20 JUNE 1980 (FOUO 6/80) 1 OF 1

JPRS L/9158

20 June 1980

USSR Report

PHYSICS AND MATHEMATICS

(FOUO 6/80)

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USSR REPORT

PHYSICS AND MATHEMATICS

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CONTENTS

CRYSTALS AND SEMICONDUCTORS

UDC 538.61

MAGNETO-OPTIC EFFECTS IN FERROMAGNETIC MATERIALS

Moscow VESTNIK AKADEMII NAUK SSSR in Russian No 2, 1980 pp 15-23

[Article by Doctor of Physicomathematical Sciences G. S. Krinchik]

[Text] The development of magneto-optics began with the discovery of the effect of rotation of the light polarization plane in glass placed in a magnetic field, discovered by Faraday in 1845. Since that time this scientific direction has studied the characteristics of light interaction with magnetized material. Classical magneto-optics mainly investigated phenomena related to light and was essentially a section of optics. Problems of classical magneto-optics were exhausted at the beginning of our century and it turned out that this section of science was completed.

The second stage in development of magneto-optics began in the 1950s when a new approach arose to study of the interaction of light and matter: the derived information began to be used to investigate the structure of the material itself--a magnetically ordered crystal. This problem can already be related to the physics of magnetic phenomena (although magneto-optics is actually at the junction of physical optics and magnetism). In the 1950s this section of physics began to be developed at MGU [Moscow State University imeni Lomonosov] with regard to the problem of investigating magnetically ordered crystals from the results of the interaction of light, passing through or reflected from them, with these crystals.

Magneto-optic spectroscopy should primarily be distinguished in the indicated section of magneto-optics. The problem of investigating a magnetically ordered crystal can be postulated in a manner similar to how main data on the structure of the atom and on the arrangement of electron energy levels are found from optical spectra, by observing the dependence of some magneto-optic effect on the wavelength of light, thus finding the natural frequencies and identifying them with the electron energy spectrum in the magnetically ordered crystal.

When setting up these investigations, many scientists felt that it would be impossible to find natural frequencies in the continuous spectrum due to the complexity of the energy structure of the crystal. Investigations of FIAN [Physics Institute imeni P. N. Lebedev of the USSR Academy of Sciences] in the field of metal-optics and of MGU in the field of the magneto-optics of metals dispersed these doubts. Because of improvement in the method of investigations and the progress achieved in understanding the structure of metals, it was possible to find the natural frequencies and to identify them with characteristic interband intervals.

Discovery of the nontrivial effect of variation of reflected light intensity during rotation of the magnetization vector in a crystal was of important significance. When the magnetization vector is rotated with respect to crystallographic axes, the band spectrum varies and this leads to variation of the reflection coefficient. Because of the fact that the variations occur at strictly specific locations of the Brillouiun zone, the spectrum is well structured and clearly marked natural frequencies are observed in it. For example, the transition of 0.3 eV was identified with that between the exchange-split bands (Figure 1) for the best studied ferromagnetic material --classical nickel. Thus, one can immediately conclude that the main parameter of ferromagnetic material--exchange splitting--is equal to 0.3 eV for nickel.

Magneto-optical spectroscopy has the following advantages over ordinary optics: first, it is based on the differential effect--variation of the reflection coefficient during field modulation is measured and therefore it is easier to observe the characteristics of the crystal structure on magneto-optic spectra than when measuring the total reflection coefficient; second, the signs of magneto-optic effects depend on the sign of the electron spin in the sub-band where optical transition occurs, which permits determination of this sub-band.

A model of the electron structure of nickel with reverse order of levels was proposed on the basis of this information. It was previously assumed that nickel has the same structure as its neighbor--copper, in which the electron conduction band at the L-point is located above the d-electron band. To explain our experiment we had to reverse the order of the sequence of the bands and to create a model with reverse order of levels (Figure 2). The hole pocket in the vicinity of the L-point disappeared and some other effects appeared which were later confirmed in Fermi experiments. The model of ferromagnetic nickel with reverse order of levels and exchange splitting of 0.3 eV is now the generally accepted model.

Easily distinguishable transitions which can be identified with a specific distance between levels and from which we can reconstruct the electronic structure of the investigated crystal, are always visible on the magneto-optic spectra in magnetically ordered dielectrics: ferrite-garnets, ferrite-spinels and orthoferrites.

The narrow ion lines of rare-earth metals, for example trivalent-europium or terbium placed in a magnetically ordered ferrite-garnet crystal, are

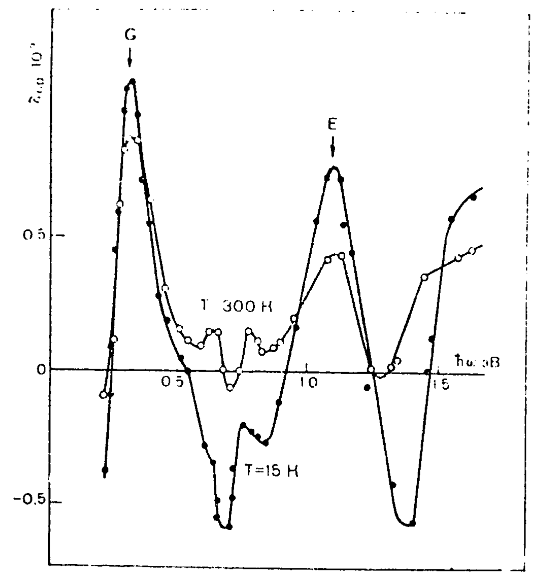

Figure 1. Orientation Magneto-Optic Effect (Variation of Reflected Light Intensity During Rotation of Magnetization Vector Related to Variation of Zonal Structure) in a Single Crystal of Nickel in the Plane (110). The maximum of G at 0.3 eV corresponds to optical transition between exchange split bands.

manifested most clearly. In this case very many spectral lines are observed within a small energy range and the spectrum varies sharply as a function of the magnetic state of the crystal (Figure 3). For example, when the magnetization vector in the crystal rotates (in a field on the order of several oersteds), the absorption line of specific frequency can either be opened or it can be completely closed. We call this effect the controlled optics of a ferromagnetic crystal.

The narrow lines of rare-earth ions provide information about the spectrum of rare-earth ions in magnetic crystals. The overall pattern of the magneto-optic spectral structure (from the ultraviolet to the infrared) of a magnetic crystal is characterized primarily by allowed strong transitions in the ultraviolet region which determine the magneto-optic properties of crystals of important practical significance.

The absorption of ferromagnetic dielectrics decreases upon moving to the visible and infrared regions of the spectrum--this is the region of the magneto-optics of transparent ferromagnetic materials. The discovery of transparent ferromagnetic materials in the 1950s and the onset of the "laser era" provided an additional impetus to development of magneto-optics.

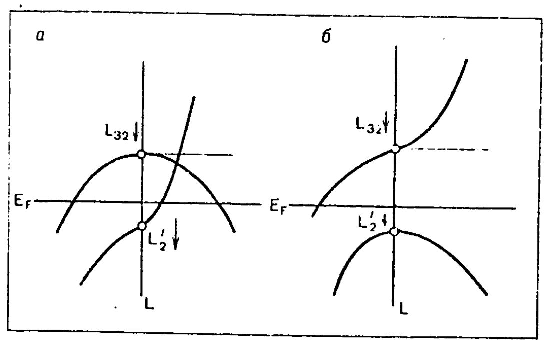

Figure 2. Model of the Band Structure of Nickel With Reverse Order of Levels--the 3 d- band (L_{32}) is Located Above the 4 s-band (L'_2): a--without regard to band hybridization; b--with regard to band hybridization

The Faraday effect was studied in the zone of transparency on ferrites-garnets and other ferrodielectrics and later on the simplest materials themselves. For example, simple gadolinium glass is magnetized by a field on the order of megagauss to the extent that its susceptibility at optical frequencies leads to rotations of the polarization plane by hundreds of degress due to the paramagnetic gadolinium ions. Similar effects were also observed in metals although the first experiments showed that they are low in value. However, we have now found that, along with ordinary, normal susceptibility which can be calculated from the Landau-Lifshits equation, anomalously high susceptibility related to interesting characteristics of the interaction of light with a magnetic crystal (for example, excitation of spin waves) is sometimes observed. Thus, study of so-called hydromagnetic magneto-optic effects will apparently become an effective tool for investigation of magnetic crystals.

Practical use of transparent ferromagnetic materials is similar to the use of magnetic crystals in the region of the SHF band (modulators, gyrators and devices for controlling an electromagnetic radiation beam). Modulators, nonreciprocal devices and magneto-optic waveguides--all devices necessary for integrated optics on transparent magnetic crystals--are created from these materials. Specifically, magneto-optic interference was observed in a thin magnetic garnet crystal: due to interference of the transmitted beams, magnetization of the crystal led to variation of the intensity of the light passing through the crystal by 20 percent.

The efficiency of devices based on transparent ferromagnetic materials depends on how rapidly the magnetic structure of the crystal reacts to variation of the external magnetic field. The effectiveness of control in magnetic terms is determined by the speed of the domain boundaries of ferromagnetic materials. Record speeds of the interface between two domains in an

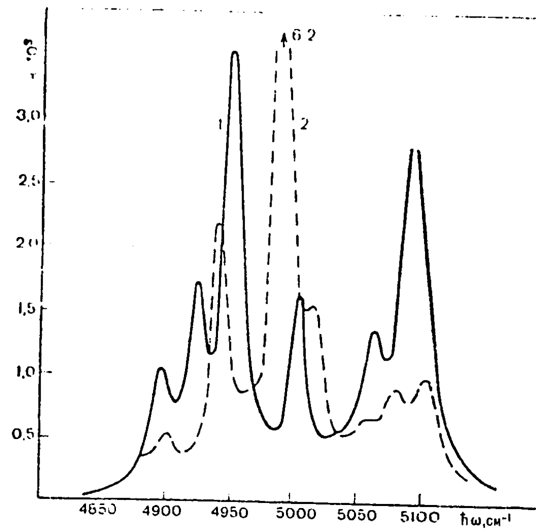

Figure 3. Variation of Absorption Spectrum of Europium Garnet Ferrite in the Region of $^7F_0 \rightarrow {}^7F_6$ During Rotation of the Magnetization Vector by 90°: curve 1--H ∥ [110], ē ∥ [001]; 2--H ∥ [110], ē ∥ [001]; plane (110); H--magnetic field; ē--electric vector of linearly polarized light wave

external magnetic field were found at the Department of Magnetism of MGU. The speed of the interface in an orthoferrite crystal reaches 20 km/s in control fields on the order of 800 Oe. The sound barrier was initially passed, that is, the excitation of sound in the crystal, and then the spin waves began to be excited, which led to a new delay in the increase of speed in the interface. Investigations in this direction are now continuing, but the speed of 20 km/s already achieved makes it possible to control the light beam in magneto-optic orthoferrite transparent materials with short switching time.

The next question which characterizes the possibilities of magneto-optics is investigation of the surface magnetic transformations in the crystals. We recall that light penetrates to a depth of less than 0.1 micron in metals. Similarly, quasi-metallic reflection can be created in ferromagnetic dielectrics by varying the wavelength of light (changing to the ultraviolet region) and light can be forced to penetrate the crystal by no more than 0.1 micron. But since most magneto-optic effects are proportional to the magnetization of a crystal, the unique possibility arises of investigating the surface layer of the ferromagnetic material regardless of its volume. This method of investigating surface magnetic properties, which we proposed and developed, has already led to some important results.

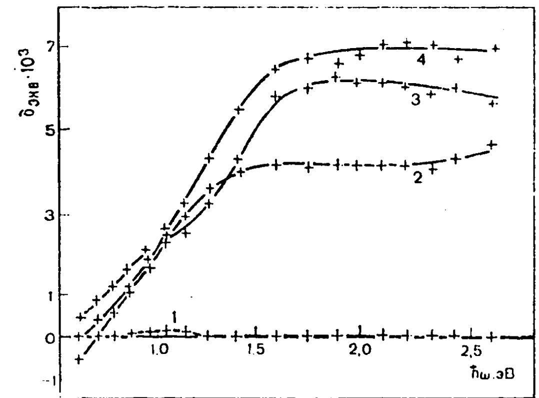

Figure 4. Frequency Dependence of Equatorial Kerr Effect Proportional to the Magnetization of the Surface Layer on Steel EP-838: 1--initial electropolished specimen, annealing in a vacuum; 2--at T = 500°C; 3--at T = 940°C; 4--at T = 1,100°C.

First, the phenomenon of surface magnetism--spontaneous magnetic transformation in the surface layer--was discovered. Due to the fact that the symmetry of circulation of magnetically active surface ions is different than that in the volume, the magnetic structure should seemingly rearrange itself only in the first atomic layer. However, because of the exchange interaction between the first and adjacent layers, this disturbance is propagated inside the crystal to typical depths on the order of 0.1-2 microns. A macroscopic "cloak"--a surface layer--is created, surface magnetism occurs and magnetic reconstruction of the surface domain occurs.

Rearrangement of the magnetic structure of hermatite to orthoferrite type (the type of magnetic ordering of another crystal) was first discovered by using the magneto-optic method.

There are also simpler examples of important magnetic phase transformations on the surface of ordinary crystals, ordinary steels and so on. As an illustration one can cite the structural materials for thermonuclear reactors. We carried out this work jointly with the Institute of Metallurgy imeni A. A. Baykov of the USSR Academy of Sciences. Due to the fact that the austenizing additive evaporates in nonmagnetic steel in a vacuum space with very slight heating of the specimen (to 200°C), phase transition is completed in the surface layer: the steel changes from nonmagnetic austenitic to the ferromagnetic state (Figure 4). The effect is absent in the initial state or in the case of a polished surface of the specimen since there is no magnetic phase on the surface.

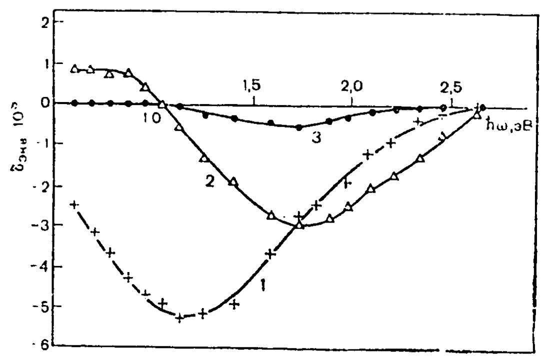

Figure 5. Equatorial Kerr Effect Proporatioal to Magnetization of Surface Layer. $ZrNiH_3$ Compound Heated in Air at T = 200°C for Three Hours: 1--in the absence of a field; 2--in a permanent field (easy axis); 3--in a permanent field (difficult axis)

Thus, the method of diagnosis of materials designed for thermonuclear reactors appeared. Moreover, the fact itself of formation of a ferromagnetic layer several microns thick during vacuum treatment or utilization of an item is interesting. It was established that a ferromagnetic surface film always forms in any nonmagnetic steel of the investigated type (chrome, manganese or some other stainless steels) when they are treated in vacuum tubes.

Another example of magnetic phase transformations was obtained when investigating ferromagnetic catalysts. The investigation was carried out jointly with the chemistry department of MGU, where nickel-zirconium catalysts are being developed. It turned out that their activity varies with a time from zero to some finite value. Chemists suggested that this is related to separation of nickel on the surface of the initial nickel-zirconium nonmagnetic system. This hypothesis was confirmed by investigations which we carried out using the magneto-optic method. It turned out that there is no magnetic layer on the surface and there is no magneto-optic effect in the initial state of nickel-zirconium nonmagnetic alloy. When the specimen is heated in an active gas (the magnetic phase does not form in a vacuum in this case), a layer appears which yields the typical magneto-optic curves corresponding precisely to ferromagnetic nickel, that is, a ferromagnetic layer which is the basis of the catalyzing component, is formed on the surface.

When this process was investigated in an external magnetic field, it turned out that it significantly affects the nature of formation of the magnetic layer in the surface region (Figure 5). Specifically, the presence of a magnetic field during treatment of a catalyst makes the latter sharply anisotropic in the magnetic sense.

A less understandable phenomenon is the effect of the magnetic field on the rate of heterogeneous chemical reaction, for example, in carbonylization of nickel. In this case the rate of reaction varies in a periodic manner as a function of the value of the magnetic field with continuous variation of the magnetic field in the region where nickel saturation occurs. The time dependence of the oscillatory processes occurring on the surface of ferromagnetic semiconductors--so-called chalcogenide spinels--was also observed.

Let us turn to investigation of magneto-optic effects with low resolution (on the order of several microns).

As noted above, the surface properties of magnetic materials can be studied by reducing the depth of light penetration and by thus acting only on the surface layer. Let us now imagine that, besides a restriction in depth, the light beam impinging on the investigated material is limited spatially. Based on this idea, one can create a device which permits measurement of the magnetic characteristics of magnetic material in a volume on the order of $10^{-13}cm^3$ since the measurements can be made on a section of one square micron (with maximum optical resolution) and with depth of light penetration less than 0.1 micron. We developed this method to investigate natural small magnetic formations existing in ferromagnetic materials. This natural formation on the order of fractions of a micron wide is, for example, the interface between two domains. Magneto-optic signals reaching the device from the point of emergence of the domain boundary to the surface of the ferromagnetic material, that is, from an area measuring on the order of 0.5-1 square micron, were measured.

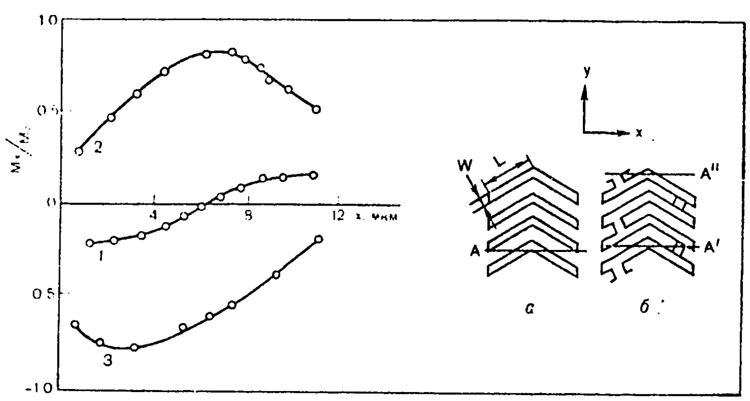

Figure 6. Magnetization Distribution of Elements of a Chevron Readout Sensor Along Lines A, A' and A" (Curves 1, 2 and 3, Respectively) In a Field of H_y = 60 Oe: a--components of sensor for stretching bubbles; b--central component for recording; L = 20 microns and W = 4 microns

Development of a device designed for physical investigations was completed approximately five years ago. It turned out that by this time engineering required the development of artificial magnetic components of very small dimensions. It should be noted that the tendency toward miniaturization of magnetic devices will be developed in the future. Similar to how the method of magnetic measurements brought about a revolution 20 years ago in conversion from ordinary objects of investigations to film objects (having 3-4 times less volume) and vibrating magnetometers, sensitive electronic circuits and so on had to be created, the field of measuring new magnetic components must now be organized. These components not only became thinner (their thickness comprises fractions of a micron)--their area was reduced by a factor of one million: a single component is located on an area of 10 X 10 square microns. The unique method of measurement for the time being which meets the requirements of increased sensitivity and resolution is the magneto-optical method.

So-called bubbles--cylindrical magnetic domains--are used as micron components formed in thin transparent magnetic crystals. Application of a magnetic field causes a reduction in the area of the magnetic phase of one direction. Spheres (their height is equal to the thickness of the crystal), which move along the crystal by means of a specially applied grid of control permalloy elements, are formed from this phase with a further increase of the field. Thus, a million of these information recording components can be located in a crystal 1 cm^2 in area.

A chevron readout sensor is used for signal recording. Approaching the readout system, the bubble is first severely stretched by the first rows of elements, then passes through the central element between whose individual regions are bridges for transmission of current. Thus, a magnetoresistive readout sensor is achieved since the electric signal is recorded by variation of the resistance of these central elements. The magnetization of the elements in a given field at any point can be measured with typical dimensions of a single component of 2 X 10 square microns (Figure 6). As a result the main functional characteristic of the given device--distribution of magnetization in its components--can be restored. The dependence of magnetization on the magnetic field at a specific point of the given component can also be measured.

The described device is a unique magnetic microscope which can be used for different purposes. By varying the magnetic structure of the crystal by means of the magnetic field, one can record the variation of reflected light intensity and can see the distribution relief of magnetization through the components. If light polarization varies, the effect caused by the normal component of magnetization is recorded and then the effect caused by its tangential components is recorded. As a result all three independently measured magnetization components are restored.

Let us present yet another example of a modern magnetic device with micron components. So-called integrated magnetic heads with film components are

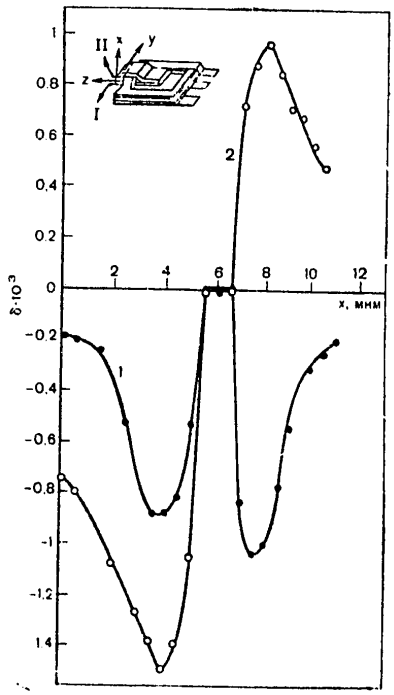

Figure 7. Distribution of Magnetization on Working Surface of Integral Magnetic Head: curve 1 shows the dependence of the tangential component of magnetization I_X; curve 2 shows the dependence of the normal component of magnetization I_Z. The zero values of magnetization correspond to the gap of the head.

now being developed. The current winding of the head is a system of non-magnetic films, the magnetic circuit is a system of sprayed films of magnetically soft material, the tip has an information-recording section measuring 2 X 100 square microns and that in the best heads measures 2 X 20 square microns. The described method of micron resolution permits one to study the magnetization distribution of this section, which is the main characteristic determining the efficiency of the device. By studying the tangential and normal magnetization component separately, complete information can be found for calculating the magnetic fields at any distance from the head (along the vertical and horizontal) and one can determine the efficiency of the components (Figure 7).

The given examples show that the new scientific trend--the magneto-optics of ferromagnetic materials, developed at the Chair of Magnetism of the

Physics Department of MGU, led to development of new methods of physical investigations and laid the bases of the crystal optics of magnetically ordered crystals. This made it possible to discover a number of new physical effects and to work out methods of investigation and checking of magnetic components and systems of modern computer equipment.

The scientific communication of G. S. Krinchik was heard with great interest at a meeting of the Presidium of the USSR Academy of Sciences. Summarizing the results of the discussion, the President of the USSR Academy of Sciences, Academician A. P. Aleksandrov noted the great significance of investigations of magneto-optic phenomena in ferromagnetic materials, carried out at MGU, for modern computer technology and wished further success in development of this important direction.

[8144/1102-6521]

6521
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FLUID DYNAMICS

GAS AND WAVE DYNAMICS

Moscow GAZOVAYA I VOLNOVAYA DINAMIKA in Russian 1979 signed to press 9 Jan 79 pp 2, 199-200

[Annotation and table of contents from book edited by Kh. A. Rakhmatulin, "Moskovskiy Universitet" Publishing House, 200 pages, 300 copies]

[Text] Annotation:

This collection includes articles reflecting both traditional and new directions being developed at the chair of gas and wave dynamics of the Mechanics-Mathematics Department of Moscow State University. The bulk of the works presented are devoted to problems of gas dynamics and the dynamics of a solid deformable body. This collection is intended for use by specialists in the field of continuum mechanics, graduate students and students.

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CSO: 1862

UDC 532+533+629.135

PROBLEMS OF FLOW AROUND BODIES WITH THREE-DIMENSIONAL CONFIGURATION

Novosibirsk ZADACHI OBTEKANIYA PROSTRANSTVENNOY KONFIGURATSII in Russian 1978 signed to press 25 Dec 78 pp 2, 126

[Annotation and Table of Contents from book "Zadachi obtekaniya prostranstvennoy konfiguratsii" edited by N. F. Vorob'yev, 400 copies, 126 pages]

[Text] The collection includes papers on calculation of flow around bodies with three-dimensional configuration. The problem of a supersonic flow around delta-shaped aircraft (wing-air scoop-fuselage) is considered in the first paper within the framework of linear theory with regard to the effects of diffraction with reflection. Two papers are devoted to justification and realization of a second-order numerical scheme for approximation of calculating nonviscous gas-dynamic flows at supersonic speeds. Problems related to calculation of incompressible flow around wings according to the discrete vortex scheme of the wing are outlined in one paper. One paper considers the problems of organizing communication (dialogue) of man and machines, which occur when solving problems of flow around bodies.

The collection is of interest to specialists involved in problems of flow around bodies.

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NUCLEAR PHYSICS

UDC 669.018:539.1

RADIATION DAMAGE IN REFRACTORY COMPOUNDS

Moscow RADIATSIONNOYE POVREZHDENIYE TUGOPLAVIKH SOYEDINENIY (Radiation Damage in Refractory Compounds) in Russian 1979 signed to press 29 Aug 79 pp 2-4, 160

[Annotation, introduction and table of contents from book by Mikhail Savvich Koval'chenko, Valeriy Vladimirovich Ogorodnikov, Yuriy Ivanovich Rogovoy, Aleksandr Gavrilovich Krayniy; Atomizdat, 1,300 copies, 160 pages]

[Text] This book systematizes available data on radiation damage in refractory compounds. It examines the fundamentals of the theory of radiation damage in solids as it applies to binary compounds; mechanisms which create radiation defects; changes in internal energy, structure and properties of refractory compounds under the effects of ionizing radiation; behavioral characteristics of borides irradiated in connection with burn-up of boron; as well as the phenomenon of recovery of structure and properties of refractory compounds during post-radiation annealing.

This book is intended for scientific workers and engineers working in the field of radiation material science and reactor construction. It may also be useful to students and post-graduates in the corresponding specialties.

Tables - 24. Figures - 83. Bibliographical entries - 203.

Introduction

Decisions of the 25th CPSU Congress pointed out the necessity for further accelerated development of nuclear energy and an increased proportion of nuclear power stations in the overall energy balance of the country. The development of nuclear energy, which is following a path toward creation of more powerful nuclear reactors and development of fast-breeder reactors, requires the development of new materials, which are capable of performing under the difficult conditions of simultaneous exposure to high mechanical stress and temperatures, aggressive agents and ionizing radiation.

For these reasons the prospective materials for nuclear energy are refractory compounds, their alloys and compounds. Devoted to the question of the effects of irradiation on solids are: monographs of S.T. Konobeyevskiy [66], G. Dins and G. Vineyard [37], V.S. Bavilov and N.A. Ukhin [8], M. Thomson [123], S.T. Kishkin [54], V.V. Pen'kovskiy [101], A.M. Shalayev [136], Ye.A. Markovskiy, M.M. Krasnoshchekov, V.I. Tikhonovich and V.G. Chernov [16], V.P. Gol'tsev [25], O.A. Troitskiy and V.G. Shteynberg [125], B. Kelly [49], B. Lastman [76], A.K. Semenyuk and V.I. Khivrich [68], Yu.I. Likhachev and V.Ya. Pupko [77]; a number of collections [15, 33-35, 81, 102, 126]; and a number of abstracts [9, 19, 22, 43, 51, 119, 127]. Further, the effects of ionizing radiation on instruments, electronic components and radiotechnical materials are examined in monographs [14, 139]. In these works primary attention is devoted to metals, semiconductors and ionic crystals.

This work presents the results of systematic study of the effects of nuclear reactor radiation on the structure and properties of refractory compounds -- specifically, compounds of transition metals with such non-metals as B, C, N (borides, carbides, nitrides), as well as reciprocal compounds of these materials.

Metallic refractory compounds (compounds of metals with non-metals) are characterized, along with a high melting temperature, by a high degree of hardness, thermal and electrical conductivity and chemical durability under the effects of various agressive agents, including molten metals [52, 53, 98, 110-112, 114-118, 121]. They have a unique crystal-chemical structure and a complex nature of chemical bonding [2, 4, 24, 69, 124]. This uniqueness is manifested in the fact that, judged by electrical properties, they appear as typical metals, while at the same time, judged by mechanical properties, they resemble oxide-based ceramic materials and covalent crystals.

Compounds formed from non-metals (B_4C, BN and others) exhibit semiconductive properties and have a high melting temperature, hardness and chemical durability. Thermal conductivity of these compounds depends primarily on the lattice parameter, which can be quite great as a result of low atomic mass.

The realm of possible use of carbides and nitrides in reactors is in structural elements in the core zone, in moderators, reflectors and matrices for nuclear fuel dispersion. Additionally, some carbides (alloys of uranium, thorium and plutonium carbides with niobium and zirconium carbides) can be used as cathode materials for conversion of nuclear energy into electrical energy [105]. Carbides and nitrides can be used as coatings on refractory metals and alloys used in reactor construction [20, 38].

The large cross section of slow neutron capture by boron allows borides to be used in regulating devices and as a biological shield against neutron radiation [102].

This work examines the fundamentals of the theory of radiation damage in solids, primarily binary compounds. It also sets forth experimental data on radiation durability of refractory compounds and their theoretical interpretation. In particular, attention is devoted to mechanisms for radiation damage, change in structure and properties of refractory materials under the effects of ionizing radiation, the peculiarities of radiation damage to borides in connection with (n,α)-reaction in ^{10}B nuclei, as well as the phenomenon of recovery during annealing. An attempt is made to establish a quantitative relationship between changes in structure and changes in properties.

Contents

[141-12184]

12184
CSO: 1862

PROSPECTS FOR USING RELATIVISTIC ELECTRON BEAMS IN INDUSTRIAL PROCESSES

Moscow VESTNIK AKADEMII NAUK SSSR in Russian No 11, 1979 pp 57-68

[Article by Doctor of Technical Sciences Ye. A. Abramyan]

[Text] The fluxes of fast, accelerated electrons were used for the first time in engineering at the end of the last century to obtain x-radiation. Many properties of an electron beam -- high propagation rate, the possibility of high energy concentration, relative simplicity of generation and control -- today provide the basis for the operation of many instruments and devices. In certain cases accelerated electrons interact with matter, causing various useful effects: light emission (on a television screen), penetrating radiation (in the x-ray machines), heating and welding of metals (in the electronic welders). In other instruments -- the electron tubes and the devices for generating superhigh frequency emission -- the beam is used to transport energy, close electric circuits and other targets.

The rapid development of nuclear engineering and technology during the postwar years has promoted the development of new methods of working materials based on the use of gamma-quantum and accelerated charged particle fluxes. Obviously, one of the most developed methods of radiation technology at the present time is the use of a relativistic (having almost the speed of light) electron beam on matter.

Interaction of Electrons and Matter

The nature of the interaction of a fast-electron flux with matter in the general case depends on the energy and intensity of the beam and also the duration of the irradiation. With high beam density, heating and evaporation material can take place. If the intensity does not exceed several hundreds of watts per square meter, and the exposure time is on the order of 0.1 seconds, the temperature of the irradiated material rises insignificantly, and ionization plays the primary role.

The electron beams used for radiation treatment of products on an industrial scale have the following characteristic parameters: an energy of 0.15 to 10 Mev, an average power of 3-150 kilowatts. In this energy range the electron energy losses in the matter take place basically as a result of multiple collisions with orbital electrons of the atoms; for each collision the primary electron is repelled, and the bound electron either separates from the atom or goes into orbit with greater energy. The trajectories of the primary electrons resemble brownian motion although the displacement in the initial direction predominates. Fig 1 shows the trajectory of the electrons having an initial energy of 0.15 Mev in the ordinary atmosphere. In a material with high density, the theoretical picture of the electron transmission is retained, and only the scale of the image changes. Fig 2 shows the ionization density distribution in the depths of the material in the electron energy range of 1-10 Mev. The determination of the thickness of the layer λ in which the nonuniformity of the ionization density is $\pm 20\%$ is of practical interest. For unilateral irradiation of a material with a density ρ by electrons having an energy E, $\lambda(cm)=0.33E(Mev)/\rho(g/cm^3)$, and in the case of two-way irradiation $\lambda(cm)=0.8E(Mev)/\rho(g/cm^3)$.

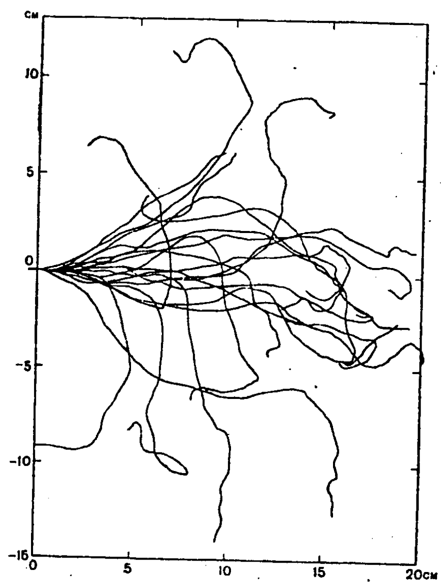

Figure 1. Standard electron trajectories with an initial energy of 0.15 Mev emitted into the atmosphere (calculated by the Monte Carlo method for room air temperature)

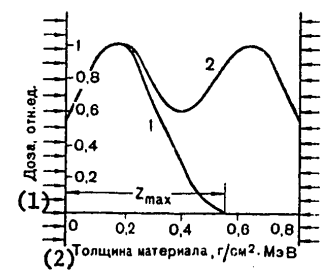

Figure 2. Ionization density distribution of the material for one-way (1) and two-way (2) irradiation

Key:

1. Dosage, relative units
2. Thickness of the material, g/cm^2-Mev

The unit of measure of the absorbed dosage of one rad corresponds to absorption in 1 g of the irradiated material with an energy of 100 ergs (or 1 Mrad-10 joules/g). Thus, the irradiation with a dosage of 25 Mrad of material with a density of $\rho=1$ g/cm^3 leads to heating by 60°C. In order to eliminate the overheating of the material with large irradiation dosages it is performed in several steps.

As is obvious from the presented relations, the relativistic electrons have high penetrating capacity; in the atmosphere the maximum mean free path z_{max} of the electrons with an energy of 1 Mev is 3.8 meters; in water it is 4.3 mm. This makes it possible to emit a beam of electrons from an evacuated volume where acceleration takes place through a thin foil into the air and machine parts directly in the atmosphere.[1] As the material for the emission windows, foil is used made from light metals -- titanium, aluminum and others; the thickness of the windows will usually be 15-100 microns.

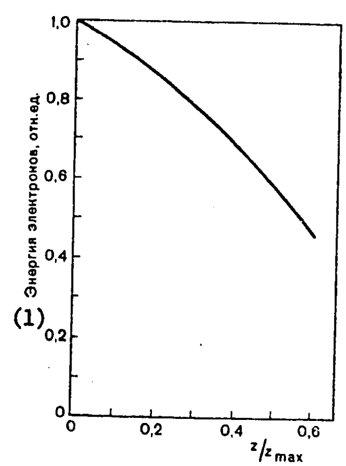

Figure 3. Ratio of the most probable energy of the electrons passing through the material to the initial energy as a function of the thickness of the material.
z_{max} is the depth of penetration of the electrons; the electron energy is 0.1 to 1 Mev, and the material is titanium

Key:

1. Electron energy, relative units

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[1]In some cases in order to avoid oxidation of the materials, the irradiation zone is filled with inert gas -- most frequently nitrogen.

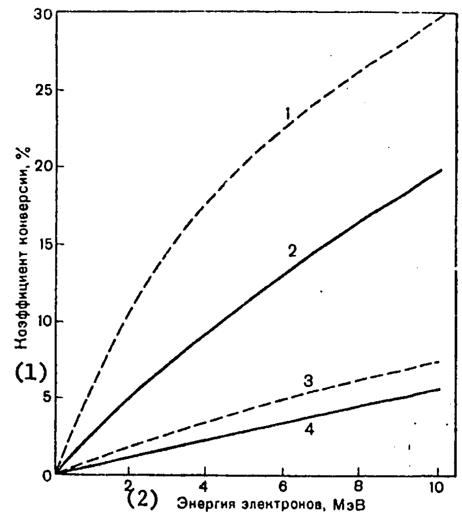

Figure 4. The conversion factor for conversion of the energy of the accelerated electrons into bremsstrahlung energy as a function of the electron energy for tungsten (1 and 2) and aluminum (3 and 4) targets.
Curves 1 and 3 correspond to a total energy of the gamma-quantum flux, 2 and 4, to the energy directed along the path of the beam.

Key:

1. Conversion factor, %
2. Electron energy, Mev

On passage of the electrons through the foil they lose part of their energy and are deflected from the initial direction. Both processes have a probability nature. Fig 3 shows the energy loss by the beam on passage of it through different layers of the material. As a rule, the electron losses in the emission window are 1-2% for energies of about 1 Mev and to 10-15% for an energy of 0.15 to 0.2 Mev.

On bombardment from the irradiated products and on passage through the foil, the beam generates the secondary electron flux. With an increase in the energy of the primary flux, the probability of returning in the opposite direction for the primary or knock-on secondary electron decreases.

The greater part of the existing industrial units with electron beams have electron energy below 1.5 Mev. This eliminates the danger of the occurrence of residual radioactivity, the threshold energy of which exceeds this level.

Radioactive isotopes created by bremsstrahlung

Element	^{9}Be	^{2}H	^{127}Y	^{7}Li	^{81}Br	^{14}N	^{31}P
Threshold energy, Mev	1.67	2.23	9.8	9.8	10.7	10.65	12.35

Thus, the danger of the appearance of radioactivity becomes significant only with an energy of 9-10 Mev.

With an increase in the electron energy, the losses to bremsstrahlung increase (see Fig 4). With an energy on the order of 1 Mev, these losses are negligibly small and they are not considered when calculating the energy balance of the irradiation process. With a beam energy of 4-6 Mev, the proportion of the energy converted to bremsstrahlung is tens of percentages. Therefore, the irradiation of the thick layers of the material with bremsstrahlung, the penetrating capacity of which is almost two orders higher than for the electrons, can become profitable.

A significantly different physical picture occurs on interaction of an intensive, concentrated electron flux with matter.

The beams with an energy to 100-120 kev and the density of 10^4 to 10^6 watts/cm^2 have been industrially assimilated; they are used for the welding and fusion of metals in a vacuum or at reduced pressure. For relativistic energies, the concentrated beam can be coupled out into the atmosphere and also used for the heat treatment of materials.

The application of the beam as a tool for the treatment and destruction of rock is of interest. In particular, on irradiation by a pulse beam, fast, adiabatic heating and cleavage of the rock take place; a significant role is also played by the electric breakdown of the charge accumulated in the body of the material.

When treating materials with an intense beam outside a vacuum, the basic problem is to maintain high energy intensity (on the order of 10^6 watts/cm^2) at a distance of tens of centimeters from the emitting device. An obvious way of decreasing the beam dispersion is to increase the electron energy. However, according to the experimental papers which have appeared in recent years,[1] the electron dispersion in the atmosphere decreases significantly both with an increase in intensity and an increase in the power of the beam. Obviously, heating of the air by the electron beam takes place, as a result of which the interaction cross section of the electrons with the medium decreases in the channels formed. The analogous fact -- anomalously deep transmission of the electron beam into the metal -- also exists in the case of electron welding of metals in a vacuum.

See: J. F. Lowry, B. W. Schumacher. "Extended Working Range for Electron Beams in the Atmosphere," NUCLEAR INSTRUMENTS AND METHODS, Vol 130, 1975, p 577.

Industrial Radiation Processes

With a certain measured irradiation, the destruction of the intramolecular bonds leads to the formation of new compounds with given properties. For variation of the structure of the materials usually significantly less energy is required than for the traditional technological processes. This fact is especially promoting the spread of radiation technology at the present time when the cost of oil and other energy sources is increasing steadily. In a number of cases the application of ionizing radiation is the only possibility for obtaining a material with given properties. The most economically advantageous regions of application of the radiation are irradiation of live organisms (sterilization of medical equipment, products, the control of insect pests) and the irradiation of polymers.

There are two basic methods of varying the structure of polymers: cross-linking -- the formation of transverse bonds between adjacent molecules -- and destruction -- the rupture of principal chain of the molecule. In the first case, the molecular weight increases and a spatial structure is formed; in the second case the mass of the molecule decreases. In both cases the physical properties of the materials formed differ from the properties of the initial products. Another energy-advantageous class of radiation technology is the chain reactions in which one act of initiation of the chemical reaction leads to a change in many of the chemical bonds.

The standard radiation processes with electron accelerators which have become widespread at the present time are presented in the table.

Industrial Applications of Intense Electron Beams with an Energy of More than 150 kev

Process	Energy, Mev	Dosage, Mrad
Cross-linking of polyethylene	0.3-4	10-25
Production of thermo-shrinking polymer products	0.3-4	10-25
Hardening of coating	0.15-0.5	2-50
Graft polymerization	0.3-2.5	1-30
Sizing of textiles	0.3-1.5	0.5-5
Manufacture of fiberglass	0.5-1	1-40
Vulcanization of rubber	0.5-10(15)	5-30
Sterilization of medical equipment	1-10	2-5
Treatment of waste water	0.5-4	0.05-1

The cross-linking of polyethylene is one of the first radiation processes mastered on industrial scale in our country and abroad. The spatial grid formed during the cross-linking decreases the fluidity and solubility of the polyethylene; the heat resistance and the impact toughness increase significantly. The high power of the radiation dosage which electron accelerators can support decreases the role of radiation oxidation of the irradiated polymers competing with the process of cross-linking and having a negative effect on the mechanical and electrical properties of the material. The cables with insulation made of radiation-modified polyethylene are used for higher current load; they retain their fitness for work for several hours at a temperature of 200 to 250°C and for hundreds of hours at 110°C. In an oxygen-free environment such insulation can be preserved for a long time at a temperature of 250 to 300°C.

Another application of an irradiated polyethylene is based on the "memory effect": on heating products made of polyethylene and subsequent deformation and then cooling in the deformed state the polyethylene can store its initial dimensions "in memory" for a long time. The heating of a product made from such a polyethylene at a temperature of 100°C returns it to these dimensions.

Radiation hardening of coatings is also one of the most widespread methods based on the application of accelerated electrons. It includes the polymerization of monomers or low-molecular polymers, the cross-linking of polymers formed and the appearance of chemical bonds between the molecules of the coating and the base. In contrast to the cross-linking and the destruction for which the modification of the polymer molecules takes place, the process of polymerization of the monomers gives a chain reaction in which the series of chemical conversions is caused by a single act of ionization of excitation. In the case of radiation polymerization, contamination is absent, whereas for chemical polymerization, catalysts are used which remain in the polymer and have a negative effect on its qualities. The process can take place at a temperature which is optimal for growth of the chains for any state of the material, including the solid phase.

The costs of the radiation and ordinary hardening of the coatings are close, but in the first case higher thermal stability, mechanical strength and chemical strength are achieved. Explosion and fire danger in the production process decrease.

In the case of graft polymerization, one polymer is grafted to another under the effect of ionizing radiation. The molecules of the copolymer formed are different from both the grafted one and the base polymer. In contrast to the radiation hardening where the basic process is polymerization of the applied layer and bonding to the substrate plays a secondary role, in this case the formation of the copolymer is the principal effect. Radiation grafting can be accomplished in a thin surface layer and in the body of the material.

The treatment of fabrics with an electron beam promotes improvement of their use and operating qualities. Radiation grafting to textiles lends them chemical and antirotting strength, wrinkle-proofness, oil resistance. It lowers the capacity for accumulation of static electric charges, contamination, and so on. Here, various radiation-chemical processes are used: cross-linking, destruction, graft polymerization, copolymerization, and so on.

The process of manufacturing multilayered fiberglass obtained by impregnation of glass fabrics with a binder made of a mixture of polyester resin and vinyl monomer and copolymerization of them is similar to the radiation modification of the fabrics. The polymer material formed has high chemical strength, high impact toughness and low density. The strength characteristics of the fiberglass obtained by the radiation method are appreciably higher than for the fiberglass manufactured by the thermochemical method.

In the case of radiation cross-linking of rubber, primary chemical bonds occur between the carbon atoms, and the spatial grid is formed which by comparison with the ordinary chemical vulcanization insures greater heat resistance, resistance to aging and deformation at high temperature, and wear resistance.

For vulcanization of tire rubber which does not achieve vulcanization by the thermal process but is already capable of retaining its shape, the tire is irradiated with electrons with an energy on the order of 10 Mev. Irradiating the product in contact with a graftable monomer, it is possible to obtain rubbers of various versions. The gas-phase graft polymerization on the surfaces of fabrics and fibers to increase their adhesion to the rubber is of interest. Obviously, this method can be used to increase the adhesion of the rubber to synthetic fabrics. Successful results have been obtained by vulcanizing extruded products made of silicone rubber and the manufacture of thin-walled products.

The primary advantage of radiation sterilization of products is the low energy expenditures. Thus, for sterilization under a dosage of 2.5 Mrads per gram of materials six calories are absorbed, which corresponds to heating of water by 6°C (in contrast to the usual sterilization by boiling). In practice all of the microorganisms receive a lethal dosage during the irradiation, and at the same time no chemical changes take place in the irradiated material. If it is necessary to keep the sterilized objects for a prolonged time, they are sealed and then irradiated. The most widespread material for packaging is polyethylene which is transparent for radiation and nonpermeable for bacteria. As a result of significant thickness of the irradiated products in many cases it is preferable to use bremsstrahlung or gamma radiation. Some medical materials (for example, surgical threads), sterilized by radiation, have better characteristics than those treated by ordinary methods.

For a number of years a study has been made of radiation sterilization of food products which permits meat, fish, berries and fruits to be stored for a long time at ordinary temperatures. However, the widespread use of this process is being held up as a result of the necessity for comprehensive and prolonged checking of possible chemical changes in the part itself. The use of food products irradiated by a dosage of about 0.1 Mrad is permissible in many countries; the possibility of sterilization by doses of 2-5 Mrads remains problematic. The process of disinfestation of grain -- irradiation of the grain stored loose with a dosage on the order of 0.1 Mrad -- in order to sterilize the insect pests is closer to realization.

The radiation treatment of industrial waste and sewage is one of the methods of decreasing the environmental pollution. Under the effect of ionizing radiation, organic and other pollutants decompose. The processes of destruction, radiolysis and other processes improve the process of purifying waste water: the precipitation and coagulation are accelerated. The cost of the treatment increases in the case of combining radiation with chemical or physical agents or with biochemical purification. Obtaining ozone by radiation and then using it to purify water is of interest.

In addition to the above-enumerated purposes of the application of electron accelerators they can obviously be used on a broad scale for the treatment of leather products, the purification of gaseous chlorine to remove hydrogen, atmospheric nitrogen fixation, irridiation of concrete and in a number of other cases.

The application of a concentrated relativistic beam for the processing of materials outside a vacuum still has not become widespread. For the welding of metal, individual devices are being used with a beam energy of about 0.15 Mev, a power on the order of tens of kilowatts and also experimental accelerators with an energy of about 1 Mev in the same power range. In the existing devices the beam diameter in the atmosphere near the emission device is 1-3 mm.

Let us note that at the present time, in addition to high energy concentration in the pulse electron beam, record energy fluxes are obtained (to $2 \cdot 10^{13}$ watts), and effective utilization of it is insured: the efficiency of the conversion of the energy to an electron flux and from the flux into matter reaches 60-90%. The application of the concentrated relativistic beams in industry is still being held up by technical complexity of their generation and significant radiation danger.

Industrial Electron Accelerators

The first devices of generating relativistic electron beams for applied purposes were based on the systems for accelerating particles used in research accelerators. Although the electron energy required by industry (0.15-10 Mev) is several orders below the energy attained on the best research devices ($2 \cdot 10^3$ Mev), more rigid requirements are imposed on the industrial accelerators with respect to reliability and efficiency; in some cases the accelerators must have minimum size and weight. The technological process with the electron accelerator must insure cheaper production by comparison with other technological methods, including with the irradiation by gamma quanta of an isotopic source. In the last 15 to 20 years, several new types of accelerators have been specially developed for industrial purposes, which has permitted the support of the growing introduction of radiation technology. There are two classes of industrial devices: direct-action accelerators (with an energy to 3-4 Mev and a power to 200 kilowatts) and linear accelerators (with an energy of 3-10 Mev, and a power to 10 kilowatts). The devices of the first class contain a high-voltage generator which generates a voltage equal to the acceleration energy and an accelerator in which under the effect of this voltage the electrons are accelerated in a potential electric field. Such devices convert up to 60-90% of the energy taken from the industrial network to the energy of accelerated electrons. In linear accelerators, the high-frequency electric field is used, and the absolute value of the high voltage of the structural elements is significantly lower; the efficiency does not exceed 5-10%.

The schematic diagram of a direct-action accelerator is shown in Fig 5, a. In addition to the accelerator and the high-voltage generator the device contains a unit for discharge of the beam into the atmosphere. If the accelerator is designed for radiation treatment of materials, the intensity of the irradiation of the target (moving perpendicular to the figure) must be no more than 100-200 watts/cm^2, and in order to increase the cross section the beam is scanned by an alternating (50-5000 hertz) magnetic field--in one or in two mutually perpendicular directions. The concentrated electron beam is emitted from a vacuum into the atmosphere through the through channel near which several vacuum pumps are installed which pump out the air which gets into it.

For accelerator energies of 0.5 to 0.7 Mev and higher the accelerators in the high-voltage generator are in a single sealed volume (vessel) filled with electrically strong gas (a mixture of nitrogen with SF_6) under a pressure of up to 15 kg/cm^3. The electric strength of this gas medium under operating conditions is 150 to 300 kv/cm, which makes it possible to create high-voltage devices which are significantly more compact than the equipment with air insulation. Thus, the accelerators are functioning successfully on an energy of 1-1.5 Mev and a beam power of several kilowatts in a vessel with a volume of less than 1 m^3. For energies of 0.15 to 0.7 Mev the accelerator can be located at a distance of several meters from the high-voltage generator, connected to it by a cable. This permits removal of the generator from the radiation-hazardous zone and a decrease in mass of the radiation shielding.

The most widespread accelerator is the acceleration tube (see Fig 5). The primary problem occurring on development of the tube is to insure electric strength with minimum length of the tube and maximum beam current. The reduction of the length of the tube increases the admissible current density (the perveance of the system), which, in turn, permits a decrease in the channel diameter in which the electrons are accelerated and the overall diameter of the tube. In the existing tubes the electric field

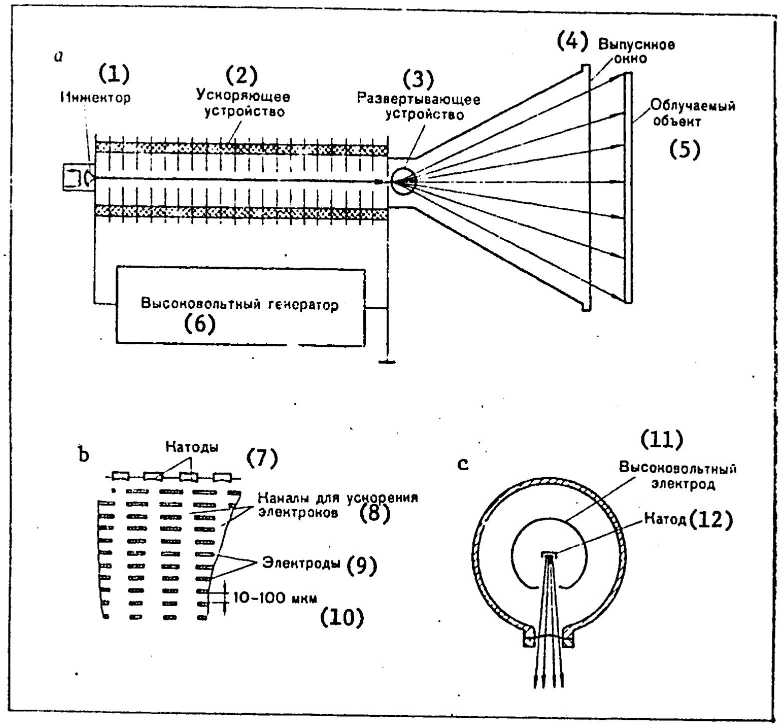

Figure 5. Direct-action accelerator.
a -- schematic diagram of the accelerator, b -- schematic of a compact multi-aperture tube, c -- cross section of the device with single high-voltage gaps for the acceleration of a ribbon beam

Key:

1. Injector
2. Accelerator
3. Scanning device
4. Discharge opening
5. Irradiated target
6. High-voltage generator
7. Cathode
8. Channels for electron acceleration
9. Electrodes
10. 10-100 microns
11. High-voltage electrode
12. Cathode

gradient is no more than 2-3 MV/m; the constancy of the gradient is insured by intermediate electrodes, the potential on which is maintained by an external voltage divider (not shown in the figure).

The most vulnerable sections for breakdown are the surface of the insulator in the vacuum and through channel on the tube axis in which the electrons move. Acceleration and breeding of secondary particles can occur in the channel, leading to the formation of an avalanche and, as a result, to breakdown of the tube. The processes causing tube breakdown still have not been subjected to calculation. The basic methods of increasing the fitness of the acceleration tube are elimination of the losses on transmission of the basic accelerator beam in the acceleration channel, attenuation of the secondary particle flux and also the use of protective spark gaps laced between the electrodes.

One of the methods of increasing the electric gradient and miniaturization of the tube obviously is smaller sectioning of it (to spacing between the electrodes of tens of microns instead of the centimeters used today) and acceleration of the electrons in many small-diameter parallel channels (see Fig 5, b).[1] It has been discovered experimentally that many of the insulating media in micron gaps are capable of withstanding a static electric field with an intensity on the order of 1 MV/cm, and the problem consists in insuring these gradients in a multilayer structure in the presence of many openings for electron acceleration.

Another version of the accelerator is used to generate a ribbon electron beam with an energy to 200-300 kev (see Fig 5, c). Here the voltage is applied to a single unsectioned vacuum gap; the average gradient of the electric field is 15-25 kv/cm. The optoelectronic properties of the system insure the required cross section of the electron flux without the scanner. Unfortunately, with an increase in voltage in such systems it is necessary significantly to reduce the gradient of the electric field, which leads to a decrease in perveance and an increase in the dimensions of the devices. The leading active studies in many laboratories of the mechanism of vacuum breakdown obviously permit the voltage level to be raised in such devices.

The high-voltage generators of direct-action industrial accelerators differ significantly from the devices for increasing the voltage used in electrical engineering. As a rule, significantly higher voltages are required here but lower powers than in the power electrotechnical systems. In addition, the high-voltage generators of industrial accelerators which generate a voltage of more than 0.5 to 0.7 MV must be placed inside a radiation-shielded facility and, consequently, be sufficiently complex. Whereas the voltage generated by high-voltage electrotechnical sources is released into the atmosphere, in the industrial accelerators all of the elements under voltage usually are located in an insulating medium which is significantly better than the air -- compressed gas, oil or a vacuum.

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[1] See: E. A. Abramyan, B. A. Altercop, G. D. Kuleshov. "Microsecond Intensive E-beams," REPORT ON THE 2ND INTERN. TOPICAL CONF. ON HIGH POWER ELECTRON AND ION BEAM, RESEARCH AND TECHNOLOGY, Ithaca, USA, 1977.

The basic principles used for high-voltage generation are mechanical charge transport, single-step transformation and staged voltage increase.

The charge transport by a moving belt is the basis for operation of one of the first high-voltage sources -- the electrostatic generator (van de Graaf generator). In the latest devices of this type a potential of about 30 MV has been reached. Versions of this system include the palletrons in which the charge is transported by a chain and the rotary generators. The essential deficiencies of electrostatic generators are low power (no more than several kilowatts) and the presence of moving parts.

The three-phase step-up transformers have in practice unlimited possibilities for increasing the generated power. As a rule, in such devices an increase in voltage is combined with rectification. In certain generators the rectifying elements are designed for the total voltage; in others, the secondary winding is made up of many sections, each of which has rectifying elements. In some devices a continuous magnetic circuit is under ground potential, the insulation between the primary and secondary windings and other elements of the generator is provided by gas gaps or solid insulation, in others the magnetic circuit is separated into individual elements insulated from each other. At the present time in a number of laboratories high-voltage generators are being developed on the basis of the three-phase transformers for a voltage on the order of 1 MV and a power of 1 Mwatt.

In the power range from 10 to 100 kilowatts, several versions of the single-phase systems are used: the stage generators, the pulse transformers with high repetition frequency, electronic transformers, and so on. One of the models of the industrial accelerators is the high-frequency resonator in which the high voltage is generated, and the electron acceleration takes place in a potential field.

The linear electron accelerators contain a waveguide in which the high-frequency field with a traveling wave is created. The wave propagation rate at each point corresponds to the speed of movement of the accelerated electrons. Beginning with an energy of 2-3 Mev, the electron velocity changes little, and the waveguide structure becomes constant. With some approximation it can be considered that with an increase in the energy of the accelerated particles, the rate and the cost of the linear accelerators increase proportionately to the first power of the energy, and the direct-action accelerators, to a power of 2.5-3. The latter is connected with the fact that with an increase in the absolute potential on the structural elements in all three directions, the length of the high-voltage gaps and insulators increases.

Trends in the Development of Process Units with Electron Beams

Simultaneously with the expansion of the sphere of use of the electron beams, the power and the output capacity of the radiation devices increase.

Whereas in the first industrial accelerators the power of the beam was units of kilowatts, in the near future it is necessary to expect the appearance of devices with a power of about 1000 kilowatts (see Fig 6). With an increase in power, the cost of the beam energy and, consequently, the cost of irradiation decreases. On the one hand, this makes the more energy-consuming radiation processes profitable, and on the other hand, it permits conversion to irradiation of massive products by bremsstrahlung generated on the internal target of the accelerator.

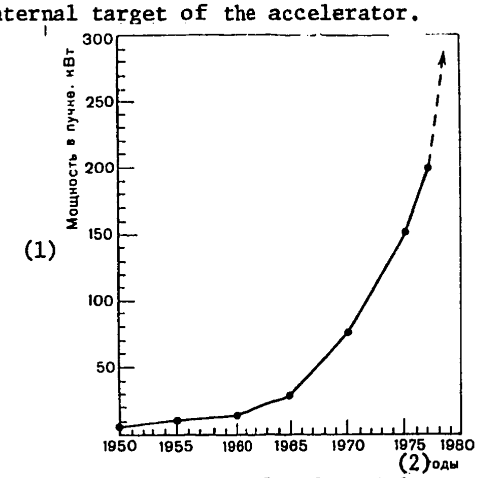

Figure 6. Growth of the power of industrial devices

Key:
1. Power in the beam, kilowatts
2. Years

It must be noted that at the present time U.S. industry is using 230 accelerators with a total power of 2000 kilowatts and 60 isotopic sources; the cost of materials treated with ionizing radiation exceeds $1 billion per year.[1] It is possible to expect that the powers of the devices and the scale of their application will increase significantly as a result of the assimilation of radiation treatment of waste water and the application of concentrated beams in mining and metallurgy. The use of radiation to treat textiles, paints and varnishes (including automobile parts) and to sterilize food have great potential possibilties. In addition to the creation of reliable accelerators and the irradiation technology, in a number of cases it is necessary to overcome a psychological barrier connected with the usual idea of radiation, the measured application of which for technological purposes presents no danger.

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[1] See: J. Silverman, "Current Status of Radiation Processing." REPORT ON THE 2ND INTERN. MEETING ON RADIATION PROCESSING, 1978, Miami, USA.

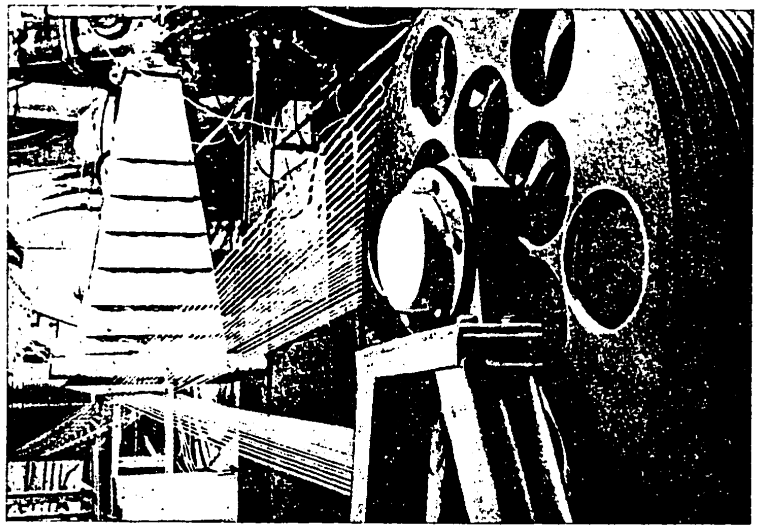

Figure 7. Irradiation zone of the first Soviet industrial device for electron beam treatment of polyolifene cable insulation

In the more distant future intense relativistic electron beams can be used to transmit energy, and the synchrotron electron emission, for technological purposes.

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OPTICS AND SPECTROSCOPY

PROCEEDINGS OF THE MOSCOW POWER ENGINEERING INSTITUTE, TOPICAL COLLECTION, PHYSICAL OPTICS

Moscow TRUDY MOSKOVSKOGO ORDENA LENINA ENERGETICHESKOGO INSTITUTA, TEMATICHESKIY SBORNIK, FIZICHESKAYA OPTIKA in Russian No 426, 1979 pp 2, 81-86

[Annotation and abstracts from the collection "Trudy moskovskogo ordena Lenina energeticheskogo instituta, tematicheskiy sbornik, fizicheskaya optika" edited by Doctor of Physicomathematical Sciences, Professor V. A. Fabrikant, Moscow Power Engineering Institute, 86 pages]

[Text] The collection contains theoretical papers carried out at the Department of Physics of MEI [Moscow Power Engineering Institute] during 1977-1978 and joined by a common theme--investigation of optical phenomena in cavities, gaseous and solid-state media. Investigations of the statistical properties of the electromagnetic field occupy a significant position. The statistics of radiation reflected from an atomic gas filling a half-space are considered. Nonlinear phenomena in scattering of an electron beam in the field of a strong electromagnetic wave are analyzed. The kinetics of radiation during free-free transitions are investigated. The effect of resonances on the threshold intensity of radiation upon optical breakdown in a gas is analyzed. The method of integral equations and the method of beam matrices are compared in papers devoted to calculation of phenomena in optical cavities and the new criterion of the stability of optical cavities is introduced. The problem of the boundaries of applicability of the diffusion theory of photon transport in solid-state photocells is considered.

The collection may be useful for specialists in optics and quantum radio physics.

UDC 535.31

The Stability of Arbitrary Spherical Cavities, Ye. F. Ishchenko and G. S. Ramazanova.

It is shown that the traditional geometric condition of stability loses its significance for cavities containing an active medium or diaphragms with transverse amplification (absorption) inhomogeneity. The criterion of stability--attenuation of the natural fields with unlimited separation from the cavity axis--is proposed. The calculating apparatus which permits an estimate of stability is presented. The possibility of reciprocity of stability for counterwaves in a circular cavity is shown.

UDC 535.31

The Applicability of Huygens Principle to Calculation of Cavities Containing a Weakly Inhomogeneous Medium, G. S. Ramazanova.

The applicability of the method of integral equations to calculation of the natural waves of cavities containing a weakly inhomogeneous medium is checked by comparison to the method of beam matrices, which follows from the wave equation. It is shown that both methods yield an identical result in approximation of infinite apertures.

UDC 621.378

Methods of Calculating the Effects of Misalignment of Open Optical Cavities, Ye. F. Reshetin.

It is suggested that the effects of arbitrary misalignment of a linear symmetrical cavity be calculated as the sum of the effects occurring due to symmetrical and antisymmetrical inclinations of the mirrors. The limits of the applicability of this approximation are estimated. Calculation of diffraction losses yields the greatest error; shifting of the field on mirrors and variation of the phase lead with misalignment coincide with exact calculations.

UDC 621.378

The Effects of Misalignment of Open Optical Cavities, Ye. F. Reshetin.

The main trends in variation of diffraction losses, phase lead and shifting and distortion of the electromagnetic field on the mirrors of linear symmetrical cavities during misalignment are studied by computer calculation. Some anomalies caused by field distortion on the mirror edges are determined.

UDC 535.14

Relaxation of the Statistical Characteristics of Radiation in A Resonance Cavity, B. A. Veklenko.

The time moments of the photon density matrix, which describes the evolution of the electromagnetic field due to instantaneous variation of the Q-factor of the resonance cavity, are found in analytical form. The calculations are based on iteration of the control equation found in the paper, which takes into account the fast time-variable processes and is related to integral differential equations.

UDC 535.14

The Statistical Properties of Radiation Coherently Reflected From a Half-Space, B. A. Veklenko.

The evolution of the photon density matrix during resonance reflection from an atomic gas filling a half-space is considered. It is shown that the statistical properties of the reflected radiation are described by binomial distribution whose parameters are determined by Fresnel formulas.

UDC 621.383.52

The Collection Coefficient in Photocells with Thin Front Layer, A. M. Vasil'yev and I. I. Tyukhov.

Collection carriers in photocells with front layer thickness comparable to the length of the free path of the carriers generated by short-wave light is considered. It is shown that use of diffusion theory in photocells with very thin layers is incorrect. The probability method of calculation, possible in this case, is presented. The values for collection of carriers are compared to those found from diffusion theory.

UDC 537.531.2

Damping Processes in a Bichromatic Field, A. K. Lebedev.

Derivation of the kinetic equation of the evolution of an electromagnetic wave of arbitrary intensity upon interaction with an electron beam injected into a rarified plasma is presented. The plasma is under the effect of a second wave of arbitrary intensity. The case of damping processes with Coulomb scattering is considered. The formulas are generalized for the case of several external waves and also for the case of a nonmonochromatic wave. The kinetic equation for the density matrix of bremsstrahlung in the field of an external classical wave is found.

UDC 537.531.2

Amplification of a Weak Wave During Bremsstrahlung of an Electron Beam in a Rarified Plasma in the Field of a Strong Electromagnetic Wave, A. K. Lebedev.

The nonlinear amplification factor of bremsstrahlung in the field of an external classical wave is analyzed. It is shown that the amplification factor is classical and differs qualitatively from the case of a very strong second wave in expansion of a second wave in intensity. Formulas for different cases of electron injection are discussed. Amplification of the radiation is suppressed for short-acting potentials.

UDC 535.14

The Density Matrix of Subsystems Under Thermodynamic Equilibrium Conditions, B. A. Veklenko.

A regular method of calculating subsystems (for example, a photon gas) which generally interacts strongly with its own environment under thermodynamic equilibrium conditions is proposed. The method is based on a combination of generalized quantum Green functions and Matsubari temperature technique.

UDC 533.9.01

The Spectra of Many-Electron Systems in a Dense Medium, L. L. Podlubnyy.

The variational principle is used for theoretical description of strong interaction of many-electron systems (atomic and ionic) with a thermostat (plasma). The energy of the ground state of the system is calculated. The formalism of functional integrals and Feynman integrals from electron trajectories in random fields is used to describe electron behavior in a dense medium.

UDC 539.18

Calculation of the Potential Curves by the Model Potential Method, I. V. Avilova.

Wave functions of Fuss's model atomic potential were used to calculate single-electron two-center integrals which are used in calculating the parameters of two-atom molecules and the characteristics of atom-atom interaction. It is shown that the model potential in the form of Fuss's atomic potential leads to comparatively simple expressions suitable for mass calculations.

UDC 533.9

The Theory of Resonance Optical Breakdown of Gases, V. A. Kas'yanov and A. N. Starostin.

A quantum kinetic equation is found for electrons in a plasma in the field of an intensive electromagnetic wave during photon resonance of radiation with energy of some atomic (molecular) transition. The instantaneous and adiabatic activation of the field and the saturation mode are considered. Estimates of the reduction of the threshold intensity during resonance optical breakdown compared to the nonresonance case are presented.

UDC 532.537.226

The Ratio of Relaxation Times for Strongly Polar Fluids, V. P. Kobelev and M. S. Checheybayev.

Experimental data for the relaxation times of strongly polar fluids are analyzed. A relation is found to estimate the microscopic relaxation times for strongly polar fluids from measurements of the macroscopic relaxation time and permeabilities based on a new expression of the local field. The calculating data are in good agreement with experimental data.

UDC 537.531.2

An Equation for the Density Matrix of High-Intensity Bremsstrahlung, G. B. Tkachuk.

An expression is derived for the density matrix of bremsstrahlung. The equation takes into account photon-electron interaction in all orders of perturbation theory. Electron interaction with scattering centers is described in Born approximation. Taking into account many-photon processes is necessary when considering the interaction of high-intensity radiation with the plasma.

UDC 537.531.2

The Effect of Shielding the Coulomb Potential On Bremsstrahlung Amplification of a Monoenergetic Electron Beam, A. K. Lebedev.

The effect of shielding on the polarization-frequency characteristics of the bremsstrahlung of a monoenergy electron beam in a plasma is considered. Suppression of amplification with an increase of shielding and also disappearance of the anomaly in weakly linear amplification is shown. Graphs of the dependence of radiation polarization and the amplification factor as a function of frequency for different values of the shielding parameter from zero to infinity are presented.

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THERMODYNAMICS

UDC 536. 48

POROUS MATERIALS IN CRYOGENIC EQUIPMENT

Minsk PORISTYYE MATERIALY V KRIOGENNOY TEKHNIKE (Porous Materials in Cryogenic Equipment) in Russian 1979 signed to press 2 Nov 79, pp 2, 221

[Annotation and table of contents from book by Leonard Leonidovich Vasil'yev, Galina Ivanovna Bobrova, Svetlana Aleksandrovna Tanayeva; Nauka i Tekhnika, 1,040 copies, 224 pages]

[Text] This book examines original designs of cryogenic equipment which utilize porous elements: cryogenic heat tubes, steam chambers, porous nozzles, porous cryogenic conductors, porous cryogenic intakes, etc. It presents results of experimental studies of heat exchange in porous cryogenic cable and porous conductors and the thermo-physical characteristics of structural and thermal-insulating materials in cryogenic equipment in the 10-400°K temperature spectrum. It analyzes results of studies of thermal properties of porous thermal insulation and powders over a broad temperature spectrum in operational use. Structural materials are presented in the form of various polymeric compositions.

This book is intended for workers in scientific research institutes, planning organizations and design bureaus and engineering-technical workers, university students and post-graduate students.

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