

AUTHORS: Boltaks, B. I., Prokhorova, V. M., 57-28-5-13/36  
Novozhilova, L. I.

TITLE: Diffusion of Antimony in Germanium Alloyed With Antimony  
(Diffuziya sur'my v germanii, legirovannom sur'moy)

PERIODICAL: Zhurnal Tekhnicheskoy Fiziki, 1958, Vol. 28, Nr 5,  
pp. 990-995 (USSR)

ABSTRACT: In this paper the authors communicated the results of  
the investigation of the antimony diffusion in monocry-  
stalline germanium ingots, which had been alloyed with  
different amounts of antimony. These preliminary results  
are part of the general investigation conducted in the  
laboratory of the influence of the donor- and acceptor  
impurities on the diffusion processes in the semiconduc-  
tor. The diffusion coefficients were measured in a wide  
temperature interval (from  $\sim 650$  to  $\sim 920^{\circ}\text{C}$ ) and in nume-  
rous samples (numbering 60). Table I and figures 1-4 show  
the obtained results from each series of samples with a  
uniform antimony content. The relative antimony content  
in germanium was too low as to result in a marked modifi-

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cation of the lattice constant of germanium or of the eigenfrequency. For this reason the observed increase of  $D_0$  can be attributed to the augmentation of the activation entropy  $\Delta S$ . Apparently this is connected with the general increase of the system entropy, which is caused by the transition of the system from an ordered into a less ordered state, as the concentration of the impurities also leads to an increase of the concentration of vacancies in the lattice and therefore to an increase of disorder in the system (table 3, figure 8). The increase of activation energy observed with an increase of the antimony concentration does not fit into the usual conceptions on the character of the influence of the impurities on the binding energy of the lattice. Apparently factors as yet unknown play a rôle here. The modification of the free energy of the system possesses a minimum value at any temperature and at any arbitrary concentration, this value corresponding to the most stable state of the system at the respective concentration.

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Further experimental experience on the influence of low

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impurity concentrations on the diffusion processes will permit to determine the diffusion character in solids, in particular in semiconductors. There are 8 figures, 3 tables and 13 references, 10 of which are Soviet.

ASSOCIATION: Institut poluprovodnikov AN SSSR, Leningrad  
(Leningrad, Institute for Semiconductors, AS USSR)

SUBMITTED: August 17, 1957

1. Antimony--Diffusion    2. Antimony-germanium alloys  
--Properties

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AUTHOR: Boltaks, B. I.

57-28-5-14/36

TITLE: On the Problem of the Anomalous Diffusion Velocity of Some Elements in Germanium  
(K voprosu ob anomal'noy skorosti diffuzii nekotorykh elementov v germanii)

PERIODICAL: Zhurnal Tekhnicheskoy Fiziki, 1958, Vol. 28, Nr 5, pp. 996-998 (USSR)

ABSTRACT: In order to determine the causes of an anomalously high diffusion velocity of the elements of period I and VIII of the periodic system in germanium it is sufficient to investigate the causes for their solubility in germanium. The author devoted this paper to this problem. As can be seen from table 2, the elements of period I and VIII, as contrary to period III and V are completely lacking p-electrons, which cause the basic binding in the crystal lattice of germanium. On the other hand, the difference between the electronegativity of these elements and that of germanium is very small. Also ion formation plays an insignificant rôle here. All these facts contribute to an

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unstable state of the atoms of period I and VIII in the sites of the crystal lattice of germanium, leading to their low solubility and their high diffusion velocity. For this reason, the anomalously high diffusion velocity and the low solubility of the elements of period I and VIII of the periodic system is caused by the considerable difference between the electron configuration of the shell of the valence electrons of these elements and the germanium atoms. This difference is less marked for elements of the period III and V, these exhibiting therefore a better solubility and a smaller diffusion velocity in germanium. The here presented considerations are also valid for other semiconductors and can be used as a criterion for the choice of quickly or slowly diffusing impurities in semiconducting materials. In this instance, however, the values of electronegativity of the solvent atoms and of the dissolved substance must be taken into account. If the difference in electronegativity is great, a new phase will be formed because of the ion binding. This will result in another diffusion character. The author is indebted to A. F. Ioffe for discussion of the problem.

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On the Problem of the Anomalous Diffusion  
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There are 2 tables and 7 references, 4 of which are  
Soviet.

ASSOCIATION: Institut poluprovodnikov AN SSSR, Leningrad  
(Leningrad, Institute for Semiconductors, AS USSR)

SUBMITTED: January 28, 1958

1. Chemical elements--Diffusion 2. Germanium crystals--Analysis

Card 3/3

AUTHORS: Boltaks, B. I., Sozinov, I. I. 57-28-5-17/36

TITLE: Influence of the Electric Field on the Diffusion of Antimony in Rock Salt Crystals (Vliyuniye elektricheskogo polya na diffuziyu sur'my v kristallakh kamennoy soli)

PERIODICAL: Zhurnal Tekhnicheskoy Fiziki, 1958, Vol. 28, Nr 5 pp. 1012-1018 (USSR)

ABSTRACT: In the present paper antimony served the authors as an object for the investigation of diffusion in rock salt, antimony being an element with chemically amphoteric properties. The antimony diffusion was investigated in wide temperature range as well as the influence of a constant electric field on the diffusion. The obtained results partly supplement the existing experimental data and the conceptions on the diffusion mechanism of foreign impurities in the lattice of rock salt. The first series of experiments was devoted to the determination of the diffusion coefficient of antimony in NaCl-crystals at different temperatures of diffusion annealing, (figure 2). The second series essentially amounted to an examination of the character of the influence of a constant electric field on the antimony diffusion in NaCl. The shift of

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in Rock Salt Crystals

the maximum of the concentration curves towards the anodes indicated, that the antimony in NaCl crystals is shifted in the form of negative ions. The analysis of these curves also permits to evaluate the value of the charge of the diffusion ions. It can be assumed, that the antimony exists in the NaCl lattice in the state of treble charged negative ions  $Sb^{3-}$ . It was shown, that the dependence of the diffusion coefficient on temperature can be expressed by the equation:

$$D_{Sb \rightarrow NaCl} = 0,076 \exp(-1,8 \text{ eV}/kT) \text{ cm}^2/\text{sec}$$

From a comparison of the ionic radius of  $Sb^{3-}$  with the ionic radii of other negative ions,  $Br^-$  and  $J^-$  (table), which diffuse by anionic vacancies, it can be concluded, that such a dislocation mechanism is possible in the case of the ion diffusion of  $Sb^{3-}$ . In order to satisfy the neutrality conditions three anion vacancies must be created for each  $Sb^{3-}$  ion in the lattice of NaCl. This amount of vacancies can exceed the thermally equalized concentration and can cause local disturbances in the lattice as well as the occurrence of a new phase. In the table also data on the activation energy of the  $Cl^-$ ,  $Br^-$  and  $J^-$ , and  $Sb^{3-}$  ions at the diffusion in NaCl are

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compared and the electron affinity of these elements is given. In this case an apparently not random regularity is observed. The reduction of the activation energy with an increase of the radius of the impurity ions can be caused by the greater deformation of the surrounding medium and the reduction of the potential energy connected with it. On the other hand, the probability of a separated existence of the impurity atoms and of the electrons absorbed by them is increased by the reduction of the electron affinity of the element. This can also lead to a reduction of the activation energy during diffusion. The possibility of a separate existence of the impurity atoms and of the electrons absorbed by them (during the period  $t_a < t_i, t_i$  denoting the "life" of the ionic state) must also lead to a deviation from Einstein's equation, disregarding which complexes (or phases) are produced. This effect also was observed. There are 6 figures, 1 table and 13 references, 6 of which are Soviet.

ASSOCIATION: Institut poluprovodnikov AN SSSR, Leningrad (Leningrad, Institute for Semiconductors, AS USSR)  
SUBMITTED: August 17, 1957 1. Antimony--Diffusion 2. Electric fields--Applications  
Card 3/3 3. Sodium chloride--Crystal structure

**AUTHORS:** Boltaks, B. I., Mokhov, Yu. N. 57-28-5-22/36

**TITLE:** Self-Diffusion and Diffusion of the Impurities in Lead Telluride and Lead Selenide (Samodiffuziya i diffuziya primesey v telluride i selenide svintsa)

**PERIODICAL:** Zhurnal Tekhnicheskoy Fiziki, 1958, Vol. 28, Nr 5, pp. 1046-1050 (USSR)

**ABSTRACT:** In the present paper the authors communicated the results of the investigation of the self-diffusion of tellurium and the diffusion of antimony and tin in lead telluride as well as data on the diffusion of antimony and selenium (self-diffusion) in lead selenide. Lead telluride and-selenide crystallize in a structure of NaCl-type. The character of binding, however, in these compounds differs considerably from a pure ion binding, which is distinctive of rock salt. The combination of ion- and covalent binding in PbTe and PbSe leads to a reduction of the heat of formation as related to the gram equivalent and therefore also leads to a reduction of the cohesive forces between the components of these compounds (Ref 4). The relatively small values of the activation energy during self-diffusion in PbTe agree with the small values of the heat of formation of these

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Lead Telluride and Lead Selenide

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compounds. The heat of formation of PbTe equals 16,8 kcal/g-mol, which is considerably less than in a considerable number of analogous semiconductor compounds. The dislocation of Sb and Sn in the crystal lattice apparently proceeds according to the lead vacancies, and is accompanied by the formation and the destruction of the complexes  $Sb_2$ ,  $Te_3$ ,  $SnTe$ , and  $Sb_2Se_3$ , the cohesive forces of which are greater than those of the components of the base lattice. This latter phenomenon apparently causes the observed "anomaly" in the interrelations between the values of the activation energy in the self diffusion and the heterodiffusion of the investigated elements in PbTe and PbSe. As the heat of formation of PbSe is greater than that of PbTe the considerably higher values of the activation energy for the self- and heterodiffusion in lead selenide in comparison to lead telluride become understandable. There are 2 figures, 2 tables, and 5 references, 4 of which are Soviet.

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Lead Telluride and Lead Selenide

57-28-5-22/36

ASSOCIATION: Institut poluprovodnikov AN SSSR (Institute for Semiconductors,  
AS USSR)  
Leningradskiy politekhnicheskij institut im. M.I. Kalinina  
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SUBMITTED: September 18, 1957

1. Lead selenide--Impurities
2. Lead telluride--Impurities

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21(7)

## AUTHORS:

Boltaks, B. I., Plachenov, B. T.,  
Semenov, Ye. V.

SOV/20-123-1-18/56

## TITLE:

On the Absorption Coefficient of  $\gamma$ -Rays of  $\text{Co}^{60}$  in Semiconductors  
(O koeffitsiyente pogloshcheniya  $\gamma$ -luchey  $\text{Co}^{60}$  v  
poluprovodnikakh)

## PERIODICAL:

Doklady Akademii nauk SSSR, 1958, Vol 123, Nr 1, pp 72-75  
(USSR)

## ABSTRACT:

The present paper gives the results of measurements of the  $\gamma$ -ray absorption coefficient of  $\text{Co}^{60}$  ( $E_{\gamma 1} = 1.17$  MeV,  $E_{\gamma 2} = 1.33$  MeV) in some semiconductor materials of different degrees of purity and different modifications as well as in some metals (Al, Zn, Pb). Measurements were carried out with respect to these metals mainly for the purpose of checking the experimental method. The measuring apparatus used is schematically shown in form of a drawing. The measuring results are given in a table. The results obtained by the present paper differ from those obtained by other authors by not more than 3.5%. The absorption of  $\gamma$ -rays

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On the Absorption Coefficient of  $\gamma$ -Rays of  $\text{Co}^{60}$   
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of  $\text{Co}^{60}$  in the materials under investigation is caused nearly entirely by Compton (Kompton) scattering. Photoelectric absorption is less than 1% in the case of most of the samples investigated. An exception was formed only by the Te, Pb and PbTe samples; the share of photoelectric absorption in them amounted to ~8, ~25 and ~15% respectively. The absorption coefficient values given in the table were calculated by means of the usual formulae of the theory of the absorption of  $\gamma$ -rays in matter. The difference between measured and calculated absorption coefficients is larger in semiconductors than in metals. Besides, the absorption coefficient also of infinitesimally small concentrations depends on impurities in the investigated semiconductors (and in selenium also on structure, i.e. on the modification of the sample). Semiconductors differ from metals mainly by the concentration of the free current carriers. The authors determined the temperature dependence of absorption on  $\gamma$ -rays in the case of some samples of germanium, silicon, and tellurium with different degrees of purity and different characters of conductivity.

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On the Absorption Coefficient of  $\gamma$ -Rays of  $\text{Co}^{60}$   
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On the same samples the Hall (Khol) effect was measured, and the variation of the concentration of current carriers in the investigated temperature interval was determined. The results of these investigations, which are shown by 2 diagrams, make it perfectly clear that the absorption coefficient of

$\text{Co}^{60}$   $\gamma$ -rays increases in the semiconductors under investigation in proportion to the concentration of the free current carriers. A similar dependence holds also if  $\text{Sn}^{113}$  serves as a source of the  $\gamma$ -rays. The results obtained do not agree with the present theory of Compton (Kompton) scattering (in which binding of the electrons in atomic electron shells is neglected). Therefore, these results ought to be subjected to careful theoretical analysis. The authors thank V. A. Sokolova for her help in carrying out measurements. There are 4 figures, 2 tables, and 4 references, 1 of which is Soviet.

ASSOCIATION: Institut poluprovodnikov Akademii nauk SSSR (Institute for Semiconductors of the Academy of Sciences, USSR)

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21(6)

AUTHORS: Boltaks, B. I., Sokolov, V. I.

SOV/20-123-3-18/54

TITLE: On the Coefficient of Absorption (of the Decrease in Intensity) of Beta-Rays in Semi-Conductors (O koeffitsiyente pogloshcheniya (oslableniya intensivnosti) beta-luchey v poluprovodnikakh)

PERIODICAL: Doklady Akademii nauk SSSR, 1958, Vol 123, Nr 3, pp 446-448 (USSR)

ABSTRACT: The authors investigate the relation between the mass absorption coefficient of  $\beta$ -rays and some characteristic features of semiconductor materials, especially of a special structure of the energy spectrum of electrons in semiconductors (presence of a forbidden zone). The following semiconductor materials were investigated: S, Se, Te, Ge, InSb, <sup>65</sup>As, <sup>76</sup>Ge, CdTe, ZnTe, PbTe, PbSe, and also the alkali-halogen compounds NaCl, CuBr, KCl, KBr, KJ. The following radioactive isotopes were used as sources of the  $\beta$ -radiation: <sup>35</sup>S, <sup>45</sup>Ca, <sup>185</sup>W, <sup>90</sup>Sr, <sup>204</sup>Te, <sup>32</sup>P.

The investigation was carried out on thin films produced by evaporation in vacuum. Plates of condensator mica were used as base layers. The absorption coefficients were measured by means of end-window counters on a standard measuring apparatus of type B.

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in Intensity) of Beta-Rays in Semi-Conductors

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The values of the intensity were determined as functions of the thickness of the film and the linear absorption coefficient  $\mu$  was deduced from the found data. A diagram gives the values of the relative absorption coefficients of the  $\beta$ -rays of the radioactive isotope  $P^{32}$  for sulphur, selenium, and tellurium. The abscissa axis of these diagrams represents the width of the forbidden zone ( $\Delta E$ ) of the energy spectrum of the electrons in these materials. Analogous diagrams are given for binary semiconductor compounds of zinc blende structure and also for alkali-halogen compounds and semiconductors of NaCl structure. The following conclusions may be drawn from these diagrams:

- 1) For the investigated semiconductors and alkali-halogen crystals, the mass absorption coefficient of  $\beta$ -rays is essentially different from the mass absorption coefficient of aluminum.
- 2) Notwithstanding the noticeable spread of the data, a regular increase of the absorption coefficient was observed if the forbidden zone decreased in width. This regularity was found for any group of substances of equal structure and similar physico-chemical properties. In order to check this result,

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the authors investigated 2 modifications of the same substance—selenium which have forbidden zones of different width. The absorption of crystalline selenium was found to be by  $\sim 40\%$  higher than that of amorphous selenium. The found dependence of the mass absorption coefficient of  $\beta$ -rays on the width of the forbidden zone of the semiconductors and alkali-halogen crystals agrees qualitatively with the modern theories for the mechanisms of the absorption of  $\beta$ -rays in matter. The results of this paper have only a qualitative character and more precise qualitative investigations are necessary. There are 3 figures and 4 Soviet references.

ASSOCIATION: Institut poluprovodnikov Akademii nauk SSSR (Institute of Semiconductors of the Academy of Sciences, USSR)

PRESENTED: July 14, 1958, by A. F. Ioffe, Academician

SUBMITTED: May 19, 1958

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~~24(6)~~ 24.7700  
AUTHORS: Boltaks, B. I., Gutorov, Yu. A. 66246 SOV/181-1-7-2/21

TITLE: Some Data on the Diffusion and Effect of Impurities on the Electrical Properties of Gallium Antimonide

PERIODICAL: Fizika tverdogo tela, 1959, Vol 1, Nr 7, pp 1015-1021 (USSR)

ABSTRACT: 99.98% pure antimony and 99.97% pure gallium were molten in vacuum with continuous mixing and cleaning by the layer method; hole-type conductivity (hole concentration  $\sim 10^{17}/\text{cm}^3$ ) was determinable along the whole length of the cast. The cast was divided into 4 equal parts and each part was mixed with 0.1 wt % of either In, Sb, Se, or Te in a repeated vacuum melting. Three plates each with the size of 3.8 . 4.5 . 16 mm of the melts of each mixture were prepared. The dependence of the electrical conductivity on temperature and the Hall-effect were measured by known methods for these samples. The influence of the additions In, Sb, Se, and Te on the electrical properties of GaSb is shown in table 1 (specific conductivity, concentration of current carriers, mobility). The dependence on temperature of the specific conductivity and the Hall constant are graphically represented

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Some Data on the Diffusion and Effect of Impurities SOV/181-1-7-2/21  
on the Electrical Properties of Gallium Antimonide

(Figs 1,2). In order to investigate diffusion, further samples were prepared by means of the layer melting process (GaSb was stoichiometrically synthesized, Sb-purity 99.90%). The surface of the samples was directly covered by the tracer impurities  $\text{In}^{114}$ ,  $\text{Sn}^{113}$ , and  $\text{Sb}^{114}$ . The annealing temperature varied between  $320^\circ$  and  $650^\circ\text{C}$ , the annealing time between 24 and 114 hours. The hole concentration is cited to be  $(0.5 \div 2.0) \cdot 10^{17} \text{ cm}^{-3}$ .  $\text{Se}^{75}$  and  $\text{Te}^{127}$  diffused from the vapor phase into the sample. After annealing thin layers were removed from the samples and their radioactivity was measured, as a criterion for the coefficient of diffusion. The results are represented in diagrams and tables. The following conclusions may be drawn: The activation energy rises by diffusion of impurity atoms in GaSb in the order: In, Sn, Sb, Te. In the same order increases also the influence of these elements on the dielectric properties of GaSb. The decrease of the activation energy with increasing ion radius of the diffusing particle does not depend on the.

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Some Data on the Diffusion and Effect of Impurities on the Electrical Properties of Gallium Antimonide SOV/181-1-7-2/21

ion radius but on the number of valency electrons, which cause the linkage of particles in the GaSb-lattice. There are 6 figures, 3 tables, and 10 references, 2 of which are Soviet.

ASSOCIATION: Institut poluprovodnikov AN SSSR Leningrad (Institute of Semiconductors of the AS USSR, Leningrad) ✓

SUBMITTED: July 30, 1958

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81767

S/181/60/002/02/01/033  
B006/B067

24.7700

AUTHORS: Boltaks, B. I., Kulikov, G. S., Malkovich, R. Sh.

TITLE: The Influence Exercised by Gold on the Electrical Properties of Silicon

PERIODICAL: Fizika tverdogo tela, 1960, Vol. 2, No. 2, pp. 181-191

TEXT: Gold belongs to those impurity elements which show low solubility and high diffusion rate in silicon. In the present article, the authors present the results of their investigations of the influence exercised by gold on the electrical properties of n-type and p-type silicon of different resistivity. First, the influence exercised by gold impurities on the resistivity of silicon is dealt with. The samples had a primary resistivity of 1.3-46 ohm.cm (n-type) and 0.5-87 ohm.cm (p-type). Gold was introduced partly by diffusion from gold vapors, partly by diffusion from a thin gold layer applied to the sample at temperatures of 1080-1380°C during 3-33 hours. The results are illustrated in a table and two diagrams. It was found that samples alloyed with gold in such a way show a relatively low-resistance surface layer; the electrical properties

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The Influence Exercised by Gold on the  
Electrical Properties of Silicon

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in the interior deviate considerably from those on the outer layer; the resistivity in the interior strongly increased, whilst the carrier concentration strongly decreased. In n-type Si resistivity attains  $\sim 10^5$  ohm.cm, in p-type Si,  $10^3 - 10^4$  ohm.cm; the electron and hole concentrations decrease to  $10^{10} - 10^{11} \text{ cm}^{-3}$  and  $10^{12} - 10^{13} \text{ cm}^{-3}$ , respectively. In the following, the carrier distribution is investigated with respect to the quantum states. Fig.3 shows a schematical representation of the distribution of the local levels. A large number of details are given. The width of the forbidden zone decreases with increasing temperature according to  $\Delta E = \Delta E_0 - \alpha T$ ;  $\alpha = 2 \cdot 10^{-4} \text{ ev/deg}$ ,  $\Delta E_0 = 1.21 \text{ ev}$ . The temperature dependence of the level of the chemical potential in n-type and p-type silicon was investigated for the two possible cases of temperature dependence of the activation energy. Data on n-type silicon are to be found in Fig. 4; Fig. 5 shows those obtained for p-type silicon. In the following, the plotting of the diagram which shows the dependence of resistivity on the gold concentration, is discussed. It was plotted by using all curves given in Figs. 4 and 5. It was found

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that by introducing gold, n-type Si can be transformed into p-type Si, that in the inverse case, however, by the introduction of gold into p-type Si, resistivity also increases without any change in the type of conductivity. The latter attains maximum resistivity at 291°K with  $4.6 \cdot 10^5$  ohm.cm. The experimental and theoretical data are briefly compared. In conclusion, the authors thank L. L. Korenblit for discussions. Mention is made of A. A. Shteynberg. There are 6 figures, 1 table, and 10 references: 6 Soviet, 2 American, 1 German, and 1 Irish.

ASSOCIATION: Institut poluprovodnikov AN SSSR Leningrad (Institute of Semiconductors of the AS USSR, Leningrad)

SUBMITTED: April 16, 1959

X

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84586

S/181/60/002/010/008/051  
B019/B070

9.4310 (2104,1143,1160)

AUTHORS: Boltaks, B. I., Kulikov, G. S., and Malkovich, R. Sh.

TITLE: Electric Transport of Gold in Silicon 11

PERIODICAL: Fizika tverdogo tela, 1960, Vol. 2, No. 10, pp. 2395-2399

TEXT: A thin layer of gold (Au-198) was laid on to the polished surfaces of two silicon samples (5.5.2 mm) which were then pressed together. The whole was placed in a water-cooled chamber filled with helium (Fig. 1). Heating was done by direct current which also served to produce the electric field necessary for the transport of gold. The temperature was measured by an optical pyrometer. Experiments were made in the temperature range 1075 - 1350°C. It was found that in the temperature range from 1075°C to about 1280°C, the gold in silicon migrates preferably to the cathode. At higher temperatures, the direction of transport is reversed (Fig. 3). It is considered improbable that this phenomenon is due to the change in the ionization character of the gold atom. It is rather surmized that the observed phenomenon is due to the associated motion of the ions with the electrons. According to V. B. Fiks, an impurity ion in a metal

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or semiconductor moves under the action of two different forces. The first force is due to the electric field and the second is due to the motion of the electrons toward the anode. The experimentally determined value of the mobility of gold in silicon as a function of temperature is graphically shown in Fig. 4. The values were obtained from a measurement of the rise of p-n junction with radioactive gold. The results obtained here are in good agreement with those calculated by Fiks (Ref. 4). It is established that the associated motion of gold atoms with electrons plays an important role in the transport of gold in silicon. The following values were obtained for the diffusion coefficient: in the temperature range 1200-1370°C about  $4 \cdot 10^{-7}$  -  $4 \cdot 10^{-6}$  cm<sup>2</sup>/sec, at 900°C about  $5 \cdot 10^{-10}$  cm<sup>2</sup>/sec, and at 1088°C about  $4 \cdot 10^{-8}$  cm<sup>2</sup>/sec. Also the solubility of gold in silicon was studied with radioactive gold. The results obtained agree well with those of the other authors (Fig. 5). No difference in the solubility was found for different types of conductivity. There are 5 figures and 10 references: 4 Soviet, 5 ~~US~~, and 1 ?

ASSOCIATION: Institut poluprovodnikov AN SSSR Leningrad (Institute of Semiconductors of the Academy of Sciences USSR, Leningrad)

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Electric Transport of Gold in Silicon

S/181/60/002/010/008/051  
B019/B070

SUBMITTED: March 23, 1960

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86418

24.7700 (1043, 1143, 1559)  
26.2420

S/181/60/002/011/002/042  
B006/B056

AUTHORS: Boltaks, B. I. and Syue Shi-in'

TITLE: Diffusion, Solubility, and Effect of Silver Impurities Upon the Electrical Properties of Silicon

PERIODICAL: Fizika tverdogo tela, 1960, Vol. 2, No. 11, pp. 2677 - 2684

TEXT: The authors give a report on the results they obtained by investigating the diffusion, solubility, and effect of silver upon the electrical properties of n-type and p-type silicon single crystals (resistivity of 9 - 24 and 20 - 100 ohms·cm, respectively). The diffusion of the silver impurities was investigated by using  $Ag^{110}$  and a standard method. Silver was applied from an  $AgNO_3$  solution to the ground surfaces of the specimens, after which they were subjected to a heat treatment (1100 - 1350°C). The diffusion coefficient was between  $3 \cdot 10^{-9}$  and  $2.4 \cdot 10^{-8}$  cm<sup>2</sup>/sec; its temperature dependence (Fig.1) may be expressed by the relation  $D = 2.0 \cdot 10^{-3} \exp(-36800/RT)$  cm<sup>2</sup>/sec. The migration of silver  
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Diffusion, Solubility, and Effect of Silver  
Impurities Upon the Electrical Properties of  
Silicon

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S/181/60/002/011/002/042  
B006/B056

ions in silicon under the action of a constant electric field was also investigated, and it was found that the silver ions move toward the cathode. For the purpose of investigating the solubility, 1.2 mm thick silicon sheets were coated with a thin layer of silver and heated in quartz ampoules filled with helium, after which the  $Ag^{110}$  activity in the sheet was determined. The solubility of silver in silicon was found to be  $2 \cdot 10^{17}$  at/cm<sup>3</sup> at 1350°C, and  $6.5 \cdot 10^{15}$  at/cm<sup>3</sup> at 1200°C. Thus, the solubility of silver in silicon is 3 to 5 times as high as that of gold. Further, the impurity levels of silver in silicon were determined. Figs. 5 and 6 show the temperature dependence of the resistivity of n-type and p-type Si single crystals, from which the donor and acceptor levels ( $E_{Ag}^d$  and  $E_{Ag}^a$ , respectively) of silver in silicon was determined from the equation for the chemical potential  $\mu = E_{Ag}^{d(a)} (\pm) kT \cdot \ln \left[ \frac{1}{2} \left( \frac{N_{Ag}}{N_a(d)} - 1 \right) \right]$  for n-type (p-type) silicon. Here,  $N_{Ag}$  is the silver concentration in Si;

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Diffusion, Solubility, and Effect of Silver Impurities Upon the Electrical Properties of Silicon S/181/60/002/011/002/042 B006/B056

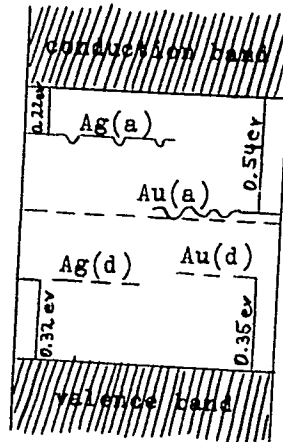
$N_a$  and  $N_d$  are the initial concentrations of the acceptor (elements of the third group) and donor impurities (fifth group) in p-type and n-type Si, respectively. It was found that  $N_{Ag} \approx 10^{17}$  at/cm<sup>3</sup>;  $N_{a(d)} \sim (3 - 4) \cdot 10^{14}$  at/cm<sup>3</sup>; the electron and hole concentrations were of the order of  $(5 - 6) \cdot 10^{13}$  cm<sup>-3</sup>. The position of the energy levels may be seen from Fig.7. Data on the effect of silver impurities upon the electrical properties of the Si single crystals are compared with theoretical results in a table, which were taken from earlier papers or had been obtained by the methods given there. Fig.8 shows the dependence of carrier concentration and resistivity upon the silver concentration at 18°C.

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Diffusion, Solubility, and Effect of Silver  
Impurities Upon the Electrical Properties of  
Silicon

S/181/60/002/011/002/042  
B006/B056



There are 8 figures, 1 table, and 3 Soviet references.

ASSOCIATION: Institut poluprovodnikov AN SSSR Leningrad (Institute of  
Semiconductors of the AS USSR, Leningrad).

SUBMITTED: February 20, 1960  
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Номер образца	2 До измерения средин				Температура прогресса, °C	4	
	тип проводимости	удельное сопротивление, ом · см	концентрация носителей, см <sup>-3</sup>	холодоская подвижность, см <sup>2</sup> /в · сек.		тип проводимости	удельное сопротивление, ом · см
n-201	n	114	5.0 · 10 <sup>14</sup>	1140	1200	14.8	
n-202	n	12.4	4.0 · 10 <sup>14</sup>	1270	1200	16.0	
n-251	n	13.1	4.0 · 10 <sup>14</sup>	1200	1250	26.3	
n-252	n	13.1	4.0 · 10 <sup>14</sup>	1200	1250	25.9	
n-20	n	21.2	2.5 · 10 <sup>14</sup>	1190	1300	25.3	
p-90	p	93.3	2.0 · 10 <sup>14</sup>	337	1300	1.1 · 10 <sup>5</sup>	
p-91	p	101.5	1.8 · 10 <sup>14</sup>	350	1300	1.6 · 10 <sup>5</sup>	
p-81	p	83.7	2.2 · 10 <sup>14</sup>	342	1320	1.3 · 10 <sup>5</sup>	
p-82	p	90.3	2.0 · 10 <sup>14</sup>	348	1320	1.7 · 10 <sup>5</sup>	
p-27	p	27.5	5.6 · 10 <sup>14</sup>	408	1500	1.1 · 10 <sup>5</sup>	
p-368	p	3680	5.5 · 10 <sup>12</sup>	310	1350	25.3	
p-170	p	1715	1.3 · 10 <sup>12</sup>	306	1350	928	
n-10	n	23.0	2.0 · 10 <sup>14</sup>	1370	1330	22.5	
n-25	n	13.0	4.0 · 10 <sup>14</sup>	1200	1340	12.1	
n-32	n	14.6	3.75 · 10 <sup>14</sup>	1150	1320	15.1	
p-12	p	74.2	2.5 · 10 <sup>14</sup>	340	1320	70.3	
p-31	p	82.4	2.0 · 10 <sup>14</sup>	380	1340	76.2	

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3 После введения серебра		5 расчет	
изм			
концентрация носителей, см <sup>-3</sup>	43	концентрация носителей, см <sup>-3</sup>	17
коллоидная подвижность, см <sup>2</sup> /в X Xсек.	145	коллоидная подвижность, см <sup>2</sup> /в сек.	18
тип проводимости	n	тип проводимости	p
удельное сопротивление, см · см	16	удельное сопротивление, см · см	141
концентрация носителей, см <sup>-3</sup>	3.9 · 10 <sup>14</sup> 3.4 · 10 <sup>14</sup> 2.1 · 10 <sup>14</sup> 2.0 · 10 <sup>14</sup> 2.0 · 10 <sup>13</sup>	концентрация носителей, см <sup>-3</sup>	3.3 · 10 <sup>14</sup> 2.6 · 10 <sup>14</sup> 1.7 · 10 <sup>14</sup> 1.7 · 10 <sup>14</sup> 3.2 · 10 <sup>13</sup>
коллоидная подвижность, см <sup>2</sup> /в X Xсек.	1090 1160 1140 1170 1240	коллоидная подвижность, см <sup>2</sup> /в сек.	1400
удельное сопротивление, см · см	13.6 17.0 26.7 26.7 141	удельное сопротивление, см · см	300
концентрация носителей, см <sup>-3</sup>	1.8 · 10 <sup>11</sup> 1.4 · 10 <sup>11</sup> 1.7 · 10 <sup>11</sup> 1.2 · 10 <sup>11</sup> 1.8 · 10 <sup>11</sup>	концентрация носителей, см <sup>-3</sup>	1.7 · 10 <sup>11</sup> 1.6 · 10 <sup>11</sup> 1.6 · 10 <sup>11</sup> 1.4 · 10 <sup>11</sup> 4.9 · 10 <sup>11</sup>
коллоидная подвижность, см <sup>2</sup> /в X Xсек.	314 278 280 304 310	коллоидная подвижность, см <sup>2</sup> /в сек.	300
удельное сопротивление, см · см	6.7 · 10 <sup>6</sup> 3.6 · 10 <sup>6</sup>	удельное сопротивление, см · см	5.5 · 10 <sup>6</sup>
концентрация носителей, см <sup>-3</sup>	2.0 · 10 <sup>14</sup> 5.2 · 10 <sup>12</sup>	концентрация носителей, см <sup>-3</sup>	2.5 · 10 <sup>9</sup> 5.5 · 10 <sup>9</sup>
коллоидная подвижность, см <sup>2</sup> /в X Xсек.	1240 1060	коллоидная подвижность, см <sup>2</sup> /в сек.	300
удельное сопротивление, см · см	4.7 · 10 <sup>4</sup> 1100 1040 4.0 · 10 <sup>4</sup>	удельное сопротивление, см · см	314 306
концентрация носителей, см <sup>-3</sup>	2.8 · 10 <sup>14</sup> 2.7 · 10 <sup>14</sup>	концентрация носителей, см <sup>-3</sup>	314 306

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X

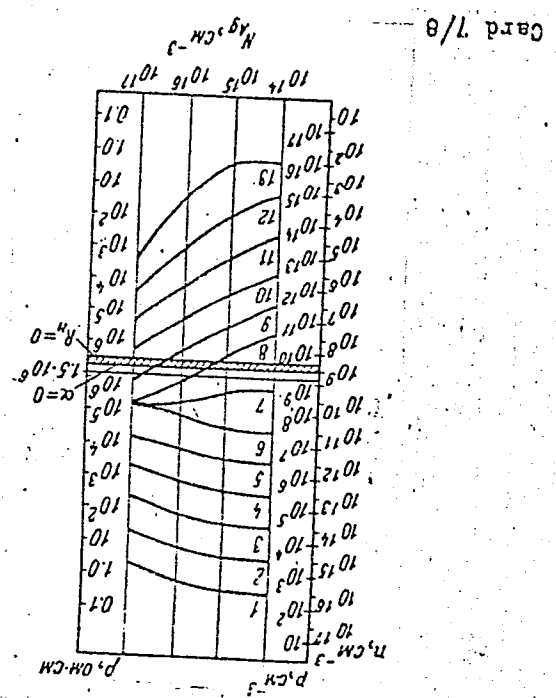
Рис. 8. График зависимости конгезионного сопротивления  $\sigma_{\text{конг}}$  от времени  $t$  и угла наклона  $\alpha$  трапециевидной носительской токи и угла наклона  $\alpha$  трапециевидной носительской токи от конгезионного сопротивления  $\sigma_{\text{конг}}$  (при  $T = 180^\circ \text{C}$ ).

Исходные данные конгезионного сопротивления  $\sigma_{\text{конг}}$  (в см<sup>2</sup>) и соответствующие значения угла наклона  $\alpha$  (в градусах):

- 1 -  $\sigma_{\text{конг}} = 10^1$  ( $\alpha = 0.45$ );
- 2 -  $\sigma_{\text{конг}} = 10^2$  ( $\alpha = 0.45$ );
- 3 -  $\sigma_{\text{конг}} = 10^3$  ( $\alpha = 0.45$ );
- 4 -  $\sigma_{\text{конг}} = 10^4$  ( $\alpha = 0.45$ );
- 5 -  $\sigma_{\text{конг}} = 10^5$  ( $\alpha = 0.45$ );
- 6 -  $\sigma_{\text{конг}} = 10^6$  ( $\alpha = 0.45$ );
- 7 -  $\sigma_{\text{конг}} = 10^7$  ( $\alpha = 0.45$ );
- 8 -  $\sigma_{\text{конг}} = 10^8$  ( $\alpha = 0.45$ );
- 9 -  $\sigma_{\text{конг}} = 10^9$  ( $\alpha = 0.45$ );
- 10 -  $\sigma_{\text{конг}} = 10^{10}$  ( $\alpha = 0.45$ );
- 11 -  $\sigma_{\text{конг}} = 10^{11}$  ( $\alpha = 0.45$ );
- 12 -  $\sigma_{\text{конг}} = 10^{12}$  ( $\alpha = 0.45$ );
- 13 -  $\sigma_{\text{конг}} = 10^{13}$  ( $\alpha = 0.45$ );
- 14 -  $\sigma_{\text{конг}} = 10^{14}$  ( $\alpha = 0.45$ );
- 15 -  $\sigma_{\text{конг}} = 10^{15}$  ( $\alpha = 0.45$ );
- 16 -  $\sigma_{\text{конг}} = 10^{16}$  ( $\alpha = 0.45$ );
- 17 -  $\sigma_{\text{конг}} = 10^{17}$  ( $\alpha = 0.45$ );
- 18 -  $\sigma_{\text{конг}} = 10^{18}$  ( $\alpha = 0.45$ );
- 19 -  $\sigma_{\text{конг}} = 10^{19}$  ( $\alpha = 0.45$ );
- 20 -  $\sigma_{\text{конг}} = 10^{20}$  ( $\alpha = 0.45$ );

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Legend to the table: 1) Number of specimen; 2) Before introduction of Ag; 3) After introduction of Ag; 4) Experiment; 5) Calculation; 6) Type of conductivity; 7) Resistivity, ohm.cm; 8) Carrier concentration,  $\text{cm}^{-3}$ ; 9) Hall mobility,  $\text{cm}^2/\text{v}.\text{sec}$ ; 10) Heating temperature,  $^{\circ}\text{C}$ ; 11) like 6); 12) like 7); 13) like 8); 14) like 9); 15) like 6); 16) like 7); 17) like 8); and 18) like 9).

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PHASE I BOOK EXPLOITATION

SOV/5898

BR

Boltaks, Boris Iosifovich

Diffuziya v poluprovodnikakh (Diffusion in Semiconductors) Moscow, Fizmatgiz, 1961. 462 p. (Series: Fizika poluprovodnikov i poluprovodnikovyykh priborov) 15,000 copies printed.

Ed.: V. D. Kozlov; Tech. Ed.: N. Ya. Murashova.

**PURPOSE:** The book is intended for physicists, chemists, and metallurgists investigating the physicochemical properties of semiconductors. It may also be useful to engineers and technologists in the development and manufacture of semiconductor devices.

**COVERAGE:** The physical concepts underlying the mechanism of self-diffusion and diffusion of impurities in semiconductors are discussed, with a review of the available experimental data being included in the discussion. Individual chapters deal with the mathematical analysis of diffusion problems and experimental methods of measuring diffusion coefficients in semiconductors. The last chapter briefly reviews the problems of the solubility of impurities in semiconductors and the decomposition of supersaturated solid solutions. The author

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Diffusion in Semiconductors

SOV/5898

thanks V. P. Zhuze, Professor; M. I. Kornfel'd, Professor; A. R. Regel', Professor; and G. S. Kulikov, R. Sh. Malkovich, and Antonina Vasil'yevna Boltaks. There are 357 references: 120 Soviet (including 1 translation), 198 English, 38 German, and 1 Czech. References are listed following each chapter.

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Ch. I. Structural Defects and Impurities in Semiconductors	13
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34246

S/181/62/004/002/041/051  
B102/B138

26.2532

AUTHORS: Boltaks, B. I., and Fedorovich, N. A.

TITLE: Diffusion and solubility of silver in bismuth telluride

PERIODICAL: Fizika tverdogo tela, v. 4, no. 2, 1962, 550-552

TEXT: Silver-doped  $\text{Bi}_2\text{Te}_3$  is an effective material for the negative side of a thermocouple.  $\text{Ag}^{110}$  diffusion and solution was studied with p-type  $\text{Bi}_2\text{Te}_3$  single crystals grown by the Bridgman method. The conductivity of the specimens was  $\sim 500 \text{ ohm}^{-1} \text{ cm}^{-1}$ , the thermo-emf coefficient was  $\sim 200 \text{ uv/deg}$ . They were cut partly in parallel and partly perpendicular to the cleavage plane. Diffusion annealing was carried out in an argon atmosphere. Diffusion was investigated by using  $\text{Ag}^{110}$  tracer and removing thin layers, and was found to be highly anisotropic; in the cleavage plane the diffusion rate was 3-5 orders of magnitude higher than in the cross direction.  $D_{\parallel}$  was changed from  $\sim 10^{-8}$  to  $\sim 10^{-5} \text{ cm}^2/\text{sec}$  between 100 and 500°C and  $D_{\perp}$  from  $\sim 10^{-11}$  to  $\sim 5 \cdot 10^{-8} \text{ cm}^2/\text{sec}$  between 300 and 500°C.

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31246

S/181/62/004/002/041/051

diffusion and solubility of silver ... B102/B158

$$D_{\parallel} = 2.2 \cdot 10^{-3} \exp(-0.42/kT) \text{cm}^2/\text{sec}$$

$$D_{\perp} = 2.5 \cdot 10^{-1} \exp(-1.17/kT) \text{cm}^2/\text{sec}.$$

The anisotropy in diffusion is attributed to structural anisotropy. The order of the atomic layers is ...-Bi-Te<sub>II</sub>-Te<sub>II</sub>-Bi-Te<sub>I</sub>-Bi-Te<sub>II</sub>... so that three Te plus two Bi layers form a quintet, which is separated from the next one by a greater distance. Ag, and other elements of the first group can only penetrate in an interstitial manner. These interstitial atoms are easily ionized and form donors. Copper diffusion in Bi<sub>2</sub>Te<sub>3</sub> displays the same effects. The same specimens were used to study Ag solution. Annealing time was varied between 17 and 96 hours depending on the temperature. The solubility measured in the range 200-500°C, was  $(1 - 3.5) \cdot 10^{19}$  atoms/cm<sup>3</sup>. Saturation is reached above 400°C. The students V. P. Kokoyev and Li Min-i are thanked for measurements. There are 2 figures and 2 references: 1 Soviet and 1 non-Soviet. The reference to the English-language publication reads as follows: R. O. Carlson, J. Phys. Chem. Solids, 13, 65, 1960.

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34246

Diffusion and solubility of silver ...

S/181/62/004/002/041/051  
B102/B138

ASSOCIATION: Institut poluprovodnikov AN SSSR Leningrad (Institute of Semiconductors AS USSR, Leningrad)

SUBMITTED: October 26, 1961

X

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24.7400

36168

S/181/62/004/003/006/045  
B152/B102

AUTHORS: Boltaks, B. I., and Matveyeva, N. N.

TITLE: Diffusion of phosphorus in silicon

PERIODICAL: Fizika tverdogo tela, v. 4, no. 3, 1962, 609 - 614

TEXT: In the diffusion of phosphorus atoms in p-type silicon, a not yet fully clarified deviation was observed from the distribution function

$$\operatorname{erfc}(x/2\sqrt{Dt}) = 1 - \frac{2}{\sqrt{\pi}} \int_0^{x/2\sqrt{Dt}} \exp(-x^2) dx$$
 which holds for other elements

of groups III and V. This deviation is explained by evaporation of phosphorus from the Si surface during diffusion. The Si single crystals (20 - 40 ohm·cm) used for the experiment were ground, etched in SF-8 (SR-8), washed, and then introduced in quartz tubes together with small amounts of P32. The tubes were evacuated and sealed, and heated in a furnace. One part of the furnace with the crystal had always the same temperature (1200°C) while the temperature of the other part containing the phosphorus was 1200°C in one and 250°C in another series of measurement. The holding Card 1/4

Diffusion of phosphorus ...

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B152/B102

periods were 12 and 24 hrs, respectively. To determine the distribution, thin layers were removed from the crystal and the radioactivity was measured. A calculation of the diffusion equation, with consideration of the evaporation of the diffusing substance, gives a family of curves for various evaporation probabilities of the P atoms (Fig. 4). Corresponding experiments with low P vapor pressures showed a distinct maximum. This maximum did not appear at constant saturation vapor pressure. Preliminary experiments with n-type Si yielded the distribution  $\operatorname{erfc}(x/2\sqrt{Dt})$  under analogous test conditions. There are 7 figures and 7 references: 1 Soviet and 6 non-Soviet. The four most recent references to English-language publications read as follows: E. Tannenbaum, Solid State Electronics, 2, 123, 1961; L. A. D'Asaro, Solid State Electronics, 1, 3, 1960; F. A. Cunnell and C. H. Gooch, J. Phys. Chem. Solids, 15, 127, 1960; J. W. Allen, J. Phys. Chem. Solids, 15, 134, 1960.

ASSOCIATION: Institut poluprovodnikov AN SSSR Leningrad (Institute of Semiconductors AS USSR, Leningrad)

SUBMITTED: September 29, 1961  
Card 2/4

Semiconducting phases in the system  $A_3^{II}B_2^{VI}-A^{II}B^{VI}$  (? - Sic.).  
L. V. Kradinova, I. K. Polushina.

Anomalous scattering of x-rays in  $Ga_2Se_3$  and its solid solutions.  
A. A. Vaynolin and M. M. Markus.  
(Presented by A. A. Vaynolin--25 minutes).

Papers not presented.]

Diffusion of impurities in gallium arsenide. B. I. Boltaks, V. I. Sokolov,  
F. S. Shishiyanu.

Influence of the impurities silver and gold on the electrical properties  
of gallium arsenide. B. I. Boltaks, V. I. Sokolov, F. S. Shishiyanu.

Report presented at the 3rd National Conference on Semiconductor Compounds,  
Kishinev, 16-21 Sept 1963

1  
Diffusion and solubility of impurities in bismuth telluride.  
B. I. Boltaks, N. A. Fedorovich.  
(Presented by B. I. Boltaks--15 minutes).

Report presented at the 3rd National Conference on Semiconductor  
Compounds, Kishinev, 16-21 Sept 1963

S/181/63/005/003/036/046  
B102/B180AUTHORS: Boltaks, B. I., and Fedorovich, N. A.

TITLE: Diffusion and solubility of cadmium in bismuth telluride

PERIODICAL: Fizika tverdogo tela, v. 5, no. 3, 1963, 944-946

TEXT: The authors used p-type  $\text{Bi}_2\text{Te}_3$  single crystals grown by the Bridgman method to investigate  $\text{Cd}^{115}$  diffusion along and across the C-axis by the tracer method ( $\text{Cd}^{115}$ ). Diffusion along the C-axis was studied by successive removal of thin layers; across the C-axis (i. e. parallel to the cleavage plane) by contrast autoradiography. In both cases the experimental data fit in very well with the straight lines in the log D-versus- $1/T$  graph, which are given by

$$D_{\parallel} = 488 \cdot 10^{-3} \exp(-0.48\text{ev}/kT) \text{cm}^2/\text{sec}$$

$$D_{\perp} = 10^2 \exp(-1.8\text{ev}/kT) \text{cm}^2/\text{sec}.$$

The diffusion shows distinct anisotropy; e. g., at  $530^{\circ}\text{C}$   $D_{\parallel}$  and  $D_{\perp}$  differ by 3.5, at  $350^{\circ}\text{C}$  by almost 6 orders of magnitude. The solubility was  
Card 1/2

Diffusion and solubility of cadmium ...

S/181/63/005/003/036/046  
B102/B180

studied with the same samples in the range 250-550°C. Determined from the tracer saturation level, it was  $2 \cdot 10^{18}$  -  $6 \cdot 10^{18}$  at/cm<sup>3</sup>. The temperature dependence of the solubility has a maximum at 400°C. There are 2 figures.

ASSOCIATION: Institut poluprovodnikov AN SSSR, Leningrad  
(Institute of Semiconductors AS USSR, Leningrad)

SUBMITTED: October 29, 1962

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S/181/63/005/004/015/047  
B102/B186

AUTHORS: Boltaks, B. I., and Sokolov, V. I.

TITLE: Investigation of the diffusion of cadmium in indium antimonide by autoradiography in layers

PERIODICAL: Fizika tverdogo tela, v. 5, no. 4, 1963, 1077 - 1081

TEXT: The Cd diffusion in InSb was investigated in the range 250 - 500°C by means of Cd<sup>115</sup> tracer and autoradiographic activity control using Agfa-Sino X-ray films. With this method, which allows an accuracy of within 5 - 10%, the diffusion coefficients and the Cd solubility were determined for n-type InSb single crystals oriented along [111], with the parameters  $\rho = 0.007 \text{ ohm}\cdot\text{cm}$ ,  $n = 1.65 \cdot 10^{16} \text{ cm}^{-3}$ ,  $\mu = 54000 \text{ cm}^2/\text{v}\cdot\text{sec}$ . After Cd<sup>115</sup> had been electrolytically deposited on the polished and etched surface placed in aqueous CdCl<sub>2</sub> solution, the crystal was subjected to diffusion annealing in an argon-filled quartz ampoul; then the radiogram was taken and photo-metrized in order to obtain the Cd distribution curve. The temperature dependence

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Investigation of the diffusion...

S/181/63/005/004/015/047  
B102/B186

of the diffusion coefficient is given by  $D = 1 \cdot 10^{-15} \exp(-1.1/kT)$ ; this is, if compared in a  $\log D=f(1/T)$  plot, somewhat above the curve obtained by Wilson and Heasell (Proc. Phys. Soc., 79, 403, 1962). The Cd solubility in InSb was calculated from the maximum concentration; the temperature dependence of the solubility has a retrograde character and has its maximum at  $400^{\circ}\text{C}$  ( $2.5 \cdot 10^{21} \text{ cm}^{-3}$ ). The method is also suited for  $\beta$ - and  $\gamma$ -active isotopes. There are 5 figures.

ASSOCIATION: Institut poluprovodnikov AN SSSR, Leningrad (Institute of Semiconductors AS USSR, Leningrad)

SUBMITTED: October 29, 1962

Card 2/2



L 17998-63

EWP(q)/EWT(m)/BDS AFFTC/ASD RDW/JD

ACCESSION NR: AP3001281

S/0181/63/005/006/1620/1624

AUTHORS: Boltaks, B. I.; Fedorovich, N. A.

TITLE: Rediffusion of silver impurities from a solid solution of  $Bi_2Te_3$  -  $Bi_2Se_3$

SOURCE: Fizika tverdogo tela, v. 5, no. 6, 1963, 1620-1624

TOPIC TAGS: diffusion, rediffusion, Ag, Bi, Te, Se, I, semiconductor, diffusion coefficient

ABSTRACT: The environing atmosphere during rediffusion of silver impurities in semiconducting samples of bismuth telluride-bismuth selenide was investigated in order to discover the role of this atmosphere in the process. Preliminary data on this study were presented by the authors (Termoelektricheskiye svoystva poluprovodnikov. Izd. AN SSSR, L., 1963) at II Soveshchaniye po termoelektrichestvu (Second Conference on Thermoelectricity, February 1962). It was shown that an oxidizing atmosphere facilitates emergence of alloying admixtures to the surface of a sample. The diffusion coefficient of silver in the tested alloy was computed with proper consideration of movement of the boundary formed by bound impurities (growth of the oxide film), and the value of this coefficient proved to be  $10^{-8}$  cm<sup>2</sup>/sec at 300C. The results thus found indicate that conditions for rediffusion

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ACCESSION NR: AP3001281

2

of silver involve not only oxidation of the bismuth telluride-bismuth selenide alloy but also the possibility of rapid diffusion to an interface. The introduction of iodine into such an alloy imposes a supplementary bond on the migrating silver, hindering its movement to the surface. Orig. art. has: 6 figures and 4 formulas.

ASSOCIATION: Institut poluprovodnikov AN SSSR, Leningrad (Institute of Semiconductors, Academy of Sciences, SSSR)

SUBMITTED: 16Jan63

DATE ACQ: 01Jul63

ENCL: 00

SUB CODE: PH

NO REF SOV: 005

OTHER: 001

Card 2/2

BOLTAKS, B.I.; FEDOROVICH, N.A.

Rediffusion of a silver impurity from the solid solution  
 $\text{Bi}_2\text{Te}_3 - \text{Bi}_2\text{Se}_3$ . Fiz. tver. tela 5 no.6:1620-1624 Je '63.

(MIRA 16:7)

1. Institut poluprovodnikov AN SSSR, Leningrad.

BOLTAKS, B.I.; SHISHIYANU, F.S.

Diffusion and solubility of silver in gallium arsenide. Fiz. tver.  
tela 5 no.8:2310-2316 Ag '63. (MIRA 16:9)

1. Institut poluprovodnikov AN SSSR, Leningrad.  
(Silver) (Gallium arsenide) (Diffusion)

BOLTAKS, B.I.; DZHAFAROV, T.D.

Effect of local electric fields on the diffusion of antimony  
in germanium. Fiz. tver. tela 5 no.10:2818-2824 0 '63.

(MIRA 16:11)

1. Institut poluprovodnikov AN SSSR, Leningrad, i Institut fiziki  
AN Az. SSR, Baku.

BOLTAKS, B.I.; DZHAFAROV, T.D.

Diffusion of gallium in inhomogeneous silicon. Fiz. tver. tela 5 no.12:  
3611-3613 D '63. (MIRA 17:2)

1. Institut poluprovodnikov AN SSSR, Leningrad.

BOLTAKS, B.I.; SOKOLOV, V.I.

Diffusion of gold in indium antimonide. Fiz. tver. tela 6  
no.3:771-775 Mr '64. (MIRA 17:4)

1. Institut poluprovodnikov AN SSSR, Leningrad.

ACCESSION NR: AP4034936

S/0181/64/006/005/1511/1519

AUTHORS: Boltaks, B. I.; Dzhafarov, T. D.; Sokolov, V. I.; Shishiyani, F. S.

TITLE: Diffusion and electrical transfer of zinc in gallium arsenide

SOURCE: Fizika tverdogo tela, v. 6, no. 5, 1964, 1511-1519

TOPIC TAGS: solid diffusion, semiconductor, semiconductor conductivity, metallographic examination, zinc diffusion, gallium arsenide

ABSTRACT: The test material consisted of single crystal samples of n-type GaAs with resistivity ranging from  $8 \cdot 10^{-3}$  to  $2 \cdot 10^{-2}$  ohm $\cdot$ cm and of p-type GaAs with resistivity of  $5 \cdot 10^{-2}$  ohm $\cdot$ cm. Measurements were made by radioactive and electrical methods. It was found that the Zn distribution in both types of samples, as well as the distribution of current carriers introduced by the diffusion, depends on the boundary concentration. When this value is low, the concentration curve is described by erfc function. At boundary concentrations greater than  $4 \cdot 10^{19}$  cm $^{-3}$ , the concentration profile is step-like. It was found that at high Zn

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ACCESSION NR: AP4034936

concentrations the concentration of current carriers is but  $1/5$  to  $1/8$  the Zn concentration. The diffusion coefficient of Zn depends on the boundary concentration. Metallographic study has shown that when the concentration curve for n-type

GaAs is step-like, polished sections show two transitions:  $p^+ - p$  and  $p - n$ .

In p-type GaAs, there is always but the one transition:  $p^+ - p$ . The authors have found that in the temperature interval 830-1130C Zn is displaced in GaAs in the form of positive ions, the effective charge decreasing with rise in temperature. This decrease follows from the entrapment of ions by electrons. The diffusion mechanism is thought to involve three diffusion currents, due to negatively charged ions in vacancies, positively charged ions in interstices and neutral Zn ions. Orig. art. has: 7 figures.

ASSOCIATION: Institut poluprovodnikov AN SSSR, Leningrad (Institute of Semiconductors, AN SSSR)

SUBMITTED: 10Dec63

DATE ACQ: 20May64

ENGL: 00

SUB CODE: EC

NO REF SOV: 004

OTHER: 007

Card 2/2

ACCESSION NR: AP4041688

S/0181/64/006/007/1925/1929

AUTHORS: Boltaks, B. I.; Kulikov, G. S.

TITLE: Diffusion of silver on the surface of silicon

SOURCE: Fizika tverdogo tela, v. 6, no. 7, 1964, 1925-1929

TOPIC TAGS: silver, silicon, diffusion, transport process, surface diffusion, autoradiography

ABSTRACT: Free diffusion and electron transport of silver on a silicon surface was investigated by an autoradiographic method in order to determine the kinetics of these processes. The object of the investigation was single-crystal n-type silicon and the diffusion was investigated on the (100), (110), and (111) crystallographic planes in the temperature range 300--1000C. Ag-110 was used as the radioactive tracer. Two batches of samples (parallelepipeds measuring ~3 x 5 x 20 mm) were tested -- with ground and with chemically

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ACCESSION NR: AP4041688

polished surfaces. The test procedure is described. The results show that the coefficient of diffusion of silver over a polished silicon surface depends on the crystallographic orientation of the surface, but diffusion over a ground surface displays no such dependence. The diffusion coefficient in either case has an exponential time dependence. An increase in the dislocation density leads to an abrupt increase in the rate of diffusion of silver on the silicon surface, with accumulations of silver clustering in the regions with maximum dislocation density. Tests of the diffusion of silver in a constant electric field have shown that the silver on the surface is in the form of neutral atoms and partially in the form of negative ions. This, together with the data on the effect of the dislocations on the surface diffusion, points to a vacancy mechanism of silver diffusion on silicon. Orig. art. has: 6 figures and 1 table.

ASSOCIATION: Institut poluprovodnikov AN SSSR, Leningrad (Institute of Semiconductors, AN SSSR)

Card 2/5

ACCESSION NR: AP4041688

SUBMITTED: 20Nov63.

DATE ACQ:

ENCL: 02

SUB CODE: SS

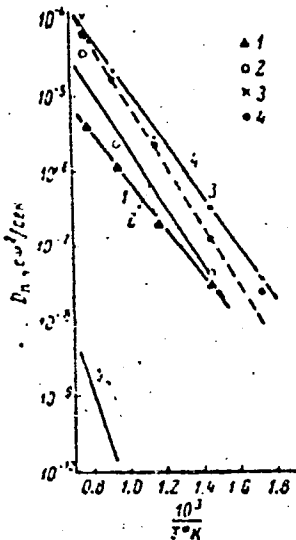
NR REF SOV: 005

OTHER: 000

Card 3/5

ACCESSION NR: AP4041688

ENCLOSURE: 01



Temperature dependence of the coefficient of surface diffusion of silver for different crystallographic planes  
1 - (110), 2 - (111), 3 - (100), 4 - (110), (111), (100),  
5 - volume diffusion

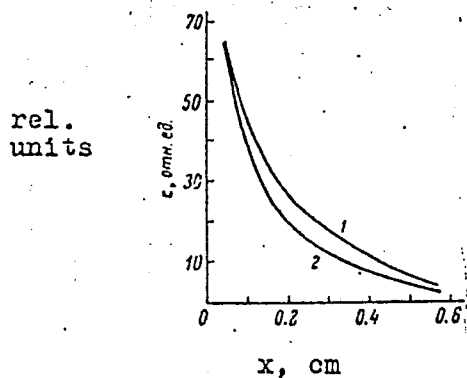
1--3 - polished surfaces, 4 - ground

All points are averages for two or three samples

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ACCESSION NR: AP4041688

ENCLOSURE: 02



Effect of constant electric field on the diffusion of silver over the surface of silicon

1 - to anode, 2 - to cathode

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L 10361-65 EWT(m)/ENP(b) LJP(τ)/ESD(gs)/AEDC(a)/AFWL/ASD(a)-3/AFTC(p)/  
AS(mp)-2/SSD/ESD(t)/RAEM(t) JD

ACCESSION NR: AP4046650

S/0181/64/006/010/3181/3183

AUTHORS: Boltaks, B. I.; Grabchak, V. P.; Dzhafarov, T. D.

TITLE: Diffusion of antimony in inhomogeneous germanium 27 B

SOURCE: Fizika tverdogo tela, v. 6, no. 10, 1964, 3181-3183

TOPIC TAGS: antimony, germanium, single crystal, diffusion coefficient, carrier density

ABSTRACT: The authors report experimental data on the influence of the internal electric field, due to a nonuniform distribution of aluminum, on the diffusion of antimony in germanium. The initial samples were single-crystal p-type germanium of  $\approx 1$  ohm.cm resistivity. Aluminum was introduced by diffusion from the gaseous phase for one-and-a-half hours at 850°C. Two batches of samples were prepared: in one, the aluminum concentration was a maximum at the surface, and in the other, it was a maximum in the interior and decreased toward the

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L 10361-65

ACCESSION NR: AP4046650

surface. The diffusion of antimony from the vapor phase was investigated in the range 720--900°C. The effective diffusion coefficient of Sb was found by the p-n junction method, as well as by means of a radioactive isotope ( $Sb^{124}$ ). In the first batch, the concentration gradients of Al and Sb had the same direction and two p-n junctions were produced. In samples of the second batch the Al concentration gradient in the surface region was opposite to the antimony gradient and only one p-n junction was obtained. Below 900C, where  $N_{Sb} \geq n_i$  in the surface region ( $n_i$  is the intrinsic carrier density) the same direction of the concentration gradients reduced the effective diffusion coefficient of Sb, and the opposite direction of the gradients increased this coefficient. As the temperature rose and the intrinsic carrier density  $n_i$  increased, the effective diffusion coefficient of antimony in inhomogeneous samples approached the value of  $D_{Sb}$  for homogeneous samples. The value of the diffusion coefficient ranged from  $10^{-12}$  at the lowest temperature to  $10^{-10}$  cm<sup>2</sup>/sec at the highest temperature. Tests on the dif-

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L 10361-65

ACCESSION NR: AP4046650

fusion of antimony in homogeneous germanium heavily doped with gallium ( $p \approx 1 \times 10^{20} \text{ cm}^{-3}$ ) and in lightly doped material (p-type Ge, doped with gallium, carrier density  $\approx 3 \times 10^{15} \text{ cm}^{-3}$ ) showed that the difference between the surface concentrations and diffusion coefficients of antimony for these two types of sample was slight. Orig. art. has: 2 figures and 1 formula. 2.

ASSOCIATION: Institut poluprovodnikov AN SSSR, Leningrad (Institute of Semiconductors, AN SSSR); Institut fiziki AN Azerb. SSR, Baku (Institute of Physics, AN Azerb. SSR)

SUBMITTED: 26May64

ENCL: 00

SUB CODE: SS

NR REF SOV: 002

OTHER: 001

Card 3/3

L 52515-65 EWT(1)/EWT(m)/EWP(+)/EWP(b) IJP(c) JD

ACCESSION NR: AP5010706

UR/0181/65/007/004/1021/1027

AUTHOR: Boltaks, B. I.; Shishiyamu, F. S.

24  
23  
B

TITLE: On thermal conversion of gallium arsenide

SOURCE: Fizika tverdogo tela, v. 7, no. <sup>27</sup>4, 1965, 1021-1027

TOPIC TAGS: gallium arsenide, thermal conversion, carrier density, Hall effect, copper extraction

ABSTRACT: The purpose of the investigation was to study the kinetics of thermal conversion, especially the kinetics of diffusion propagation of thermoacceptors upon annealing of gallium arsenide, to acquire additional data on the nature of thermoacceptors, and to ascertain the possibility of extracting copper from gallium arsenide with the aid of zinc. The effect of annealing on the concentration and mobility of the carriers was investigated in n-type single crystals with initial electron concentration  $\sim 8 \times 10^{16} \text{ cm}^{-3}$ , and mobility  $\sim 3700 \text{ cm}^2/\text{V-sec}$ . The annealing temperatures ranged from 700 to 1200C, the annealing duration was 7 hours at each temperature, and the cooling rate was 300-400 deg/sec. The kinetics of the thermal conversion was studied by observing the displacement of the p-region boundaries, occurring upon annealing of n-type samples. The effect of annealing

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L 52515-65

ACCESSION NR: AP5010706

on the carrier concentration and mobility is shown in Fig. 1 of the Enclosure. The results established that thermal conversion is the consequence of diffusion of thermoacceptors from clustering points (such as the surface or structural defects) into the volume of the crystal. The data obtained confirm the existing opinion that the main cause of thermal conversion of gallium arsenide is the copper impurity. The possibility of extracting copper from gallium arsenide with the aid of zinc was investigated by coating copper-saturated samples of gallium arsenide with a thin layer of zinc and annealing in sealed ampoules. The carrier density was determined by the Hall effect and the transparency of the samples was investigated with an infrared microscope. The hole concentration decreased by several orders of magnitude after annealing at various temperatures. The results showed that the presence of a zinc layer on the surface hindered the thermal conversion of gallium arsenide. Similar results were obtained with cadmium. Orig. art. has: 6 figures

ASSOCIATION: Institut poluprovodnikov AN SSSR, Leningrad (Institute of Semiconductors, AN SSSR)

SUBMITTED: 01Sep64

ENCL: 01

SEC CODE: SS

NR REF SOV: 000

OTHER: 008

Card 2/3

L 52515-65

ACCESSION NR: AP5010706

0 ENCLOSURE: 01

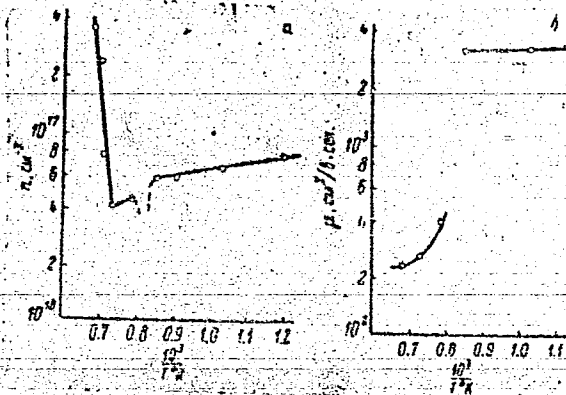


Fig. 1. Effect of annealing temperature on the concentration (a) and mobility (b) of the carriers.

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L 29961-66 EWT(m)/EWP(t)/ETI IJP(c) JD

ACC NR: AP6012520

SOURCE CODE: UR/0181/66/008/004/1312/1314

AUTHOR: Shishiyanu, F. S.; Boltaks, B. I.

ORG: Institute of Semiconductors, AN SSSR, Leningrad (Institut poluprovodnikov AN SSSR)

TITLE: Energy levels of Ag and Au in GaAs <sup>v1</sup>

SOURCE: Fizika tverdogo tela, v. 8, no. 4, 1966, 1312-1314

TOPIC TAGS: gallium arsenide, gold, silver, impurity level, forbidden band, temperature dependence, electric conductivity, Hall constant, ENERGY BAND

STRUCTURE  
ABSTRACT: This is a continuation of earlier work by the authors (FTT v. 7, 1021, 1965 and earlier) dealing with the diffusion and capture of Ag and Au in GaAs. The present study is devoted to the energy levels which are produced in the forbidden band of GaAs when doped with Ag or with Au. A series of experiments was made on the temperature dependence of the electric conductivity and the Hall constant, making it possible to determine the impurity levels of Ag and Au in GaAs. The measurements were made at the temperature range 77-770K. The doping reversed the conductivity of the single-crystal n-GaAs samples to p-type. Because of the low solubility of the alloying material in the host, it was necessary to investigate the electric properties of GaAs against the background of thermal conversion. In

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L 29961-66

ACC NR: AP6012520

the case of Ag, an acceptor level was observed at  $0.11 \pm 0.01$  ev above the top of the valence band, as compared with  $0.15 \pm 0.01$  ev in a control sample subjected to thermal conversion by annealing. In the case of Au, the 0.15 level was observed in the control sample, as well as two acceptor levels in the doped samples, corresponding to  $0.090 \pm 0.005$  and  $\sim 0.02$  ev above the top of the valence band. It was also noted that when samples doped with Au and samples subjected to thermal conversion or doped with Cu are simultaneously annealed, the latter samples lose the 0.15 ev level and acquire 0.09 and  $\sim 0.02$  ev levels. The shallow acceptor level (0.02 ev) is unstable and vanishes on subsequent annealing. To observe deeper Au and Ag levels it would be necessary to use purer GaAs samples. Orig. art. has: 2 figures and 2 formulas.

SUB CODE: 20/    SUBM DATE: 29Nov65/    ORIG REF: 003/    OTH REF: 001

Card 2/2 CC

ACC NR: AP7006199

(A)

SOURCE CODE: UR/0363/67/003/001/0026/0028

AUTHOR: Kulikov, G. S.; Boltaks, B. I.; Savin, E. P.

ORG: Institute of Semiconductors, Academy of Sciences, SSSR (Institut poluprovodnikov Akademii nauk SSSR)

TITLE: Diffusion of phosphorus through an oxide film in silicon

SOURCE: AN SSSR. Izvestiya. Neorganicheskiye materialy, v. 3, no. 1, 1967, 26-28

TOPIC TAGS: phosphorus, silicon dioxide, silicon, physical diffusion

ABSTRACT: In order to determine the causes of the masking effect of oxide films on the surface of silicon, experiments were conducted on the diffusion of phosphorus in oxide layers and also in silicon through oxide layers of various thicknesses. Diffusion coefficients measured for phosphorus in quartz as an analog of an oxide film on silicon, and also values of the activation energy and preexponential factor  $D_0$  indicate that starting at 1000°C and above, the diffusion coefficient of phosphorus in silicon dioxide is smaller than in silicon. The masking effect of oxide layers on silicon during the diffusion of phosphorus (for moderate times) is due to a limitation of the concentration of the diffusing impurity on silicon under the oxide layer. This is caused by the small value of the diffusion coefficient of phosphorus in  $SiO_2$  as compared to diffusion in silicon. The masking effect also arises in the diffusion of elemental phosphorus and when the source of the diffusion is phosphorus

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UDC: 546.18:532.72:546.28

ACC NR: AP7006199

pentoxide. At 1100°C (source temperature 325°C) and a diffusion time of 6 hr, a good masking effect is provided by oxide layers 0.6 micron thick. Orig. art. has: 5 figures.

SUB CODE: 07,20/ SUBM DATE: 13Dec65/ OTH REF: 004

Card 2/2



REEL #6/  
BOKOV, V.F.  
to  
BOLTAKS, B.I.

DNF