the given technical production level to fabricate a single device, referenced to the actual outlays, i.e., it is a cost expression or the economic equivalent of the efficiency of a production system. The introduction of a cost indicator for production process losses in semiconductor manufacturing is quite important to ascertain the production sections having a poor efficiency, to refine the production process, modernize equipment, determine the most efficient organizational and technical measures as well as to plan work on the comprehensive mechanization of semiconductor device production. The utilization of the cost coefficient η_C makes it possible to determine the efficiency of new technological processes, equipment and production systems. Because of the fact that the cost coefficient η_C characterizes the actual outlays and estimates the production process losses expressed in terms of cost, accounting for production process losses using this indicator can make it possible to efficiently distribute the facilities for production and correctly plan the major kind of losses in semiconductor production.

It follows from what has been presented above that the cost coefficient of production process efficiency is more indicative than the good product yield coefficient in the case of a comprehensive technical and economic analysis of technological and production processes, and can be widely utilized in industrial and trial production to analyze processes, evaluate the effectiveness of an improvement in a production process as well as introduce new technology, equipment and methods of labor organization. The coefficient η_C can also be used when analyzing the level of production process losses within sections.

Questions of Procedure in Analyzing a Production Process

If in the initial stage of planning a production system the decisive role is to be played by the comprehensive analysis, and correspondingly, the cost indicator for production process efficiency based on the economic model adopted above, then in the stage of developing the lines incorporated in the system, when determining their optimal composition (and production volume) and selecting the order for the layout of the control operations, the analysis should be carried out for the process realized directly in the line; the major role is played here by the characteristic indicators of the production process, including those for the estimation of the level of production process losses and the yield coefficient, κ and η_B.

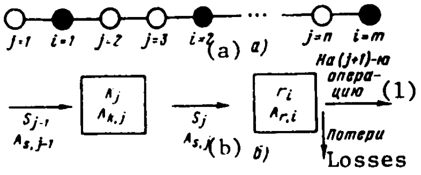

Figure 12.5. Process schematics.

a. Production process;
b. Local production process;

Key: 1. To the (j + 1)th operation.

Because of the fact that one is usually not successful in restoring defective products in semiconductor device production, while the procedure for the sequencing of the operations, with rare exceptions, cannot be changed, the production process can be represented as a string of production process operations, j = 1, 2, ..., n, between which there are i = 1, 2, ... m quality control operations (Figure 12.5). The requisite operations on a product are performed during the production process to obtain the requisite properties in it. Quality control operations should not change the product, but are intended to check its state and its conformity to the established requirements.

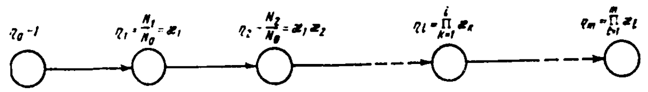

Figure 12.6. Simplified model of a production process.

It is apparent that a sequential and detailed analysis of a local production process is extremely difficult, since it is necessary to take into account a large number of factors, including random ones. We will note that in such an analysis, the aggregate of n operations must take into account at least about $\sum_{j=1}^{n} 2^j$ factors, for example, when n = 10, about 2,000, while in the production of planar transistors, the number of operations is considerably greater. Considering what has been said above and the difficulties of a procedural nature in the analysis of complex systems, it is expedient to recommend the use of a simplified approach in the analysis of a production process for the manufacturing of semiconductor devices.

A production process can be represented by a rather simple model (Figure 12.6): a signal $\eta_0 = 1$ is fed to the input of a series string of attenuators with overall independent random absorption factors κ_i, where this signal is attenuated in step with its propagation through the system (the intermediate value is $\eta_l = \prod_{k=1}^{l} \varkappa_k$) and at the output of the system, takes on the value:

$$\eta_m = \prod_{l=1}^{m} \varkappa_l.$$

The utilization of this model substantially simplifies the analysis of the complex system under consideration. It is obvious that the simplified model treated here can be used to analyze a production process if the parameters being monitored and their ranges of permissible values are chosen in accordance with the assumptions indicated above. As has already been noted, the major indicator in the analysis is the production cost of the devices, in accordance with a change in which one may also estimate the expediency of selecting those quality control conditions under which the production process can be analyzed based on the simplified model described here.

The most important conditions for the efficiency of automated systems are reliable equipment operation, and the reduction of losses of the second and third kinds to a minimum. Questions of assuring reliable operation of automated machines and lines, which do not lead to fundamental differences in the conditions of semiconductor production, are not treated in this book.

12.4. Some Methods of Determining the Optimal Parameters of Semiconductor Production Lines and Systems

The basis for the substantiation of an efficient production system structure is the technological process. Any system, in being a single integral complex of mutually related components, possesses a definite structure which allows for the singling out of a hierarchy of elements, where these elements possess properties of subsystems relative to the main system. For this reason, without segregating such elements, i.e., without determining the structure, it is impossible to either set about the planning of the major system components or analyzing the system. The fundamentals of a systems approach to the planning of automated production and the terminology were set forth above (see §12.2). In setting about the solution of a specific problem in the area of project planning, it is essential to take into account the fact that for relatively simple production systems, which take the form of continuous flow line production or shops with equipment which is grouped together with respect to the production process principle, the subsystems can be considered to be individual equipment units. For such a complex system as a comprehensively mechanized production system for semiconductor devices, it is necessary to treat larger facilities, equipment groups, as the subsystems, i.e., individual lines and sections. For this reason, the problem of rigorously substantiating the optimal breakdown of the production of electronic equipment products into lines and sections, or, in other words, the problem of selecting an efficient structure for it, is a far from simple one. The specific features of semiconductor production which were enumerated above even more underscore the impact of technology on the level and nature of the entire production process. When selecting an efficient production system structure, the main criterion becomes certain common parameters of the production process; the nature and reliability of the production process, the high level of production process losses and their statistical nature which govern the layout of the quality control equipment and the collection points between sections and the duration of the working cycle in the sections begin to play a more important part. Of the production process factors which govern the breakdown of comprehensively mechanized production of semiconductor devices into stages, we shall single out the following main ones:

1. A change in a processing unit, which is determined by the nature of the process itself and, as a rule, related to a jump like change in the batch processing coefficient and correspondingly, to a change in the working cycle T_p (for example, after breaking a wafer into chips or following a classification operation).

2. Special technological features of a process, including the existence of technological unity, common methods and operations which make it possible to bring them together into a single complex with a single final goal, which ends in the output of the object (or part), which is subjected to quality control and stored with the process stock.

3. The level of production process losses ascertained during quality control operations, which when significant, also substantially changes the working cycle of subsequent operations.

Having taken these production process factors as the initial ones for the primary logical substantiation of an efficient production structure, one can analyze these factors and come up with a quantitative evaluation of them. By way of example, we shall consider the technological process for the fabrication of silicon planar transistors. The analysis is carried out for the following major steps: 1.0. the fabrication and treatment of the wafers; 2.0. the fabrication of the wafers with the transistor structures; 3.0. the separation of the wafers into chips; 4.0. the assembly of the device; 5.0. finish operations (classification tests of the device and final operations)*.

The indicated classification most completely conforms to the actually adopted production process for the fabrication of planar devices, which makes it possible to obtain data for a reliable analysis of each step.

We shall consider three variants of the basic structural packaging of the devices proposed for production: a cold-welded metal-glass package, a hot-welded TO18 metal-glass package, and a plastic package. We have conditionally taken the overall production volume to be 30 million good devices per year, with 10 million devices each in each structural package variant. The major parameters of the production process, which govern its breakdown into independent production sections or lines, are given in Table 12.2. An analysis of Table 12.2 confirms the

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*Building up epitaxial films, which is in essence an independent step, is not considered in this example, and because of this, as a rule, this specific territorial feature is considered a specialized production step. The entire first step may also be singled out as such production.

TABLE 12.2. The Parameters of the Major Steps in the Comprehensively Mechanized Production of Silicon Planar Transistors

Major Parameters of the Process	1.0. Fabrication and Processing of the Wafers	2.0. Fabrication of Wafers with Structures				3.0. Separation and Packaging	4.0. Assembly		5.0. Finishing Operations	
		2.1. Chemical Treatment	2.2. Diffusion and Deposition	2.3. Photolithography	2.4. Test Probe Measurements		4.1 Mounting	4.2 Hermetic Sealing	5.1. Classification and Testing	5.2. Concluding Operations
Designation of the unit fed to the next stage (product or group carrier), items	Wafer	Wafer in the process of producing the structure				Carrier with chips (cassette holder or plate)	Strip carrier with devices which are: unencapsulated	hermetically encapsulated	Device	Marked and packed device
Number of units with different parameters or structural features, which determines the need for various equipment or its realignment (number of parallel sections), units	1	1	1	1	1	1	3	3	3	3
Production process yield, %	80.0	100.0	90.0	95.0	85.0	80.0	90.0	99.0	90.0	95.0
Good production volume (product referenced), 10^6 product pieces annually	83.7	67.7	67.7	61.0	57.9	49.2	13.1 x 3	11.8 x 3	11.7 x 3	10.5 x 3
Group coefficient (number of products placed on the group carrier)	2400	2400	2400	2400	2400	150 2400	25	1.0 25.0 25.8	Classification-1 100 - 2000	- 1

TABLE 12.2 [cont.]

Major Parameters of the Process	1.0.	2.1.	2.2.	2.3.	2.4.	3.0.	4.1.	4.2.	5.1.	5.2.
Number of units (or carriers) put out from a section, 10^3 units annually	34.9	28.2	28.2	25.1	24.1	372.7 20.5	524 x 3	11,800.0 472.0 59.0	11,700 x 3 5.8x3	10,500 x 3
Output cycle of a step (periodicity of unit output), T_p, min/unit	6.2	7.5	7.5	8.3	8.7	0.6 10.2	0.4	0.02 0.4 3.2	0.08 36.2	0.02

necessity of segregating the following stages of the production process into independent lines or sections: 1.0, 2.4, 3.0, 4.0, and 5.0. For the plastic packaged device, steps 4.1 and 4.2 should be singled out as independent sections. This cannot be said for stages 2.1, 2.2 and 2.3, as well as stages 3.1 and 3.2 for devices in a metal-glass package, having a common production facility and a minor change in the production output cycle.

The structure of the comprehensively mechanized production treated above for silicon planar transistors is shown in Figure 12.7.

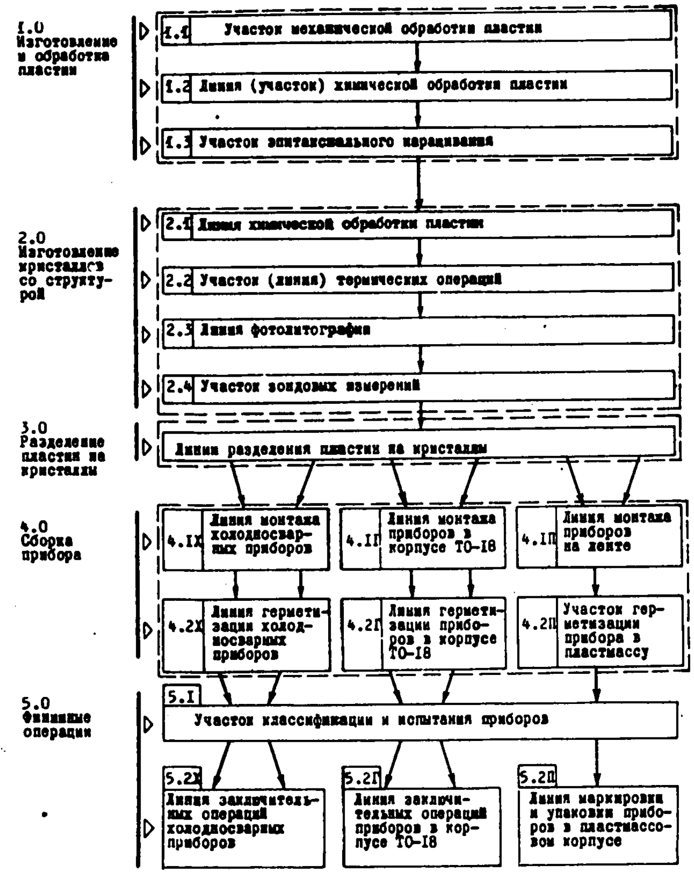


Figure 12.7. Structure of comprehensively mechanized production of silicon planar transistors.

Key: 1.0. Fabrication and processing of the wafers;
- 1.1. Section for mechanical treatment of the wafers;
- 1.2. Line (or section) for chemical treatment of the wafers;
- 1.3. Epitaxial growth section;

Key to Figure 12.7 [cont.]:

- 2.0. The fabrication of the chips with the structure;
  - 2.1. The line for chemical treatment of the wafers;
  - 2.2. The section (or line) for heat treatment operations;
  - 2.3. The photolithography line;
  - 2.4. The test probe measurement section;
- 3.0. The separation of the wafers into chips: the lines for separating the wafers into chips;
- 4.0. Assembly of the device;
  - 4.IX. Line for the mounting of cold welded devices;
  - 4.II. Line for mounting the devices in a TO-18 package;
  - 4.IP. Line for mounting the devices on a strip;
  - 4.2X. Line for hermetically sealing cold welded devices;
  - 4.2G. Line for hermetic sealing the devices in TO-18 packages;
  - 4.2P. Section for hermetically sealing the device in plastic;
- 5.0. Finishing operations;
  - 5.1. The section for device testing and classification;
  - 5.2X. The line for concluding operations on cold welded devices;
  - 5.2G. The line for concluding operations on devices in TO-18 packages;
  - 5.2P. The line for marking and packing devices in plastic packages.

The Task of Substantiating the Optimal Productivity of Lines (or Optimal Production Volume) and the Equipment Composition Corresponding to It During the Developmental Stage

The volume of comprehensively mechanized production being planned can be determined as a result of analyzing the following factors:

- --The national economic demand for devices of the given type and the prospects for an increase in this demand in upcoming years;
- --The level of the so-called critical volume, i.e., the production volume below which the outlays for comprehensive mechanization are not justified;
- --The specific production engineering conditions for creating comprehensively mechanized production: areas, the volume and capabilities for coordinated deliveries of semi-finished products, etc.

However, the factors cited above are only limitations imposed on the output quantity of the production being planned and allow for the possibility of a rather wide variation in it. For this reason, the calculation of the structure and composition of equipment in practice is usually based on a specified production volume, which is the rounded-off maximum technically feasible value of device output under the given conditions. The productivity and other technical capabilities of the equipment employed in the system, both the newly designed equipment and that which existed previously, are limited to finite values governed by the technical level of the equipment. We will note that the composition of a line is discrete, and the productivity of the individual equipment units in the general case may not always be strictly be interrelated, much less have a common specified device output quantity.

Because of this, it can be said that the composition of the equipment designed for any arbitrarily selected or predetermined production volume does not always yield the best results for the given composition with this production volume. As has already been noted, market conditions and other limitations imposed on the production volume during equipment selection make it possible to establish this quantity within a rather wide range; for this reason, it is expedient to formulate the problem of determining the optimum production volume by working from a specified technological level for the process, which is characterized by the equipment indicators, as well as from the major criterion: minimal production cost taking into account the limiting factors mentioned above.

When selecting an efficient structure for a comprehensively mechanized production system, we worked from the basic principle: a modular configuration for it. It is obvious that having determined the optimum production volumes for the individual modules (lines or sections), incorporated in the production system, we thereby resolve the question of choosing the optimal volume for the entire system. For this reason, only a production line is treated in the following. The task has two aspects: having determined the optimum volume, we simultaneously determine the line composition corresponding to it. The criterion taken as the basis for the design calculations is the production cost per unit of output product. It is assumed that the specified equipment productivity in each production process operation, including that maximum feasible value for newly developed equiment, as well as the production process sequence for their configuration, i.e., the structure of a line, can change only through an increase or decrease in the amount of equipment in definite production process operations.

We designate $\sum_{=-}^{i=n} l_i \Phi$ as the quantity of equipment units in a line (l_i is the number of equipment units for the i-th operation); Q is the line productivity, pieces per year; C is the production cost of a unit of output product, in rubles.

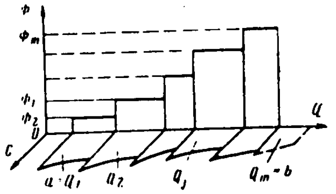


Figure 12.8. The proposed relationship between the number of line equipment units, line productivity and production cost per unit of output product.

We shall consider a three-dimensional system of coordinates with the ori gin at point O and having axes of OQ, OΦ and OC. As has already been noted, the line has a discrete composition. Then the functions of Φ, Q and C can be represented graphically (Figure 12.8). Only a productivity segment is being treated: [a, b], i.e., Q_E [a,b]. In fact, let a line composition of Φ_1 appear at point a = Q. It is clear that Q_1 can increase up to Q_2 by virtue of several factors (the equipment load factor, the labor intensity, etc.), which have an impact on line productivity while its composition is constant. A further increase in line productivity can be achieved only by virtue of changing the composition of the line by adding a certain number of equipment units for certain production process operations. The production cost of a unit of output product in the sections $[Q_1, Q_2]$, $[Q_2, Q_3]$, ..., $[Q_{m-1}, Q_m]$, ..., $[Q_{m-1}, Q_m]$ can be expressed by the formula:

$$C_k = D_k/Q_k$$

where:

$$Q_{kE}[Q_j, Q_{j+1}] \left(\begin{array}{c} 1 \leqslant k \leqslant m-1 \\ 1 \leqslant j \leqslant m-1 \end{array} \right)$$

C_k is the production cost per unit of output product in the k-th section with a constant line composition, in rubles; D_k are the overall annual expenditures for the output product in the k-th section in the case of constant line composition, rubles.

It is apparent that the expression $C_k = D_k/Q_k$ is the equation of a hyperbola. We formulate the problem in this fashion: it is necessary to determine that line composition having a productivity $Q_E(a, b)$ which would provide the minimum production cost per unit of output product. It follows from Figure 14.8 that to solve the problem posed here, it is necessary to find the points Q_1, Q_2, ..., $Q_{mE}(a, b)$ and to choose from them the point Q_j having the minimal production cost per unit of output product. The composition of the line corresponding to the point Q_j will also be optimal.

The Task of the Optimal Placement of Quality Control Operations and the Layout of the Test Equipment in the Planning of Comprehensively Mechanized Production

The main function of the quality control system for the operations in the semiconductor device production process is the timely and complete ascertaining of defective products. Sufficiently complete detection is possible with an appropriate choice of quality control parameters and limits for their permissible values.

The selection of the quality control system should be first of all subordinate to these requirements just as to the requirements for control of the production process, but with the simultaneous condition of assuring the least expenditures for quality control and generating the minimum production cost of a good device. It is especially important to solve this problem when designing new comprehensively mechanized lines, which is always accompanied by the development of not only the production process equipment but also new quality control and instrumentation hardware. For this reason, we shall pose the problem of the optimal distribution of quality control operations in the production process with the major condition that of generating minimal outlays for quality control and production of semiconductor devices, through the timely ascertaining and rejection of defective products. The method of solving this problem is based on two presumptions; the production process is characterized by stable indicators, while the requirements placed on the goodness of products in the quality control operations make it possible to sufficiently completely detect defective products.

The technological process of producing semiconductor devices, as was noted above, should be represented by a rather large number of parameters in a detailed analysis. The analysis of systems similar to that treated here became possible in recent years through the development and refinement of numerical methods using computers capable of operating with data files of a rather large size. Mathematical methods are described in [67, 70] for the optimization of the structure of comprehensively mechanized lines, including the application of one of the numerical analysis methods for cumbersome systems, the random search technique, to the optimization of a quality control system for semiconductor device production operations.

CHAPTER THIRTEEN EQUIPMENT FOR PURIFYING MEDIA AND PROVIDING THE MICROCLIMATE IN THE MAJOR OPERATIONS OF A PRODUCTION PROCESS

13.1. Requirements Placed on Production Process Media. The Main Methods of Purifying Media

Diverse kinds of production process media (water, air, nitrogen, hydrogen, etc.) are needed in semiconductor production, where they are employed in various stages of device fabrication, something which determines the different levels of requirements placed on them. The purist liquid and gaseous media are needed when treating the surface of a semiconductor, which actively interacts with its environment. Even under high vacuum conditions, a monoatomic layer of oxides is formed on the surface of a semiconductor in a few seconds.

The phenomena which take place at a surface can have a substantial impact on the level and stability of device parameters. For this reason, production processes and special equipment complexes which provide for high quality preparation and monitoring of water and gas parameters are of particular importance.

Purified water is widely used in practically all stages of production to wash parts and prepare solutions. The technical requirements placed on water parameters are given in Table 13.1.

For the operations involving the preliminary washing of wafers, water is used having a specific electrical resistance of 5 MOhm · cm; for finish washing operations, water is considered acceptable when it has a specific electrical resistance of 16 to 18 MOhm · cm and a contaminating particle size of no more than 0.5 μm.

Water contaminants are broken down into four main groups: mineral, desolved organic impurities, suspended solid particles and microorganisms. Special measurement hardware and cleaning techniques have been developed for each kind of pollutant. The diversity of techniques and equipment to obtain ultrapure water makes it possible to select the optimum variants in each specific case. In this case, it is necessary to take into account the characteristics of the initial water and the requirements placed on the level of purity of the water produced.

TABLE 13.1. Technical Requirements Placed on Water Parameters

Parameters	Grade of Water A	B	V
Electrical resistivity at 20° C, no less than, MOhm · cm	18	15	5
Oxidability, no more than (with respect to $KMnO_4$), mg O_2/1	0.8	0.8	1.2
Silicic acid content, mg/1, no more than	0.01	0.02	0.05
Content of microparticles 1 μm and more in size, units/ml	up to 10	not checked	not checked
Microorganism content, colonies/ml	5 - 10	5 - 20	≤ 50

The standard production process for water purification includes three main stages: the preliminary preparation, the main purification and finishing purification. The preliminary preparation combines the following operations:

--The clarification of the water, i.e., the removal of coarse dispersed and colloidal impurities, which is accomplished by means of coagulation, liming, and the use of magnesium to remove silicon;

--Mechanical separation of suspended particles using a filtering layer (sand, crushed anthracite, marble, diabase, granite, etc.);

--Condensation, distillation and electrical coagulation to remove organic impurities;

--Sorption by means of macroporous and isoporous anion exchangers to remove organic impurities.

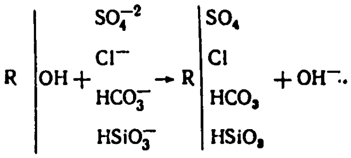
The major methods of removing truly dissolved substances from water to obtain desalinated water are described below. The first of them provides for the repeated distillation of the water. The amount of impurities following distillation amounts to up to 20 mg/l, and the specific electrical resistance of the water is about 300 KOhm · cm, which does not meet the requirements for semiconductor production technology. Following triple distillation in quartz equipment, the resistivity of the water reaches 3 MOhm · cm, however, this is also insufficient to perform a number of finishing operations.

Ion exchange techniques are most frequently used to desalinate water: sorption of ionic impurities by means of ion exchange resins and the removal of ionic impurities by an electrical direct current with the electrodialysis using selective membranes made of ion exchange materials.

Water which has been cleaned of inorganic impurities by means of ion exchange resins is called deionized. The purification of water using ion exchange resins is based on the ability of certain resins to bind ions of impurities which are water soluble. The resin composition is conditionally depicted in the following manner: R-H is the cationic resin, R-OH is the anionic exchange resin (R is the organic radical of the given resins). Natural water is a very dilute solution of mineral salts, primarily sulfates, chlorides and bicarbonates of calcium, magnesium and sodium. Iron and manganese cations are contained in somewhat smaller amounts in water as well as anions of the following acids: salicic, phosphoric, nitric, etc. When water passes through a cationic exchange resin, cations of the mineral salts are substituted for the hydrogen ions, as a result of which, an acid solution is produced at the output of the ion exchange column in accordance with the following reaction:

$$R\left|H + \begin{matrix}Fe^{+3}\\Ca^{+2}\\Mg^{+2}\\Na^{+}\end{matrix} + \begin{matrix}SO_4^{-2}\\Cl^{-}\\HCO_3^{-}\\HSiO_3^{-}\end{matrix}\right. \rightarrow R\left|\begin{matrix}Fe\\Ca\\Mg\\Na\end{matrix} + H^{+} + \begin{matrix}SO_4^{-2}\\+Cl^{-}\\HCO_3^{-}\\HSiO_3^{-}\end{matrix}\right. .$$

In H-cationized water, which leaves an ion exchange column, the gram equivalent acid content basically corresponds to the concentration of the salts of the strong acids formed in the original water at the moment of the ion exchange reactions. With the further passage of the water through the anion exchange resin, the SO_4^{-2}, Cl^- and other anions are trapped in accordance with the following reaction:



$$R\left|OH + \begin{matrix}SO_4^{-2}\\ Cl^-\\ HCO_3^-\\ HSiO_3^-\end{matrix}\right. \rightarrow R\left|\begin{matrix}SO_4\\ Cl\\ HCO_3\\ HSiO_3\end{matrix}\right. + OH^-.$$

The OH^- which is liberated with the substitution of the ions combines with the H^+ ion and forms a molecule of water:

$$H^+ + OH^- = H_2O$$

There are traces of ionic contaminants contained in water under actual conditions where the water has passed once through a cation exchange resin (first purification stage). To increase the degree of purity, a repeat cleaning is provided which is similar to the first stage; used as the second stage in modern equipment are mixed action filters (FSD), filled with a mixture of cation and anion exchange resins. The filter can be represented as a set of parallel and series connected cation (K) and anion (A) exchange microfilters (Figure 13.1).

The quality of deionized water is primarily defined by the specific resistivity, which is inversely proportional to the concentration of residual ionic impurities. A chemically pure water with a specific resistivity of 18.3 MOhm · cm at a temperature of 25° C or 25.4 MOhm · cm at 20° C can be obtained in theory by means of ion exchange.

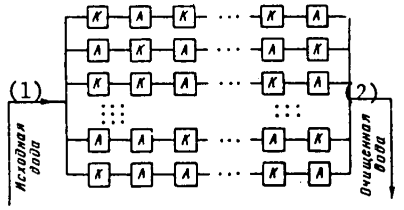


Figure 13.1. Schematic showing the working of a combined action filter.

Key:
1. Initial water;
2. Purified water;
K = Cationic exchanger filters;
A = Anionic exchanger filters.

The technique for obtaining desalinated water by means of ion exchange membranes and the application of direct current is called electrodialysis. The essence of this demineralization method consists in the removal of ions of dissolved salts by continuous electromigration with the application of a DC electric field through cation and anion permeable membranes (Figure 13.2). In this case, there is the directional transport of cations towards the cathode and anions towards the anode. As a result, the water is desalinated in the even chambers 2, 4 and 6 and the salts are accumulated in the odd salt accumulation chambers 3 and 5. The usual process of electrolysis of the water containing the dissolved salts takes place in the

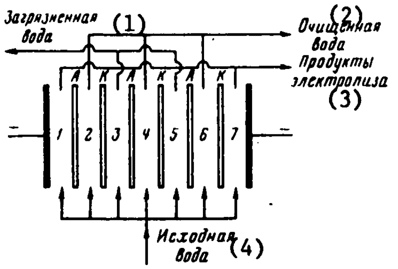


Figure 13.2. Schematic of an electrodialyzer.

Key:
1. Polluted water;
2. Purified water;
3. Electrolysis product;
4. Initial water.

end chambers 1 and 7 where the electrodes are placed, in which case, gaseous hydrogen is liberated at the cathode:

$$2H^+ + 2e^- = H_2$$

while oxygen is liberated at the anode as a result of the hydroxyl ions giving up electrons:

$$4OH^- - 4e^- = 2H_2O + O_2$$

During electrodialysis, polarization processes also take place in ion exchange membranes for the purpose of obtaining completely desalinated water [71], where these processes lead to unproductive expenditures of electrical power, which to a considerable extent limits the capabilities of this purification method [72]. This method is economically expedient to make water fresh which has a comparatively large content of mineral salts and is used in the preliminary processing stage.

Electrodialysis and ion exchange techniques have been combined into a new process: electro-ion exchange, in which the sections of the electrodialyzer are filled with ion exchange resins. The method makes it possible to simultaneously carry out the processes of the sorption of ion impurities from the water being purified by ion exchange as well as electrochemical desorption of them with the application of an electric current. The resins in R-H and R-OH forms traps and concentrates the ions of the water being purified, which then migrate through the membranes with the action of the applied voltage. The introduction of ion exchange fillers into the chambers of the electrodialyzer makes it possible to reduce the electrical resistance of the system. This leads to a reduction in the voltage, which is due to the absence of polarization. However, there is a phenomenon similar to polarization at the points of contact between the particles of the ion exchange resins and the membranes, and which leads to the electrolytic decomposition of the water into hydroxyl and hydrogen ions. Because of this process, the mixed layer of ion exchangers is recovered, which can be represented in the form:

$$H^+ + OH^- + R_1Na + R_2Cl = R_1H + R_2OH + NaCl.$$

As a result, the salts are concentrated in the salt accumulation chambers, while a considerably desalinated water is obtained in the desalinization sections.

The reverse osmosis technique occupies a special place among purification methods [73]. The essence of it consists in the fact that if a pressure is applied to a solution which is in contact with a semipermeable membrane, where this pressure exceeds the natural osmotic level, pure water begins to filter through this membrane, while the dissolved impurities, in being concentrated, are drained off in the sludge. This method makes it possible to reduce the concentration of salts in water and to hold back almost all suspended particles prior to the ion exchange stage. As compared to the techniques cited above, this method makes it possible to partially or completely eliminate the use of resins and chemical reagents, considerably reduce the metal input requirements for the equipment which is built and curtail the number of attending personnel and the area occupied.

In holding back the dissolved salts, the membrane simultaneously proves to be a molecular filter, capable of retaining bacteria, pyrogenic agents and the majority of organic substances encountered in natural water. The process of reverse osmosis takes place at room temperature, does not require recovery of the filters, because of which the economic outlays are small. Reverse osmosis is also promising both for the preliminary purification of water from dissolved organic and ionic impurities and for the finish purification from suspended microparticles.

Progress in semiconductor production is responsible for the rise in the requirements placed on the purity of all of the materials used in production. Because of the sharp decrease in the dimensions of device components, when estimating the quality of the water being used, with the exception of salt content (specific electrical resistivity), it is necessary to take into account the size and quantity of the suspended microparticles. The requirements placed on water used in finish operations are especially high; in this case, the preliminary and fine scrubbing filters should assure the absence of microparticles more than 0.2 µm in size.

The most effective method of cleaning out microorganisms is purification by means of filters; in this case, the water being cleaned should be sterilized beforehand by intense ultraviolet radiation.

The major production process operations in semiconductor production are carried out in a gas environment: pure nitrogen, argon, oxygen, hydrogen or in mixtures based on them. In this case, the gas production process medium can perform the functions of a reagent (for example, the operations of epitaxial film growth and diffusion from a gas phase), a protective environment (for example, the operations of annealing and melting-in) or a filler gas. Correspondingly, distinctions are also drawn in the requirements placed on the degree of purification of the medium: when processing in a reducing medium, oxygen impurities and water vapors are harmful; in neutral media, oxygen, hydrogen and water vapor impurities are harmful; in oxidizing media, hydrogen impurities are harmful, and in individual cases also water vapor; in all cases, dust particles are harmful. Because of this, all of the gases used in semiconductor production are subjected to purification which assures a volumetric oxygen content of no more than 0.0005% (for hydrogen used in epitaxial growth, this requirement is even higher: the volumetric oxygen content should not exceed 0.00001%); the water vapor content (relative to the dew point) is no higher than -65° C to -75° C. When using nitrogen, argon and oxygen, the volumetric content of the hydrogen in them should not exceed 0.001%.

The technique of catalytic hydrogenization has become the most widespread method of removing oxygen; in this case, the gas being purified (nitrogen and inert gases with about 4% added hydrogen) is passed through a tank with a catalyst: palladinized alumogel, and in it, the hydrogen present bonds the oxygen. The residual volumetric fraction of oxygen obtained with this cleaning technique amounts to no less than $1 \cdot 10^{-4}$ %.

TABLE 13.2. Requirements Placed on Production Rooms

Rooms	Electronic-Vacuum Environment Class	Dust Content, Particles/l	Quality Control Particle Size, μm	Air Temperature, °C	Moisture Maintenance Precision, %
General purpose, air conditioned	III	>700		In accordance with SN 245-71	In accordance with SN 245-71
Special purpose, air conditioned	II	≤700	2.0	± 2	± 10
Clean (sealed areas)	Ib	≤200	1.0	± 2	± 10
Clean rooms	Ia	70 - 5	0.5	± 2 (>23)	± 10 (>50)
Especially clean rooms	>Ia	<5	0.5	± 1 (≤23)	± 5 (≤50)

For greater purification of hydrogen from oxygen and all other impurities, a diffusion technique is employed which is based on the capability of hydrogen alone of diffusing through a palladium membrane. This method theoretically makes it possible to completely purify the hydrogen. Contamination of the hydrogen occurs subsequently by virtue of gas emission by the system and the infiltration of air from without into the main line when transporting the hydrogen to the user.

The most effective and widespread method of drying gases is the physical adsorption technique. Silica gel and zeolite, which have a well developed surface and the capability of adsorbing water vapor are the most widely used as the solid adsorbents.

All of the gases employed are subjected to dust removal, where especially high requirements are placed on gases employed in the processes of producing semiconductor device structures (epitaxy, diffusion, dielectric isolation, etc.).

The quality and reliability of semiconductor devices are also governed to a considerable extent by the purity, and primarily the humidity and absence of dust in the air environment of production rooms. Contaminants are introduced into the environment through unsealed places in the structural members (about 15%), through special clothing and footwear (about 30%) and the remaining 55% occur during the production process and are a consequence of the imperfection of the air distribution system [74].

Special rooms - sealed areas equipped with air conditioners and special dust removal systems - are constructed to meet the special requirements placed on the air environment, which are determined by the specific features of the production of the electronic hardware products [the electronic and vacuum environment requirements (EVG)]. Local dust protection units are employed to carry out the production processes which are the most critical as regards the degree of environmental purity. These include clean rooms, which provide an air environment with specified and maintained constant temperature, humidity, pressure, dust content as well as direction and speed of air flow. Even higher requirements as regards the degree of dust removal are provided by dust shielded chambers and boxes; they are employed to carry out the most important operations during the photolithography process, in the fabrication of photographic templates, etc. The requirements placed on production rooms are given in Table 13.2 [75].

13.2. Equipment for Centralized Water Purification

Water purified by means of deionization in centralized purification equipment should have a specific resistivity of no less than 1 MOhm · cm at a temperature of 20 ± 2° C, an oxidability referenced to oxygen of no more than 1.5 mg/l and a salicic acid content of no more than 0.2 mg/l.

The UTs-1, UTs-2, UTs-5 and UTs-10S units with outputs of 1, 2, 5 and 10 m^3/hr respectively are used for centralized water purification.

Two sections are incorporated in the centralized water purification unit [76]: the ion exchange unit itself and the recovery station. The equipment complement of the ion exchange unit consists of a water heater, a mechanical filter, filtration columns, a combined action filter, a tower type degaser with fans and two tanks for collecting the dionized water and a resin wetting tank. Included in the equipment complement of the recovery station, which is intended for preparing the recovery solutions, are an ejector system for the preparation of the working acid and alkali solutions, a solid alkali solvent tank and two dosage units: for the alkali and the acid.

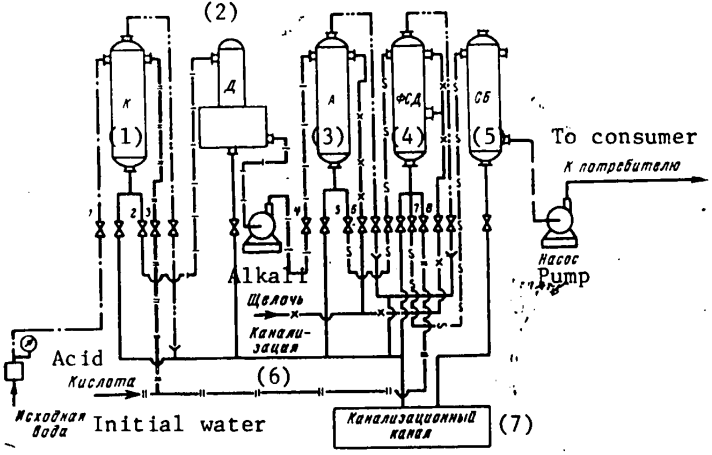


Figure 13.3. Production process scheme showing a centralized water purification facility.

Key to Figure 13.3:
1. K = Cation exchange filter;
2. D = Degasifier
3. A = Anion exchange filter;
4. FSD = Combined action filter;
5. SB = Collecting tank;
6. Drainage;
7. Drainage conduit.

The water incoming to the unit is heated up to a temperature of 20 to 25° C by the heater, which is a housed pipe heat exchanger, in which the water flows through the pipes, while the steam flows through the space between the pipes. The pipe arrays and the pipes themselves are made of stainless steel. Standardized purification production processes, assemblies and components are used in the units. Two similar production process lines are employed. One such line is shown in Figure 13.3. While one carries out the purification, the other carries out the recovery. Thus, two cation exchange filters K, a degaser D, two anion exchange filters A and two combined action filters FSD and a collecting tank for the deionized water SB are incorporated in the equipment complement of the unit.

The raw water (—·—) is fed from above through valve 1 into cationic exchange filter K, and then the H-cationized water (—1—) is fed through valve 2 to degaser D, where the free carbon dioxide gas which is formed as a result of the decomposition of the carbonates and bicarbonates in the raw water is removed from it. The water is fed from the degaser by a pump through valve 4 to the anion exchange filter, in which the oxygen radicals are absorbed. This completes the first purification stage; the specific resistivity of the water after this amounts to 2 to 3 MOhm · cm. The water is then fed through valve 5 to the combined action filter, FSD, of the second purification stage. The desalinated water (— —) having a resistivity of 5 to 6 MOhm · cm is collected in the collecting tank and is fed by a pump to the user for direct utilization or supplemental finishing purification.

The exchange capacity of the resins is exhausted during the process of purifying the water. The exhaustion of the H-cation exchange filters is determined from the overshoot in the cations being extracted; in anion exchange filters in the first stage, it is determined from the overshoot in the chloride, and in the second stage, based on the overshoot in the salicic acid anion. With the detection of such overshoots, the appropriate filter is disconnected for recovery work.

The process of recovering ion exchangers in a filter consists of three sequential operations:

--The breaking up of the ion exchange resin with a flow of water from bottom to top to eliminate the compressed nature of the ion exchange material, which is produced when filtering under pressure and can lead to the nonuniform flow of the recovery solution, and consequently, to incomplete restoration;

--The recovery itself, i.e., the passage of a restoring solution through the ion exchanger (from top to bottom through valves 3 and 6); cation exchangers are restored by a solution of sulphuric or nitric acids (—>>—), anion exchangers are restored by a solution of sodium hydroxide, sodium carbonate or bicarbonate (—X—). During restoration, the hydrogen ions displace the metal cations retained during the operating cycle from the cation exchanger; the hydroxyl group OH^- ions displace the anions of the acids, and the exchange capability of the resins is restored. To recover filters with a mixed layer of ion exchangers, the acid and alkali solutions are fed through valves 7 and 8 from below and above respectively, while the filtrates are dumped from the top and through the center drain;

--Washing the recovery products and excess regenerating material from the ion exchanger by a flow of water from the top down. Water from the mains and deionized water is used for the flushing.

The filtration column (Figure 13.4) is intended for extracting ions from water by means of the KU-2-8, EDE-10P, AN-31 and AV-17-8 ion exchange resins. The distribution system 3 for the water, which is made of vinyl plastic piping with holes, and the distributor for the delivery of the recovery solutions, are located in the upper portion of the column. There are 67 drainage caps 7, which take the form of a set of vinyl plastic discs with polyethylene washer inserts, mounted in the lower portion of the column on plate 1. The drainage is intended to prevent the removal of resin. A hatch 2 is located above the drainage system for removing the resin during the repair of the drainage system; there is a branch pipe in the cap of the hatch to which one can connect another pipe and remove the resin hydraulically. The housing of the filtration column 5 is made of a steel pipe, the diameter of which is calculated as a function of the output of the unit. There is an inspection window 6 in the upper portion of the column housing, through which one can observe during operation. The hatch 4 in the upper cover serves for topping out the resin during the operation of the unit. The column is mounted on a welded frame and can also be mounted both separately and as part of other units.

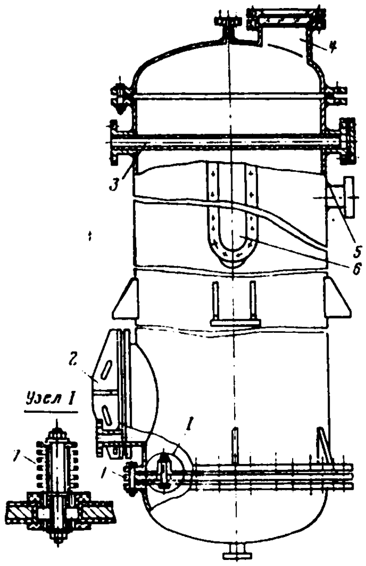


Figure 13.4. Filtration column

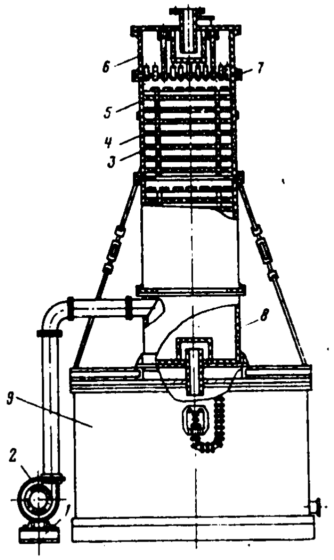


Figure 13.5. Degasifier.

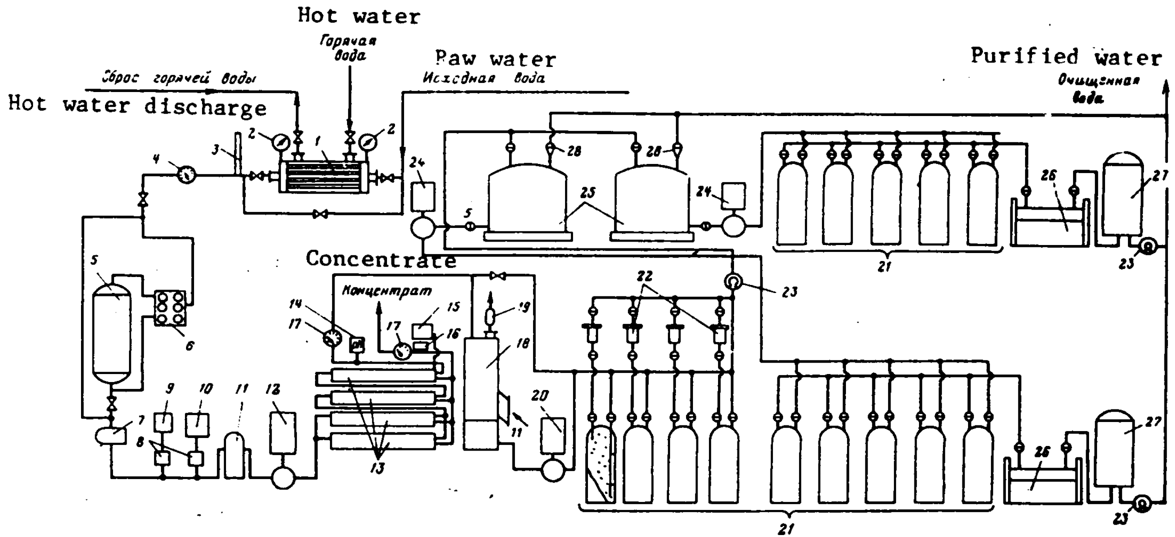


Figure 13.6. Basic production process scheme for producing ultrapure water.

Key: 1. Heat exchanger; 2. Manometer; 3. Thermometer; 4. Water meter; 5. Mechanical filter; 6. Set of automatic valves with programming mechanism; 7. Coarse cleaning filter (preliminary); 8. Dosage pump; 9. Sulphuric acid tank; 10. Sodium hexametaphosphate tank; 11. Coarse cleaning filter; 12. High pressure pump; 13. Roller type reverse osmotic elements; 14. pH meter; 15. Salinity meter; 16. Clock; 17. Flow rate meter; 18. Degasifier; 19. Fan; 20. Pump; 21. Combined action filter; 22. Filter; 23. Resistivity meter; 24. Pump; 25. Collecting tank; 26. Ultraviolet sterilizer; 27. Fine cleaning filter; 28. Regulating valve.

The degasifier (Figure 13.5) is intended for the removal of carbon dioxide from the H-cationized water. The cylindrical vinyl plastic housing 8 consists of three sections, 5 and 6, filled to a height of 2.6 m with vinyl plastic chordal baffles. The baffles are made so that the plates 3 of one row overlap the gaps between plates 4 of the next row. The water exits on top through a branch pipe and is uniformly distributed by a special plate 7 over the surface of the attachment. There are 48 water distribution branch pipes on the plate and 8 branch pipes for the air outlet. The branch pipes for water distribution are distributed uniformly over the area of the plate. Raschig rings are also used to fill the body of the degasifier. The degasifier column is mounted on tank 9, in which the water is collected following degasification. An ESU-1 level indicator is mounted in the tank. Air is delivered to the lower portion of the column from fan 2, which is mounted on frame 1 alongside the tank. The air from the fan goes upward to counter the flow of water and goes out into the atmosphere.

The combined action filter is intended for holding the mixture of KU-2-8 chS and AV-17-8 chS ion exchange resins. The housing is made from steel pipe, the diameter of which is computed as function of the output of the unit; the internal surface of the pipe is rubber coated. The structural design of the combined action filter is similar to the structure of the conventional filtration column described above, with the exception of the center drain unit.

The basic production process scheme for producing ultrapure water at a rate of 2 m^3/hr is shown in Figure 13.6. A high degree of purity is assured by virtue of the use of a multistage processing system, which includes the removal of microparticles in the mechanical filter 5 (the removal of particles with dimensions of more than 20 μm); the coarse cleaning filters 7 and 11 remove particles larger than 6 μm; the fine cleaning filters 22 and 27 remove particles larger than 2 μm and 0.2 μm respectively; the purification employs the reverse osmosis technique using roller type elements 13, degasification, double ion exchange purification in combined action filters 21 as well as ultraviolet sterilization. To provide for continuous system operation, collecting tanks 25 with a capacity of 10 m^3 each are provided where necessary for the restoration of the combined action filter; additionally, the combined action filters are structurally designed so that they allow rapid replacement with a filter which has been restored in a separate special section. Where a greater purified water consumption is required, the collecting tanks make it possible for two production process finishing "lines" to operate in parallel, which boosts the system output up to 4 m^3/hr.

The unit for water purification using reverse osmosis (Figure 13.7) is intended for water purification in a semiautomatic operating mode, and when operated in conjunction with combined action filters, makes it possible to obtain water with an electrical resistivity of 8 to 10 MOhm · cm. The starting water, which is cleaned in a mechanical filter, is fed into the purification block. All of the assemblies of the purification block are mounted on frame 1, to the bottom frame of which the high pressure pump 9 is fastened as well as the tank for the acid solution 7 and the tank for the washing solution 8. There are three purification modules 5, a filtrate flow rate indicator 4 and a concentrate flow rate indicator 6, as well as filters for cleaning the washing solution 3 and a pH meter 2 all arranged in vertcal racks in the frame. The installation is controlled from a control console, on which there are the following: pushbuttons for checking the

Figure 13.7. Installation for water purification using reverse osmosis.

operability 10; for resetting the alarm signal and turning the unit on again 15; "Alarm Signal Cutoff" toggle switch 14; small monitor lights for installation operation; the adjusting control for pH meter 12; ammeter 13; counter 11; and the main switch with mechanical interlocking 16. The power panel is located inside the control console and power is brought into the console from below.

The basic production process schematic of the water purification unit using reverse osmosis is shown in Figure 13.8. Th initial water at a pressure of 3 to 4 kgf/cm^2 is fed through valve 1, mechanical filter 2, valve 3, and electromagnetic valve 6 to the multistage centrifugal pump 7 via a pipe into which a 33% acid solution is also fed from tank 24. The acid is supplied to correct the pH of the initial water, which should fall in a range of 5.2 to 5.6. The water is delivered by pump 7 at a pressure of 28 kgf/cm^2 through open valve 21 and pipe 15 in part to filtration modules 14 and in part recirculates through bypass valve 23. In flowing through modules 14, the water is collected in the collector 13, and then passes through the flow rate meter 12 and is fed through valve 9 to the user or for further purification. The pressure of the water fed into the modules is monitored by means of manometer 20 and contact manometer 19. The concentrate is drained from the modules 14 through receiving manifold 16, valve 17 and valve 11. The concentrate pressure is checked by a manometer and adjusted by valve 17. A portion of the water incoming for purification is fed through valve 22 to sensor 8 to check the pH and is dumped into the drain.

In the case where the purification modules 14 become fouled, they are chemically flushed with a solution prepared in tank 4. A 2% (by weight) solution of citric acid is used to wash out iron, with the subsequent addition of ammonia (NH_4OH) to obtain a pH = 4. In the case where calcium sulphate is washed out, the same solution is used, but with a pH of 7 to 8. Calcium carbonate is washed out using a solution of sulphuric or nitric acid with a pH of 4 while organic substances are removed by an alkali solution with a pH of 13.

The solution is delivered by pump 7 from tank 4 through valve 3, sensor 5 and valve 6 to the filtration modules 14; the filtrate is then returned through valve 9 to tank 4. Prior to returning to tank 4, the concentrate is cleaned in

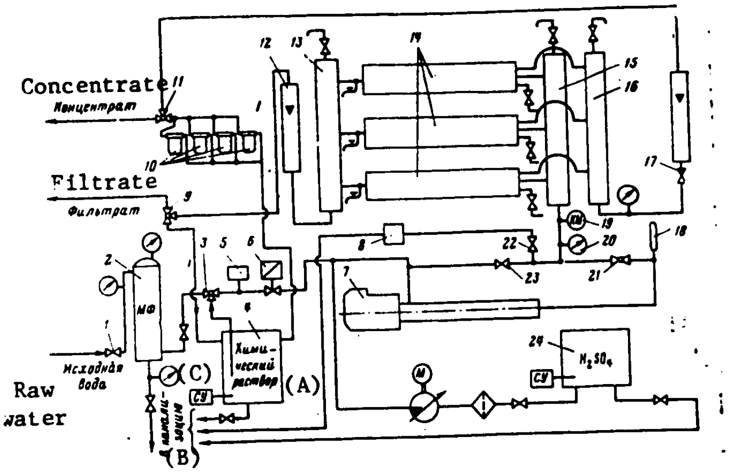


Figure 13.8. Production process scheme for the water purification unit using reverse osmosis.

Key: A. Chemical solution;
B. To the drain;
C. SU = Not further defined.

filters 10. A contact thermometer 18 is installed at the outlet from the pump 7 on the pressure delivery line, where this thermometer disconnects the unit when the temperature goes higher than the permissible value.

13.3. Equipment for Finish Water Purification

Following the preliminary purification of water with a resistivity of 1 MOhm · cm and more, it fed for thorough desalinization to a finish purification installation. The configuration of a string of finish purification units, designed for the use of ion exchange in a mixed layer of KU-2-8 chS and AV-17-8 chS ion exchange rosins, includes type UF-100A, UF-250 and UF400A units. Also incorporated in the configuration of a string of finish purification installations are type UFE-100 and UFE-250 units, which employ the technique of electrodialysis with intermembrane filling using a mixture of the ion exchange materials indicated above. The outputs of the units are 100, 250 and 400 liters per hour respectively; the electrical resistance of the water following purification in the units is 15 to 20 MOhm·cm at a temperature of 20 °C. The units should be placed close to the points where the water is used. In this case, to prevent contamination by the atmosphere of the assembly shops during the recovery of the spent resins, this process is carried out at a central location in an isolated room using special recovery equipment. For this purpose, the filtration column of the finishing units is made so as to be easily disassembled. The continuous monitoring of the course of the process is accomplished using a continuous flow meter and an instrument for measuring the water resistivity at the filter column inlet and outlet.

The UF-250 finishing water purification unit is shown in Figure 13.9. Desalinated water with an electrical resistivity of 2 to 3 MOhm·cm, obtained from the centralized unit, is fed through sensor 1, inlet valve 2 and direct reading flow meter 3 to the filter column 5, and then through outlet valve 6 and sensor 7 to the user.

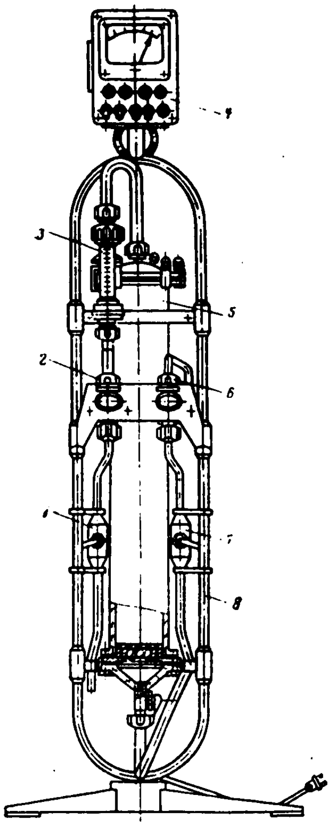


Figure 13.9. The UF-250 final water purification unit.

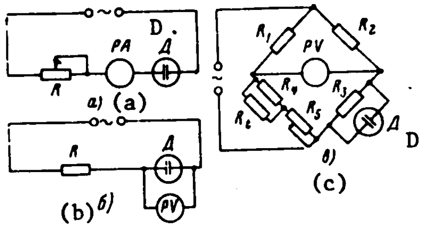


Figure 13.10. Water resistivity metering circuits.

The degree of water purification is monitored by means of instrument 4, which indicates the resistivity of the water at the outlet. When the resistivity falls below the permissible value, a signal light on the panel of the instrument turns on, the initial water feed valve into the filter turns off and the filter is disconnected for restoration. The filter is made in the form of a cylindrical housing of plexiglass. There is a drainage disk in the lower portion. There is a plug in the upper cap of the filter for the release of air from the filter in the initial operating period of the unit. A direct reading flow meter serves to measure the water rate of flow incoming for purification. Its housing is also made of plexiglass. There are divisions which show the water rate of flow on the exterior surface of the housing.

The sensors of the flow-through meter for monitoring the water resistivity, which are secured to the frame of the unit 8, consist of a cup and a nozzle, made of plexiglass. Two stainless steel electrodes are screwed into the cup, where the gap between the electrodes is set during the adjustment of the instrument. The sensor is connected to the measurement instrument by a shielded cable. The basic electrical resistivity measurement circuits for deionized water are shown in Figure 13.10.

The operation of the meter, a block diagram of which is shown in Figure 13.10a, is based on the measurement of the current flowing through a measurement cell, D. With a constant voltage applied to the circuit, when the resistivity of the solution in the measurement cell changes, its resistance changes, and consequently also the current flowing through the circuit. Thus, one can judge the resistivity of the solution in the cell from the current in the circuit, i.e., R = f(I).

The scale of the microammeter PA is graduated in values of the resistivity (MOhm · cm).

If the additional resistance R in the circuit of Figure 13.10b is chosen two to three orders of magnitude greater than the resistance of the cell being measured, D, then a change in the current flowing through the circuit with a change in the resistance of D from D_{max} to D_{min} can be disregarded in practice.

Thus, one can judge the resistance of the measurement cell by measuring the voltage drop across it, i.e., $R = f(\Delta U)$.

The scale of the millivoltmeter PV is graduated in values of the resistivity (MOhm · cm).

Figure 13.11. Unit for segregating and recovering resins.

The operation of the meter, the measurement portion of which is depicted in Figure 13.10c, is based on the measurement of the imbalance of the bridge which is due to the change in the resistance of the measurement cell D, inserted in one of its arms.

The thermistor R_t serves to compensate for the change in the water resistivity with a change in temperature.

The imbalance signal is fed following amplification to the meter, the scale of which is graduated in MOhm · cm.

The URS-1 installation (Figure 13.11) is used to segregate and recover the KU-2-8 chS and AV-17-8 chS ion exchange resins, which are used up in the UF finish purification installations, where this unit can also be used as a finish water purifier with an output productivity of 800 liters per hour when the two filtration columns operate in parallel, or as a unit for producing desalinated water having a resistivity of 1 MOhm · cm and higher from the water mains. In the latter case, the filter columns which are loaded with the resin mixture, are connected in series through a degasifier and the output productivity of the unit will be 400 liters per hour.

The unit has two columns for the ion exchange resins, a degasifier column for the removal of carbon dioxide which is filled with Raschig rings made of polyethylene tubing, as well as a pump for delivering water from the degasifier tank to the second purification stage. Located on the control panel for the unit is a meter for measuring the water resistivity, which makes it possible to determine the quality of resin recovery or the thoroughly desalinated water which is produced. An ejector system is provided in the unit for the preparation of the recovery solutions.

The UFE-250 finish water purifier (Figure 13.12) takes the form of a composite structure, consisting of the support frame, electrodialyzer, direct reading flow meters, cutoff valves, sensors, electrical circuitry and a piping system. The support frame consists of a frame, base and sheathing; the frame and the base take the form of a welded structure of angle irons and serve for the housing and securing of all of the assemblies. The direct reading flow meters, electrical circuitry, valves, solution tanks, water resistivity sensors and piping system are located within the support frame. The dialyzer is secured to the front wall of the frame. The instruments for metering the electrical parameters (ammeter and voltmeter) are mounted on the front panel of the unit as well as the water resistivity measurement block and the current density adjustment control. The cutoff valves are fastened to the inclined front panel. The side walls of the frame are covered with removable bent steel section sheathing. The rear wall of the frame is covered with a removable door. There are a plug connector for the electrical current (power mains), a grounding bolt and outlets for the production process pipes on the rear wall of the base. A group disconnect switch is located on the right side wall of the base. There are holes in which handles are inserted in the side walls of the frame for moving the unit.

Figure 13.12. The installation for the finish purification of water using electroionization.

The electrodialyzer takes the form of a composite structure of two electrode chambers E, desalinization chambers D and brine chambers B, the number of which depends on the output productivity of the installation. The chambers are assembled in the following sequence: E--B--D--B--D...B--E.

All of the chambers are separated from each other by cation and anion exchange membranes and are joined together through gaskets using studs, which are insulated with polyvinylchloride tubing. To provide for a gap between the electrode and the membrane in the electrode chambers and between the membranes in the brine chamber, gaskets are inserted made of perforated and corrugated vinyl plastic film. There are holes which are plugged with plugs in the upper portion of the desalinization chambers, through which the resins are loaded in; there are holes in the lower portion for water delivery to the electrode and brine chambers.

There are manifolds for water distribution to the chambers in the upper and lower portions of the electrodialyzer; there are air vents in the upper portion for the removal of air from the desalinization and electrode chambers. Direct reading flow meters are installed in the unit for the measurement of the purified water flow (unit output) and the water flow in the electrode and brine chambers.

The unit operates continuously and requires no chemical regeneration. The recovery of the resins takes place during the desalinization process by virtue of the partial electrolysis of the water into H^+ and OH^- with the application of direct current.

The major user of ultrapure water is equipment for the chemical treatment of wafers. This fact is taken into account in the design of equipment for water purification. A schematic of a recirculation system for producing ultrapure water is shown in Figure 13.13. The major components of the system are secured in a dust free box, in the working volume of which the chemical treatment unit is placed. For reducing the water flow rate and expenditures related to its purification, a provision is made in the system for the capability of the repeat use of a portion of the water (with a resistivity of more than 1 MOhm · cm) following the washing operation. In structural terms, the system consists of the block of filters 1, the water delivery unit 2, the water return unit 3 and the fine cleaning filter for the deionized water 4.

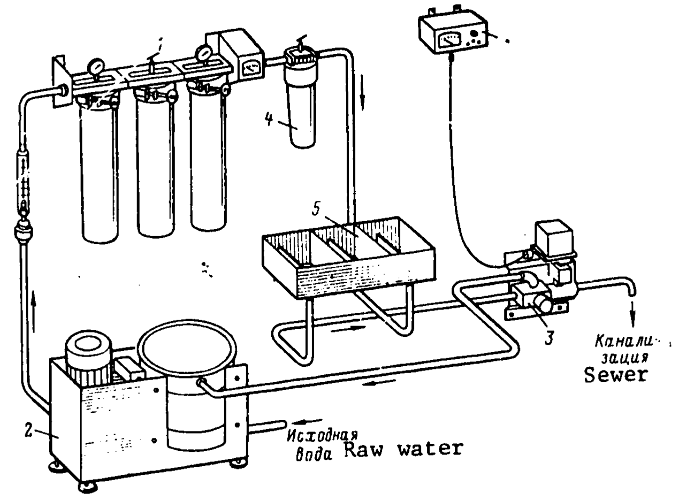


Figure 13.13. The recirculation system for producing ultrapure water.

Key:
1. Block of filters;
2. Water delivery unit;
3. Water return unit;
4. Fine cleaning filter;
5. Cascaded washing bath;
6. Resistivity meter.

The incoming water in the block of filters (Figure 13.14) is sequentially cleaned of mechanical particles larger than 2 µm in the preliminary cleaning filter 6, which takes the form of a three layer filtration system: two layers of cardboard, which play the part of a preliminary filter and a substrate, as well as a layer of filtering material positioned between them (the extended filtration surface is achieved by virtue of corrugating the filtering layers). The water is then purified of organic impurities by their sorption by a layer of macroporous anionic exchange material or activated charcoal (filter 7), and also cleaned of ionic impurities in a mixed layer of ion exchangers (combined action filter 8). The units of the filter are changed in step with the degradation of water quality, which is checked by resistivity meter 9, as well when the hydraulic resistance increases above a set level by virtue of the clogging of the filters, which is registered by manometer 4. The block is also equipped with a flow rate meter 2 and a check valve 1, which prohibits the flow of water in the return direction when the system is disconnected.

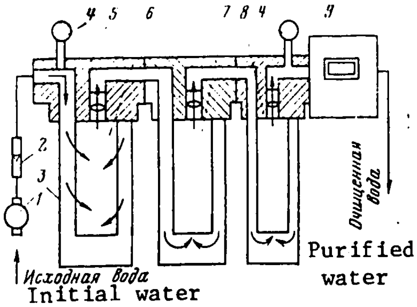


Figure 13.14. Basic schematic of the block of filters.

Key:
1. Check valve;
2. Flow rate indicator;
3. Filter housing;
4. Manometer;
5. Housing;
6. Preliminary cleaning filter;
7. Filter for removing organic contaminants;
8. Filter for removing ionic impurities;
9. Resistivity meter.

Following the fine cleaning filter, the water is fed to the user (in Figure 13.13, to the cascade washing bath 5), and then to the return unit and through the open valve is dumped into the drain. Upon the signal from the meter 6 when the drain water reaches a specified resistivity, the valve is switched and the water is fed into the collecting tank of the water delivery unit.

To retain the deionized water parameters achieved following purification, the retaining fittings are made of technical plexiglass and teflon, while the distribution system for the water delivery from the intermediate centralized purification equipment, is made of high pressure polyethylene pipes, vinyl plastic pipes or seamless cold drawn pipes of corrosion resistant steel; high pressure polyethylene pipes or teflon 4D pipes are used to deliver the deionized water from the finish purification units. The piping should be able to be disassembled for ease of washing and repair. The pipes are washed no less than once per quarter with a 3 to 5% solution of hydrogen peroxide or sodium chlorate which is kept in the piping for no less than one hour. After the solution is drained out, the internal surface of the pipes are flushed with type V deionized water until a resistivity of the flushing water of 1 MOhm · cm and an oxidability of no more than 1.5 mg O_2/l are achieved.

13.4. Equipment for Gas Purification and Drying

The installations for the chemical adsorption purification of nitrogen and hydrogen used in semiconductor production have an output productivity of from 100 to 1 nm^3/hr*; installations for the adsorption purification of air have an output of from 6,000 to 30 nm^3/hr and diffusion purification units for hydrogen have outputs of 4, 10 and 50 nm^3/hr. The major impurities which must be removed from the gases being cleaned are moisture, oxygen, hydrogen and dust.

The basic production process scheme for the purification of nitrogen in the UOGA-50 (I), operating as part of a complete set with the BUV-50 (II) excess hydrogen removal unit, is shown in Figure 13.15. In the case of operation with simultaneous restoration of one of the adsorbers (for example, A_1), the isolation fittings are set in such a position by the switching of the control levers that the nitrogen incoming for purification goes into adsorber A_1, heated by the heater built into it, and extracts the moisture released from the silica gel. The restoration takes place at a temperature of 180 to 190° C.

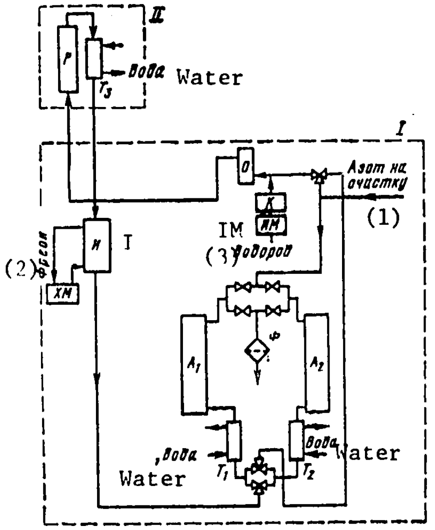


Figure 13.15. Basic production process schematic of the UOGA-50 nitrogen purification unit.

Key:
1. Nitrogen for purification;
2. Freon;
3. Hydrogen;

IM = Actuating mechanism;
K = Electromagnetic valve;
O = Purifier [filled with palladium catalyst];
R = Reactor;
A_1 = Adsorber 1;
T_1 = Heat exchanger 1.

To avoid the failure of the seals of the isolation fittings because of exposure to high temperatures, the nitrogen is water cooled in a heat exchanger T_1 following A_1 (T_2 in the case of restoration of adsorber A_2). Then hydrogen is added to the nitrogen through electromagnetic valve K and the automatically controlled valve of the actuating mechanism IM in an amount which is 0.5 to 1.5% greater than the stoichiometric ratio for the amount of oxygen impurity. The nitrogen and hydrogen mixture is fed to the purifier O, which is filled with a palladium catalyst, in the presence of which the hydrogen bonds the oxygen so that at a temperature of 90 to 100° C, the residual volumetric fraction of the latter amounts to less than $1 \cdot 10^{-4}\%$. Then the nitrogen being cleaned is fed into the reactor

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*At normal atmospheric pressure.

R of the hydrogen removal unit, where the following reaction takes place:

$$\mathrm{CuO}\ \underset{+}{\overset{350^\circ\,\mathrm{C}}{\text{——}}}\ \mathrm{H_2}\rightarrow \mathrm{Cu}+\mathrm{H_2O}.$$

The copper oxide, which is precipitated on alumogel, assures a residual volumetric oxygen content of less than 1 · 10^{-3}%. Being cooled in the heat exchanger T_3 to a temperature of 30 to 35° C, the nitrogen is fed to heat exchanger I, which is cooled by freon by the MF-56M type refrigerator KhM. When cooled down to 3 to 5° C, a large fraction of the moisture condenses in the evaporator and is drained from it through an automatic condenser outlet tap; and additionally the sorption capability of the adsorbent is increased. The nitrogen is fed from the evaporator to the adsorber A_2, where the residual moisture content is reduced down to 10 mg/m^3, and fed into the mains through the FAG-50 dust removing filter F. When the copper oxide turns to copper in the reactor P, valve K cuts off the hydrogen feed. The removal of the oxygen now no longer takes place in purifier O, but in the reactor P in accordance with the reaction:

$$\mathrm{Cu}\ \underset{+}{\overset{350^\circ\,\mathrm{C}}{\text{——}}}\ \mathrm{O_2}\rightarrow 2\,\mathrm{CuO}.$$

The residual volumetric oxygen content is 1 · 10^{-4}%. The valve K is automatically controlled [77].

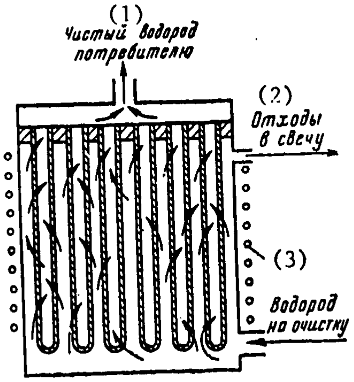


Figure 13.16. Schematic showing the operation of a palladium filter for hydrogen purification.

Key:
1. Pure hydrogen to the user;
2. Waste to the flare;
3. Hydrogen for purification.

The installation is equipped with automatic instruments for monitoring the residual oxygen and hydrogen content (PKG-1S) as well as the moisture content (DV-1). The configuration of the UOGA-100 unit is similar to that described above. Zeolite is packed in the adsorbers in the UOGA-25 unit. The evacuation of the moisture liberated from the zeolite during recovery is accomplished by means of a nitrogen (or air) flow which is exhausted into the atmosphere.

The units for the adsorption and catalytic purification of hydrogen differ from the nitrogen purification units in that there are no blocks in them which involve the dosing of hydrogen into the flow being purified or for monitoring its residual content.

In the hydrogen purification units (UOGV), heat exchanger T_3 (Figure 13.15) is inserted directly after the purifier O.

The UOGV units can be employed where it is necessary to remove hydrogen and moisture from oxygen.

TABLE 13.3

GAS PURIFICATION EQUIPMENT

Characteristic	Type of Installation						
	UOGA-100+ +BUV	UOGA-50+ +BUV	UOGA-25M+ +BUV	UOGV-100	UOGV-50	UOGV-25M	ODV-10
1) Gas being cleaned	Nitrogen	Nitrogen	Nitrogen	Hydrogen	Hydrogen	Hydrogen	Hydrogen
2) Nominal working pressure, MPa	0.05-0.2	0.05-0.2	0.05-0.2	0.05-0.2	0.05-0.2	0.05-0.2	0.6-1.1
3) Output, nm^3/hr	100	50	25	100	50	25	10
4) Relative impurity content:							
a) Oxygen, %	$2\cdot10^{-4}$	$2\cdot10^{-4}$	$1\cdot10^{-4}$	$2\cdot10^{-4}$	$2\cdot10^{-4}$	$1\cdot10^{-4}$	$<1\cdot10^{-4}$
b) Hydrogen, %	$1\cdot10^{-3}$	$1\cdot10^{-3}$	$1\cdot10^{-3}$				"
c) Moisture, mg/m^3	10.5	10.5	2.8	10.5	10.5	2.8	<2.7
d) 0.7 μm dust particles, part/1	2 - 3	2 - 3	2 - 3	2 - 3	2 - 3	2 - 3	Complete removal
5) Degree of explosion proofing:							
Production process unit	VCha-T1	VCha-T1	VCha-T1	VCha-T1	VCha-T1	VCha-T1	Not explosion proofed
Control console		-------- Not explosion proofed --------					
6) Power consumption, KW	9.6	9.6	9.6	9.6	9.6	9.6	4.2

TABLE 13.3 [Continued]

GAS PURIFICATION EQUIPMENT

	ODV-4	ODV-50	KFOG-3	UOV-B-0.5	OUV-B-2	UOV-B-5	UOV-10	UOV-20	UOV-30	UOV-100
1)	Hydrogen	Hydrogen	N_2, H_2 Air	Air	Air	Air	Air	Air	Air	Air
2)	0.6-1.1	1.0-1.1	0.1-0.6	0.6-0.8	0.4-0.8	0.6	0.4-0.8	0.4-0.8	0.4-0.8	0.4-0.8
3)	4	50	1 - 3	30	120	300	600	1,200	1,800	6,000
4a)				-	-	-	-	-	-	-
4b)	$<1\cdot10^{-4}$	$<1\cdot10^{-4}$	$<1\cdot10^{-4}$	Not Removed			-	-	-	-
4c)	<2.7	<2.7	$1\cdot10^{-3}$	Not Removed			-	-	-	-
4d)	Total* removal	Total* removal	5.0	100	100	100	100	100	100	100
5a)	Not explosion proofed	VCha-T1	2 - 3	Not Removed [sic]		-	-	-	-	-
5b)	-	Not explosion proofed	Not explosion proofed	Not Explosion Proofed		-	-	-	-	-
6)	1.2		6	0.5	0.5	0.5	12	24	34	84

* 1. Argon and other inert gases can be purified in nitrogen purification equipment.

2. Oxygen can be purified in hydrogen purification equipment.

3. CO_2 and hydrocarbons are adsorbed by different types of zeolites in the adsorbers of the indicated units.

A complete finish purification complex (KFOG), consisting of a scrubber unit, recovery block and a recovery storage tank set, is produced for the finish purification of production process gases. The purification unit consists of three modules, each of which is designed for an output of 1 nm^3/hr. The interchangeable tanks are filled with a reagent depending on which gas is to cleaned of which impurity. To remove oil and moisture from air, the UOV-B and UOV series installations are employed. The first with heatless recovery of silica gel and the second with recovery using heated air. In installations with heatless recovery, more than 30% of the air being dried is consumed for the needs of the latter, where the minimum working pressure for them amounts to 0.4 MPa.

The characteristics of the major gas purification units are given in Table 13.3.

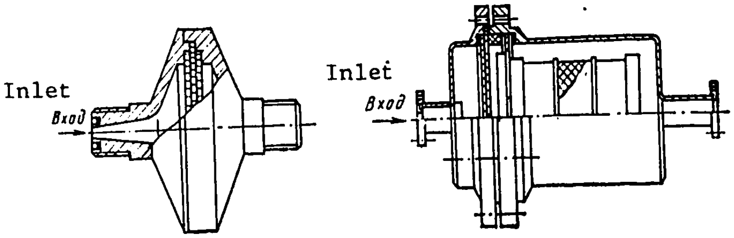


Figure 13.17. Various structure designs for type FAG dust removal filters.

The greatest degree of hydrogen purification is obtained in diffusion purification installations. The action of a diffusion purifier is based on the utilization of the differing penetrating power of the hydrogen being cleaned and the impurities through tubular filters, fabricated from a palladium alloy (Figure 13.16). To speed up the purification process, it is carried out at a temperature of 430 to 470° C and a gas pressure of 0.6 to 1.1 MPa. In the case of diffusion purification of hydrogen, even without preliminary degasification of the piping, the residual volumetric oxygen content amounts to $1 \cdot 10^{-5}$ to $1 \cdot 10^{-6}$%, while the moisture runs down to 1.3 mg/m^3 [78].

The series of type FAG filters (Figure 13.17) with an output of from 0.3 to 200 nm^3/hr is being produced to remove dust from production process gases. The use of the LFS-2 filtering material (lavsan fiber) makes it possible to remove 0.3 μm particles from gases at flow rates of 5 to 10 cm/sec in filters having an output of up to 6 nm^3/hr and particles with a size of 0.5 μm in filters with an output of up to 200 nm^3/hr [79].

13.5. Gas Purity Monitoring Instruments

The most widespread automatic instruments for monitoring the purity of gases used in semiconductor device production are cited in Table 13.4.

The KIVG meter is most often used to monitor the humidity of gases; this meter is an automatic continuously operating coulometric type device intended for

TABLE 13.4. Gas Monitoring Instruments

Instrument	Medium Being Tested	Medium Being Tested [sic]	Measurement Ranges	Remarks
PKG-1S	Nitrogen Hydrogen	Oxygen	$1 \cdot 10^{-4}\% - 1 \cdot 10^{-2}\%$	Produced as part of the equipment complement for the UOGA and UOGV installations
PKG-1S	Nitrogen	Hydrogen	$2 \cdot 10^{-3}\% - 2 \cdot 10^{-2}\%$	The same
DV-1	Nitrogen Hydrogen Oxygen Air	Moisture	2.8 to 100 mg/m^3	The same
"Tsirkon"	Nitrogen Inert gases	Oxygen	$1 \cdot 10^{-6} - 100\%$, 9 scales	There should be no traces of H_2, CO or other impurities which react at 800° C in the presence of platinum with oxygen in the medium being measured
GL-5108	Nitrogen Hydrogen Inert gases	Oxygen	$1 \cdot 10^{-4}\% - 5 \cdot 10^{-4}\%$ $5 \cdot 10^{-4}\% - 1 \cdot 10^{-3}\%$	
"Baykal-I"	Nitrogen	Moisture	0 to 900 mg/m^3, 9 scales	
"Baykal-II"	Hydrogen			
"Baykal-III"	Oxygen Air Inert gases			
Aerosol particle counter	Nitrogen Hydrogen Oxygen Air Inert gases	Dust	0.4 to 10 μm	
KIVG	Nitrogen Hydrogen	Moisture	1 to 900 mg/m^3, 7 scales	

measuring microconcentrations of moisture in gases with automatic signaling of the ultimate values of the quantity being measured. The operation of the meter is based on the principle of the continuous extraction of water vapors by a film of hygroscopic material from a precisely apportioned flow of the gas being analyzed and the simultaneous electrolytic decomposition of the water which is extracted into hydrogen and oxygen. In this case, the steady-state electrolysis current serves as a measure of the quantity of water vapor incoming into the instrument per unit time. Partially hydrated phosphorus anhydride is used as the hygroscopic material. Given a constant rate of flow of the gas being analyzed through the sensitive element, the electrolysis current is proportional to the concentration of water vapor in the gas. A basic schematic of the KIVG meter is shown in Figure 13.18. Instruments of the KIVG type measure microconcentrations of moisture of from 0 up to 1,000 million particles of water vapor with respect to the gas volume.

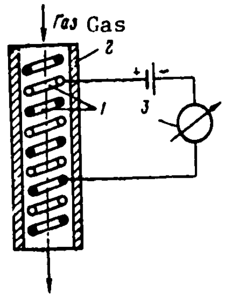


Figure 13.18. Basic schematic of a coulometric humidity analyzer.

Key: 1. Helical platinum electrodes, coated with an adsorbent (P_2O_5);
2. Fluoroplastic tube;
3. Meter.

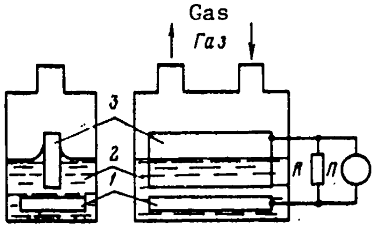


Figure 13.19. Schematic of an electrochemical cell of a galvanic oxygen analyzer.

Key: 1. Lead anode;
2. Electrolyte (KOH);
3. Silver cathode;
R = Variable resistance;
П = Meter.

The GL-5108 stationary automatic galvanic gas analyzer is intended for the continuous measurement of microconcentrations of oxygen in various gases. Its operation (Figure 13.19) is based on the measurement of the electrochemical effect in a galvanic element, which is proportional to the concentration of oxygen in the gas being studied where its flow is constant. The oxygen is initially adsorbed by an electrolyte on the protruding surface of a cathode, which is wetted by virtue of capillary forces, and then goes over into the volume of the electrolyte in the form of ions, as a result of which, an electrical voltage appears across the cell electrodes which is approximately proportional to the oxygen concentration in the gas. The sensitivity of the galvanic element depends on the geometric dimensions of the cathode, increasing with an increase in its surface area.

The "Tsirkon" instrument is produced to monitor the microimpurities of oxygen in nitrogen, in argon and in other inert gases. The sensitive element is a cartridge of 85% zirconium dioxide and 15% calcium oxide, permeable to oxygen ions. Platinum electrodes are applied to the walls of the cartridge; the current between the electrodes is proportional to the number of oxygen ions diffusing through the cartridge wall. Since the measurement takes place at a temperature of 800° C, the instrument can be used for gases which do not contain traces of hydrogen, carbon monoxide and other impurities which react with oxygen in the presence of platinum at the temperature of the process. The instrument makes it possible to measure the volumetric oxygen content in gases down to $1 \cdot 10^{-5}\%$.

The AZ-5 meter, which is intended for measuring the number of dust particles (larger than 0.3 μm) in the air of rooms makes it possible to ascertain sources of dust and to study its migration. To determine the number of particles contained in a pure gas medium, a gas stream is produced which within the field of view of a microscope is illuminated by a beam of light. In the absence of dust in the air (or gas), the light from the illuminator does not get into the microscope. If a dust particle appears in the air, then it scatters the light which is collected by the microscope objective and falls on the cathode of a photomultiplier. The photomultiplier converts the flash of light scattered by the dust particles to electrical pulses, which are counted by an electrical circuit. The dust content measurement range is 0 to 300,000 dust particles per liter of air.

Pipes made of stainless steel, aluminum (for neutral gases and air) as well as fire refined copper and teflon are used to transport the purified gases to the point of consumption. Only vacuum tight corrosion resistant fittings are used on the piping layouts for the purified gases. The feed system for the purified gases (with the exception of hydrogen) is made disconnectable, with seals at the points of vacuum connections made of rubber or fluoroplastic, for periodic cleaning (no less than once a year) of the piping. Nondisconnecting connections are used for the transport of purified hydrogen.

The cleaning of the purified gas transport systems is accomplished in the following sequence:

--The cleaning of the interior surface with metallic gophers;

--Wiping out with a clean, bleached coarse calico cloth, wetted with khladon-113 [sic], and then purging with dry nitrogen or cleaned dry air; thereafter, repeated wiping with bleached coarse calico wetted with ethyl alcohol, and purging with dry nitrogen or air until the smell of the alcohol disappears.

13.6. Clean Rooms. Dustproof Chambers and Boxes

A clean room (Figure 13.20) is a hermetically sealed volume, consisting of the main working room and a vestibule. The production process equipment is installed in the working room; there are locks in side panels for transferring products into the clean room without degrading the parameters of the air environment inside the room. To avoid sucking the ambient air inside the room, an excess pressure of from 2 to 5 mm H_2O is maintained in the room. The forced air delivery units 1 are placed in the upper portion of the room to supply dust free air. The framework for the false floor 4 also consists of cells in which metal sheets with holes punched in them are installed and wooden gratings are placed on top, which provides for uniform removal through louvers of the air forced into the room. The wall panels have several variants: those which are blank panels 2, those with a window 6, having a door, with a transfer lock 5 - and can be secured to the framework and to each other by means of plates in any sequence [74].

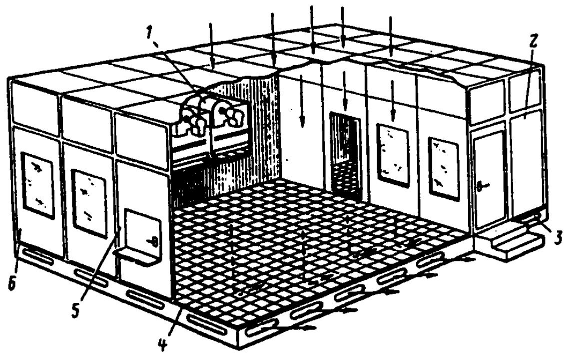


Figure 13.20. General view of the KCh-1 clean room.

Key:
1. Forced blower unit;
2. Wall panel with door;
3. Window for air outlet;
4. Perforated floor;
5. Wall panel with transfer lock;
6. Wall panel with window.

Figure 13.21. The D-3 filtration module.

Clean rooms of a different structural design are known and have also found applications: those with vertical or horizontal air flows [75, 80].

The D-3 filtration module (Figure 13.21) is also widely used to house the production process equipment and perform operations in a dust free environment; this module takes the form of a dismantlable frame structure, on which three ceiling dust removal units 4 are mounted. The corner racks 2 and the frame 3 of the main framework are made of bent shaped steel; the racks are secured to the floor by means of binder strips 1, made of sheet metal. The floor of the room in which the module is installed serves as the floor for the module. The walls 5 are made of transparent plexiglass, assuring all-around access in the working space of the module. The doors are fastened to the support posts by means of hinges, which automatically clamp the doors in the closed position. Windows are left between the door and the floor, through which air is forced out into the room. The ceiling dust removal unit takes the form of a housing in which a centrifugal fan and coarse and fine cleaning filters are mounted on shock absorbers.

Figure 13.22. The SMP-1 dustproof assembly table.

The operation of the module systems is controlled from control console 6, on which there is a common cutoff switch and toggle switches for actuating each of the three dust removal units as well as signal lights for the mains power and fans, and potentiometers for controling the air delivery rate by means of changing the r.p.m. of the electric motors.

The D-3 module can also serve as a section in a clean production process corridor, since it has the capability of being joined to the same module on its wide side and one of its long sides.

Dustproof chambers of various structural designs are used to create a dust free environment in the working space for the production process equipment. The SMP-1 dustproof assembly table is shown in Figure 13.22, where this table is intended for assembly, hook-up and quality control operations in a dust free environment. The equipment for performing production process chemical and photolithographic operations was described earlier in Chapters 2 and 5. Dustproof boxes with a vertical air flow are used to house such equipment. The structural design of the boxes makes it possible to put together complete production process line sets using them and where necessary, rearrange the equipment in an operationally timely manner, depending on the changed production process.

The operational principle of local dust removal installations is based on the continuous flushing of the working space with a uniform flow of dust free air. The air collected from the room (which in individual cases can be a clean room) passes through a coarse cleaning filter, made of modified fluoroplastic. This is the primary coarse cleaning of large dust particles. The cleaning efficiency is 70 to 80%. The precleaned air is then fed by the forced air delivery unit to the fine cleaning filter, where the FPP-15-1.7 filtering material practically completely cleans the air of dust and uniformly distributes the air flow over the output cross-section of the filter. The air then moves in the working space, capturing dust particles along its path and removes them from the work area.

CHAPTER FOURTEEN PRODUCTION PROCESS CONTROL SYSTEMS AND EQUIPMENT IN THE PRODUCTION OF DISCRETE SEMICONDUCTOR DEVICES AND INTEGRATED CIRCUITS

14.1. General Information on the Control of Production Processes in Semiconductor Production

The refining of semiconductor hardware and technology is accompanied by the increasing number and complexity of the interrelationships in technological processes and the appearance of new production process operations and precision equipment. Such production is complex as regards the organization, equipment and technology, as well as the methods and tools for process control. Figure 14.1 depicts the internal links between the stages of the planar process (solid lines) and some of the control processes (dashed lines). Effective control of such production is possible only based on automated control systems (ASU) using computers. An automated control system for a production process (ASU TP) solves the problems of retrieving and processing data on the state of the process, and the output of the control signals to the actuating mechanisms for the adjustment of the parameters.

The controlled units in this case are machines and instruments, while the data is transmitted by electrical, optical and other systems. Usually, an automated production process control system is incorporated as a subsystem in a single integrated control system for a production complex.

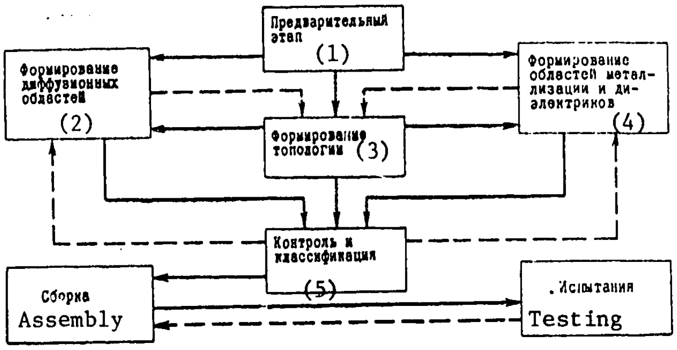


Figure 14.1. Schematic showing the functional links in the production process for the fabrication of a planar structure.

Key:
1. Preliminary stage;
2. Production of the diffusion regions;
3. Formation of the topology;
4. Production of the metalization and dielectric regions;
5. Quality control and classification.

The introduction of an automated control system for a production process is usually preceded by the step of controlling the stages or operations in a technological process using local controllers, which provide for process stability and relatively constant parameters, for example, temperature, gas pressure, etc. over time. The use of computers makes it possible to realize a higher level of control problem solution: the number of controlled parameters increases, the control algorithm is more complicated, rapidly changeable control programs are used and the computer memory is employed to take into account the dynamics of the process.

Automated control systems for production processes permit the following:

--An increase in the technical economic and other production indicators of technological processes, determined by the organization of the production;

--The stabilization and optimization of the output of a products list of products by virtue of assuring a large number of controllable parameters with a complex algorithm and rapidly changeable control program in accordance with the dynamics of the process.

The production process technology for the production of discrete semiconductor devices and integrated circuits, as a controlled system, is characterized by multifaceted physical and physical-chemical phenomena [89], a large number of operations which differ in the content of the production process methods, the equipment used as well as the number of factors which are uncontrolled and difficult to take into account. The latter take the form of the degrees of freedom in the technological process which are not equipment related. In essence, they are uncontrolled and can exert a substantial influence on the production results. In contrast, for example, to machine building or some other processes of chemical production, there is no unique correspondence between the number of variable process parameters, set of data sensors and the corresponding actuating mechanisms in the technological process for the fabrication of discrete semiconductor devices and integrated circuits.

The target functions of automated control systems for production processes are based on the specific features of the process: the controlled system and the extent to which it is technically prepared for being controlled. The expansion of the functional assignments of automated control systems for production processes in semiconductor device production is accomplished within the framework of a single complex: the refinement and automating of the production tools, and the development of methods and tools for control and testing. Because of this, the automated control systems for production processes, introduced into semiconductor device production, differ in terms of their structure, software and hardware.

The software for automated process control systems is based on statistical control techniques, primarily on methods of correlation and regression analysis. Depending on the nature of the process dynamics, the extent to which the process is debugged and its controllability, various statistical methods can be used.

Search techniques are employed predominantly to analyze and correct nonsteady-state processes, for which the construction of statistical models and their identification with the controlled facility are practically infeasible. Nonparametric statistics are usually employed in these cases and the volume of the calculations is small.

It is expedient to employ adaptive methods when controlling, working out and debugging processes which are characterized by a considerable fraction of non-steady-state behavior. In this case, the statistical links between the quality function and the process factors are determined, and information retrieval systems based on computers can be used.

Optimal techniques are employed for almost steady-state processes for the purpose of ongoing quality control and final optimization. These methods are based on regression models and require a large set of calculations.

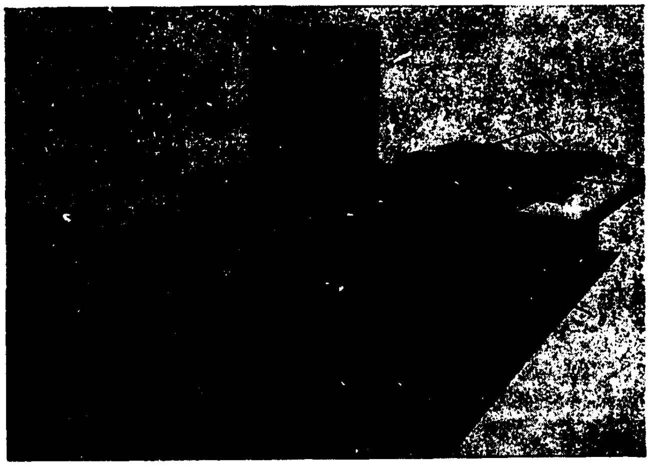


Figure 14.2. A group of quality control posts.

Depending on the degree to which the production process as a whole is prepared for control and depending on the stages involved, structural configurations are possible for automated production process control systems at various functional algorithmic levels. The classification of automated production process control systems according to the functional algorithmic criterion [81] reflects the practical content of work on the comprehensive automation of production processes.

The least complex are control systems for a single production process operation or group of operations of the same type, for example, a group of quality control stations for testing the parameters of discrete semiconductor devices and IC's. The structure of such a system is rather simple (Figure 14.2); the signals from the sensors 5 are fed to the interfaces 4 with computer 3, are processed in accordance with the control program and the control action is fed to the actuating elements of the production process unit 6. The correction of the control program and the output of information to the indicating displays are accomplished on the operator's control console 1. The operator control console is coupled to the computer by the data input-output unit 2. The introduction of such systems makes it possible to substantially increase the volume of data used in the control process, limit erroneous actions of an operator and boost equipment productivity by increasing the control pace.

More complex in terms of structure and function are systems which solve problems of process optimization for the purpose of satisfying a particular quality criterion. Such systems are utilized to control a stage in the production process, the operations in which are linked to the unity of the equipment used or the conditions under which the process is carried out, for example, for the processes of diffusion and oxidation in the manufacture of integrated circuits.

The software for such systems is based on adaptive and optimal statistical techniques. The structure of the system is characterized by the presence of devices for the analysis, comparison and prediction of process dynamics and can contain feedback loops for self-teaching (the correction of the mathematical model and control routines). The speed of such a control system makes it possible to conduct the production process in a mode close to the optimal, and in real time, something an operator cannot achieve in the case of a multiple factor process.

Multilevel automated production process control systems, which control complex technological processes on the scale of production sections and shops, solve an even broader group of functional problems. Along with the tasks of optimizing the production process, such an automated production process control system can also solve problems of organizational control, the optimization of the products list, etc., i.e., the control of the production process is accomplished within the framework of comprehensive control of a production subdivision.

14.2. Computers and Information Control Complexes. Peripherals.

The main link in an automated production process control system is a computer having an all-purpose functional structure. Computers of the following types are effectively utilized in the domestic electronics industry: the "Elektronika-100" (the "Elektronika-100I" is a version using integrated circuits), the "Saratov" (the "Saratov-2" is a version using integrated circuits) and the M-6000. The "Minsk-22", "Minsk-32", etc. computers are also used in multilevel automated production process control systems.

The "Elektronika-100" is designed as a desk top computer, and the structure provides for easy replaceability of the modules and the computer is convenient to operate. The "Elektronika-100" computer with the appropriate selection of peripherals is used in control computer, data and computer as well as information and instrumentation complexes. The standard software for the "Elektronika-100" computer is rather well developed.

The "Saratov" minicomputer is close to the "Elektronika-100" in terms of its functional capabilities.

The M-6000 minicomputer is of interest for the development of various kinds of automated production process control systems. It is a part of the set of the aggregate system of computer hardware (ASVT-M). The structure of the computer is adapted for the connection of up to 54 peripherals, including various data processing and input-output units, something which permits a wide variation in the set of functions which can be performed as regards information retrieval, as well as the real time monitoring and control of processes.

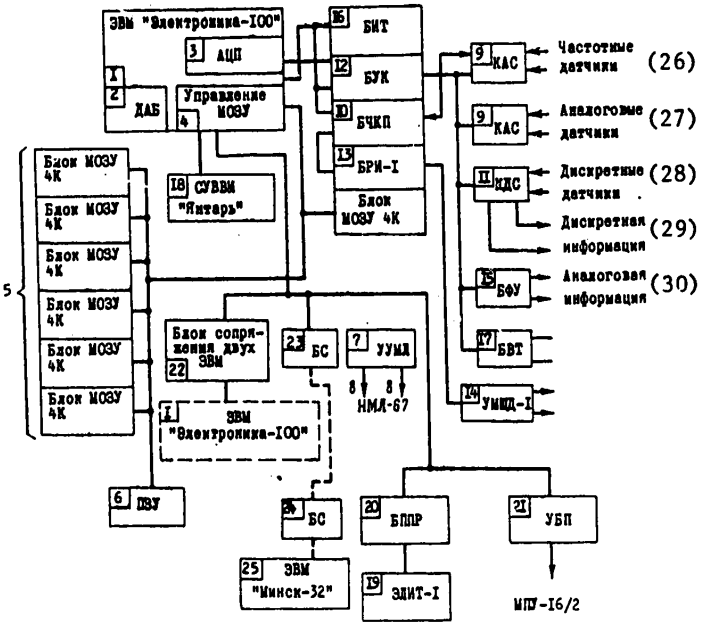


Figure 14.3. Block diagram of a control computer complex [82].

Key:
1. The processor ("Elektronika-100" computer);
2. Arithmetic unit (DAB);
3. Analog to digital converter (ATsP);
4. Controller for the increased capacity main memory (control of the MOZU [magnetic core storage]);
5. Peripheral magnetic core storage units;
6. Read-only memory (PZU);
7. Magnetic tape controller (UUML);
8. NML-67 magnetic tape storage units;
9. Analog signal switchers (KAS);
10. The frequency to code conversion block (BChKP);
11. Digital signal switcher (KDS);
12. Control unit for the switchers (BUK);
13. Pulse distribution unit (BRI-1);
14. Step motor power amplifier (UMShD-1);
15. Fixed voltage level unit (BFU);
16. Data display block (BIT);
17. Remote display (BVT);
18. System of data input-output hardware (SUVVI);
19. CRT text display (ELTI-1);
20. Series-parallel repeater (BPPR);
21. High speed printer (UBP);
22. Unit for interfacing two computers;
23. First communications interface unit;
24. Second communications interface unit;
25. "Minsk-32" computer;
26. Frequency sensors;
27. Analog sensors;
28. Digital sensors;
29. Digital information;
30. Analog information.

The realization of a particular functional structure for an automated production process control system is based on the set of hardware for performing the various functions. The contents of a set is governed by the functional algorithmic level of the automated production process control system being realized. In line with the overall requirements, the set of hardware for automated production process control systems should provide for the capabilities of retrieving, storing and processing large data files and executing a broad functional program in real time. This is achieved by connecting a large set of various peripherals to the computer. As an example, one can cite the hardware of the "Raduga K-50" control computer complex (UKV) [82]. A block diagram of such a complex is shown in Figure 14.3. The function of the units corresponds to the captions underneath the figure. The control computer complex functions with the direct input (or output) of information on the production process from analog and frequency transducers (the total number is 8,192), as well as digital sensors (up to 6,144). The technical capabilities of the "Raduga K-50" control computer complex in terms of retrieving, storing and processing large data files make it possible to use it as the topmost component in an automated production process control system, as one of the control assemblies for an automated production process control system as well as the lowest section in the complex hierarchical structure of an automated production process control system.

There are a certain number of loops in complex information and computer systems for automated production process control systems in which data is sequentially retrieved, transmitted, processed, displayed or stored. An integral part of each loop of a control complex as a whole is the programming software. Programs for control computer complexes can be broken down into groups in accordance with the functional purpose for such programs [83]. Programs in the first group are loosely linked to specific content problems which are solved by the control computers. These are programs which set up the system, test monitoring routines as well as programming automation programs and a library of standard subroutines. The second group of programs is determined to a greater extent by the specific tasks being carried out by the control computer complex, and depends in many respects on the control hardware. This group includes programs which support the monitoring of the course of the execution of the organizing programs; the monitoring of the operation of the system of peripheral equipment (transducers, actuating mechanisms, data displays); monitoring the input and output information; failure analysis, as well as the continuation of task execution after the determination of errors and dropouts.

The specific and special requirements placed on control computer complexes are taken into account by programs of the third group. These are programs for processing the signals from analog, frequency and digital sensors, programs for processing the information from the operator, correcting the mathematical model of the facility as well as controlling and feeding out information to the indicating displays.

The general design principle for the structural configuration of the software of the automated production process control system, which is shown in Figure 14.4, is formulated in [83].

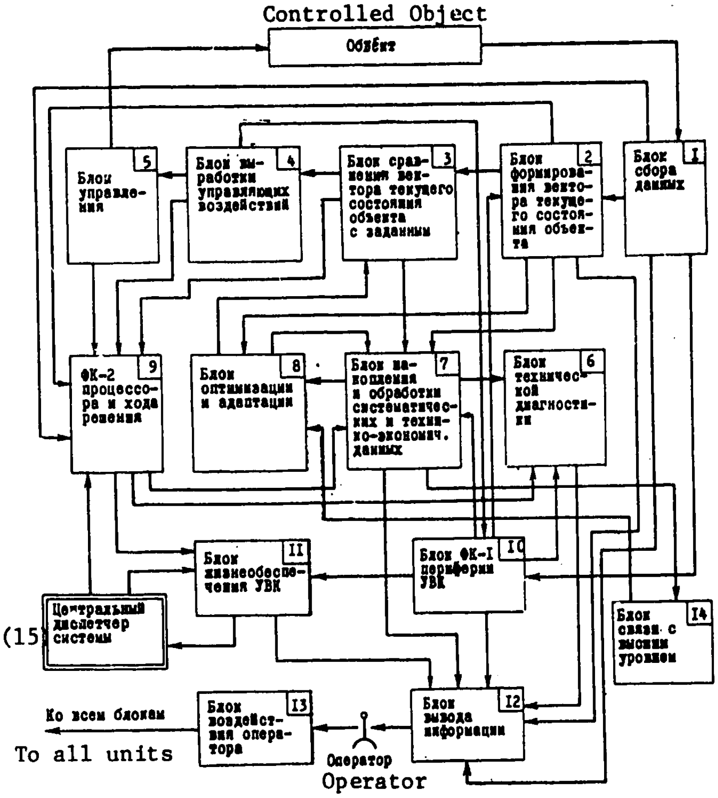


Figure 14.4. Generalized block diagram showing the software for an automated production process control system [83].

Key:
1. Data retrieval unit;
2. Unit for generating the vector of the current status of the controlled object;
3. Unit for comparing the current status vector of the controlled object with the specified vector;
4. Unit for generating the control actions;
5. Control unit;
6. Equipment diagnostics unit;
7. Unit for storing and processing system and technical-economic data;
8. Optimization and adaptation unit;
9. FK-2 processor and course of the solution [sic];
10. Block FK-I of the control computer complex periphery;
11. Control computer complex life support unit;
12. Information output unit;
13. Operator effects unit;
14. Unit for higher level interfacing;
15. Central dispatcher for the system.

The control loop consisting of the first five units performs the major control functions. In this case, the generation of the current status vector for the controlled facility is realized based on the data collected concerning the process, the data on the reliability of the input information incoming from the unit for functional monitoring of the sensors, the communications channels and partially the input information, as well as data from the operator's console. The current status vector of the controlled unit is compared with the vector specified by the mathematical model of the controlled facility, which is being corrected during the control process.

The functional reliability of automated production process control systems is assured by diagnostics hardware, units for functionally monitoring the processor and course of task execution, as well as the life support units for the control computer complex.

The set of functional blocks of the given software is applicable to a broad class of production process control systems and allows for the standardization of individual blocks within the framework of various structural-functional automated production process control systems.

The analysis of the course of the production process over some period of time and the construction of a model of the production process, if this is possible based on data on the controlled object, are necessary for the development of a structural and functional scheme as well as the support facilities of an automated production process control system for a specific production process which solves the problems of optimizing the controlled object. These tasks are performed by an automated data retrieval and processing system (ASOI).

The data retrieval and operational processing system for a planar transistor production shop [84] does the following: calculates the mean and ultimate values for the variation of the production process parameters; calculation of the output yield process for wafers and chips on a wafer; the determination of the interval distribution of the parameters being measured; the storage and feed-out upon interrogation of the data on the results of the past ten operations in the process of fabricating the functional structure of the transistor and two assembly operations for each production batch as well as the information on the course of the production process over specified time intervals (weeks, months); the generation of messages on the pace of the production cycle. Provisions are made in the system for the self-checking of the functioning and the monitoring of information at the system input and output. This system includes quality control instrumentation and information control complexes, which are tied together through the computer interfaces or by means of data stores. The shop system for the retrieval and operationally timely processing of the data on the prodution process for the planar transistors is shown in Figure 14.5. The quality control instrumentation complex automatically measures the parameters of test cells and transistor structures, and has a programmed transition from the mode for the rejection and classification of transistors according to the product groups to the mode of quantitative measurements of the parameters for the selection of devices, as well as the statistical processing of measurement results and the generation of histograms showing the distribution of the quantitative values of the measured parameters.

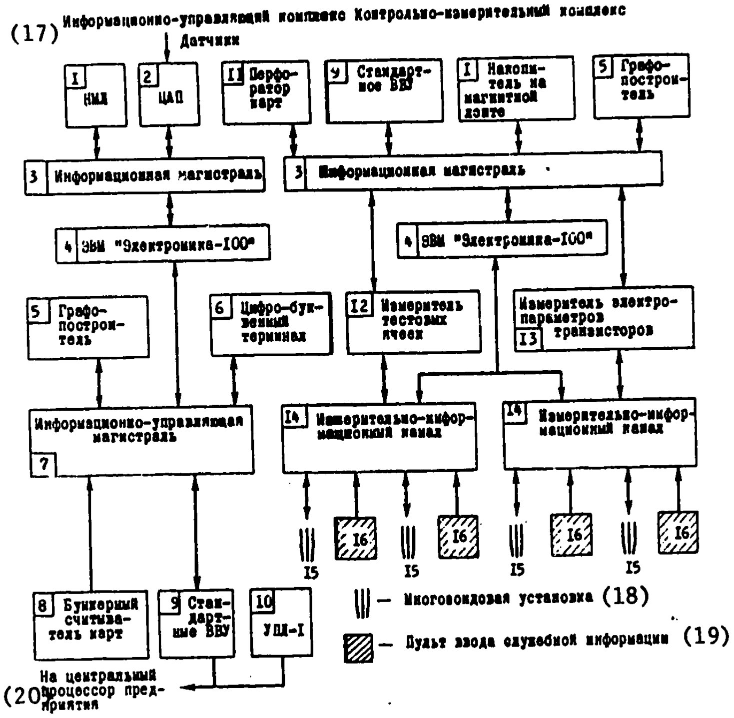


Figure 14.5. A shop level system for the retrieval and operationally timely processing of information [84].

Key:
1. Magnetic tape storage;
2. Digital to analog converter;
3. Data trunk;
4. "Elektronika-100" computer;
5. Data plotter;
6. Alphanumeric terminal;
7. Data control trunk;
8. Hopper card reader;
9. Standard input-output hardware;
10. Tape puncher;
11. Card puncher;
12. Test store location meter;
13. Meter for the electrical parameters of transistors;
14. Instrumentation data channel;
15, 18. Multiple probe installation;
16, 19. Service data input console;
20. To the central processor of the enterprise.

The generated measurement results are fed out to a printer and to punched tapes, or are transmitted to the computer of the data control complex. A provision is made for the entry of service data in the computer of the quality control instrumentation complex from the operator's work position.

The data control complex performs the following functions: determines the optimal values of the modes for specific operations in the production process based on the results of estimating the quality of previous operations in the production process and data for the starting wafers; queries the sensors concerning the course of the process; checks the readiness of the production process equipment; analyzes the operation of the equipment and generates the symbol for its operational readiness; and displays the information and signals emergency conditions.

14.3. Automated Production Process Control Systems for Several Production Steps

Individual steps in the production of discrete semiconductor devices and integrated circuits can in and of themselves be numbered among complex processes as regards the nature of the production process dynamics, number of variable parameters and the relationships between them. This applies primarily to the steps in the fabrication of the functional structures of IC's.

The information cited in the previous section attests to the comparatively great possibilities of the level attained with the functional support and hardware and software of automated control systems for complex production processes. The realization of this level is governed at the present time in many respects by the system being controlled. For this reason, the design examples treated below for automated production process control systems for individual production steps in the fabrication of semiconductor devices and integrated circuits reflect the aggregate of results in the comprehensive system: "Production process - automated production process control system".

We shall treat some of the results of a quantitative analysis of the production process for two stage boron diffusion into silicon from a liquid diffusant in a gas vehicle flow based on the data of [85].

The analysis is based on statistical modeling using linear regression methods for the influence of 14 production process factors on the surface resistance of the diffusion layer, the diffusion depth and thickness of the oxide, as well as on the coefficients of variation in these quantities. It was determined using the results of an active experiment that under the conditions of the experiment, the acting factors can be broken down into three groups:

--Controlling factors: the time of diffusant passage; the time for the first passing of dry oxygen in the second stage; the time for the passage of moist oxygen in the second stage;

--Controlled factors: the temperature in the diffusion region in the first stage and the temperature in the diffusion region in the second stage;

--Regulated factors: the specific resistivity of the starting silicon; the temperature of the thermostatically controlled feeder; the argon flow rate through the furnace during the time of diffusant passage; the argon flow rate through the

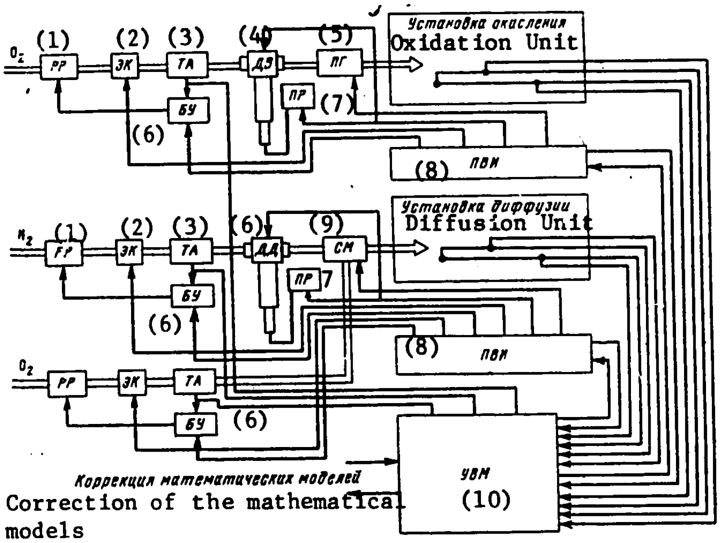


Figure 14.6. Basic schematic showing the control of diffusion and oxidation processes [86].

Key:
1. RR = Gas flow rate regulator;
2. EK = Electromagnetic valve;
3. TA = Hot-wire anemometer: gas flow rate sensor;
4. DV = Water dosing apparatus;
5. PG = Steam generator;
6. BU = Control unit for the gas flow regulator;
7. PR = Electromechanical drive for the dosing apparatus;
8. PVI = Time interval programmer;
9. SM = Gas mixer;
10. Control computer.

feeder with the liquid diffusant; the oxygen flow rate during the diffusant passage; the oxygen flow rate during deoxidation; the oxygen flow rate in the second stage; the deoxidation time in the first stage; the passage time of the dry oxygen in the second diffusion stage.

Some of the third group factors, in the case of difficulties with regulation, can move over into the second group. In governing oneself with such a breakdown, one can plan programs for the functioning of an automated production process control system which realize the following target functions:

--Maximum process reproducibility at a specified quality level for series production;

--Maximum process reproducibility following readjustment (when shifting from one products list to another);

--Mode optimization when the output product characteristics are varied where the product is produced by a given technological process in controlled production process experimentation systems under trial production conditions.

Also used as controlling factors along with the time intervals are the rates of flow of the gases, water vapor and diffusant in the automated production process control system for the diffusion and oxidation process during the fabrication of IC's [86]. A schematic of such a system is shown in Figure 14.6.

The production process is time controlled by a time interval programmer, which switches the system hardware in accordance with the specified program.

The tasks of monitoring and analyzing the stability of the fabrication process for the functional structures of IC's during the stages of the oxidation and diffusion operations with the corresponding technological processing are handled by the automated system proposed in [87]. The control computer hardware for this system is based on the "Elektronika-100" computer and operates in real time; it is equipped with a set of punched tape data input-output consoles, a set of peripheral magnetic core stores, a central post and can contain up to 64 data transmit-receive peripherals, up to 10 data punchers, up to 16 "Meandr" meters-classifiers and up to 16 automated data retrieval units.

The system for the industrial production of epitaxial silicon structures can also be treated as an example of an automated production process control system in the semiconductor production step [88]. The set of hardware for a single module in such an automated production process control system includes two "Elektronika-100" computers, which operate in a complete duplication mode, as well as data input-output hardware ("Konsul-254" electric typewriters), central posts (analog signal switchers with timers) and a central control console. Some six production process units (12 reactors) are connected to each automated production process control system module. The automated production process control system functions in accordance with the schematic shown in Figure 14.7. (X and $X_{\text{упр}}$ are the vectors for the input and control actions, and the optimization parameters are: ρ is the resistivity and d is the epitaxial film thickness).

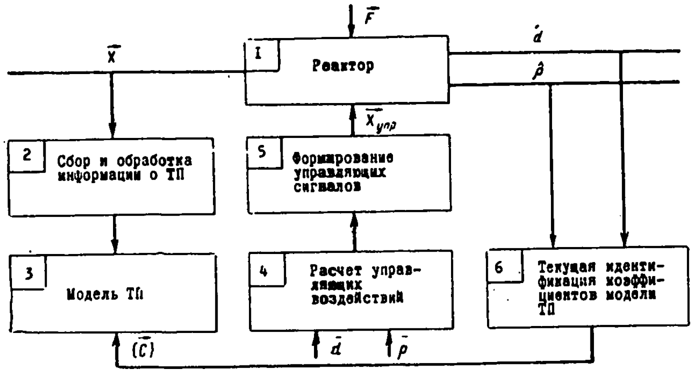


Figure 14.7. Block diagram of the automated production process control system for the fabrication of epitaxial structures [88].

Key:
1. Reactor;
2. Retrieval and processing of data on the production process;

Key to Figure 14.7. [cont.]:
3. Production process model;
4. Calculation of the control actions;
5. Generation of the control signals;
6. Current identification of the coefficients of the production process model.

During the control process, information on the criterion for the conduct of the process and the number of the operating reactor, the main hydrogen flow rate, the flow rate of hydrogen through the vaporizer, the admission of the water containing mixture into the reactor, the flow rate of the hydrogen for the dilution of the water containing mixture, the flow rate of the water containing mixture from the tank, the concentration of silicon tetrachloride in the hydrogen and on the temperature of the pyramid (on the RF induction unit current). The signals from the sensors from all of the units are fed to the central posts, are processed (compared with the specified values) where signals are present concerning the operation of the units when building up a layer, and the resulting signals are fed out to the central control console. The model is corrected in the computer (linear regression models of the process are employed) and the control signals are fed out to the system for regulating the water containing mixture. When the specified epitaxial film thickness is achieved, the process is terminated.

Thus, automated production process control systems for the industrial production of electronics hardware products differ in terms of structure, hardware and software, handle different functional tasks and have differing degrees of efficiency. However, the overall trends in the design, support and functioning of automated production process control systems make it possible to predict the rather complete standardization of the techniques and tools for automated production process control systems in the semiconductor device and IC industry in the years just ahead.

CHAPTER FIFTEEN COMPREHENSIVELY MECHANIZED PRODUCTION LINES FOR CERTAIN MASS PRODUCED TYPES OF SEMICONDUCTOR DEVICES AND INTEGRATED CIRCUITS

The structure and design of comprehensively mechanized and automated lines in semiconductor production are governed in the final analysis by both the structural design and production process features of the devices, the technology, the products list and volume of production. As applied to standard production process schemes for the production of semiconductor devices (see the Introduction, I-4), there are comprehensively mechanized lines for the production of point contact and alloy diodes and lines for the major steps in the production of planar semiconductor devices and integrated circuits, including photolithography lines, lines for the assembly of transistors and integrated circuits, lines for the final operations, etc.

The structural design features of lines are also governed to a considerable extent by the method of transporting the products, and the structural design of the interoperation and production process packaging. The most widely used means of packing and placing products in comprehensively mechanized lines and some of the characteristic lines for the mass production of semiconductor devices are described below.

15.1. Product Packing and Placement Hardware for the Major Steps in the Comprehensively Mechanized Production of Semiconductor Devices

In the mass production of semiconductor devices, the main component of the material load flow is the products being processed (the wafers of semiconductor materials, chips, parts of chips, and devices in various stages of completion), which are transferred systematically and in large amounts from operation to operation. Additionally, components of the material load flow are the production process packages and auxiliary materials (chemical reagents, coolants, etc.). A load flow with conveyor systems is the most organized type. Besides belt transporters, pneumatic transport and trays riding on an air cushion are used for this purpose. In the case of small physical volumes of materials which are supplied periodically, transport using manual or mechanized carriages, or manual delivery of the loads in specialized accessories is employed.

As was noted above (Chapter 12), the use of through-going production process satellites and a batch packing for transport between operations is an all-purpose engineering solution when setting up the material flow on automated lines. This can be seen in the example considered above (§12.4) of the production process of the fabrication of a silicon planar transistor (also see I.11). Special satellites or group packing are used in all steps of this process. These are through-going group cassette holders, which differ in the basic material, in all stages of the fabrication and treatment of the wafers (1.0 and 2.0).

In the steps of separating the waters into chips and assembly (3.0 and 4.0), the group carriers are segments of strips with the load in special cassette holders or flexible strips. The stage of finish operations is characterized by the wide scale use of through-going satellite carriers with the load in case containers.

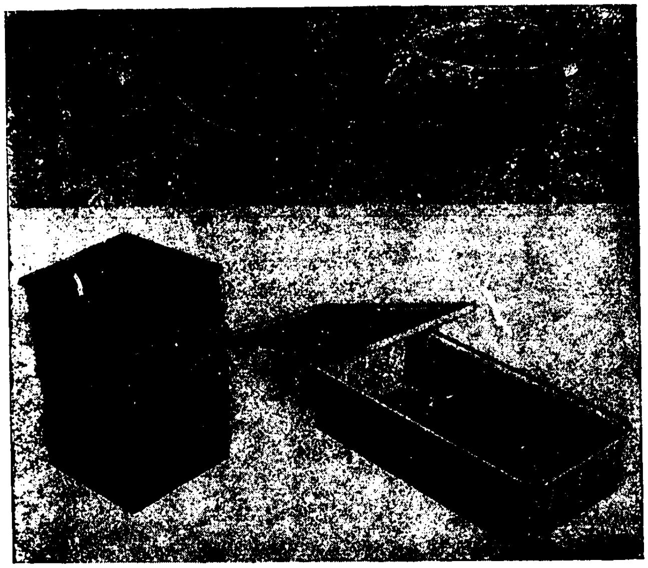


Figure 15.1. Basket container for the loose holding of products.

Nonetheless, the hardware used in comprehensively mechanized production of semiconductor devices for packing and holding the products is distinguished by a considerable diversity of structural forms and materials used.

Each kind of equipment has devices related to the placement, transport and loading and unloading of the products being processed, the considerable diversity of which is predetermined by the narrow specialization of the devices for product placement and arrangement as applied to the specific type of product.

The following are used at the present time as the standard hardware for the placement and holding of chips, capsules for devices, mounting bases, leads and finished devices on production lines:

--Basket container for the loose holding of products (Figure 15.1);

--Multicell flat and basket holders for the ordered arrangement of products (Figure 15.2);

--Cases for the oriented stowage of products (Table 15.1);

--Strip carriers for products, made in the form of small strip segments or wound into a roll (Figure 15.3).

A characteristic feature of modern comprehensively mechanized lines is the choice of a minimal products list of packing and layout hardware for products using this products list in the greatest number of operations, i.e., using the so-called through-going pack. The specific features of the various product packs are noted below where they are used as through-going holder packs.

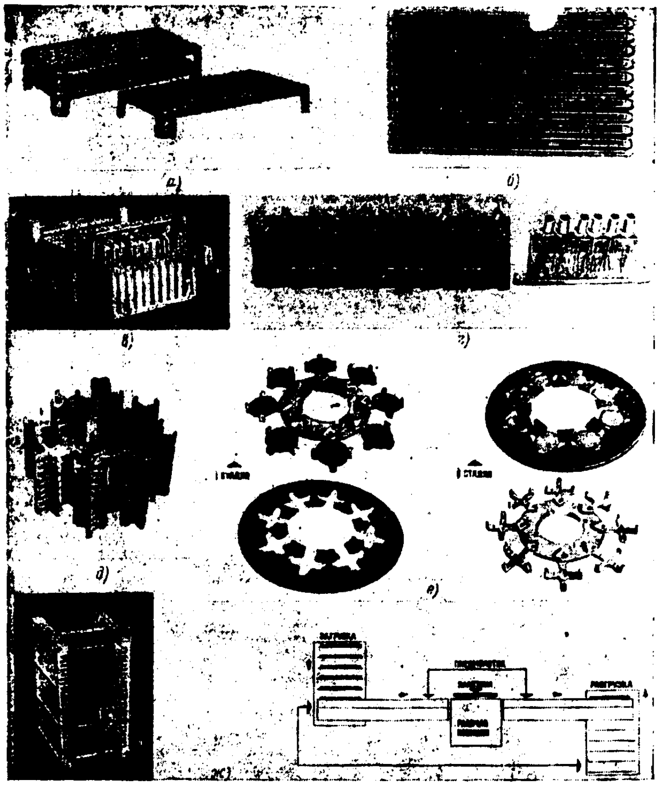


Figure 15.2. Multiple cell flat and basket cassette holders for the ordered placement of products.

Key:
- a. Cassette holder for products with circular packages;
- b. Cassette package for holding unencapsulated transistors;
- c. Fast unloading holder for the stowage of leads with a bead in the production of diodes;
- d. Cassette holder for the stowage of transistors in TO-18 packages;
- e. Flat cellular cassette holder for the stowage of wafers;
- f. Set of devices for transferring wafers from plastic to flat metallic cassette holders;
- g. Multistory cassette holder for wafers or IC frames.

The basket package for the loose holding of products is distinguished by structural simplicity and relatively large capacity for holding the products. However, the unordered loose storage is impermissible for many kinds of products. This type of product layout is the most applicable for storage between operations for low priority products in the case of small series production. As a through process holder, the basket pack with the loose holding of the products is applicable in limited cases (mass galvanic processes, for holding substandard products, etc.).

Multicell flat and basket holders (see Figure 15.2) have found the greatest applications in the production of discrete semiconductor devices and integrated circuits in performing operations manually. The accounting for the products is facilitated in multicell holders, where these products have a definite orientation. The use of such cassette holders as the through-going package is made difficult because of the complexity of mechanizing the loading and unloading of the products. The most preferred approach is to employ such a method of arranging the products where it is possible to design simple accessories and devices for the batch transferral of products into all or a certain portion of the holder cells (see Figure 15.2c). Multicell cassette holders made in the form of shelves (see Figure 15.2g) make it possible to automate the loading and unloading of products (in a specific case, wafers of semiconductor materials) using step vertical travel devices. These kinds of multicell cassette holders are being successfully used as through process holders in photolithography lines.

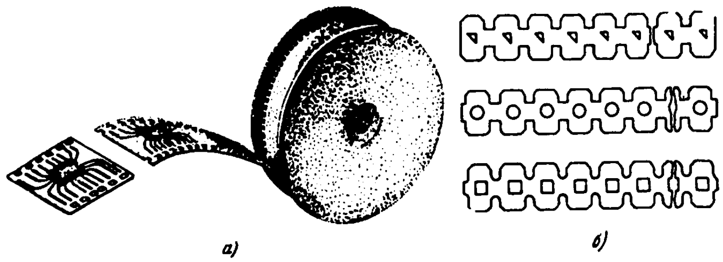


Figure 15.3. Strip carriers.

a. Strip carrier wound into a roll;
b. Multipass pack for holding transistors.

Cases for the oriented stowage of products by means of stacking (the products are placed one on the other) are adapted for gravity feed loading and unloading of the products with the action of the weight of the product itself in the case of a vertical or inclined configuration of the case [89]. The case system, just as in the case where multiple cell cassette holders are used, creates the conditions for rapid counting and taking the number of products into account. The cases themselves, in being a kind of package, can serve as the structural components of loading and unloading as well as transport devices, which makes it most effective to use the case system specifically on those lines where it is necessary to have a single package for servicing the large number of kinds of equipment. As can be seen from Table 15.1, the profile of the cases is worked out to obtain the initial blanks by a progressive technique: pressing the material through a draw die (extrusion). Further processing consists only in cutting the shaped billets into measured segments.

The stowing of discrete semiconductor devices and IC's using strip carriers is widely used in mechanized lines to produce small products, predominantly those of a flat shape (for example, "Minimod" IC packing [42], the production of transistors

TABLE 15.1. Standardized Cases for Oriented Holding of Products

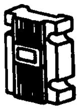
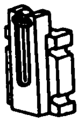
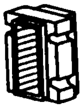
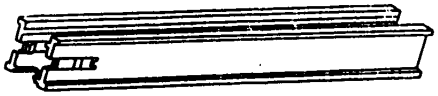
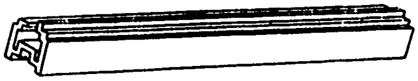
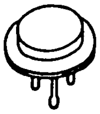
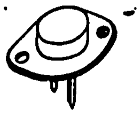
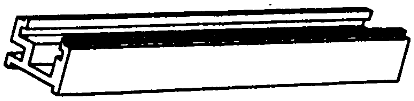
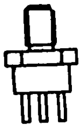
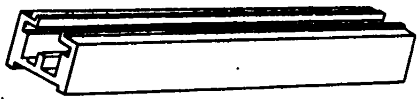
Kind of Product	Type of Case Holder	Function
1	2	
  		For the stacking of flat and bulk satellite carriers; for devices in flat packs with pin leads, and for low power transistors.
		For the holding of products in flat packages with stub leads.
 		For holding power transistors in KT-18 and TO-3 packages
		For holding devices with a screw fastener

TABLE 15.2. The Standardization of Hardware for Holding Products Using Standard Basings

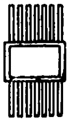
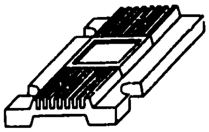
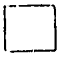
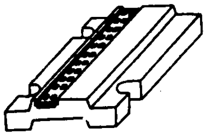
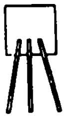
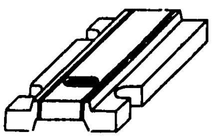
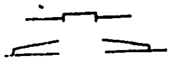
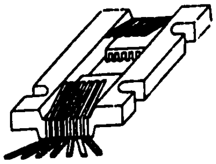
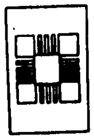
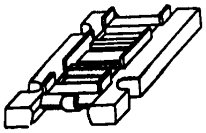
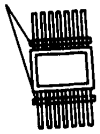
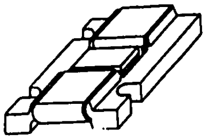
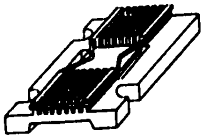
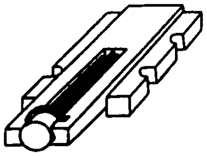
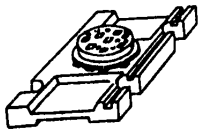
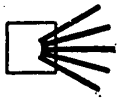
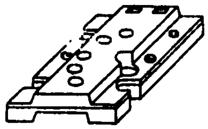
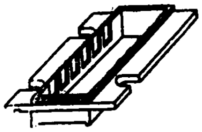
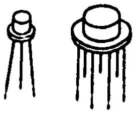
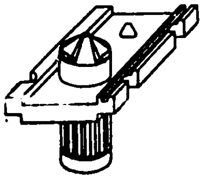
Function 1	Kind of Product 2	Base 3	Remarks 4
For integrated circuits			For automating quality control, test and individual operations when producing IC's in flat packs.
For chips			For the oriented group holding of chips, testing the parameters of the chips and automatically feeding the equipment for group or individual connection of the chips.
For unencapsulated devices			For automating the production of single chip and unencapsulated devices
For the "compressible packet" connecting device			For use as a connecting device during tests of flat pack integrated circuits.
For integrated circuits on a strip			For use in the production of integrated circuits using polyimide film.
For IC's with MOS structures	Shorting clamps 		For the production of integrated circuits with MOS structures, which require the shorting of the leads to protect against static electricity.
For flat devices			For the capless securing of products in satellites.

TABLE 15.2. [cont.]

Function 1	Kind of Product 2	Base 3	Remarks 4
For devices with leads			To secure low power transistors.
For hybrid IC's			To perform assembly and final operations in the fabrication of hybrid IC's.
For integrated circuits			For the automation of the production of unencapsulated IC's.
For products in flat packs with stub leads			For the automation of measurement and testing operations on products having a flat package with stub leads.
For products with flexible leads			For the mechanization and automation of the production of devices having flexible leads (TO-5 packages).

and IC's in plastic packages, etc.). In a number of cases, the strip carrier is used as a multipass pack for the placement and step feed of transistors with flexible leads (Figure 15.3). The strip segments, as a tool for the stowing of products, are made of metal, including the structural material of the products, if a portion or components of the devices themselves will be made from this same strip. Long multimeter strips, rolled onto spools, are made of plastics: polyimide, mylar or in the form of multilayer transfer strips, one of the layers of which has adhesive properties for the temporary securing of flat products, such as chips of semiconductor materials. Production process satellite carriers (Table 15.2) have been used recently as the packing for the individual stowage of integrated circuit chips and bulk products (transistors and IC's in TO-5 packages, flat packs with stub leads, etc.). All of the kinds of packages which were noted above may be used for the group placement of products placed in production process satellite carriers. A production process satellite carrier is a device f r the oriented placement and reliable securing of one or more products. The satellite carrier provides for the execution of a number of test operations involving temperature exposure (from -60 to +140° C) without removing the product from it; it also provides for chemical and mechanical treatment (marking, painting, contacting), etc. In being a through-process package, which goes directly with the product into the working region of the equipment when performing production processes, the satellite carrier should be made of materials having the requisite heat resistance, should stand up to mechanical loads including abrasion, and be immune to chemical corrosion, which occurs during the course of the production process. It is economically expedient to reprocess such material predominantly with injection molding machines. Polycarbonate (a heat resistance of less than +120° C), arylox (a heat resistance of up to +140° C), polyarylate (a heat resistance high than +140° C) and a number of other thermoplastics are the most widely used for these purposes.

15.2. A Comprehensively Mechanized Line for the Assembly of Pulse Diodes

The comprehensively mechanized pulse diode assembly line (Figure 15.4) which is of the intermittent flow-line type provides for the execution of the production process for the diodes from the operation of loading the cassette holders with the device elements to the quality control of the external appearance of the finished device.

The equipment incorporated in the line is characterized by a high level of mechanization and output productivity (4,500 to 6,000 devices per hour). The products are transferred using a through-going multiple place cassette holder (25 devices).

The line can be broken down into three sections: the section for producing the junction (positions I-VII), the diode assembly section (position III) and the quality control section (position VIII).

The major operations of the production process for diode assembly which are carried out on the line are the following. At positions I and III, the holders with the compensators and the assembled fittings. The loaded cassette holders are then fed to position II, where the lower and upper halves of the holder are joined, after which the assembled cassettes are fed to positions VI-VII. Here, the operators place the cassette holders under microscope 5 and check the correctness of the loaded elements of the devices. The cassette holders are then fed to the welding unit 3. After completing the welding process, the cassettes are fed to position VIII, where the operator extracts the devices from the cassettes and carries out an external inspection. Good devices are forwarded to the subsequent operations.

The main production process is producing the p-n junctions and is accomplished on the welding unit. The unit has two electric heaters for preheating the cassette holders, which provide a temperature of +300° C, as well as two molybdenum heaters, by means of which the working temperature in the welding region for the device elements is maintained at 1000 + 200° C. Nitrogen is fed to the installation to provide an inert medium in the regions for the welding and preliminary heating. The welding unit and the enclosure for preheating the cassettes are mounted on

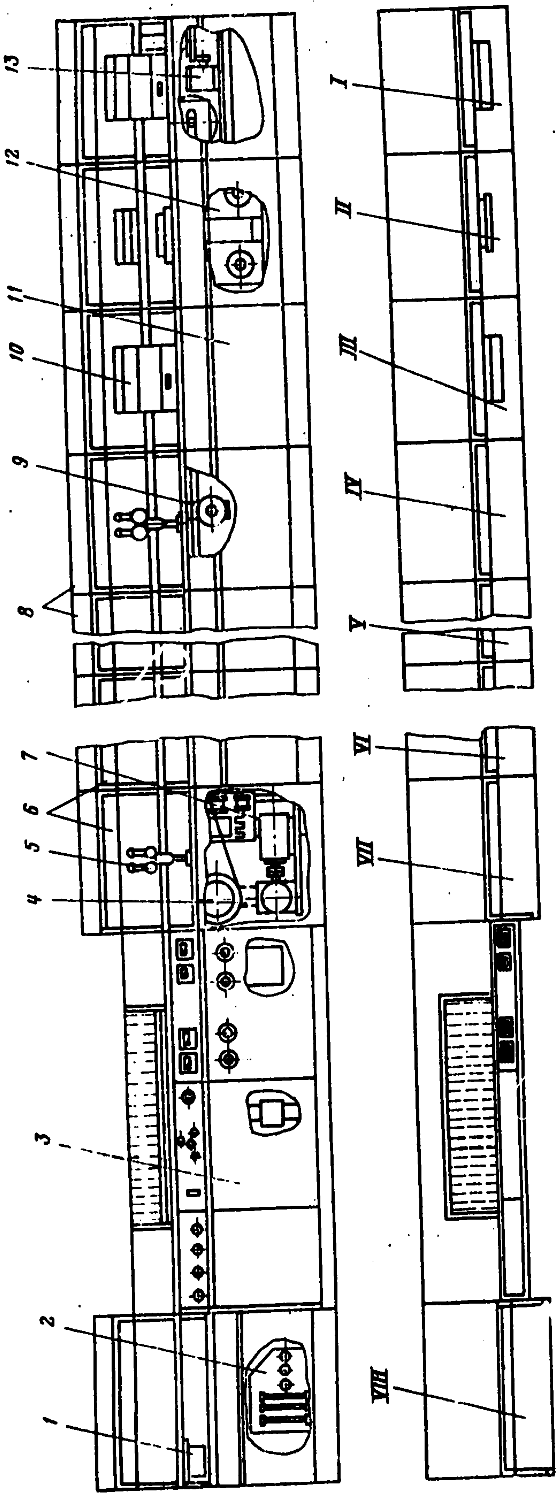


Figure 15.4. A comprehensively mechanized line for assembling diodes.

three support plates, which are positioned in the frame. Water is fed through a header for cooling and heat removal during the process of operating the unit. The temperature of the drain water should be higher than 30° C. This is accomplished by using a valve to regulate the quantity of water fed into the heaters.

The cassette holders are moved in the operation of loading the device components (positions I-III) and for quality control (positions IV-VII) by means of the transporter 4, which consists of the drive, including an asynchronous electric motor and reducer, tension roller, support rollers 9, limiters and the belt. The rate of travel of the transporter belt is 7 m/min. The electric motor is controlled by means of the instruments and hardware located on panel 7. The conveyor 13 moves the loaded cassettes from positions IV-VII to the welding operation and then on to position VIII, and also returns the free cassettes from the last operation to position II. The cassettes are placed in positions IV-VII on the conveyor so that the cassette pin by means of which the conveyor chain, which has a ring for catching the cassettes, moves the cassette along the guides and must necessarily be located at the front of the cassette relative to the conveyor travel. By virtue of adjusting the conveyor speed (up to 1.17 m/min), the welding time is set in a range of from 17 to 45 seconds. The conveyor consists of a drive which includes a DC motor and reducer, the tensioning unit for the chain 1 and the drive sprocket wheels.

The work of the operators at all of the working positions, with the exception of the welding unit, is carried out on the tables 11, which have a protective enclosure 6, in the upper portion of which there are lights 8. The tables and protective enclosures take the form of welded metal frames. The tables have metal sheathing, an upper plate and boxes, where the requisite tools and attachments are located. The framework of the protective enclosure is covered with plexiglass walls. There are plates with guides in the protective enclosures along which the cassette holders travel.

The magnetic loader 10 at working positions 1 and 3 provide for the placement of the device holders, as well as the assembled fittings in a vertical position for the purpose of convenience in loading them into the cassette nests. The magnetic field is generated by two electromagnetic coils, which are controlled by means of the apparatus and instruments located on panel 12.

There are direct reading flow meters and valves on gas panel 2 for adjusting the amount of nitrogen fed into the welding unit.

15.3. The Comprehensively Mechanized Assembly Line for D226 Diodes

The comprehensively mechanized line for the assembly of silicon alloy D226 diodes provides for the execution of the production process for the indicated diodes from the loading of the chips into the cassette holders to the packing of the finished devices. The line equipment is arranged in the production process sequence shown in the schematic of Figure I.9. The line equipment can be broken down into three sections: the equipment for producing the junction; the section for assembling the diode, and the section for production process testing, classification and final assembly.

The line is characterized by a high level of mechanization and equipment productivity. The group method of assembly and treating the parts is employed in the labor intensive operations of loading the graphite cassettes prior to alloying, unloading the cassettes after the flashing-off operation, and checking for a hermetic seal and tinning of the leads.

A line speed monitor panel is installed on the line. Information is fed to the panel from monitor points on the line, and from the operations of checking the volt-ampere characteristics of the junctions. Such information precludes the role of a subjective factor in determining whether a product is good. The presence of a speed checking panel makes it possible to strictly account for the finished products and control the course of the production process in an operationally timely manner.

The group loading of the graphite cassettes with gold spacers, silicon chips, graphites plug and aluminum electrodes is carried out using a semiautomatic loading unit. Some 100 of the indicated elements are loaded simultaneously. The loading is accomplished by means of vibration loaders and group vacuum suction attachments.

The junctions are fused in a carousel type vacuum furnace with an automatic operational cycle.

The fused-in junctions in the cassette holders are forwarded to the cassette unloader, where the group unloading of the cassettes is accomplished by means of a vacuum suction attachment and the quality of the alloying is visually inspected. The graphite cassettes from the unloader are again fed to the semiautomatic loader in fluoroplastic cassettes which loosely hold 400 items in each one and are forwarded to the etching unit. The junctions are washed with deionized water in this same unit. The junctions are dried in an ultraviolet conveyor furnace, after which they are transferred to the unit for automatically applying a protective coating and drying them. To provide for high device reliability, the operations of drying the junctions and applying the protective coating are carried out in a nitrogen atmosphere. The cassette holders are transferred in this case into the units in a hermetically sealed package through a special lock, which has an inert gas delivery system. The junctions, which have been varnished and placed by an automatic unit in the nests of the fluoroplastic cassette holders, undergo drying in a radiative heat furnace with a controlled environment. The junctions are then fed in the cassette holders to the unit, where in addition to cutting the leads with a special attachment, a sample 20% quality control check is made of the junction parameters based on the "Go--No go" principle. The junctions with the trimmed aluminum leads are fed to a semiautomatic unit for attaching the junctions to the final leads.

A unit for assembling the diodes on a continuous belt is of particular interest, where the assembled junctions are fed to this unit. The belt serves as the transporting element and simultaneously as the material for the fabrication of the chip holder of the diode being assembled. Some 14 operations are carried out in the unit: from the cutting out of the perforations and the forming of the chip holder to the cutting out of the sealed diode.

The following operations are performed in the assembly unit: 1) The cutting out of the perforations and the forming of the chip holder on the strip; 2) The degreasing of the strip; 3) The welding on of the lower lead; 4) The application of flux and the tinning of the chip holder; 5) The washing away of the flux; 6) The drying of the strip; 7) The placement of the junctions on the strip in special cassette holders; 8) The soldering of the junctions to the strip; 9) The placement of the capsules on the chip holder (on the strip); 10) The welding of the capsule onto the chip holder (strip); 11) The crimping of the capsule tube; 12) The welding on of the capsule tube; 13) The welding on of the upper lead; 14) Cutting the finished and assembled diode out of the strip.

The finished diodes which are cut out of the strip have burrs at the cutout points. The burrs are removed on an automatic roll flattening unit, from which they are forwarded to the operations of checking the hermetic seal, thermal cycling, and quality control of the electrical parameters and mechanical testing. The devices are then sent on to the degreasing and drying operation, which is carried out in an automatic unit. This operation is necessary for the subsequent operations of tinning the leads, and painting and drying the diodes.

The leads are tinned in an automatic unit by the batch method. The diodes with the tinned leads are automatically fed to a diode washing and drying installation. The diodes which are dried out after washing are forwarded to a painting and drying unit.

The painted and dried diodes undergo testing for moisture resistance and are then forwarded to a automatic classifier. The D226 diodes are classified with respect to the electrical parameters into four groups, according to the inverse current and forward voltage drop under normal conditions.

The marking and drying of the labeling for the diodes are carried out in an automatic marking and drying unit. The labeling is dried in a radiative heat chamber of the automatic unit, after which the electrical parameters of the devices are tested. The visual inspection of the external appearance of the finished device is made by an operator at a separate working position.

The good diodes which have been checked for external appearance are packaged in cardboard strips (in an automatic packing unit). The cardboard strips with the diodes loaded in them in an automatic unit in groups of 20 pieces each are then manually loaded into cardboard boxes in packs of 5 each and turned over to the warehouse.

15.4. Comprehensively Mechanized Lines for the Major Steps in the Production of Planar Transistors and Integrated Circuits

In contrast to the standard assembly lines for specific types of diodes treated above, a trend has been noted in recent years towards the design of all-purpose lines, suited to the production of a broad products list of semiconductor devices, both discrete types and IC's, manufactured using planar technology. Lines are described below which are used in photolithographic processes, in the assembly and final operations in the production of planar transistors and integrated circuits.

An Automated Photolithography Line

Automated lines used in production for photolithography processes are described in detail in Chapter 5, which is devoted to equipment for photolithography processes. Given below in Figure 15.5 is a schematic of yet another structural variant of an automated photolithography line using four track installations, operating on the principle of linear transport of the wafers using a so-called air cushion. The scheme for transporting the wafers on an air cushion is shown in Figure 15.6. The use of this method of moving the wafers, which precludes contact between the working surface of a wafer and the tool (tweezers), reduces the formation of breaks at the edges of wafers as well as the breakage of large diameter wafers to a considerable extent. Depending on the number of working tracks used in the production process, one can obtain a productivity of 100, 200, 300 and 400 wafers/hr.

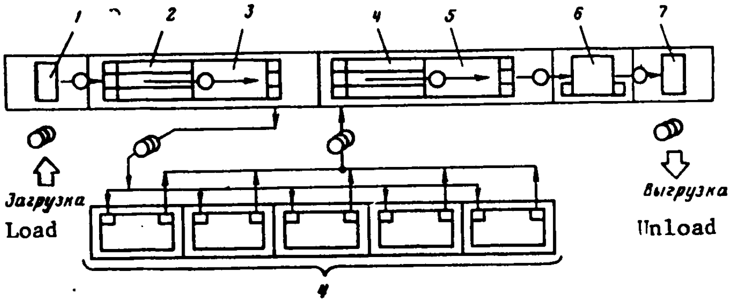


Figure 15.5. An automated photolithography line.

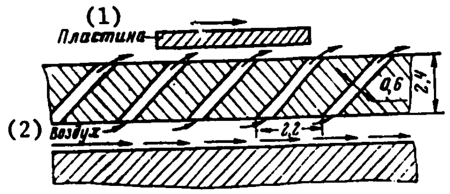


Figure 15.6. Schematic showing the transport of wafers on an "air cushion".

Key: 1. Wafer;
2. Air.

The line (see Figure 15.5) consists of an automated comples for producing the relief in the photoresist and an automated complex for forming the topology on the semiconductor wafer. It includes automated unit 2 which applies the photoresist film to the surface of the semiconductor wafer; automated unit 5, intended for developing the relief of the photoresist on the wafer surface; installation 3 which heat treats the photoresist applied to the wafer; the match-up and exposure unit 4; unit 6 in which the developing of the wafers, the precision of the matching and the dimensions of the elements are quality controlled and the photoresist film thickness is measured; the devices for loading the wafers into the cassettes, 1, and unloading them from the cassettes, 7.

A wafer does not come in contact with either the tools or the hand of an operator on the line during the entire production process; this prevents the contamination, damage and breakage of the wafers. The use of a set of standardized cassettes for wafers of various diameters makes it possible to resolve questions of production organization in an optimal manner. The wafers are reloaded from one type of cassette to another by means of joining them together and tipping over, which makes it possible to significantly curtail the labor requirements for the transloading operations. Automatic reloading of the cassettes into devices for receiving and feeding out the wafers is also used in the line for the purpose of utilizing the given devices as automatic storage holders ahead of installations with a semiautomatic operating mode. The use of the line described here in the production of integrated circuits with individual processing of the wafers using the "cassette to cassette" technique, as well as the control of the sequence and duration of the production process operations (the feeding of the wafers to the working position, the production processing mode and the feeding of the wafers to the receiving cassette), which are realized from the control console, make a whole series of advantages possible, including:

--Precise observance of the processing modes at the working positions;

--A constant output productivity for the holding of the wafers between operations;

--The lack of contact between the working surface of the wafers and the tools or hand of an operator;

--The elimination of large diameter wafer breakage during their transportation;

--The choice of optimal productivity by virtue of a 1, 2, 3 or T-track layout;

--Operation in accordance with a specified program which assures precise reproducibility of the production process modes, which precludes the influence of subjective factors to the maximum extent.

An Automated Assembly System

One of the problems of assembly automation is feeding preoriented chips which have been classified into groups to the assembly operations [91]. As an example of a solution to this problem, one can cite the TAC-1000 system designed by Teledyne Tac (U.S.), in which all of the operations are automated - from the probe testing of the wafers to the connection of the chips.

The new system consists of a set of equipment, including the unit for probe testing the wafers, the installation for match-up and assembly, a strip sorter, an optical autorecorder, installation for scribing and breaking the wafers, a matching unit, a measurement unit, chip sorter, indexing device and chip separation unit.

A semiconductor wafer is placed on the probe unit, in which the parameters of the chips are checked; the results are recorded on a photographic plate, in which case, they are arranged in a manner similar to the layout of the chips in the wafer. Then the wafer is glued to an adhesive film and broken into chips. A broken wafer on the film and the photographic plate with the recorded measurement results for the devices are mounted on a common frame in an oriented manner, where this frame is placed on the sorter. The chips are removed from the film in this unit and glued to strips in accordance with the categories recorded on the photographic plate. Chips of a particular group are fastened to each strip, where these chips are glued to the strip in an oriented manner and are ready for assembly.

Rejected chips are not removed from the film. This system has made it possible to sharply boost the productivity of the operations of preparing chips for assembly. The automated TAC-1000 system, according to advertisement data, provides for sorting up to 5,000 semiconductor chips per hour. This system has made it possible to avoid the operations of restowing chips, sorting them, manual orientation as well as a number of others.

A Line for Final Operations in Integrated Circuit Production Using Production Process Satellite Carriers

The line (Figure 15.7) provides for performing the final operations of integrated circuit fabrication, starting with the cutting of them out of the frames and ending with the packing.

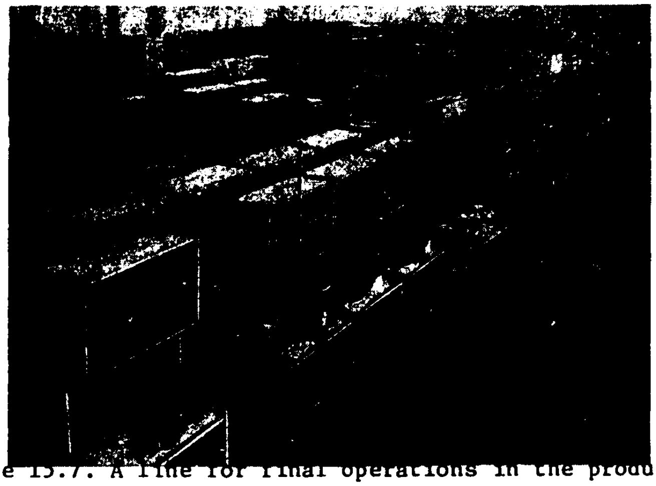


Figure 15.7. A line for final operations in the production of integrated circuits using production process satellite carriers.

An automated holding case system for loading (Figure 15.8), unloading (Figure 15.9) and transporting the products (Figure 15.10) is used in the line, where this system is standard for the design of standardized hardware for holding devices from a broad products list using production process satellite carriers. The use of such a system makes it possible to implement a high level of production organization on the IC fabrication section and to obtain a high productivity in each operation.

The line equipment is arranged in accordance with the production sequence for the processes being performed.

The oriented loading of the satellite carriers into the holding cases from a vibration hopper is accomplished in the packing automat. Then the integrated circuits are cut out of the frame in a semiautomatic unit, they are packed in the satellite carrier and it is loaded into the case. The loaded case is fed to

Figure 15.8. A standardized assembly for loading satellites into a cylindrical case.

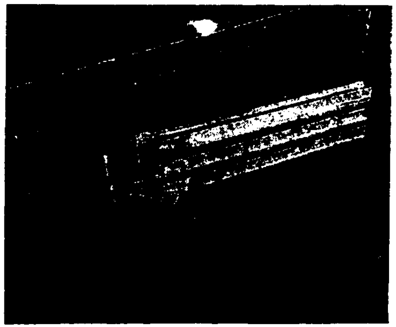


Figure 15.9. Standardized assembly for unloading satellites from a cylindrical case.

the unit where the integrated circuits are checked visually. The operation of securing the integrated circuits in the satellites by means of caps is carried out in the next semiautomatic unit. The devices are automatically loaded into the working position and they are automatically unloaded into the holding case following the operation of installing the caps.

The integrated circuits are automatically sorted into three groups in the universal sorter: "Good", "Reject", "No Contact". The sorter has a carrying case system for loading the devices into the contacting position and unloading them while maintaining their orientation following the measurements. This provides for a significant reduction in rejects based on the external appearance of the integrated circuits. The cases with the IC's are fed from the sorter to an automated flow-line chamber, where the IC parameters are measured after they are exposed to temperatures of -65 and +140° C. The devices are automatically loaded from the case. The exposure time in the chamber is from 1 to 12 minutes. The average rate of change of temperature in the useful volume of the chamber in a range of 25 to 140° C is 2°C/min and in a range of from +30 to -65° C, is 1.5°C/min.

The integrated circuits are then fed to an automatic unit where a label is applied to the package, something which is monitored visually. In the subsequent operation, the labeling is varnished and then the IC's are fed to the drier.

The electrical and thermal conditioning stand is intended for simultaneously conditioning 2,000 IC's by exposing them to square wave pulses at a frequency of 50 Hz and temperatures of 50 to 125° C. It is possible to simultaneously condition up to 10 types of integrated circuits in the stand, depending on which interchangeable printed circuit boards with holders for the IC's are used in the test stand. The temperature fluctuation at the operating point is less than 2° C during the aging process. Each thermal control unit provides for a temperature setting precision of +1° C. The time needed to reach the operating conditions in

Figure 15.10. Case for the transportation of products.

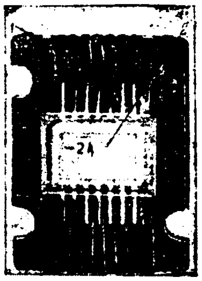


Figure 15.11. Production process satellite carrier.

the heat chamber is no more than 120 minutes. The display unit provides for monitoring the operating modes in all of the printed circuit boards loaded into the heating chamber.

The automated IC sorter takes the form of a standardized version of the sorter noted above. It provides for sorting the IC's into 12 groups upon instructions from an external meter. The cases with the IC's of each group are fed to the installation for removing the caps, where the caps are removed and the integrated circuits in the satellite are unfastened. The cases with the IC's in the satellite carriers are fed to this operation in the case where it is necessary to remove an IC from the satellite. The integrated circuits are transported to the finished product warehouse following packaging in a special installation.

Integrated circuit unloading devices made in the form of eight position case holders which are automatically controlled are used in the majority of installations, where these units provide for filling the devices after the production process operations are performed.

The contacting devices used in the individual installations provide for the automatic connection of the leads of the circuits being tested to the instrumentation hardware (see §9.4). When testing integrated circuits, the connecting devices are replaced after no more than three minutes. The range of working temperatures at which one million actuations is guaranteed runs from -65 to +155° C.

As was described above, the cases used in the complex provide for the storage, stacking, loading, unloading and transport between operations of the production process satellite carriers with the IC's. The capacity of a single case is 150 satellites. The cases are fabricated by means of extrusion from an aluminum alloy; the structural design provides for holding the circuits in the case during transportation between operations and makes it possible to load and unload them while preserving the orientation of the IC's.

The cases can also be used for the placement of satellite carriers with flat pack IC's having pin leads in TO-5 packages with standard basing, similar to the basing of the satellite carrier for flat integrated circuits. The production process satellite carrier (Figure 15.11) takes the form of the housing 1 and the cover 2, and is fabricated from polysulfone, polyarylate, arylox and polycarbonate. The indicated plastics have good heat resistance (about +130° C), wear resistance and immunity to corrosive media.

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