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TRANSLATIONS ON USSR SCIENCE AND TECHNOLOGY
PHYSICAL SCIENCES AND TECHNOLOGY
(FOUO 13/79)

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PHYSICAL SCIENCES AND TECHNOLOGY

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GEOPHYSICS, ASTRONOMY AND SPACE

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NEW METHOD OF WAVE FRONT RESTORATION

Moscow DOKLADY AKADEMII NAUK SSSR in Russian manuscript received 18 Jul 78
Vol 244 No 1,1979 pp 83-85

[Article by S. D. Andrenko, academician of the Ukrainian SSR Academy of Sciences; A. Ya. Usikov, and V. P. Shestopalov, Institute of Radio Physics and Electronics of the Ukrainian SSR Academy of Sciences, Khar'kov]

[Text] It is known [1,2] that obtaining a hologram is essentially the same as recording an interference pattern formed as a result of the superposition of two waves: the reference and subject coherent with it, scattered on the investigated object. The photographic plate located in the region of interaction of the waves is a diffraction grating after exposure and processing. For reproduction (restoration) of the subject wave, the photographic plate (hologram) is located at the same place and in the same orientation as for exposure, and a transmitted wave identical to the reference wave is directed at it.

The holograms existing at the present time are distinguished among each other by the method of processing the photosensitive layer (phase, amplitude), the depth of the fixed interference pattern (plane, volumetric), the combination of phase fronts (plane, spherical) subject and reference waves (shadow, Fresnel, Fraunhofer and Fourier holograms) and the holography angle (axial and extra-axial). In the restoration phase of an image contained in different holograms, the same physical effect is used. For these purposes, the phenomenon of diffraction of the volumetric (plane or spherical) waves of the reproducing field on the hologram as a diffraction grating is used.

Let the transmitted, uniform plane wave be incident at an angle ϕ on a diffraction grating (hologram) with period ℓ. As is known [3], the field scattered by the grating is a superposition of the departing plane wave, the propagation directions of θ_n in free space are defined by the expression

$$\sin\theta_n = \sin\varphi + n\frac{\lambda}{l}, \quad (1)$$

where n = 0, ±1, ±2, ... is the number of the harmonic of the diffracted wave spectrum, λ is the wavelength in free space.

In the case of holographing two plane waves interfering at an angle of 2ϕ, the relation between the period of the hologram, the wavelength and the angle ϕ has the form

$$l=\frac{\lambda}{2\sin\varphi}, \qquad (2)$$

which makes it possible to obtain the formula

$$\sin\theta_n=(1+2n)\sin\varphi. \qquad (3)$$

The analysis of (3) indicates that in the spectrum of the plane waves scattered by the hologram there are diffraction harmonics with number n = 0, ± 1, ± 2, ... (in optics they are called the diffraction order). The harmonic with the index n = 0 corresponds to the propagation of the incident wave. For n = -1, $\theta_{-1} = -\phi$. This means that the given wave is propagated in precisely the same direction as the subject wave with the formation of an interference pattern. The remaining values of n = 1, ± 2, ... correspond to the additional waves which were absent among the initial waves. Each number of the diffraction harmonic corresponds to its image. Here numerous images occur, the superposition of which on each other usually is undesirable and even harmful.

This situation is characteristic for holograms with any dependence of the diffracted field near the grating on the coordinate, except sinusoidal. If the scattered field (in particular, passing through the grating) is subject to a sinusoidal law, the waves are formed only with indexes n = 0, ± 1 (the Rayleigh grating). It is necessary to note that in spite of the sinusoidal distribution of the illumination of the photographic plate, the image of the hologram obtained still is not of a completely sinusoidal nature. Therefore when restoring real holograms by the volumetric wave method, the auxiliary waves and, consequently, the images must unavoidably exist although their intensity decreases with an increase in the harmonic number. The auxiliary image in the wave with the number n = 1 has the same intensity as the basic image observed in the wave field with n = -1.

From (3) it follows that for small holography angles the harmonics of the diffracted restored spectrum are not separated (the axial hologram). Noticeable spatial separation of the restored images can be obtained only when working with the extra-axial holograms ($\phi \neq 0$).

Thus, the nature of the physical phenomenon itself used when restoring the holographic image--the diffraction of the volumetric waves on the periodic structures--leads to the fact that along with the restoration of the axial and imaginary images on irradiation of the holograms by light from the restoring source, a background light flux occurs. This fact has a significant negative effect on the quality of the images restored by the indicated method and lowers the efficiency of the restoration itself. In order to improve the diffraction efficiency of the hologram and decrease the number of additional images when restoring the holograms it is necessary to use the phenomenon of diffraction of the surface (nonuniform) waves on the periodic structure--interferogram. Let us note that the effect of the conversion of surface waves to volumetric waves has already been used in the instruments of diffraction electronics [4], for the creation of elements of integrated circuits and metrologic measurement units of dielectric wave guides, antenna areas in the milimeter and submilimeter wave bands [5], in integral optics for energy input (output) to the light guides [6, 7] and also in the development of the logical elements of optical computers.

Formally, the solution of the problem of diffraction of a surface wave on a grating is analogous to the case of incidence of a uniform plane wave on this structure. It reduces to the boundary problem of diffraction of a plane wave incident on the grating at the imaginary angle ϕ = arcsin c/v_ϕ, where v_ϕ is the phase velocity of the surface wave, c is the speed of light in a vacuum. The spectrum of the scattered waves occurring during surface wave diffraction on a periodic obstacle differs theoretically from that in the case of transmission of a plane uniform wave through the grating. Actually, on diffraction of the surface waves on the grating, superposition of the nonuniform (surface) and uniform (volumetric) plane waves leaving the grating and departing from it occurs. The directions of propagation of the harmonics in free space are defined by the expression

$$\sin \theta_n = \frac{c}{v_\phi} + n\frac{\lambda}{l}. \qquad (4)$$

In as much as for surface waves $v_\phi < c$ and $c/v_\phi > 1$, the harmonics propagated in the form of plane, uniform waves leave the array at the real angles only if n is negative. This means that among the waves leaving the wave grating there will be no waves with positive indexes and with n = 0 (the zero harmonic corresponds to the incident wave), and the spectrum of the scattered waves will be significantly more narrow than occurred in the case of diffraction of uniform plane waves.

It is this fact that is defining when using the phenomenon of the diffraction of surface waves on gratings for restoration of holograms.

Let us note that in the development of holography, the process of improvement of the quality of the restored image is one of the most important, and it was realized by various methods. The transition from axial (D. Gabor) to extra-axial holograms (E. Leyt and Yu. Upatnieks) made it possible to achieve spatial separation of the real, imaginary and auxiliary images. The volumetric hologram method (Yu. N. Denisyuk) was used to obtain a unique restored image. Consequently, the use of the conversion of surface waves to volumetric waves for restoration of holograms is another version of solving this problem.

The problem of image restoration in this case consists in the fact that the restoring wave is introduced into the plane wave guide which is connected with the hologram. The surface wave of the light guide diffracts on the hologram elements (grating elements) and in the spectrum of the scattered waves defined by (4) the restored image occurs. It is significant that by selecting the deceleration characteristics of the light guide in the case of simple holograms it is possible to obtain a restored image in the harmonic of the diffracted spectrum, the direction of propagation of which coincides exactly with the subject wave during exposure.

The schematic of the realization of the phenomenon of diffraction of surface waves on periodic structures is distinguished by simplicity, reliability and high efficiency. This fact has been established experimentally in the milimeter (5) and optical bands (6, 7) for realization of devices for electromagnetic energy output from planar wave guides.

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PHYSICS

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STATUS, PROSPECTS OF HOLOGRAPHY WITH THREE-DIMENSIONAL RECORDING

Moscow VESTNIK AKADEMII NAUK SSSR in Russian No 12, 1978 pp 50-54

[Article by Corresponding Member, USSR Academy of Sciences Yu. N. Denisyuk]

[Text] The basic principle of holography, the recording of a proportional wave field by its mixing with a predetermined reference wave, was proposed, as is well known, by the English physicist D. Gabor in 1949[1]. In essence, Gabor discovered the ability of a photographic recording of a two-dimensional interference pattern to reproduce the wave fields whose interference produced the pattern.

It is known, however, that the interference phenomenon is not limited to a plane: light waves interfere with each other in three-dimensional space wherever they are superimposed, forming a so-called "standing wave." Essentially, the ordinary interference pattern is a plane section of such a wave. In 1962, the author of the present article showed that the imaging ability of such a section is only a part of the complex of imaging abilities possessed by a spatial material model of the whole standing wave pattern[2]. A general diagram of this primary phenomenon of holography is given in Fig. 2.

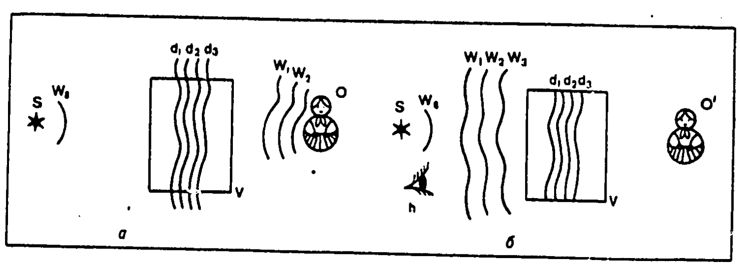

Fig. 1. Mechanism of the Three-Dimensional Hologram.
a. During recording, the antinodal surfaces d_1, d_2, d_3... are formed where the phases of the reference wave from source S and the wave from the object O coincide. b. during reconstruction, the photographic deposit which was formed at the locations of the antinodal surfaces (d_1', d_2', d_3'...) reverses

the direction of movement of the reconstructing wave where its phases coincide with those of the wave from the object, transforming it into the object wave.

In the recording process, radiation from a monochromatic source S (Fig. 1-a) falls upon an arbitrary object. The radiation scattered by the object (waves W_1, W_2...), interfering with the radiation propagating from the source S (wave W_s), forms a stationary standing wave pattern (the antinodal surfaces of these waves are designated d_1, d_2, d_3...). A solid V, filled with a transparent light-sensitive emulsion, is placed in the standing-wave field. After exposure and development, a structure whose density reproduced the distribution of light in the standing wave is formed in the solid.

We now turn to reconstruction (Fig. 1-b). Suppose that the three-dimensional model of the standing wave which we have obtained is illuminated with light from a point source located in the same place as the reference source S during the recording process. We note that in this case, in contrast to two-dimensional holography, the reconstruction source need not be monochromatic: an ordinary white light source may be used in reconstruction of three-dimensional holograms.

We will begin by considering the interaction with the three-dimensional hologram by the monochromatic component of the source radiation whose wavelength is the same as that of the source which was used to make the hologram. It is evident from the very concept of interference that at all the standing wave antinodes, the phase values of the reference wave, and accordingly of the monochromatic component of the reconstructing wave, will correspond with the phase values of the light wave scattered by the object. Only the directions of propagation will differ: while the object wave propagated from right to left, the reconstructing wave propagates from left to right.

The effect of the three-dimensional hologram is precisely the fact that the photographic deposit (metallic silver, transparent dielectric and so on) formed at the antinodes reflects the radiation incident on it and accordingly reverses the direction of propagation of the reconstructing wave. The reversal takes place where the phase of the reconstructing wave coincides with the phase of the object wave, so that the hologram transforms the source wave into a radiation wave reflected from object O. The properties of the object wave are reproduced through the entire cross section of the three-dimensional hologram, and accordingly no false images are present.

Thus, each individual antinodal surface recorded in the hologram reconstructs the wave function of the radiation scattered by the object. The effect of the depth of the hologram is simply that because of light interference in layers at different depths the hologram selects from the continuous spectrum and reflects in the reverse direction only the monochromatic component which was used in the recording.

The mechanism of reproduction of the spectral content of the radiation by means of a three-dimensional hologram is analogous to the mechanism of reproduction of the spectral composition by Lippmann photography, and in its general features amounts to the following (Fig. 2):

during recording of the hologram, a number of parallel reflecting layers d_0, d_1, d_2... are formed at the intersections of antinodes; these are spaced at a distance equal to half the wavelength λ_0 of the light recorded in the hologram. If the hologram is reconstructed by radiation of the same wavelength, the light reflected by the different layers has path differences which differ by multiples of twice the distance between layers, i.e. λ_0, and by in-phase addition forms a single reflected wave W. The process of wave addition in this case is expressed by vector diagram a.

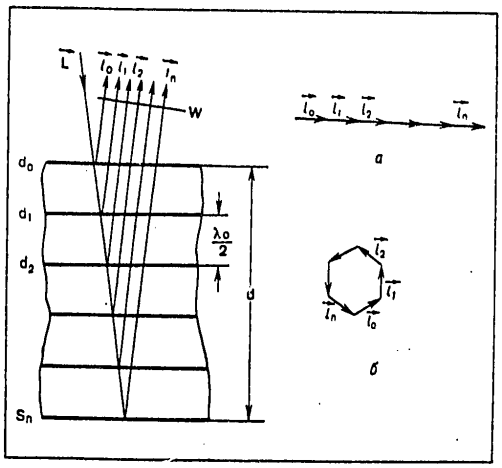

Fig. 2. Reconstruction of Spectral Composition by a Three-Dimensional Hologram. If the wavelength of the reconstructing light corresponds with the wavelength λ_0 of the light recorded in the hologram, then the light reflected by layers d_0, d_1, d_2... (rays $\vec{\ell}_1, \vec{\ell}_2, \vec{\ell}_3$) is added synphasally and forms a reflected wave W. Diagram a expresses the addition process in vector form. If the wavelength of the reconstructing light differs from λ_0, than the light reflected from layers d_0, d_1, d_2... is added nonsynphasally and is canceled out (diagram b).

If the hologram is reconstructed by light of some different wavelength λ, the path difference between layers will remain a multiple of λ_0 but not of λ. Accordingly the light reflected from the different layers will undergo out-of-phase addition and will cancel itself. The vector diagram of this process is shown in Fig. 2-b.

We determine the breadth of the spectral line produced from a continuous spectrum by a hologram of thickness d. Let light with a wavelength $\lambda = \lambda_0 + \Delta\lambda$ fall on the hologram. It follows from diagram b that to bring the intensity of the total reflected wave to zero requires that the phase difference between waves reflected by the first and subsequent layers should be equal to 2π and the path difference to λ. Since each layer produces a an additional path difference $\Delta\lambda$, and since the total number of layers $n = 2d/\lambda_0$, neglecting the difference between λ_0 and λ, the condition can be written as follows: $\Delta\lambda\, 2d/\lambda_0 = \lambda$.

The total breadth of the line produced (from minimum to minimum) can be found by multiplying $\Delta\lambda$ by 2:

$$\lambda/\delta\lambda = d/\lambda. \qquad (1)$$

If a number of spectral components are recorded simultaneously in the three-dimensional hologram, then during reconstruction each harmonic will react only with "its own" monochromatic component. Thus it turns out that a three-dimensional hologram can also reproduce a complex spectral composition of light.

In essence, the three-dimensional hologram is the most perfect type of image known to us. In fact, it may be considered as a unique optical equivalent of the object, which behaves toward radiation incident on it in the same way as the original object does. The basis of this circumstance is evidently the fact that the structure of the three-dimensional hologram repeats certain critical elements of the structure of the object. Quantitatively, it has been possible to confirm such assumptions only for the simplest phase objects with a vector distribution of the reflective index over the coordinates[3].

In general terms, the discussion which identifies the connection between the structure of the simplest phase object with the structure of its three-dimensional hologram is as follows (Fig. 3):

we express the function for the distribution of the dielectric constant of the phase object as an expansion into three-dimensional harmonics whose orientation is specified by the wave vectors $\vec{k}_n$. A plane wave incident on an object with a wave vector $\vec{K}_s$ and a wavelength λ will interact only with the harmonics whose spatial wavelength Λ and angle of orientation relative to the incident wave $\theta/2$ are subject to the Bragg condition:

$$\lambda = 2\Lambda \sin \theta/2. \qquad (2)$$

We consider the interaction of the incident wave with one such harmonic $\vec{k}_n$.

The wave $\vec{K}_n$ reflected by the harmonic propagates at a specular reflection angle $\theta/2$ with respect to the wave vector of the harmonic $\vec{k}_n$. It is easy to show that the spatial wavelength Λ of the standing wave produced by addition of the incident and reflected waves is also subject to relation (2).

Thus it appears that the intensity distribution function for the standing wave produced by reflection of light from the three-dimensional harmonic is identical to the distribution function of the dielectric constant of this harmonic. If we sum the radiation reflected by all harmonics, it is easy to conclude that the structure of the standing wave produced by reflection from the object, and accordingly the structure of the hologram, imitates the spatial harmonics of the object with which the wave incident on the object interacts.

Thus in essence it turns out that in the hologram is inscribed the structure of the object, with its space-frequency spectrum subjected to filtering. As a result of this filtering, the structure of the object in coordinate space is diffused and enters the solid in which the hologram is recorded.

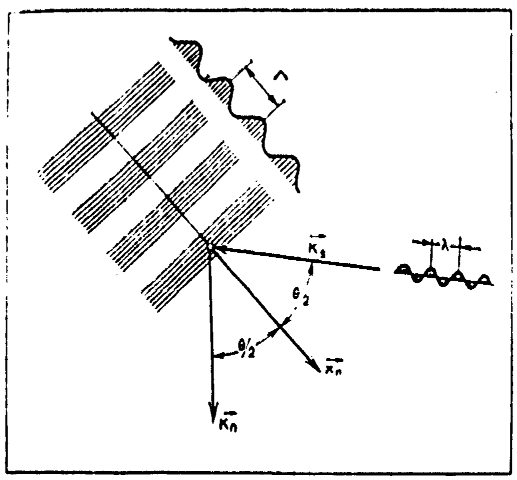

Fig. 3. Relation of the Structure of the Phase Object to the Structure of its Hologram.
A plane wave with a wave vector $\vec{K}_S$ and a wavelength λ falls on one of the spatial harmonics of the Fourier expansion of the refractive index function of the object. By coincidence of the conditions for reflection from the object with those for interference of the incident light and that reflected by the harmonic, the intensity distribution function of the resultant standing wave reproduces the distribution function of the refractive index of harmonic $\vec{k}_n$.

Subsequent investigations have shown that the phenomenon of representation of wave fields by a solid interference pattern is of an even more general nature than was previously supposed. It turns out that not only standing waves but the traveling intensity waves produced during interference of light with various wavelenghts are capable of correctly reproducing wave fields.

Fig. 4 shows two plane waves V_1 and V_2 of light with wave vectors $\vec{K}_1$ and $\vec{K}_2$ having different values. As a result of interference of these waves, an intensity harmonic with antinodal surfaces designated W_1, W_2... is produced.

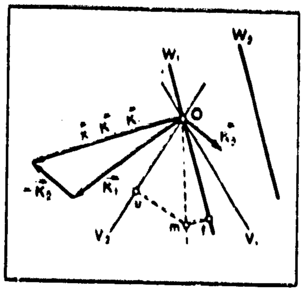

Fig. 4. Imaging Properties of Traveling Intensity Waves.
A traveling intensity harmonic with characteristic vector $\vec{k}$ is formed by the interference of two plane waves with wave vectors $\vec{K}_1$ and $\vec{K}_2$ and wavelengths λ_1 and λ_2. The antinodal surfaces of this harmonic are designated W_1 and W_2. If on a traveling material model of this harmonic is incident one of the waves that formed it, $\vec{K}_1$ for example, it is transformed into the second wave of the pair, e.g. $\vec{K}_2$ The apparent violations of the law of specular reflection in the process are compensated by relativistic effects.

The orientation and wavelength of this harmonic is determined by the wave vector $\vec{K}$, equal to the difference between the wave vectors K_1 and $\vec{K}_2$. The direction of movement corresponds to the direction of movement of the interfering wave with the larger vector value $\vec{K}$.

Suppose that the intensity harmonic has been recorded in the solid medium so that a moving system of reflectors W_1, W_2... corresponds to the antinodal surfaces. It seems at first glance that such a system would not have imaging ability, if only because the difference in the absolute values of the vectors $\vec{K}_1$ and $\vec{K}_2$ would mean that the surface of the moving reflector would not be a bisectrix of the angle formed by fronts V_1 and V_2, and accordingly would not make possible the reflective transformation of these waves.

However, it turns out that the laws and geometry with respect to the distribution of waves V_1 and V_2 and surfaces W_1 and W_2... which are characteristic of the optics of moving media result in a mutual transformation of waves V_1 and V_2 (with allowance for relativistic deviations from the law of specular reflection).

In fact, it becomes apparent on more detailed consideration of the process of reflection of wave V_2 from surface W_1 that while wave V_2 is propagating from point u to point m located on the bisectrix of the angle formed by the interfering waves, foint f of the reflective surface W_1 reaches the same point m. In other words, the wavefront V_2 still meets reflector W_1 in such a way that the mirror transformation of wave V_2 into wave V_1 is effected.

It is not only the direction of propagation of the waves which is correctly transformed by the system of reflectors W_1, W_2.... It turns out that as a result of the Doppler shift produced by movement of reflector W_1, the frequency of wave V_2 is transformed into the frequency of wave V_1, resulting in a complete mutual transformation of waves V_1 and V_2.

Since any wave of complex form can be represented as a superposition of plane waves, it appears that the law which we have been discussing is applicable to the general case of waves of any configuration.

The ability of traveling intensity waves to represent wave fields is one of the phenomena located at the interface of nonlinear optics and holography and may have important applications in so-called "dynamic holography" for correction of the shape of wavefronts. This question will be discussed in detail somewhat later.

An important stimulus to the development of three-dimensional recording holography came from the work of the Americal investigator P. van Heerden[4]. The basis of this work is the hypothesis of R. I. Berl', according to which each element of information in human memory is stored not in the form of a single spatially localized cell, but in the form of a single excitation harmonic filling the entire cortex of the brain.

This method of information storage has a number of advantages. For example, damage to one or several parts of the brain would thus not result in the complete disappearance of any part of the information. Van Heerden pointed out that a possible analog of such an information recording process in optics is the three-dimensional hologram and proposed to use it as a basis for the development of optical memory.

Considering the three-dimensional hologram for the purpose of developing memory units, its unquestioned advantage over the two-dimensional hologram is the fact that it can record a number of images simultaneously in the same volume of photographic material (without mutual interference). Such an operation may be carried out by recording images at various wavelengths or with different tilts of the reference wave. In both cases, the intensity harmonics recorded in the hologram interact during readout only with the reference wave with the direction and frequency which were used for the recording.

Van Heerden's work also uncovered a property of the three-dimensional hologram which is extremely interesting for computer engineering, that of carrying out operations peculiar to so-called "associative memory," i.e. the possibility of extracting from memory the whole of a certain element of information stored in it by presentation of a part of it. In general terms the mechanism of this phenomenon is as follows:

suppose that during recording the light from a complex object consisting of the arrow O_1 and the cross O_2 (Fig. 5) falls on the hologram. The light from each pair of points in such an object creates within the hologram V its own specific spatial harmonic (harmonics β, γ, δ in Fig. 5) which differs from the other harmonics by its wavelength and spatial orientation.

Suppose that during reconstruction, monochromatic light from only one part of the complex object recorded in a hologram of this sort falls on the hologram: for example, light from the cross O_2. Since all the harmonics recorded in the hologram differ from each other, each of them can interact only with light from the pair of points that formed it, thus transforming the light from the first point of the pair into light from the second and vice versa. Thus the light from each point of the cross also interacted during recording with light from all the other points of the cross and with light from all points of the arrow, so that the hologram on which light from the cross falls will reconstruct the image of the entire cross O_2 and the image of the arrow O_1. Thus the hologram, to which only a part of the situation--the cross--was presented, "remembers" that the situation as a whole included both the cross and the arrow. This method of recording, which is distinguished by the lack of a point reference source, subsequently received the name of "nonreference holography."

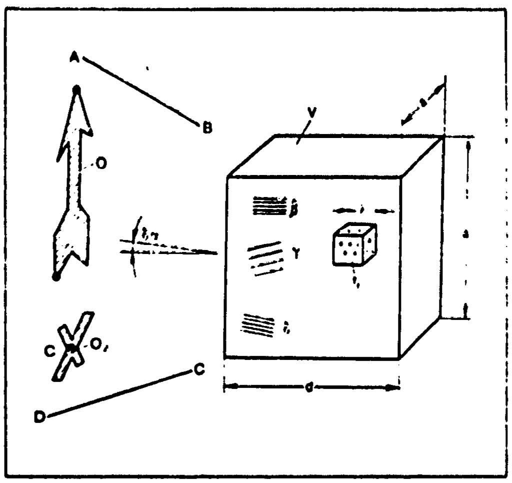

Fig. 5. Creation of Optical Memory by Means of Three-Dimensional Holography. The record in the three-dimensional hologram has the properties of associative memory. If a hologram with a record of some situation (e.g. the arrow O_1 and the cross O_2) is reconstructed by part of this situation (e.g. by cross O_2), the entire situation is reconstructed, i.e. the images of both the cross and the arrow. As regards the stored information, the hologram behaves as if the information were located in spatially localized cells whose size is equal to the wavelength λ of the light used to read it and each of which contains η light-sensitive centers.

Van Heerden suggested the use of alkali halide crystals with colored centers, which lose their color under the influence of light, as a medium for recording three-dimensional holograms. He obtained an estimated value of 10^{13} bits/cm^3

as a possible density of information recording in holograms recorded in such crystals, which immediately attracted the attention of many companies developing computers to this subject.

The calculations were based on the following considerations:

if the information is recorded in the usual manner in spatially localized cells, using light of wavelength λ, the smallest cell in which such recording can be done is a cube whose edge is equal to the limit of resolution, i.e. λ. The size of the signal which can be reproduced by such a cell will be proportional to the number η of light-sensitive centers included within it, while the noise value will be proportional to the square root of the number of centers. On the other hand, it is well known that the number of bits of information which can be recorded in a memory system consisting of n cells is equal to the number of cells multiplied by the base-2 logarithm of the signal-to-noise ratio in a single cell:

$$C = n \log_2 \sqrt{\eta}. \quad (3)$$

It can easily be estimated that when $\lambda = 1$ micron and the concentration of dyed centers is 10^{15} per cm^3, formula (3) gives a value of 10^{13} bits/cm^3. But in practice it is impossible to implement such a memory with recording of information in localized cells: it is not known by what method the small cells could be imprinted in the substance or what optical device could be used to read out the signals recorded in them.

Van Heerden pointed out in his paper that the number of phase cells characteristic of holographic recording and the signal-to-noise value coincide with the corresponding parameters for recording in spatial cells.

Actually, the number of phase cells is determined by the number of independent plane waves which can be recorded in the hologram. In angular terms, these waves fill the entire half-space around the hologram, i.e. a solid angle ABCD whose size is in the radian range (Fig. 5), while spectrally they fill a range of wavelengths comparable to that used in recording wavelength λ. Each independent plane wave, corresponding to a single phase cell, is characterized by an angular divergence equal to the angular resolution of the hologram $d\alpha = \lambda/a$ (see Fig. 5) and a spectral line width $\delta\lambda$ equal to the spectral resolution of the hologram (see formula (1)). Dividing the solid angle (on the order of a few radians) by $d\alpha^2$ and multiplying the result by the number of spectral lines resolvable by the hologram $\lambda/d\lambda = d/\lambda$, we find that the number of phase cells in a three-dimensional hologram is equal to its volume V divided by λ^3, coinciding with the number of independent spatial cells which could fit into the volume. A similar coincidence applies to the signal-to-noise ratio.

The idea of using three-dimensional holography for a large-capacity optical memory was taken up by many scientists, but work in this area has still not given the desired result. At the same time, it has stimulated the development of photographic materials for volume recording and has served as the basis for development of a new field, so-called "dynamic holography."

First, van Heerden's proposal to record three-dimensional holograms in alkali halide crystals was tested experimentally. It turned out, however, that such holograms had extremely low diffraction efficiency, since the recording was of an amplitude character. Much more extensive possibilities were opened up by the proposal to record three-dimensional holograms in electrooptic crystals, especially lithium niobate. In this case the recording is particularly of a phase character, there is not absorption, and the diffraction efficiency of the hologram may reach 100%.

The mechanism for recording holograms in lithium niobate crystals is as follows: photoelectrons produced in the crystal under the influence of light are redistributed both by the effect of drift on the internal field of the crystal and as a result of diffusion of electrons from illuminated areas of the crystal to nonilluminated ones.

The nonuniform charge distribution in the crystal results in electrostatic fields which in turn produce an uneven modulation of the refractive index. In this process, because of the anisotropic nature of the medium, the refractive index modulation function can, generally speaking, be shifted relative to the light distribution function in the interference pattern produced by the modulation. This property leads to an extremely interesting effect, the directed transfer of energy from one of the waves interacting within the hologram to the other[5].

In general terms, the effect of this energy transfer between the object and reference waves is as follows (Fig. 6):

suppose that two plane waves R and S interfere in the volume V of the hologram. The graph of light intensity distribution in the interference pattern which is formed is shown by a dotted line in the figure (left).

Under the influence of light, a harmonic of the distribution of the refractive index n(x), shifted along the crystal axis c by an amount Δx (solid line) is induced in the crystal. If this shift corresponds to a change in path length for the interfering waves equal to $\lambda/4$, the interaction of the waves with the structure of the hologram can lead to a significant increase in the energy of one of the waves at the expense of the other.

Limiting ourselves to a first-order approximation, we can explain the essence of the transfer of energy by means of the shifted three-dimensional grating as follows:

we replace the harmonic of the refractive index by a system of semitransparent reflecting surfaces Z_1, Z_2, Z_3, located at the maxima of the refractive index. The process of interaction of waves with each element of this structure, for example with reflector Z_3, may be considered as a complete analog of the mixing of two interfering waves in the semitransparent mirror of an interferometer. Each wave propagating away from such a mirror is the sum of two components. For example, the wave S' is the result of addition of light from wave S, which has passed through mirror Z_3, and light from wave R, which has been reflected by the mirror. Depending on the phase relationship of waves S and R, these components may be added or subtracted; one possibility is that one of the waves, for example R', is completely extinguished, and all the energy passes to the other wave (this case S'). Since the phase relationship of waves R and S at the reflecting surface Z_3 depends on the size of the shift along the x axis, the ratio of intensities of waves R' and S' propagating away from the grating depends on the position of the grating relative to the interference pattern of the waves R and S incident on it.

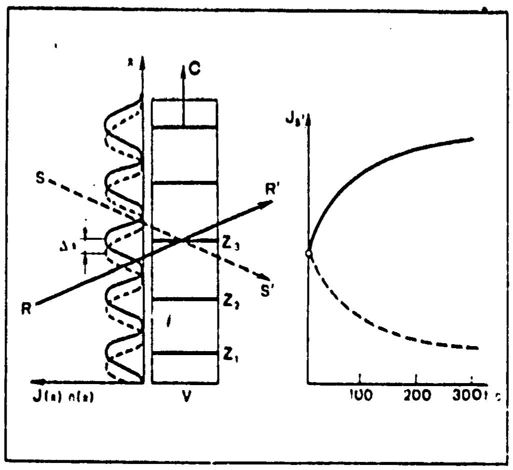

Fig. 6. Transfer of Energy Between the Object and Reference Wave by Means of a Shift in the Grating Produced in Lithium Niobate.
The interference pattern of two plane waves R and S (the dotted curve J(x)) is recorded in the crystal as a harmonic of the refractive index which is shifted relative to it (the solid curve n(x)). When waves R and S interact with this shifted grating the energy of one of the waves is transferred to the other. At the right is a graph of the time change in intensity of one of the waves, S', for shifts in two directions corresponding to changes in the direction of the optical axis C of the crystal.

The dynamics of the process of redistribution of the energy between two waves as they interact with the lithium niobate crystal is shown in the graph on the right of Fig. 6.

The solid line corresponds to the case in which the intensity of S' is increased during reconding of the hologram, while the dotted line represents the case in which the direction of the optical axis C of the crystal, and accordingly the direction of shift of the reflective index grating, changes in the opposite direction and the energy passes from wave S to wave R.

This effect is by no means the only one observed during experimental recording of holograms in lithium niobate crystals, but it became the point of departure for development of a new direction of three-dimensional holography, so-called "dynamic holography." Interest in investigation of th.s subject arose as a result of M. S. Soskin's proposal to use the energy redistribution effect of diffraction in a shifted grating for correction of the shape of laser light wavefronts.

It can in fact be shown that if an irregularly-shaped intensity wave from a tunable laser is introduced into a light-sensitive medium V at the same time as a weak-intensity, correctly-shaped wave S, by producing a shift in the structure of the hologram relative to the structure of the interference patterm amounting to a quarter wave all the energy of wave R can be transferred to wave S (Fig. 7). The final result of this process will be the transformation of the wave with the irregularly-shaped wavefront into the regular wave.

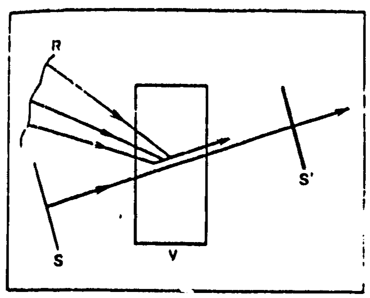

Fig. 7. Correction of the Shape of a Laser Wavefront Using a Dynamic Shifted Three-Dimensional Hologram.
A weak wave of correct shape S and a strong irregular laser wave R fall on a three-dimensional light-sensitive material V with real-time reaction to light. In the crystal is formed a hologram which is shifted a quarter wavelength relative to the interference pattern corresponding to it. This hologram transforms the irregularly-shaped wave R into the correct regular wave S'.

It is essential that such an operation narrow the spectral composition of the radiation while it corrects the wavefront. As was explained previously, the imaging abilities of the hologram extend to the case of traveling intensity waves when the frequencies of the interfering waves are different. Accordingly, if wave S is monochromatic and wave R has a complex spectral composition, a number of traveling gratings are formed in the hologram, and these transform the spectral components of wave R into the narrow monochromatic component of wave S.

A theoretical analysis of these possibilities conducted by D. I. Stasel'ko and V. G. Sidorovich using as an example the case of mutual transformation of two plane waves with allowance for the dynamic character of interaction of light with the hologram showed that one of the plane waves can indeed be converted into the other with high efficiency. Later, however, it was found that this process had been treated previously in other terms in nonlinear optics.

Thus the development of holography and nonlinear optics is leading to their conjunction and the resulting formation of the new method of dynamic holography. The contribution of holography to this process is that it gives the possibility of converting light not only in terms of spectral composition but also in terms of the spatial configuration of the wavefront.

We shall consider further the problems in development of a theory of three-dimensional holograms. Thus far we have not made explicit use of so-called "kinematic theory," which neglects extinguishment of the reconstructing wave as it passes through the thickness of the hologram and secondary interaction of the reconstructed wave with the structure of the hologram. While it correctly describes the basic mechanism of the three-dimensional hologram, this theory does not offer any quantitative relationships. In particular, it cannot be used to calculate the so-called "diffraction efficiency" of the hologram, i.e. the relationahip between the light flux incident on the hologram and the light flux which forms the image reconstructed by it.

A knowledge of the laws governing diffraction efficiency and the parameters on which it depends is extremely important in the selection of photographic materials to be used for the making of the hologram and in the development of processes for preparing the materials. For this purpose, a certain arbitrary quantity, the diffraction efficiency of the simplest spatial grating produced by recording the interference pattern of two plane waves, is used as the characteristic of the photographic material. To solve this extremely important problem, H. Kogelnik proposed the so-called "coupled-wave theory," which made it possible to determine rather accurately both the diffraction efficiency and some other parameters of the simplest types of holograms[6].

We consider the process of recording and reconstruction of the simplest type of holographic grating.

Suppose that two plane waves $\vec{R}$ and $\vec{S}$ have been recorded in the hologram. As a result, a harmonic phase grating, a system of plane layers d_1, d_2, d_3..., with a variable refractive index, have been formed in the medium (Fig. 8). If one of the plane waves which formed the structure, $\vec{R}$ for example, falls on the structure, according to the assumptions of the kinematic theory this wave, passing through the hologram without attenuation, will be transformed inside it into the wave $\vec{S}$. The reconstructed wave will leave the hologram without interacting with its structure.

The coupled-wave theory introduced some extremely natural refinements into these assumptions. Clearly the reconstructed wave $\vec{S}$ reacts with the structure until it leaves the hologram and accordingly is partially converted into wave $\vec{R}'$ (Fig. 8), while wave $\vec{R}$ in turn is converted into wave $\vec{S}$ ($\vec{S}'$) and so on.

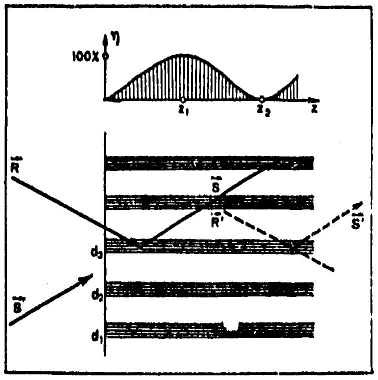

Fig. 8. Coupled-Wave Theory.
The holographic grating formed by waves R and S is reconstructed by wave R. According to kinematic theory, this reconstructs wave S, which leaves the hologram. Coupled-wave theory allows for the fact that wave S in turn reconstructs wave R (wave R'), wave R' again reconstructs wave S (wave S') and so on. Above is a graph of change of diffraction effectiveness with thickness of the hologram.

Thus, on the initial incident and reconstructed waves are superimposed secondary waves which coincide with them directionally but differ in phase. The result of addition of these waves is nontrivial.

For example, in the case considered, with a hologram thickness Z_1 all the energy is transferred to the S' wave, i.e. the diffraction efficiency becomes equal to 100%. When the thickness of the hologram is further increased to Z_2, all of the energy passes to wave R and the diffraction efficiency of the hologram is equal to zero, and so on.

Using coupled-wave theory, Kogelnik showed that the diffraction efficiency of a phase reflection grating approaches 100% with sufficient thickness. With an amplitude grating of the same kind, the efficiency cannot exceed 7.2%.

We must bear in mind the fact that coupled-wave theory cannot be considered a second-order theory of three-dimensional holograms. In fact, by its very concept the hologram is an instrument for recording information about a complex wave field which can be represented as a sum of a number of plane waves. From this point of view, it is only for convenience that we can use the name of "hologram" for a grating formed by the recording of an interference pattern of two plane waves whose properties are treated by Kogelnik's theory.

Kogelnik's theory cannot be considered a theory of the elementary mechanism of the hologram, the process of recording and reconstruction of two plane waves, on the basis of which a general theory accounting for the laws of recording and reconstruction of an arbitrary wavefront composed of a number of plane waves might be constructed.

In the first approximation this approach has, indeed, been fully borne out: since it does not take account of secondary scattering, the resultant field may be represented as the sum of the fields of radiation scattered by the individual gratings.

The purpose of the second-order theory is to account for the manner in which radiation scattered by one grating reacts with all the other gratings recorded in the hologram. In this case, the light field reconstructed by the hologram can no longer be represented as a simple sum of fields corresponding to the individual gratings.

One of the most fruitful paths of further development of the theory of three-dimensional holograms is based on the so-called "dynamic theory" of X-ray diffraction proposed by P. Ewald. This theory was first applied to analysis of spatial holographic gratings by Ye. Zh. Sakkotsio. It was further developed (for the recording of many gratings) in the works of V. V. Aristov and V. I. Shekhtman. The mechanism of interaction of light with the three-dimensional hologram with allowance for the effects of the dynamic theory appear most fully in the so-called "modal theory" of three-dimensional holograms proposed by V. G. Sidorovich.

In essence, the modal theory is based on the concept of a wave matched to a periodic nonuniform structure, introduced by P. Ewald. Ewald's theory succeeded in applying this concept only to the case of the simplest phase grating.

In Fig. 9, two pairs of plane waves, S_1R_1 and S_2R_2, are the matched waves of the phase grating G. Pair S_1R_1 forms a standing wave pattern whose maxima (solid arrows) coincide with the refractive-index maxima of grating G.

Pair S_2R_2 forms a standing-wave pattern whose maxima (dotted arrows) coincide with the distribution minima of the refractive index in the grating. Thus the first matched wave propagates as if in a medium with a refractive index n_{max} without alteration, while the second propagates as if in a medium with index of refraction n_{min}. The effect of the grating is only that it changes the phase difference of these pairs of waves, since the pairs are propagating through a medium with differing refractive indices.

V. G. Sidorovich showed that matched wavefronts can be correlated not only with periodic structures but also with structures formed through recording of wave fields.

It follows that each three-dimensional hologram has a characteristic system of wave modes matched to it, into which any wave which effectively interacts with a three-dimensional hologram may be broken down. Each mode passes through the three-dimensional hologram as if through a medium with a specific refractive index. The effect of the hologram is that it shifts the relative phase difference between modes.

This approach, developed for the case of hologram recording in amplifying media, made it possible in particular to give a quantitative interpretation of the formation of a self-conjugate wave during reflection of light from a so-called "Brillouin mirror."

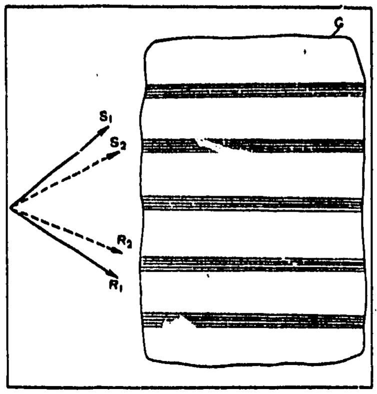

Fig. 9. The Mode Theory of a Three-Dimensional Hologram.
According to P. Ewald's dynamic theory of X-ray diffraction, it is possible to correlate with a periodic phase grating G two pairs of waves matched to it: the pair S_1R_1, the maxima of whose interference pattern (solid arrows) coincide with the refractive-index maxima of grating G and which behave as if propagating unchanges through a medium with a constant refractive index n_{max}, and the pair S_2R_2, the maxima of whose interference pattern (dotted arrows) correspond to the refractive-index minima of the grating. An analogous mode system may be correlated with a three-dimensional hologram.

Let us briefly discuss the applications of three-dimensional holography which have been implemented thus far. We should note first so-called "imaging holography," whose aim is to produce spatial representations which reproduce the complete illusion of reality in the objects represented.

The author was the first to state the possibility of using holography to produce such images in 1962. The first two-dimensional hologram, a three-dimensional representation of chess pieces, reconstructed by laser light, was produced by Leith and Upatnieks in 1964.

Subsequently it was found that imaging holography could be extremely conveniently developed by the use of recordings in three-dimensional media, using for this purpose an arrangement in which the object beam was aimed in an opposite direction to the reference beam. These holograms make it possible to carry out the reconstruction with an ordinary incandescent lamp, which is extremely convenient in practice.

The "single-beam" arrangement, the simplest system for recording a three-dimensional imaging hologram, is shown in Fig. 10.

The light from the coherent source S illuminates the object O through a photographic plate F to which a transparent emulsion layer e has been applied. The light reflected by the object (wave W) is superimposed on the incident radiation and forms in the emulsion layer of the photographic plate a standing-wave pattern which is fixed in the layer by developing.

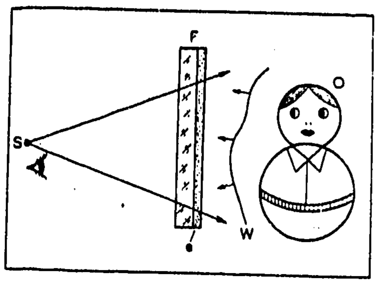

Fig. 10. Single-Beam System for Recording Three-Dimensional Imaging Holograms.

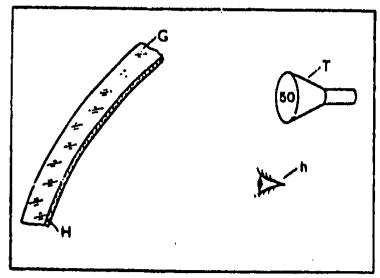

Fig. 11. Use of Three-Dimensional Holographic Copies of a Concave Mirror to Project Information into Driver's Field of Vision.

The hologram obtained in this way can be reconstructed by illumination with an ordinary incandescent lamp located at the site of source S. The reconstructed image is observed in reflected light and is in the same position as the object during recording.

The quality of the reconstructed image in this case depends to a particularly great degree on the characteristics of the photographic plate and the methods of processing it. The clearest images are given by holograms recorded on improved Lippmann photographic plates. At present such holograms are frequantly on display at various exhibitions.

Another important direction of practical application of three-dimensional holography is the development of photographic optical elements.

The first three-dimensional holographic optical elements, duplications of concave mirrors, showed that the hologram is capable of copuing the optical properties of an object. Subsequently, as techniques for manufacture of photographic materials improved, the reflectivity of such photographic mirrors was increased to 70%, and they found practical application in various areas of science and technology.

One of the most inportant applications of holographic mirrors is for projecting information into the observer's field of vision. A general diagram of such a device is given in Fig. 11.

On glass G, through which the observation is made, layer H with a stored hologram of a concave mirror is applied. This hologram does not hinder observation, since it reflects light in a comparatively narrow spectral range and is transparent in other ranges. In the focal plane of the mirror is placed a television tube T, on which various types of information are displayed, for example speedometer readings. The hologram-mirror projects the marks corresponding to this information directly into the field of vision of the observer H, who does not need to shift his gaze from the surroundings to the instrument panel in order to know his speed.

Three-dimensional holograms as optical elements have begun to be successfully applied as the dispersing elements of optical resonators, for visual projection of three-dimensional images and so on.

It should be noted that the processes which occur during recording and reconstruction of three-dimensional holograms depend to a particularly great degree on the properties of the medium in which the recording is done. Accordingly it is not surprising that the applications which have been successfully developed have been those using photographic materials developed in the preceding years (Lippmann photographic plates, bichromated gelatin and so on).

The development of a large-capacity optical memory and of devices for dynamic wavefront correction require the development of new media: light-sensitive crystals, photopolymers and various nonlinear media. Work in this area began relatively recently, but it is proceeding at a rapid pace and enables us to hope for rapid progress in these applications of holography.

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Moscow VESTNIK AKADEMII NAUK SSSR in Russian No 2, Feb 79 pp 127-143

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Ryzhov, Oleg Sergeyevich--doctor of physico-mathematical sciences, professor
Ryzhov, Eduard Vyacheslavovich--doctor of technical sciences, professor
Ryzhov, Yuriy Alekseyevich--doctor of technical sciences, professor
Ryabinin Igor' Alekseyevich--doctor of technical sciences, professor
Sadovskiy, Igor' Nikolayevich--doctor of technical sciences
Sarychev, Vasiliy Andreyevich--doctor of physico-mathematical sciences, professor
Sirazetdinov, Talgat Kasimovich--doctor of technical sciences, professor
Smirnov, Anatoliy Filippovich--doctor of technical sciences, professor
Smolov, Vladimir Borisovich--doctor of technical sciences, professor
Sokolov, Aleksandr Georgiyevich--doctor of technical sciences, professor
Solodovnikov, Vladimir Viktorivich--doctor of technical sciences, professor
Solomenko, Nikolay Stepanovich--doctor of technical sciences, professor
Staros, Filipp Georgiyevich--doctor of technical sciences, professor
Stepanov, Boris Mikhaylovich--doctor of physico-mathematical sciences, professor
Stogniy, Anatoliy Aleksandrovich--corresponding member AS Ukrainian SSR
Strel'chuk, Nikolay Antonovich--doctor of technical sciences, professor
Sumarkov, Leonid Nikolayevich--doctor of technical sciences, professor
Sychev, Vladimir Vasil'yevich--doctor of physico-mathematical sciences, professor
Tamm, Boris Georgiyevich--academician AS Estonian SSR
Troitskiy, Vladimir Aleksandrovich--doctor of physico-mathematical sciences, professor
Tupolev, Aleksey Andreyevich--doctor of technical sciences, professor
Ugodchikov, Andrey Grigor'yevich--doctor of technical sciences, professor
Ulanov, Georgiy Mikhaylovich--doctor of technical sciences, professor
Utkin, Viktor Vasil'yevich--doctor of technical sciences

Ushakov, Igor' Alekseyevich--doctor of technical sciences, professor
Fedosov, Yevgeniy Aleksandrovich--doctor of technical sciences, professor
Fedotov, Aleksey Ivanovich--doctor of technical sciences, professor
Feodos'yev, Vsevolod Ivanovich--doctor of technical sciences, professor
Khesin, Gennadiy L'vovich--doctor of technical sciences, professor
Khetagurov, Yaroslav Afanas'yevich--doctor of technical sciences, professor
Khorol, David Moiseyevich--doctor of technical sciences, professor
Chemodanov, Boris Konstantinovich--doctor of technical sciences, professor
Cherkasov, Yuriy Mikhaylovich--doctor of technical sciences, professor
Chernous'ko, Feliks Leonidovich--doctor of physico-mathematical sciences, professor
Chernykh, Klimentiy Feodos'yevich--doctor of physico-mathematical sciences, professor
Shevyakov, Aleksey Andreyevich--doctor of technical sciences, professor
Sheremet'yevskiy, Nikolay Nikolayevich--doctor of technical sciences, professor
Shikhayev, Kirill Nikolayevich--doctor of technical sciences, professor
Shkadov, Leonid Mikhaylovich--doctor of technical sciences, professor
Shlyakhtenko, Sergey Mikhaylovich--doctor of technical sciences, professor
Shnyrev, Gennadiy Dmitriyevich--doctor of technical sciences
Shukshunov, Valentin Yefimovich--doctor of technical sciences, professor
Yurevich, Yevgeniy Ivanovich--doctor of technical sciences, professor
Yusupov, Rafael' Midkhatovich--doctor of technical sciences, professor
Yakimov, Yuriy L'vovich--doctor of physico-mathematical sciences
Yakovlev, Yuriy Sergeyevich--doctor of technical sciences, professor
Yakubaytis, Eduard Aleksandrovich--academician AS Latvian SSR
Yakubovich, Vladimir Andreyevich--doctor of physico-mathematical sciences, professor
Yastrebov, Vyacheslav Semenovich--doctor of technical sciences

Department of General and Technical Chemistry

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Alfimov, Mikhail Vladimirovich--doctor of physico-mathematical sciences professor
Atovmyan, Lev Oganovich--doctor of chemical sciences, professor
Baraboshkin, Aleksey Nikolayevich--doctor of chemical sciences, professor
Belikov, Vasiliy Menandrovich--doctor of chemical sciences, professor
Buchachenko, Anatoliy Leonidovich--doctor of chemical sciences, professor
Vol'pin, Mark Yefimovich--doctor of chemical sciences, professor
Voskresenskiy, Vladimir Aleksandrovich--doctor of chemical sciences, professor
Galkin, Nikolay Petrovich--doctor of technical sciences, professor
Gel'bshteyn, Anatoliy Iosifovich--doctor of chemical sciences, professor
Gerasimov, Valentin Vladimirovich--doctor of technical sciences, professor
Gidaspov, Boris Veniaminovich--doctor of chemical sciences, professor
Gryaznov, Vladimir Mikhaylovich--doctor of chemical sciences, professor
Dremin, Anatoliy Nikolayevich--doctor of physico-mathematical sciences, professor
Dubovitskiy, Fedor Ivanovich--doctor of chemical sciences, professor

Dyumayev, Kirill Mikhaylovich--doctor of chemical sciences, professor
Yeremenko, Leonid Timofeyevich--doctor of chemical sciences, professor
Yermakov, Anatoliy Nikolayevich--doctor of chemical sciences, professor
Yershova, Zinaida Vasil'yevna--doctor of technical sciences, professor
Zakharkin, Leonid Ivanovich--doctor of chemical sciences, professor
Ivanchev, Sergey Stepanovich--doctor of chemical sciences, professor
Isagulyants, Georgiy Vacheyevich--doctor of chemical sciences
Kazarinov, Vladimir Yevgen'yevich--doctor of chemical sciences
Kalechits, Igor' Vadimovich--doctor of chemical sciences, professor
Kiperman, Saveliy L'vovich--doctor of chemical sciences
Klabunovskiy, Yevgeniy Ivanovich--doctor of chemical sciences, professor
Komarov, Yevgeniy Vasil'yevich--doctor of chemical sciences, professor
Kormer, Vitaliy Abramovich--doctor of chemical sciences, professor
Krivosheyev, Nikolay Alekseyevich--doctor of technical sciences, professor
Krol', Vladimir Aleksandrovich--doctor of chemical sciences, professor
Krylov, Oleg Valentinovich--doctor of chemical sciences, professor
Kuliyev, Ali Musa Ogly--academician AS Azerbaydzhan SSR
Leypunskiy, Ovsey Il'ich--doctor of physico-mathematical sciences, professor
Maksimov, Vladimir Fedorovich--doctor of technical sciences, professor
Manelis, Georgiy Borisovich--doctor of chemical sciences, professor
Merzhanov, Aleksandr Girgor'yevich--doctor of physico-mathematical sciences, professor
Mukhlenov, Ivan Petrovich--doctor of technical sciences, professor
Nefedov, Oleg Matveyevich--doctor of chemical sciences, professor
Nikitin, Yevgeniy Yevgen'yevich--doctor of physico-mathematical sciences, professor
Nikiforov, Aleksandr Sergeyevich--doctor of technical sciences
Ovchinnikov, Aleksandr Anatol'yevich--doctor of physico-mathematical sciences, professor
Orayevskiy, Anatoliy Nikolayevich--doctor of physico-mathematical sciences, professor
Pikayev, Aleksey Konstantinovich--doctor of chemical sciences, professor
Polak, Lev Solomonovich--doctor of physico-mathematical sciences, professor
Polukarov, Yuriy Mikhaylovich--doctor of chemical sciences
Ponomarev, Ardal'on Nikolayevich--doctor of chemical sciences, professor
Rozenfel'd, Iosif L'vovich--doctor of chemical sciences, professor
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Sakovich, Gennadiy Viktorovich--doctor of technical sciences, professor
Samsonov, Georgiy Vasil'yevich--doctor of chemical sciences, professor
Sanin, Pafnutiy Ivanovich--doctor of chemical sciences, professor
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Spiridonov, Viktor Pavlovich--doctor of chemical sciences, professor
Temkin, Menassiy Isaakovich--doctor of chemical sciences, professor
Tolstikov, Genrikh Aleksandrovich--doctor of chemical sciences, professor
Tomashevskiy, Vladislav Trofimovich--doctor of technical sciences, professor
Topchiyeva, Klavdiya Vasil'yevna--doctor of chemical sciences, professor
Tyurayayev, Ivan Yakovlevich--doctor of technical sciences, professor
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Chernyshev, Yevgeniy Andreyevich--doctor of chemical sciences, professor

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Shilov, Aleksandr Yevgen'yevich--doctor of chemical sciences, professor
Shmidt, Vladimir Sergeyevich--doctor of chemical sciences
Shorygin, Petr Pavlovich--doctor of chemical sciences, professor
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Vorob'yev, Kharlampiy Sergeyevich--doctor of technical sciences, professor
Gorlov, Yuriy Pavlovich--doctor of technical sciences, professor
Gorshkov, Vladimir Ivanovich--doctor of chemical sciences, professor
Gorynin, Igor' Vasil'yevich--doctor of technical sciences, professor
Gurvich, Lev Veniaminovich--doctor of chemical sciences, professor
Dobatkin, Vladimir Ivanovich--doctor of technical sciences, professor
Dyatlova, Nina Mikhaylovna--doctor of chemical sciences, professor
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Kiparisov, Sergey Sergeyevich--doctor of technical sciences, professor
Kozlovskiy, Lev Vasil'yevich--doctor of technical sciences, professor
Komar, Aleksey Georgiyevich--doctor of technical sciences, professor
Kopeykin, Vladimir Alekseyevich--doctor of technical sciences
Kopetskiy, Cheslav Vasil'yevich--doctor of technical sciences, professor
Kunin, Lev Lazarevich--doctor of technical sciences, professor
Lazarev, Vladislav Borisovich--doctor of chemical sciences, professor
Linchevskiy, Boris Vadimovich--doctor of technical sciences, professor
Manokhin, Anatoliy Ivanovich--doctor of technical sciences, professor
Marov, Igor' Nikolayevich--doctor of chemical sciences
Moskvin, Vladimir Mikhaylovich--doctor of technical sciences, professor
Mchedlov-Petrosyan, Otar Petrovich--corresponding member AS Georgian SSR
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Pavlov, Pavel Vasil'yevich--doctor of physico-mathematical sciences, professor
Pakhomov, Yaroslav Dmitriyevich--doctor of technical sciences
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Savvin, Sergey Borisovich--doctor of chemical sciences, professor
Sedov, Vyacheslav Mikhaylovich--doctor of technical sciences, professor
Semenenko, Kirill Nikolayevich--doctor of chemical sciences, professor

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Sokolovskaya, Yevdokiya Mikhaylovna--doctor of chemical sciences, professor
Sychev, Maksim Maksimovich--doctor of technical sciences, professor
Timashev, Vladimir Vasil'yevich--doctor of technical sciences, professor
Ugay, Yakov, Aleksandrovich--doctor chemical sciences, professor
Fedorov, Nikolay Fedorovich--doctor of chemical sciences, professor
Fedorchenko, Ivan Mikhaylovich--academician AS Ukrainian SSR
Chanturiya, Valentin Alekseyevich--doctor of technical sciences
Shevakin, Yuriy Fedorovich--doctor of technical sciences, professor
Shchelokov, Robert Nikolayevich--doctor of chemical sciences, professor
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Bliznyuk, Nikolay Kirillovich--doctor of chemical sciences, professor
Bresler, Semen Yefimovich--doctor of chemical sciences, professor
Bystrov, Vladimir Fedorovich--doctor of chemical sciences, professor
Godovikov, Nikolay Nikolayevich--doctor of chemical sciences, professor
Kayushin, Lev Petrovich--doctor of physico-mathematical sciences, professor
Kiselev, Nikolay Andreyevich--doctor of biological sciences
Kitaygorodskiy, Aleksandr Isaakovich--doctor of physico-mathematical sciences, professor
Konev, Sergey Vasil'yevich--doctor of biological sciences, professor
Lazurkin, Yuriy Semenovich--doctor of physico-mathematical sciences, professor
Mel'nikov, Nikolay Nikolayevich--doctor of chemical sciences, professor
Mokul'skiy, Mark Aleksandrovich--doctor of physico-mathematical sciences, professor
Poglazov, Boris Fedorovich--doctor of biological sciences, professor
Ptitsyn, Oleg Borisovich--doctor of physico-mathematical sciences, professor
Chernavskiy, Dmitriy Sergeyevich--doctor of physico-mathematical sciences, professor

Department of Physiology

Batuyev, Aleksandr Sergeyevich--doctor of biological sciences, professor
Gorodinskiy, Semen Mikhaylovich--doctor of medical sciences, professor
Yefuni, Sergey Naumovich--doctor of medical sciences, professor
Ivanov, Kirill Pavlovich--doctor of medical sciences, professor
Kuznetsov, Aleksey Kirillovich--doctor of veterinary sciences, professor
Lupichev, Lev Nikolayevich--doctor of technical sciences, professor
Ostrovskiy, Mikhail Arkad'yevich--doctor of biological sciences, professor
Simonov, Pavel Vasil'yevich--doctor of medical sciences, professor
Chaylakhyan, Levon Mikhaylovich--doctor of biological sciences
Shapovalov, Aleksandr Ivanovich--doctor of medical sciences, professor

Department of General Biology

Alikhanyan, Sos Isaakovich--doctor of biological sciences, professor
Butorin, Nikolay Vasil'yevich--doctor of geographical sciences
Vavilov, Petr Petrovich--member All-Union Academy of Agricultural Sciences imeni Lenin
Gogolishvili Mamiya Alekseyevich--doctor of agricultural sciences, professor
Grodzinskiy, Andrey Mikhaylovich--corresponding member AS Ukrainian SSR
Zhuchenko, Aleksandr Aleksandrovich--academician AS Moldavian SSR
Zufarov, Kamildzhan Akhmedzhanovich--academician AS Uzbek SSR
Kafiani, Konstantin Aleksandrovich--doctor of biological sciences
Mamayev, Stanislav Aleksandrovich--doctor of biological sciences, professor
Mustafayev, Imam Dzhdemir Ogly--academician AS Azerbaydzhan SSR
Plyanskiy Yuriy (Georgiy) Ivanovich--doctor of biological sciences, professor
Rapoport, Iosif Abramovich--doctor of biological sciences, professor
Skarlato, Orest Aleksandrovich--doctor of biological sciences
Sorokin, Yuriy Ivanovich--doctor of biological sciences, professor
Sushchenya, Leonid Mikhaylovich--corresponding member AS Belorussian SSR
Fedorov, Vadim Dmitriyevich--doctor of biological sciences, professor
Fedorov, Nikolay Fedorovich--doctor of technical sciences, professor
Khrushchov, Nikolay Grigor'yevich--doctor of biological sciences, professor
Shibalova, Tat'yana Artemovna--doctor of biological sciences

Department of Geology, Geophysics and Geochemistry

Bogdanov, Nikita Alekseyevich--doctor of geological-mineralogical sciences
Borisov, Aleksey Alekseyevich--doctor of technical sciences, professor
Bronnikov, Dmitriy Mikhaylovich--doctor of technical sciences, professor
Bukrinskiy, Viktor Aleksandrovich--doctor of technical sciences, professor
Burchakov, Anatoliy Semenovich--doctor of technical sciences, professor
Vakhrameyev, Vsevolod Andreyevich--doctor of geological-mineralogical sciences, professor
Vyshemirskiy, Vladislav Stanislavovich--doctor of geological-mineralogical sciences, professor
Galimov, Erik Mikhaylovich--doctor of geological-mineralogical sciences
Geodekyan, Artem Aramovich--doctor of geological-mineralogical sciences, professor
Gramberg, Igor' Sergeyevich--doctor of geological-mineralogical sciences, professor
Gritsko, Gennadiy Ignat'yevich--doctor of tekhnical sciences, professor
Demenitskaya. Raisa Mikhaylovna--doctor of geological-mineralogical sciences, professor
Dmitriyev, Leonid Vladimirovich--doctor of geological-mineralogical sciences
Drushchits, Vladimir Vasil'yevich--doctor of geological-mineralogical sciences, professor
Dyad'kin, Yuriy Dmitriyevich--doctor of technical sciences, professor
Yegiazarov, Boris Khristoforovich--doctor of geological-mineralogical sciences, professor
Yeremenko, Nikolay Andreyevich--doctor of geological-mineralogical sciences, professor

Zhamoyda, Aleksandr Ivanovich--doctor of geological-mineralogical sciences, professor
Iofin, Stanislav Leonidovich--doctor of technical sciences, professor
Kamaletdinov, Murat Abdulkhakovich--doctor of geological-mineralogical sciences
Keller, Boris Maksimovich--doctor of geological-mineralogical sciences, professor
Kontorovich, Aleksey Emil'yevich--doctor of geological-mineralogical sciences, professor
Krasheninnikov, Valeriy Arkad'yevich--doctor of geological-mineralogical sciences
Krylov, Nikolay Alekseyevich--doctor of geological-mineralogical sciences, professor
Kurlenya, Mikhail Vladimirovich--doctor of technical sciences
Kutuzov, Boris Nikolayevich--doctorof technical sciences, professor
Laverov, Nikolay Pavlovich--doctor of geological-mineralogical sciences, professor
Maksimov, Stepan Pavlovich--doctor of geological-mineralogical sciences, professor
Malovitskiy, Yankif Pankhusovich--doctor of geological-mineralogical sciences
Moksinets, Vladimir Nikolayevich--doctor of technical sciences, professor
Neruchev, Sergey Germanovich--doctor of geological-mineralogical sciences, professor
Obut, Aleksandr Mikhaylovich--doctor of geological-mineralogical sciences, professor
Rozanov, Aleksey Yur'yevich--doctor of geological-mineralogical sciences
Stepanov, Dmitriy Leonidovich--doctor of geological-mineralogical sciences, professor
Turchaninov, Igor' Aleksandrovich--doctor of technical sciences, professor
Udintsev, Gleb Borisovich--doctor of geographical sciences, professor
Chochia, Nikolay Grigor'yevich--doctor of geological-mineralogical sciences, professor

Department of Oceanology, Atmospheric Physics and Geography

Beklemishev, Konstantin Vladimirovich--doctor of biological sciences, professor
Vinogradov, Mikhail Yevgen'yevich--doctor of biological sciences, professor
Voyt, Sergey Sergeyevich--doctor of physico-mathematical sciences, professor
Golitsyn, Georgiy Sergeyevich--doctor of physico-mathematical sciences
Gusev, Aleksandr Mikhaylovich--doctor of physico-mathematical sciences, professor
Zhivago, Aleksandr Vasil'yevich--doctor of geographical sciences
Il'in, Aleksandr Vasil'yevich--doctor of geographical sciences
Kort, Vladimir Grigor'yevich--doctor of geographical sciences, professor
Mamayev, Oleg Ivanovich--doctor of geographical sciences
Mikhal'tsev, Igor' Yevgen'yevich--doctor of technical sciences, professor
Ozmidov, Rostislav Vsevolodovich--doctor of physico-mathematical sciences, professor
Sarkisyan, Artem Sarkisovich--doctor of physico-mathematical sciences, professor

Simonov, Anatoliy Il'ich--doctor of geographical sciences, professor
Sorokin, Aleksandr Ivanovich--doctor of technical sciences, professor
Trokhan, Aleksandr Markovich--doctor of technical sciences, professor
Yakovlev, Sergey Vasil'yevich--doctor of technical sciences, professor

Department of History

Agyan, Tsatur Pavlovich--academician AS Armenian SSR
Aleksandrov, Vadim Aleksandrovich--doctor of historical sciences
Alekseyev, Veniamin Vasil'yevich--doctor of historical sciences
Apakidze, Andrey Melitonovich--corresponding member AS Georgian SSR
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Arakelyan, Babken Nikolayevich--academician AS Armenian SSR
Artemenko, Ivan Ivanovich--doctor of historical sciences
Berkhin, Il'ya Borisovich--doctor of historical sciences, professor
Bobykyan, Valeriy Ivanovich--doctor of historical sciences, professor
Buganov, Viktor Ivanovich--doctor of historical sciences, professor
Buniyatov, Ziya Musayevich--academician AS Azerbaydzhan SSR
Varlamov, Konstantin Ivanovich--doctor of historical sciences, professor
Vasil'yevskiy, Ruslan Sergeyevich--doctor of historical sciences
Vinogradov, Vladilen Nikolayevich--doctor of historical sciences
Volkov, Fedor Dmitriyevich--doctor of historical sciences, professor
Galkin, Aleksandr Abramovich--doctor of historical sciences
Gaponenko, Luka Stepanovich--doctor of historical sciences, professor
Goryushkin, Leonid Mikhaylovich--doctor of historical sciences, professor
Grekov, Igor' Borisovich--doctor of historical sciences
Grigulevich, Iosif Romual'dovich--doctor of historical sciences
Gusev, Kirill Vladimirovich--doctor of historical sciences, professor
Drizul, Aleksandr Arvidovich--academician AS Latvian SSR
Yezhov, Viktor Anatol'yevich--doctor of historical sciences, professor
Ivanov, Robert Fedorovich--doctor of historical sciences, professor
Iskenderov, Akhmed Akhmedovich--doctor of historical sciences, professor
Ismagilova, Roza Nurgaleyevna--doctor of historical sciences
Its, Rufol'f Ferdinandovich--doctor of historical sciences, professor
Kapitsa, Mikhail Stepanovich--doctor of historical sciences, professor
Karasev, Viktor Georgiyevich--doctor of historical sciences, professor
Knorozov, Yuriy Valentinovich--doctor of historical sciences
Koval', Boris Iosifovich--doctor of historical sciences, professor
Kolchin, Boris Aleksandrovich--doctor of historical sciences, professor
Komkov, Gennadiy Danilovich--doctor of historical sciences, professor
Komogortsev, Ivan Ivanovich--doctor of historical sciences, professor
Korablev, Yuriy Ivanovich--doctor of historical sciences, professor
Kostyushko, Ivan Ivanovich--doctor of historical sciences
Kryvelev, Iosif Aronovich--doctor of philosophical sciences
Kuzishchin, Vasiliy Ivanovich--doctor of historical sciences, professor
Kukushkin, Yuriy Stepanovich--doctor of historical sciences, professor
Kulichenko, Mikhail Ivanovich--doctor of historical sciences, professor
Kumanev, Viktor Aleksandrovich--doctor of historical sciences, professor

Kumanev, Georgiy Aleksandrovich--doctor of historical sciences, professor
Kurbatov, Georgiy L'vovich--doctor of historical sciences, professor
Kutakov, Leonid Nikolayevich--doctor of historical sciences, professor
Kyzlasov, Leonid Romanovich--doctor of historical sciences, professor
Lebedev, Nikolay Ivanovich--doctor of historical sciences, professor
Levkovskiy, Aleksey Ivanovich--doctor of economic sciences, professor
Lisovskiy, Nikolay Kuz'mich--doctor of historical sciences, professor
Litavrin, Gennadiy Grigor'yevich--doctor of historical sciences
Magomedov, Rasul Magomedovich--doctor of historical sciences, professor
Markaryan, Eduard Sarkisovich--doctor of philosophical sciences
Markov, Gennadiy Yevgen'yevich--doctor of historical sciences, professor
Masson, Vadim Mikhaylovich--corresponding member AS Turkmen SSR
Nikhamin, Vladimir Petrovich--doctor of historical sciences, professor
Nosov, Nikolay Yevgen'yevich--doctor of historical sciences
Ostoya-Ovsyanyy, Igor' Dmitriyevich--doctor of historical sciences, professor
Pavlenko, Nikolay Ivanovich--doctor of historical sciences, professor
Pisarev, Yuriy Alekseyevich--doctor of historical sciences, professor
Pletneva, Svetlana Aleksandrovna--doctor of historical sciences
Popova, Yevgeniya Ivanovna--doctor of historical sciences, professor
Preobrazhenskiy, Aleksandr Aleksandrovich--doctor of historical sciences
Protopopov, Anatoliy Sergeyevich--doctor of historical sciences, professor
Sanakoyev, Shalva Parsadanovich--doctor of historical sciences, professor
Sevost'yanov, Grigoriy Nikolayevich--doctor of historical sciences, professor
Skrynnikov, Ruslan Grigor'yevich--doctor of historical sciences, professor
Tulepbayev, Baydabek Akhmedovich--academician AS Kazakh SSR
Tyukavkin, Viktor Grigor'yevich--doctor of historical sciences, professor
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Fomin, Vasiliy Timofeyevich--doctor of historical sciences, professor
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Kheyfets, Aleksandr Naumovich--doctor of historical sciences, professor
Cheboksarov, Nikolay Nikolayevich--doctor of historical sciences, professor
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Department of Philosophy and Law

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Bagramov, Eduard Aleksandrovich--doctor of philosophical sciences, professor
Biryukov, Boris Vladimirovich--doctor of philosophical sciences
Bogatov, Vitaliy Vasil'yevich--doctor of philosophical sciences, professor
Borodin, Stanislav Vladimirovich--doctor of juridical sciences, professor
Burlatskiy, Fedor Mikhaylovich--doctor of philosophical sciences, professor
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Voyshvillo, Yevgeniy Kazaimirovich--doctor of philosophical sciences, professor
Gott, Vladimir Spiridonovich--doctor of philosophical sciences, professor
Yermolenko, Dmitriy Vladimirovich--doctor of philosophical sciences, professor
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Ivanov, Semen Aleksandrovich--doctor of juridical sciences, professor
Il'inskiy, Igor' Pavlovich--doctor of juridical sciences, professor
Karpets, Igor' Ivanovich--doctor of juridical sciences, professor
Kozhevnikov, Fedor Ivanovich--doctor of juridical sciences, professor
Kozyr', Mikhail Ivanovich--doctor of juridical sciences, professor
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Laptev, Vladimir Viktorovich--doctor of juridical sciences, professor
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PUBLICATIONS

METHODS OF INVESTIGATING STABILITY OF NUCLEAR REACTORS

Moscow METODY ISSLEDOVANIYA USTOYCHIVOSTI YADERNYKH REAKTOROV in Russian 1977 signed to press 9 Nov 77, pp 1-4, 293-296

[Annotation, table of contents and foreword from book by V. D. Goryachenko, Atomizdat, 1,600 copies, 296 pp]

[Text] This book deals with one of the central questions of the dynamics of nuclear facilities, the stability of stationary operating regimes of nuclear power reactors. The main results of analysis of the stability of nonlinear dynamic systems of various types are discussed: with concentrated parameters, with delayed and with distributed parameters. These results are applied to derivation of stability criteria and to particular analyses of the stability of stationary regimes in nuclear reactors of various types. Considerable attention is devoted to analysis of large-scale and overall stability through nonlinear mathematical models of reactor dynamics. The analysis is based on Lyapunov's second method and frequency criteria of absolute stability.

The book is intended for specialists engaged in calculation of the dynamics of nuclear power facilities and will also be useful for persons interested in applications of the theory of stability of motion.

Figures, 58. Bibliography, 279 items.

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Foreword

The development of contemporary nuclear power engineering is characterized by a tendency to develop complex nuclear power units (YeEU) with a large specific energy output. These conditions result in increasing demands on the operating characteristics of nuclear power facilities and their performance qualities. Not surprisingly, the same requirements apply to reactor dynamics calculations. One of the central points of these calculations is the analysis of the stability of stationary operating regimes for nuclear units, for the stability of stationary regimes is the characteristic which to a considerable degree determines the viability of the unit and the possibility of normal operation.

It is no coincidence that more than 1,000 works*, mostly published in various periodicals, have been devoted to the stability of nuclear reactors, even though it might seem a very narrow question in the study of nuclear power facilities. The need for a systematic exposition of the results of stability studies of nuclear power units has become pressing, but it has seemed impossible to encompass all the material in a relatively small book. The main aim of the present book, as well as of the author's earlier book produced in 1971**, is to describe methods of theoretical study of nuclear reactor stability and several of their applications to the analysis of stability in reactors of particular types.

* For confirmation see Bibliograficheskiy ukazatel' rabot po ustoychivosti statsionarnykh rezhimov yadernykh energeticheskikh ustanovok (1954-1973 gg.) [Bibliography of Works on Stability of Stationary Regimes of Nuclear Power Units (1954-1973], Moscow, TsNIITIatominform, 1974. Although clearly incomplete and covering only the period to 1973, it still lists more than 800 works on various aspects of nuclear power unit stability.

** V. D. Goryachenko. Metody teorii ustoychivosti v dinamike yadernykh reaktorov [Stability Theory Methods in Nuclear Reactor Dynamics], Atomizdat, 1971.

In Chapters 2-5, the results of the theory of stability of dynamic systems are described, generally without proof. Facts which are of interest for applied problems, in particular the problems of nuclear power plant stability, are included. The discussion is accompanied by analysis of simplified models of reactor dynamics.

From a physical point of view, the most interesting material is concentrated in Chapters 6-9 (serving at the same time as a rather extensive illustration of the mathematical methods which can be applied). Much attention has been devoted to the most difficult problem, that of large-scale and overall stability of reactors, i.e. analysis of stability with indication of the range of allowable initial perturbations of the stationary regime. The sole exception is Chapter 9, in which thermoacoustic instability in reactors with gaseous heat carriers or fuel is studied by linearized models. This question is so complex that even with linear treatment it is not yet adequately handled in the literature.

The author considers it his pleasant duty to express his warm thanks to Ya. V. Shevelev for his interest and his critical remarks, to F. M. Mitenkov, B. I. Motorov and V. V. Plechin for moral support and assistance, and to his coworkers Yu. F. Trunin, V. A. Denisov and N. A. Babkin for their assistnace in writing individual chapters.

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PUBLICATIONS

ELECTRONIC CHARACTERISTICS AND ELECTRON-PHONON INTERACTION OF SUPERCONDUCTING METALS AND ALLOYS

Moscow TRUDY ORDENA LENINA FIZICHESKOGO INSTITUTA IMENI P. N. LEBEDEVA AKADEMII NAUK SSSR in Russian Vol 82, 1975 signed to press 31 Mar 75 p 2, 103

[Annotation and Table of Contents from book edited by Academician N. G. Basov, Izdatel'stvo Nauka, 1,500 copies, 104 pages]

[Text] The methods of preparing specimens of superconducting metals and alloys suitable for investigations of optical and tunnel characteristics are outlined in the collection. The optical properties of a number of pure metals and alloys in the infrared and visible regions of the spectrum are studied. The electron characteristics are found.

The publication is intended for scientific workers, postgraduate students and students involved in problems of superconductivity, metal optics and electron properties of metals.

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PUBLICATIONS

KINETIC EFFECTS IN ELECTRON-PHOTON SYSTEMS IN A LASER EMISSION FIELD

Kishinev KINETICHESKIYE EFFEKTY V ELEKTRON-FONONNYKH SISTEMAKH V POLE LAZERNOGO IZLUCHENIYA in Russian 1976 signed to press 15 Sep 76 p 2, 169-170

[Annotation and Table of Contents from book by Elerlanzh Petrovich Sinyavskiy, Izdatel'stvo Shtiintsa, 610 copies, 172 pages]

[Text] The light absorption coefficient in natural semiconductors is investigated in the monograph with regard to crystal lattice vibrations. An explanation of Urbach's empirical law in natural semiconductors of type $A^{III}B^{V}$, observed experimentally in these compounds, is given for the first time. Specifically, the processes of electromagnetic radiation absorption in electron-phonon systems in external fields are considered. A great deal of attention is devoted to study of the kinetic processes in semiconductors in a powerful laser emission field. The phenomenon of magneto-infrared resonance when the laser emission frequency is close to cyclotron frequency, is investigated in detail in the paper and the conditions of experimental observation of this effect are discussed.

The book is intended for scientific workers, postgraduate students and students of advances courses specializing in the field of solid-state physics and theoretical physics.

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KINETICS OF SIMPLE OSCILLATION THEORY MODELS

Moscow TRUDY ORDENA LENINA FIZICHESKOGO INSTITUTA IM. P.N. LEBEDEV AN SSSR: KINETIKA PROSTYKH MODELEY TEORII KOLEBANIY (Kinetics of Simple Oscillation Theory Models) in Russian 1976 Vol 90 pp 1-4, 208

[Annotation, Table of Contents and Introduction from monograph edited by N. G. Basov, Izdatel'stvo "Nauka," 1,350 copies, 208 pages]

[Text] The place of the kinetics of simple models in general oscillation theory is discussed. The description of simple models (with a comparatively small degree of freedom) is reduced to ordinary differential equations, as a rule, including wide-band noises. Along with direct solutions the authors discuss methods of investigating inverse problems. Applications to various fields of the natural sciences are examined. Several articles are devoted to an analysis of specific problems such as the kinetics of recombining plasma, the mechanism of solar cyclical activity, and new procedures in medical diagnosis. The collection is intended for specialists in oscillation theory.

CONTENTS

FOREWORD

This book is concerned with modeling concepts in oscillation theory and the possibilities of using related methods of theoretical analysis in a broad range of problems involving the natural sciences. The purpose of the book is first of all a methodological one. Therefore, in discussing specific problems which illustrate and clarify the general concepts of oscillation theory, the discussion here concerns the concept of the simplest models of the phenomena introduced at the initial stage and their evolution during the course of the investigation. We emphasize rather than conceal the incompleteness of the results obtained here, and examine the difficulties encountered enroute, noting the immediate goals of research involved with them without losing sight of the prospects of the entire investigation.

It is not only the methodological aspects of the problem discussed here but also the specific conclusions reached in the book that are in themselves, in our opinion, of definite value and may even be of interest to specialists in the respective branches of the natural sciences. Each chapter has been written in such a way that it may read independently of the others. All nine chapters can be considered a complete set of research carried out by their authors in the past several years. We have not attempted here to connect them by topical or logical "bridges," assuming such work at this stage to be of little interest, and have thus limited ourselves for the present only to the "Introduction" written by L. I. Gudzenko. Chapter 1 was written by L. I. Gudzenko with V. V. Yevstigneyev and S. I. Yakovlenko; Chapter 2 by L. I. Gudzenko, Yu. I. Syts'ko and S. I. Yakovlenko; Chapter 3 by L. I. Gudzenko with I. S. Lakoba and S. I. Yakovlenko; Chapter 4 by L. I. Gudzenko and V. S. Marchenko; Chapter 5 by L. I. Gudzenko and S. I. Yakovlenko; Chapters 6, 8 and 9 by L. I. Gudzenko and V. Ye. Chertoprud; Chapter 7 by L. I. Gudzenko and A. Ye. Sorkina.

The book consists of two sections. The introduction discusses the place of oscillation theory in contemporary natural sciences. A table of contents is given. The principle of separating the dynamic bonds is formulated and is then used to develop a correlation method for analyzing the inverse problem.

Section 1 uses an example of several contiguous problems of applied physics to discuss the simplest version of traditional direct problems in oscillation theory when the movement of a dynamic system about a stable stationary point is being investigated.

The purpose of this section is to seek active media for powerful sources of coherent radiation (plasma lasers in various frequency bands) and to analyze the prospects of designing power-producing reactor-lasers. The first chapter examines the conditions in a dense supercooled (for free electrons) plasma leading to inversion of the population of atomic states. Chapter 2 makes a theoretical study of several methods of preparing supercooled plasma. Chapter 3 discusses the character of recombination relaxation of plasma of inert gases and their mixture with other chemical elements. Chapter 4 formulates the requirements for the chemical composition and the parameters of the plasma, upon satisfaction of which it is possible to produce an active medium amplifying the resonance emission of atoms. And finally Chapter 5 investigates the theoretical possibility of extracting a substantial amount of energy in the form of laser emission from power devices such as atomic reactors.

In Section 2, which is more unusual in the methodological sense, the specific problems are rather different. Chapters are included here which illustrate the results of the correlation method of inverse problems in oscillation theory. In this sense Chapter 9, which does not directly develop such a method, is unique; it essentially supplements Chapter 8 on the analysis of solar cyclical activity which is generated in the course of this analysis and has independent value as well. Chapter 6 is devoted to a scheme for measuring the probabilities of nonradiational transitions of atoms (molecules, ions) in low-temperature plasma based on the correlation functions of counting. Chapter 7 discusses the principles of the correlation method of medical diagnosis based on the pulsations of major blood vessels.

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PUBLICATIONS

THERMAL PHYSICS OF FAST-NEUTRON REACTORS AND HEAT-EXCHANGE EQUIPMENT

Minsk BYSTRYYE REAKTORY I TEPLOOBMENNYYE APPARATY AES S DISSOTSIRUYUSHCHIM TEPLONOSITELEM in Russian 1978 signed to press 2 Feb 78 pp 1-6, 239-240

[Annotation, foreword and table of contents from book by V. B. Nesterenko, A. A. Mikhaylevich and B. Ye. Tverkovkin, Izdatel'stvo "Nauka i Tekhnika", 1,000 copies, 240 pp]

[Text] This book discusses methods and algorithms for thermophysical calculations for fast-neutron reactors and the heat-exchange equipment of nuclear power stations with dissociating heat carriers. The methods presented by the authors are oriented toward computer utilization and make it possible to calculate the local characteristics of heat and mass transfer and the flow resistance of dissociating heat carriers in the reactor circuits and the heat-exchange equipment. The results of calculation of the parameters of reactors and heat-exchange equipment for nuclear power stations with dissociating heat carriers currently in the design stage are presented, and experimental substantiation of these results is given.

The book is intended for scientific and engineering-technical personnel in the nuclear power field, and may be used as a textbook by university students.

Tables, 24. Illustrations, 30. Bibliography, 238 items.

Foreword

Most of the developed nations of the world are planning to develop nuclear power engineering by constructing nuclear electric power stations, which will play an increasing role in satisfying electrical requirements. In 1975-1976, 10 percent of the total electric energy produced in the European Economic Community and the USA came from nuclear power stations, and by 2000 it is planned to increase the share to 40-50 percent.

Fast-neutron reactors are the basis of present-day nuclear power engineering, and they will determine its structure and the consumption of natural uranium in the next decade. But in view of the limited supplies of cheap natural uranium, considerable expansion of nuclear power production is possible only through fast-neutron reactors in which it will be possible to produce extensive quantities of fissionable nuclear fuel, increasing the efficiency of utilization of natural uranium 30-40 times. The period during which it is economically necessary to double the production of electrical energy is 8-10 years in most countries of the world, whereas the period during which it is expected to be necessary to double nuclear power production capacities is 5 years. Nuclear power engineering can fulfill the hopes that are reposed in it and become the critical factor in energy supply if fast-neutron reactors which can double the quantity of secondary fissionable fuel in 4-6 years are developed. In this case the decisive role in the nuclear fuel balance will shift to plutonium produced in fast-neutron reactors, and the system of nuclear power stations with thermal and fast-neutron reactors will be able to assure its own development with limited use of natural uranium sources in the initial stage, with subsequent operation of the system of nuclear power stations on waste uranium and secondary plutonium produced by fast-neutron reactors.

In the USSR, the USA, France, England, West Germany, Japan and other countries, the main efforts are being concentrated on the development, construction and commissioning of fast-neutron reactors using sodium. The recent development of commercial large-capacity nuclear power stations (1200-1500 MWe) and the experience of putting demonstration stations into operation have shown that it is realistic and economically advantageous to continue the development of electric power production with fast-neutron reactors, and that these reactors are fully practicable, although the planned period for doubling of capacity will be 10-15 years, longer than required, while the unreliable operation of sodium-water-steam generators still makes it impossible to consider that the Na-Na-H_2O heat conversion system has been mastered, to expect a high percentage of utilization of capacity, or to recommend extensive construction of this type of nuclear power station.

Accordingly, in recent years the study of alternative types of breeders, gas-cooled fast-neutron reactors using helium and N_2O_4, has expanded considerably.

In foreign gas-cooled breeder development projects it is not proposed to make extensive use of the experience in helium reactor technology accumulated in thermal reactors, although a pressure of 25-40 bars was mastered in the development of high-temperature gas-graphite reactors, and it is planned to use helium at 120-170 bars to obtain significant physical advantages (large conversion ratios) in gas fast-neutron reactors as compared with sodium-cooled breeders. In the development of nuclear power stations with helium breeder reactors, considerable hopes are pinned to simplification of the heat-conversion system by changing from the three-circuit system of the sodium reactor to the two-circuit He-H_2) system, and in the long run it is hoped to implement a single-circuit gas turbine cycle based on helium.

However, in gas-cooled fast-neutron reactors using helium we are faced with the difficult problems of sealing of circuits in large-capacity power stations as a result of the great fluidity of helium, and of assuring emergency cooling of a helium breeder reactor when the sealing of the cooling circuit is broken.

Since 1965, the Institute of Nuclear Power Engineering, Belorussian SSR Academy of Sciences, has been conducting comprehensive experiments on dissociating nitrogen tetroxide as a promising heat carrier and working substance for nuclear power stations.

Nitrogen tetroxide has a number of thermophysical properties as a heat carrier and working substance for power stations which make it possible to attain calorific intensities as high as 800-1200 kW/liter in the core of a fast-neutron reactor at 120-160 bars and 200-500° C, along with good physical characteristics, a simple single-circuit heat-conversion system, improved weight and size characteristics of turbines and heat exchangers and so on.

The main properties of N_2O_4 as a heat carrier and working substance are as follows:

the large thermal effect from the chemical reactions of dissociation during heating and recombination during cooling ($N_2O_4 \rightleftarrows 2NO_2$, 623.9 kJ/kg $\rightleftarrows 2NO + O_2$, 1226.8 kJ/kg) increases the heat exchange coefficient by a factor of 2-3 through a new mechanism of heat transfer by concentration diffusion, making it possible to organize intensive heat collection in the core of the fast-neutron reactor (800-1200 kW/liter at 120-500° C and 120-160 bars) and in heat-exchange apparatus;

the saturation-curve physical and chemical properties of N_2O_4 and the low heat of evaporation (419 kJ/kg) make it possible to implement an N_2O_4-based gas-liquid cycle at temperatures 30-500° C and pressures of 2-170 bars with a high-efficiency, simple heat regeneration system;

the high thermophysical properties in a broad range of temperatures and pressures (c_p = 2.93-3.35 kJ/kg-deg at 150 bars in a temperature range of 200-450° C, γ = 150-200 kg/m^3) make it possible to increase heat extraction by a factor of 2-2.5 in comparison with sodium;

the low specific volume and residual gas pressure after the turbine make it possible to develop a compact gas turbine.

In nuclear power stations using gas-cooled N_2O_4 fast-neutron reactors, the main difficulty is that of developing and testing fuel compositions which are compatible with a dissociating gas and which contain minimum quantities of construction materials, along with reliable location and neutralization of breakdown emissions of the toxic heat carrier, and implementation of effective systems for removal of corrosion products from the heat carrier.

The foreword, introduction and Chapters 1 and 2 were written by V. B. Nesterenko, Chapter 3 by B. Ye. Tverkovkin, and Chapters 4 and 5 by A. A. Mikhalevich.

Participants in the writing of individual sections of the book were: 1.3, I. E. Nesterenko; 2.4, Ye. P. Kovaleva, L. A. Bida, M. A. Kharitonyuk and L. T. Lomako; 2.2, V. P. Gol'tsev. Section 4.2 was written by A. A. Andrizhiyevskiy. The results descrived in Chapter 5 were obtained in company with M. Ye. Salukvadze, A. N. Ioseliani and R. G. Sobolevskiy.

The authors have to express their deep gratitude to Academician of the Belorussian Academy of Sciences A. K. Krasin for his constant attention to their work.

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PUBLICATIONS

AERODYNAMIC ACOUSTIC RESEARCH

Moscow AKUSTIKO-AERODINAMICHESKIYE ISSLEDOVANIYA in Russian 1975 signed to press 31 Mar 75, pp 1-2, 98

[Annotation and table of contants from book edited by Dr of Physical and Mathematical Sciences A. V. Rimskiy-Korsakov, Izdatel'stvo "Nauka", 1,850 copies, 104 pp]

[Text] This collection contains both theoretical and experimental studies dealing with the problems of turbulent noise formation and interaction of turbulent flows with elastic bodies. The studies reflect the progress of physical research dealing with noise in rotodynamic machines, aircraft fuselages and propellors.

The book is intended for scientific personnel and engineers working on aerodynamic acoustic problems.

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PUBLICATIONS

'KIVTSET' FINELY GRANULAR COMPLEX SULFIDE-ORE PROCESSING SYSTEM DESCRIBED

Moscow TSVETNYYE METALLY in Russian No 12, 1978 p 128, inside back cover and back cover

[Text] Method and Equipment for Processing Finely Granular Complex Sulfide Ore*

In the USSR for the first time in the world a fundamentally new method and equipment have been developed for processing finely granular complex sulfide ore, which have been given the name "Kivtset."

At the present time the production of heavy non-ferrous metals--copper, zinc, lead, nickel and cobalt--is being carried out chiefly by pyrometallurgical methods, including several independent conversion processes performed with separate equipment. The melting process is multistaged and is carried out in low-efficiency cumbersome furnaces with a low level of desulfurization, which makes it necessary to preroast concentrates.

The disadvantages of the familiar processes are: the poorly effective utilization of the heating capacity of sulfide concentrates, as the result of which melting is performed with added consumption of carbon fuel; the low level of utilization of precious components of the ore, evidenced in the loss of zinc, lead, cadmium and other metals along with the slag; the low level of desulfurization; and the complex equipment design for the process.

For the purpose of improving the effectiveness of utilization of precious components of the ore, additional operations have been introduced in the system of existing technological processes. For example, for the purpose of extracting zinc from slag, the latter must be subjected to the fuming or Waelz process. The sublimates thereby obtained require additional processing for the purpose of extracting zinc and lead from them in the form of metals. Types of ore such as lead-zinc and copper-zinc-lead-containing do not have a technology which has been developed and is industrially feasible.

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*The editorial staff is repeating publication (cf. No 9, 1978, p 128) because of inaccuracy in the use of data characterizing the technical and economic indicators of the process.

By the new "Kivtset" method it is possible to process copper, copper-zinc, copper-nickel, copper-pyrite, copper-tin, lead, zinc and lead-zinc ore and concentrates.

"Kivtset" is based on combining the processes of roasting and melting the burden in the pulverized state while using oxygen, and of electrosmelting and condensing zinc into molten metal, performed in a single unit. The new equipment consists of a cyclone chamber, a separating chamber, an electric furnace and a condenser.

Carried out simultaneously in the cyclone chamber are roasting and melting of the burden and slag and matte formation.

The autogenous occurrence of the roasting-melting process is made possible on account of the heat of the reaction for oxidation of sulfides with a sulfur content of 25 percent in the burden. With a sulfur content below this limit it is possible to use a slight amount of carbon fuel.

The melt produced in the cyclone chamber continuously enters the separating chamber, from which it flows into the electric furnace, where the following processes take place simultaneously (in the case of processing a copper-zinc-containing ore):

Settling of the slag from the matte
Sublimation of zinc from the slag
Dezincing of the matte
Stripping the slag of copper

The sublimation of zinc in electrosmelting of the melt takes place according to the following reactions:

Reaction between zinc oxide and carbon monoxide
Reaction between zinc oxide and metallic iron

The above processes for the sublimation of zinc, which include both homogeneous and heterogeneous reactions, whose velocity depends on the composition of the melt and the temperature, govern the selection of quite specific relationships between the surface of contact between the slag and gas phase and the depth of the slag cell. The gas phase in the electrothermal cell consists mainly of carbon monoxide, which protects zinc vapors from subsequent oxidation when the zinc is condensed into molten metal.

Stripping the slag of copper during electrosmelting is governed chiefly by electrothermal losses, which vary with different compositions of the melt.

In the case of processing zinc-lead sulfide concentrates and ore or a mixture of zinc and lead concentrates containing 10 to 70 percent lead, 7 to 40 percent zinc, a maximum of 6 percent copper, and not less than 14 percent sulfur, instead of a cyclone chamber a burner of special design is installed. The electric furnace and condenser have the same design as the cyclone chamber, but different dimensions. And the technological process is carried out with different parameters.

How the "Kivtset" Process is Carried Out

The burden for melting, with a size not greater than 5 mm, which is first dried to one percent moisture, enters the cyclone through an ejection unit, mixed with oxygen, at a rate of 100 m/s maximum. As a result of this a cyclone effect is created: Under the influence of vortex flows centrifugal forces thrust the particles of ore or concentrate against the walls of the furnace, and the oxygen at high velocity flows around them. This results in very high speeds at which reactions take place, and in the creation of high heat release rates, and, consequently, high intensity of the process.

The mixture of the melt and gases formed in the cyclone is let out from a port in the lower end of the cyclone and drops into the separating chamber, onto a cooled baffle plate. The kinetic energy head of the melt and gases is thereby reduced. The melt flows off into a pit which communicates with the electric furnace, and the gases, after cooling and purification, leave the separating chamber and enter a unit for the recovery of sulfur. The separating chamber, if sulfide concentrates are processed, is separated from the electric furnace section of the unit by a water-cooled partition. The melt settles in the electric furnace. The slag is subjected to an electrothermal effect with the addition of coke, as the result of which the zinc and partly the lead are sublimated and are directed in the form of a vapor-and-gas mixture into the condenser, from which the zinc and lead are released in the form of raw metal.

When lead and zinc concentrates are melted, in place of the cyclone, above the separating chamber can be installed a special burner from which the mixture of oxygen and the burden is removed and is melted in the suspended state in the burner's flame.

The major technical and economic advantages of the new technology are:

1. The process is carried out in a single metallurgical unit autogenously, utilizing the heat from the oxidation of sulfides, with thorough extraction of precious components, such as copper (up to 98 percent) and noble metals (up to 97 percent), in the matte; zinc (up to 65 percent) in the molten metal, with a content of it in the original raw material of 7 to 9 percent, whereby 7 percent of the zinc changes into matte; lead, cadmium, rare metals and other volatile components, in sublimates; and sulfur, in gases rich in sulfur dioxide (up to 80 percent).

2. The imputed energy costs for the entire conversion process of treating the original raw material are 25 percent lower as compared with reverbatory smelting.

3. Combining several technological operations in a single unit makes it possible to lower operating costs as much as 30 percent, to mechanize and automate the process totally, and to improve working conditions.

Labor productivity is improved by a factor of 1.3 to 1.5 as compared with reverbatory smelting of copper-zinc concentrates.

As an example can be given "Kivtset" smelting of a mixture of copper sulfide and combined copper-zinc concentrates, using a unit with an output of 1000 tons of burden per 24-hour period.

The composition of major components of the concentrate mixture, in percentages, is: copper 14.24, zinc 8.75, lead 2.46, iron 27.4, sulfur 34, silica 3.14, and calcium oxide 1.6.

Mineralogical characteristics of the concentrate mixture: The copper is chiefly in the form of chalcopyrite, the lead and zinc are in the form of galena and sphalerite, respectively, and the iron is in the form of chalcopyrite and pyrite.

Below are given the technical and economic indicators for processing one ton of burden.

Processed:	
Burden, tons	1.0
Including, in tons:	
Mixture of combined and copper concentrates	0.833
Quartz flux (80 percent silica)	0.167
Consumed:	
Oxygen, nm^3	210
Fine coke, kg	16.7 (for recovering zinc from slag)
Electric power, kWh	339.0
Electrodes, kg	2.5
Water for cooling, m^3	2.6
Produced:	
Matte, tons	0.32
Copper, percent	45.0
Lead, percent	1.36
Zinc, percent	2.0
Raw zinc, tons	0.05
Zinc, percent	97.5
Smelting dust, tons	0.042
Lead, percent	29.6
Zinc, percent	35.0
Dump slag, tons	0.46
Copper, percent	0.35
Lead, percent	0.20

Zinc, percent	2.50
Iron, percent	34.00
Silica, percent	36.00
Smelting gases, containing 80 to 85 percent SO_2, nm^3	213 (after electric separators)

Extracted, in percent:

Copper in matte	97.5
Lead in matte	40.20
Lead in smelting dust	59.80
Zinc in raw zinc	65.00 maximum
Zinc in matte	7.00
Zinc in smelting dust	20.00
Sulfur in gases rich in SO_2	80.00 maximum
Workers required per shift to run the "Kivtset" complex	36 (listed number)
Workers required per shift to run only the "Kivtset" unit	12 (listed number)

Example of "Kivtset" Smelting of Lead Sulfide Concentrates

The following data can be given as an example of "Kivtset" smelting of lead sulfide concentrates with a unit with a capacity of 100 tons of concentrate per 24-hour period.

Composition of major components of concentrate in percent: lead 60.6, zinc 6.5, copper 0.30, iron 7.2, sulfur 20.0, silica 3.5, calcium oxide 0.92.

Mineralogical characteristics of concentrate: The predominant one is galena, whose content reaches 70 percent. Zinc is represented in the form of sphalerite. Of the ferruginous minerals in the concentrate have been observed pyrrhotite, pyrite and chalcopyrite. Copper is represented by chalcopyrite and covellite in the form of single grains.

Below are given the technical and economic indicators for processing one ton of lead concentrate.

Processed:

Burden, tons	1.162
Including, in tons:	
Lead concentrate	1.0
Quartz flux containing 90 percent silica	0.115
Lime flux containing 60 percent CaO	0.047

Consumed:

Oxygen, nm^3	265
Fine coke, kg	90 (for recovery of lead, zinc and copper)
Electric power, kWh	1000
Electrodes, kg	3.0
Water for cooling, m^3	8.0

Produced, tons:

Raw lead	0.595
Raw zinc	0.053
Dump slag	0.312

Composition of Slag, Percent:

Lead	1.38
Zinc	3.20
Copper	0.03
Iron	22.0
Silica	38.1
Calcium oxide	14.8

Smelting gases containing 50 percent SO_2, nm^3	250

Extracted, percent:

Lead in raw metal	96.5
Zinc in raw metal	80.0
Copper in raw metal	85.0
Sulfur in gases rich in SO_2	98.0

Upon conclusion of a licensing agreement, the licensee can be granted the right to use the patent, the necessary technical documentation and technical assistance in assembling, adjusting and starting up the "Kivtset" unit.

This new method and unit for processing finely granular complex sulfide ore have been patented in England, the USA, the FRG and France.

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PUBLICATIONS

LIST OF SOVIET ARTICLES DEALING WITH COMPOSITE MATERIALS

Moscow GOSUDARSTVENNYY KOMITET SOVETA MINISTROV SSSR PO NAUKE I TEKHNIKE. AKADEMIYA NAUR SSSR. SIGNAL'NAYA INFORMATSIYA, KOMPOZITSIONNYYE MATERIALY, Vol 3, No 20, 1978 p 3-6

[Following is a listing of the Soviet entries from SIGNAL'NAYA INFORMATSIYA. KOMPOZITSIONNYYE MATERIALY (SIGNAL INFORMATION. COMPOSITE MATERIALS), a bibliographic publication of VINITI. This listing is from Vol 3, No 20, 1978]

[Excerpts]

2. On the thermodynamics of the interrelationship in fibrous composition materials. Portnoy, K. I., Bogdanov, V. I., Mikhaylov, A. V. Fuks, D. L. "Dokl. AN SSSR," 1978, 240, No 5, 1154-1156.

11. P. Method for manufacturing bimetallic packets. Nesmachnyy, A. N., Bykov, A. A., Krylovskiy, A. P., Belokon', Yu. I., Ustimenko, V. A. Golovanenko, S. A., Khoroshilov, N. M., Chervyekov, V. V., Buynevitch, S. S. Authors certificate USSR, (V 23 R 3/02), No 585033, application 12.07.76, No 2388023, published 23.12.77.

12. Special features of crystallization cracks formed when welding alloys with zirconium and the possibility for eliminating them by adding trace metals to the alloy. Zenkova, E. K., Polyanskiy, V. M., Glikman, Ye. E., Popov, O. P. "Svaroch, pr-vo," 1978, No 7, 9-10.

14. On nonlinear deformation of laminated composite materials. Zinov'yev, P. A., Tarakanov, A. I. "Sb. tr. MVTU imeni N. E. Bauman," 1978, 16, 72-80.

22. Analysis of antifriction properties of composite materials of the matrix-filled type. Zabolotnyy, L. V., Klimanov, A. S., "Prob. treniya i iznashivaniya. Pesp. mezhved. nauch-tekhn. sb.," 1978, No 13, 31-34.

24. Natural vibrations and stability of three-ply shells made of composite materials. Babich, D. V., Koshevoy, I. K., "Prikl. mekhanika," 1978, 14, No 7, 49-54.

27. Phase transformations of pyrocarbide coatings on graphite fibers. Stepanova, A. N., Kirevina, T. P., Kilin, V. S., Kuteynikov, A. F. Vgatkina, M. N., Shmakov, Ye. S., "Konstrukts. materialy na osnove ugleroda," 1978, No 13, 114-117.

37. Electrochemical precipitation of iron in combination with compounds containing alkaline and alkaline-earth metals. Yakimenko, N. G., Vasyurenko, N. G., Zosimovich, D. P., "Elektrodn. npotsessy pri elektro-osazhdenii i rastvorenii metallov." Kiev, 1978, 77-79.

63. Raising corrosion resistance of concrete by impregnating it with polymers. Bazhenov, Yu. M. "Prom.str-vo," 1978, No 8, 37-38.

68. On appearance of obliteration in penetrable fibrous materials. Kostornov, A. G., "Poroshk. metallurgiya," 1978, No 6, 35-38 (English abstract).

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PUBLICATIONS

THEORY AND APPLICATION OF SEMICONDUCTOR LASER

Moscow POLUPROVODNIKOVYYE LAZERY ("Semiconductor Lasers") in Russian 1976 signed to press 6 Dec 76 pp 2-14

[Annotation, Table of Contents, Foreword and Introduction from the book by Oleg Vladimirovich Bogdankevich, Sergey Andreyevich Darznek and Petr Georgiyevich Yeliseyev, Izdatel'stvo Nauka, 8,000 copies, 416 pages]

[Text] The book is devoted to semiconductor lasers -- efficient and compact sources of coherent radiation having prospects of wide practical application. The main point in the book is devoted to injection lasers and fast electron-excited lasers. A brief survey of the characteristics and a summary of semiconductor materials used in lasers is given in the Introduction. The first part of the book contains an analysis of the radiative recombination mechanism in semiconductor compound crystals and some problems of the dynamics and main characteristics of semiconductor injection lasers. The physical processes which accompany laser operation and also the problems which arise during practical application of them are considered.

The theoretical problems and practical applications of electron-excited lasers are considered in the second part of the book; the processes of fast electron-crystal interaction, formation of excess current carriers, processes of coherent radiation interaction with the active medium in lasers of this type with different configuration of the cavity and beam, thermal modes, generation dynamics and practical application of electron-excited lasers are described.

Contents

Foreword

The needs of scientific and technical progress dictate the need to generalize numerous results of experimental and theoretical investigations concerning the properties of semiconductor lasers. These investigations comprise a vast and branched direction -- semiconductor quantum electronics, which is closely related to such new engineering disciplines of optoelectronics, lidar, optical communications and so on.

Because of a number of practical advantages, semiconductor lasers find broad application in engineering. By analogy with ordinary electronics where semiconductor devices have made it possible to sharply reduce energy consumption and the dimensions of devices, semiconductors have also made it possible to improve the efficiency of lasers and to develop miniaturized circuits in quantum electronics. At the same time the rich scientific material on the properties of semiconductor lasers, scattered in thousands of original articles, is only partially reflected in surveys and textbooks. This creates specific difficulties in expanding the sphere of applications of semiconductor lasers, since a lack of information of generalized nature frequently generates an unjustified fear of introducing new solutions of practical problems.

The authors of the book offered to the reader have attempted to cover the existing gap in scientific literature, recognizing however that an exhaustive outline of most of the problems touched on is still not possible. The material of investigations carried out at the Physics Institute imeni P. N. Lebedev of the USSR Academy of Sciences is mainly used in the book, but the results of a large number of other papers to which the corresponding references are made in the text were also used. Most attention is devoted to two types of semiconductor lasers -- injection and electron-pumped. These versions of lasers apparently now have the best prospects for further development.

The Introduction and Part 1 of the book were written by P. G. Yeliseyev and Part 2 was written by O. V. Bogdankevich and S. A. Darznek. The authors hope that the monograph will be useful both for specialists and for a wider range of readers interested in semiconductor lasers and their application.

Introduction

Physicists of the present generation are witnesses to the development of a new scientific-technical trend -- quantum electronics. Its most effective achievement was development of the laser -- a powerful radiation generator in the optical band. This event, which occurred at the beginning of the 1960's, denoted the remarkable success of the theoretical thought of physicists -- derivation of the possibility of controlling the light emission process on the basis of the stimulated emission effect.

A. Einstein (1917) predicted the stimulated emission effect in "pre-laser" times. He introduced this phenomenon into his calculations, observed by no one, on the thermal radiation balance in order to create a noncontradictory theory of this process. His result was regarded for more than 30 years as a formal method of avoiding theoretical difficulties or as an effect accomplished under "exotic," inaccessible conditions. The phenomenon of stimulated emission emerged to the forefront only with development of radio spectroscopy. It was discovered experimentally and was used beneficially in masers -- the first quantum electronics devices operating in the radiowave band.

It is now well known that the effect of stimulated emission consists in emission by an emitter having sufficient energy reserve of exactly the wavelength as that which this emission stimulates. The emitted waves fuse into a common flux, retaining identical frequencies, directions, phases and polarizations. An important aspect may be considered in this fact -- we are talking about the principle of amplification applied to any electromagnetic radiation. Many initially did not believe that most atoms or molecules subjected to the most diverse disturbances -- collisions, vibrations and so on -- can so easily match their radiative processes as now occurs in various lasers and masers.

The honor of being the father of quantum electronics belongs to Soviet scientists N. G. Basov and A. M. Prokhorov (Lenin Prize of 1962) and to the American scientist C. Townes (all three were awarded the Nobel Prize in physics in 1964).

In the most popular version, a semiconductor laser is a crystalline diode several thousandths of a cubic centimeter in volume which consumes the energy of a flashlight battery. We will further see what forces in the field of physics and technology stand behind this simplicity and what further development semiconductor lasers achieved. But we would like to emphasize the following fact here: semiconductor lasers form an isolated group among other quantum electronics devices, being distinguished by compactness and a number of other important properties which will be discussed below.

The idea of using semiconductors to generate radiation was formulated in 1958-1959 by N. G. Basov, B. M. Vul and Yu. M. Popov [1] at a time when lasers did not yet exist. In 1961 N. G. Basov, O. N. Krokhin and Yu. M. Popov [2] suggested that injection in degenerated p-n junctions be used to achieve the laser effect. A laser of this type (an injection laser) was accomplished in 1962 in a number of laboratories in the United States and the USSR on the basis of a degenerated p-n junction in the gallium arsenide (GaAs) intermetallic compound [3-7]. R. Hall and colleagues (United States) gave the first report of this.

Investigations of various materials, including GaAs, preceded successful development of a semiconductor laser. A group of Soviet physicists (D. N. Nasledov et al.) discovered the effect of spectral constriction in the emission of diodes manufactured from gallium arsenide [8]. This constriction is a precursor of the coherent emission generation mode. The fundamental research of Soviet physicists, which led to development of semiconductor lasers, was awarded the Lenin Prize in 1964. New types of semiconductor lasers appeared during the same year. N. G. Basov, O. V. Bogdankevich and A. G. Devyatkov [9] reported on achieving the laser effect upon bombardment of a CdS crystal with high-energy electrons. This paper served as the beginning of development of semiconductor electron-pumped lasers. N. G. Basov, A. Z. Grasyuk and V. A. Katulin [10] also achieved the laser effect during optical pumping.

In 1968 Zh. I. Alferov and his associates were successful in developing heterolasers -- semiconductor lasers based on heterojunctions [11]. This made it possible to achieve so much higher radiative characteristics at room temperature that heterolasers have now forced out former versions from the sphere of practical applications of uncooled semiconductor lasers [12].

The development of semiconductor heterojunctions and devices based on them was awarded the Lenin Prize in 1972 (Zh. I. Alferov, V. M. Andreyev, D. Z. Garbuzov, V. I. Korol'kov, D. N. Tret'yakov and V. I. Shveykin).

The number of semiconductor materials successfully tested in lasers now exceeded 40 -- these are most semiconductors for which methods of controlled manufacture of perfect crystals have been developed. In order to bring the characteristics of lasers to a level suitable for practical applications, rather high requirements must be fulfilled. In addition to the conditions of purity and monocrystalline nature usual for semiconductor materials, laser technology requires high internal quantum yield of emission and optical homogeneity. As a result, only some of the semiconductor lasers, among which gallium arsenide lasers operating at wavelengths of 0.85-0.91 micron dominate, have been brought up to industrial production.

Nevertheless, practical applications of semiconductor lasers were hardly unique in themselves among the numerous designations of quantum electronics devices. They rely on the following advantages of semiconductor lasers, important from the practical viewpoint:

1. Economy provided by high efficiency of converting the delivered energy to coherent emission energy.

2. Low inertia caused by short characteristic times of establishing the generation mode (10^{-10} to 10^{-9} s); the bandwidth of direct radiation modulation (through the pumping circuit) reaches 10^{10} Hz.

3. Compactness determined by the property of semiconductors to develop enormous optical amplification and, therefore, not to require a long length of the active medium to maintain the generation mode; with respect to injection lasers one can talk about miniaturization and even of microminiaturization.

4. Simplicity of the device provided by a number of factors: the absence of precision optics, rigid installation, the possibility of low-voltage power supply and compatibility with the integrated circuits of semiconductor electronics (these properties are inherent to injection lasers).

5. Readjustability of the generation wavelength, determined by the dependence of the optical characteristics of the semiconductor on such physical values as temperature, pressure and magnetic field intensity. Along with a wide selection of suitable materials, this capability of retuning of a semiconductor laser permits continuous overlapping of the spectral range from 0.32 to 32 microns.

A summary of semiconductor lasers based various materials with different pumping methods is presented in Table 1; one or several typical papers for each type of lasers are indicated in it.

Table 1. Types of Semiconductor Lasers

1) Вещество	2) Диапазон длин волн, мкм	3) Работы, в которых исследовались различные виды накачки: оптическая 4)	электронная 5)	инжекционная 6)	пробойная
$A^{II}B^{VI}$					
ZnS	0,32—0,33	[25]	[26, 27]		
ZnO	0,37—0,38	[28]	[29—31]		
ZnSe	0,46		[32]		
ZnTe	0,53		[33, 34]		
CdS	0,49—0,52	[35, 36]	[9, 37—39]	[40 *)]	[41, 42]
CdSe	0,69	[43, 44]	[37, 46]		
CdTe	0,78—0,79		[47]		
$Zn_xCd_{1-x}S$	0,33—0,49	[48]			
$Cd_{1-x}Hg_xS$	0,50—4,10	[49]			
$Cd_xPb_{1-x}S$ **)	2,5—4,3			[50]	
CdS_xSe_{1-x}	0,50—0,69	[51, 52]	[53]		
$A^{III}B^{V}$					
GaN	0,36	[55 *)]			
GaAs	0,82—0,92	[56 *), 10]	[57—59]	[8 *), 3, 4, 6, 7]	[60, 61] [65]
InP	0,89—0,91	[62]		[63, 64]	
GaSb	1,55—1,60	[66]	[67]	[68, 54]	
InAs	3,0—3,2	[69]	[70]	[71]	
InSb	4,8—5,3	[72]	[70, 74]	[45, 75]	
$Ga_xIn_{1-x}P$	0,56—0,9	[76]		[77, 73]	
$Al_xGa_{1-x}As$	0,62—0,9		[78]	[79—81]	
GaP_xAs_{1-x}	0,63—0,9		[83]	[5, 84, 85]	
$In_xGa_{1-x}As$	0,85—3,20	[87]		[88, 89]	
$InAs_xP_{1-x}$	0,9—3,2			[90, 91]	
$Al_xGa_{1-x}Sb$	1,1—1,6			[92]	
$GaAs_{1-x}Sb_x$	0,85—1,60			[93]	
$InAs_{1-x}Sb_x$	3,1—5,3			[95]	
$Al_xGa_{1-x}As_{1-y}P_y$	0,62—0,90			[94]	
$Al_xGa_{1-x}Sb_yAs_{1-y}$	0,62—1,60			[86]	
$Ga_xIn_{1-x}As_yP_{1-y}$	0,6—3,0			[86]	
A^{VI}					
Te	3,7		[96]		

(Continued)

1)	2)	4)	5)	6)	7)
$A^{IV}B^{VI}$					
PbS	4,3		[97]	[98]	
PbSe	8,5		[97]	[99]	
PbTe	6,5		[97]	[100]	
PbS_xSe_{1-x}	4,3—8,5	[101]	[102]	[103]	
$Pb_{1-x}Sn_xSe$	8—32		[82]	[104]	
$Pb_{1-x}Sn_xTe$	6,5—32	[105]	[82]	[104]	
$Pb_{1-x}Ge_xTe$	4,4—6,5			[106]	
$A^{III}B^{VI}$					
GaSe	0,59—0,60	[107]	[108]		
InSe	0,97		[109]		
$A_2^{III}B^{VI}$					
In_2Se	1,6		[110]		
$A_3^{II}B_2^{V}$					
Cd_3P_2	2,12	[111 *)] [112]			
$A^{II}B^{IV}C_2^{V}$					
$CdSiAs_2$	0,77		[113]		
$CdSnP_2$	1,01		[114]		
$A^{I}B^{III}C_2^{VI}$					
$AgGaS_2$	0,462	[115 *)]			
$CuGaS_2$	0,50	[115 *)]			
$AgGaSe_2$	0,698	[115 *)]			
$CuInS_2$	0,817	[115 *)]			

*) Наблюдались признаки вынужденного излучения.
**) Смешанный полупроводник типа $A^{II}B^{VI}$—$A^{IV}B^{VI}$.

*Features of stimulated emission were observed.
**Mixed semiconductor of type $A^{II}B^{VI}$–$A^{IV}B^{VI}$.

Key:

1. Material
2. Range of wavelengths, microns
3. Papers in which various types of pumping were investigated
4. optical
5. electron
6. injection
7. breakdown

The main scientific problems which arise with regard to development and investigation of semiconductor lasers are presented and discussed in this book. Some additional data can be found in the survey articles and monographs [13-21]. We recommend references [22-24] for familiarization with the more general problems of semiconductor physics and quantum electronics, related to semiconductor lasers.

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END