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Modulation of dielectric permittivity of photorefractive GaAs semiconductor during holographic grating recording

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The peculiarities of dielectric permittivity modulation of photorefractive GaAs crystal at recording of phase holographic grating as a result of coherent mixing of two light waves are analyzed. In the crystallographic coordinate system, a surface showing the dependence of the maximum values of the normal component of the change of the inverse tensor components of the dielectric permittivity of the crystal on the spatial orientation of the wave vector of the hologram has been constructed. Theoretical calculations take into account linear electro-optical, photoelastic and inverse piezoelectric effects. It was found that the largest values of the normal component of the change of the inverse tensor components of the dielectric permittivity of the GaAs crystal are achieved if the wave vector of the hologram lies in one of the $\{110\}$ planes and is at an angular distance of about 4° from the $\langle 110 \rangle$ axis lying in the plane. The refractive index modulation value, close to the largest value, can be achieved when the hologram wave vector is oriented along the $\langle 110 \rangle$ direction.

Keywords: photorefractive semiconductor, holographic grating, dielectric permittivity, two-wave mixing.

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1. Introduction

Photorefractive semiconductor crystals of symmetry class $\bar{4}3m$(GaAs, InP, CdTe) are promising photosensitive media for recording volumetric holographic gratings (hereinafter referred to as gratings), since they have a relatively short photorefractive response time and allow the possibility of transition to infrared spectrum range [1]. The field of practical use of photorefractive semiconductors includes such technical applications as optical systems for processing and transmitting information, devices for generating optical radiation and wavefront reversal.

Photorefractive GaAs crystals are of great interest in the creation of optical devices, which are subject to increased requirements for speed and photosensitivity. In the pioneer paper [2] it was shown that at a comparable gain of the signal wave in GaAs and $Bi_{12}SiO_{20}$ crystals, the duration of the photorefractive response for the semiconductor is $20\,\mu$s. For example, the typical photorefractive response time of $Bi_{12}SiO_{20}$ crystal upon mixing of light waves with intensity densities $100\,\mu\mathrm{Wcm}^{-2}$ and $12.5\,\mathrm{mWcm}^{-2}$ at a wavelength of 514 nm is 200 ms [3]. In [4] the possibility of achieving a relatively high gain of the signal wave ($6-7\,\mathrm{cm}^{-1}$) was demonstrated with two-wave mixing in transmission geometry on moving gratings formed in a GaAs : Cr crystal when external electric field is applied to it. The use of an undoped GaAs crystal can lead to a decrease in the signal wave gain to $4.5\,\mathrm{cm}^{-1}$ [5]. The results of studying cross-polarization coupling during contra-directional mixing of light beams in GaAs crystal are presented in [6]. This paper examines the physical mechanism of cross-polarization coupling in photorefractive crystals of the symmetry class $\bar{4}3m$. The gratings formed during two-wave mixing in GaAs crystal can have a phase-amplitude structure [7]. The additional diffraction contribution of the amplitude grating leads to change in the orientation dependence of the signal wave gain.

In recent years, while studying the features of diffraction and mixing of light waves on phase gratings in GaAs crystal, a number of interesting results was obtained [8–12]. In [8,9] the possibility of increasing the gain of the object wave and the diffraction efficiency of the hologram due to the simultaneous application of external constant electric and magnetic fields to the GaAs : Cr crystal is considered. These papers analyze cases when the magnetic field strength vector is simultaneously perpendicular to the electric field strength vector and the wave vector of the hologram. It is shown [8] that under such conditions the gain can reach $18\,\mathrm{cm}^{-1}$, which by more than two times exceeds the value of this gain obtained in [4]. During object wave retrieval as a result of diffraction of reference wave on a transmission grating formed in GaAs : Cr crystal, the achieved diffraction efficiency was 90% [9]. The analysis of the features of the light waves mixing on holographic gratings formed under the influence of moving interference pattern in GaAs/AlGaAs crystal with quantum wells is presented in [10,11]. In these papers several models of nonlinear electron transfer in GaAs crystal are considered and the correctness of their use in determining the electric field strength of spatially separated charges of a photorefractive semiconductor is assessed. In [12] a double demodulation interferometer was proposed and experimentally tested, in it a two-wave mixing scheme in GaAs crystal is used. It was demonstrated that the proposed interferometer design, due to the ability to select different demodulation modes, can be successfully used to detect mechanical vibration when monitoring the state of structure in production.

The values of the object wave gain and diffraction efficiency are largely determined by the modulation amplitude of the refraction index of the photorefractive crystal, which depends on the orientation of the grating wave vector in the crystallographic coordinate system [13]. In most of the papers known to us (see, for example, [7,13–18]), when studying diffraction and coherent mixing of waves on refraction index gratings the cases are considered when its wave vector either lies in the cut plane (100), (110), (111), or perpendicular to them. To date, the following question practically was not discussed: at what orientation of the wave vector relative to the crystallographic coordinate system the amplitude of modulation of the refractive index of the phase grating in GaAs crystal will reach its greatest value. Solving this problem will make it possible to understand more clearly: under what conditions of holographic experiment the maximum efficiency of diffraction of light waves will be achieved. From a practical point of view, this opens up the possibility of increasing the output energy characteristics of phase holograms.

The purpose of this paper is to study the dependence of the change in the maximum values of the normal component of the elements of the inverse dielectric permittivity tensor of photorefractive GaAs crystal on the direction of the grating wave vector in the crystallographic coordinate system. The directions of the grating wave vector will be found for which the amplitude of the refraction index modulation of the GaAs crystal occurred under the influence of the induced interference pattern during two-wave mixing, takes on extremely large values. When calculating the normal component, linear electro-optical, photoelastic and inverse piezoelectric effects are taken into account.

2. Methodological part

Let us consider a photorefractive semiconductor GaAs in which a sinusoidal phase grating is written with wave vector **K** arbitrarily oriented in the crystallographic coordinate system. During the coherent mixing of the reference and object light waves on the phase grating, their polarization and energy characteristics change. Equations for finding the amplitudes of mixing light waves were first obtained by Kogelnik [19] and can be presented in the form [1]:

$$\frac{dR(z)}{dz} = i\,\frac{\pi n_0^3}{2\lambda\cos\varphi_R}\,(\mathbf{e}_R^*\Delta\hat{b}\mathbf{e}_S)S(z), \tag{1}$$

$$\frac{dS(z)}{dz} = i\,\frac{\pi n_0^3}{2\lambda\cos\varphi_S}\,(\mathbf{e}_S^*\Delta\hat{b}\mathbf{e}_R)R(z), \tag{2}$$

where R and S — modules of vector amplitudes **R** and **S**; z — value of coordinate along the axis parallel to the normal to the working facet of the crystal; $\mathbf{e}_R$ and $\mathbf{e}_S$ — normalized polarization vectors of the reference and object light waves; $\Delta\hat{b}$ — change in the inverse tensor of the dielectric permittivity of the crystal; n_0 — refraction index of unperturbed crystal; λ — wavelength of light; φ_R and φ_S — angles between the wave vectors of light waves and the normal to the working facet of the crystal; i — imaginary unit. In equations (1) and (2) the factor $\pi n_0^3/(2\lambda\cos\varphi_{R,S})$ is the coupling constant, and tensor convolutions $(\mathbf{e}_{R,S}^*\Delta\hat{b}\mathbf{e}_{S,R})$ are used to set the amplitude of refraction index modulation of the phase grating in the photorefractive crystal.

In order to simplify further theoretical analysis, we use the following approximations.

1. Let us consider the simplest case when the reference and object waves have linear polarizations. In connection with this, we will assume that the following equalities will be valid for the equations of coupled wave (1) and (2): $\mathbf{e}_R^* = \mathbf{e}_R$ and $\mathbf{e}_S^* = \mathbf{e}_S$.

2. We will assume that the vector amplitudes of light waves as they propagate inside the crystal remain parallel to each other. As a result of fulfilling such polarization condition, the depth of modulation of the recording interference pattern during two-wave mixing is optimal [20], and, as a consequence, the intensity of the object wave at the output of the crystal can reach maximum values [21]. Therefore, in tensor convolutions we can assume that $\mathbf{e}_R = \mathbf{e}_S = \mathbf{e}$, where **e** — a unit vector that is used to specify the direction of the vector amplitudes of light waves.

3. The change in the inverse dielectric permittivity tensor $\Delta\hat{b}$ of the crystal used in the coupled wave equations (1) and (2) is symmetrical. Then, taking into account the first two approximations, we can assume that $(\mathbf{e}_R\Delta\hat{b}\mathbf{e}_S) = (\mathbf{e}_S\Delta\hat{b}\mathbf{e}_R) = (\mathbf{e}\Delta\hat{b}\mathbf{e})$.

We write the expression for finding the normal component of the change in the elements of the inverse tensor of the dielectric permittivity of the crystal in the form

$$\chi(\mathbf{e}) = \mathbf{e}\Delta\hat{b}\mathbf{e} = \Delta b_{mn}e_m e_n, \tag{3}$$

where χ — the normal component of the change in the elements of the inverse dielectric permittivity tensor in the direction of the vector **e**.

To find the components Δb_{mn} of the inverse dielectric permittivity tensor of the crystal, we will use the well-known expressions presented in [22]:

$$b_{11} = p_1 n_1 R_1 + p_2 n_2 R_2 + p_3 n_3 R_3,$$

$$b_{22} = p_1 n_2 R_2 + p_2 n_3 R_3 + p_3 n_1 R_1,$$

$$b_{33} = p_1 n_3 R_3 + p_2 n_1 R_1 + p_3 n_2 R_2,$$

$$b_{12} = b_{21} = p_4(n_1 R_2 + n_2 R_1) + r_{41} n_3,$$

$$b_{13} = b_{31} = p_4(n_1 R_3 + n_3 R_1) + r_{41} n_2,$$

$$b_{23} = b_{32} = p_4(n_2 R_3 + n_3 R_2) + r_{41} n_1,$$

$$R_1 = \gamma_{11}Q_1 + \gamma_{12}Q_2 + \gamma_{13}Q_3,\ \ R_2 = \gamma_{21}Q_1 + \gamma_{22}Q_2 + \gamma_{23}Q_3,$$

$$R_3 = \gamma_{31}Q_1 + \gamma_{32}Q_2 + \gamma_{33}Q_3,\ \gamma_{11} = (\Gamma_{22}\Gamma_{33} - \Gamma_{23}^2)/D,$$

$$\gamma_{22} = (\Gamma_{11}\Gamma_{33} - \Gamma_{13}^2)/D, \ \gamma_{33} = (\Gamma_{11}\Gamma_{22} - \Gamma_{12}^2)/D,$$

$$\gamma_{12} = \gamma_{21} = (\Gamma_{13}\Gamma_{23} - \Gamma_{12}\Gamma_{33})/D,$$

$$\gamma_{13} = \gamma_{31} = (\Gamma_{12}\Gamma_{23} - \Gamma_{13}\Gamma_{22})/D,$$

$$\gamma_{23} = \gamma_{32} = (\Gamma_{12}\Gamma_{13} - \Gamma_{11}\Gamma_{23})/D,$$

$$D = \Gamma_{11}(\Gamma_{22}\Gamma_{33} - \Gamma_{23}^2) - \Gamma_{22}\Gamma_{13}^2 - \Gamma_{33}\Gamma_{12}^2 + 2\Gamma_{12}\Gamma_{13}\Gamma_{23},$$

$$\Gamma_{11} = c_1 n_1^2 + c_3(n_2^2 + n_3^2), \ \Gamma_{22} = c_1 n_2^2 + c_3(n_1^2 + n_3^2),$$

$$\Gamma_{33} = c_1 n_3^2 + c_3(n_1^2 + n_2^2), \ \Gamma_{12} = \Gamma_{21} = n_1 n_2(c_2 + c_3),$$

$$\Gamma_{13} = \Gamma_{31} = n_1 n_3(c_2 + c_3), \ \Gamma_{23} = \Gamma_{32} = n_2 n_3(c_2 + c_3),$$

$$Q_1 = 2e_{14}n_2n_3, \ Q_2 = 2e_{14}n_1n_3, \ Q_3 = 2e_{14}n_1n_2.$$

Here the following notations are adopted for the nonzero components of the tensors of the linear electrooptical ($\hat{r}^S$) and inverse piezoelectric ($\hat{e}$) effects, as well as the components of the tensors of elasticity ($\hat{c}^E$) and photoelasticity ($\hat{p}^E$):

$$r^S_{123} = r^S_{132} = r^S_{213} = r^S_{231} = r^S_{312} = r^S_{321} \equiv r_{41},$$

$$e_{123} = e_{132} = e_{213} = e_{231} = e_{312} = e_{321} \equiv e_{14},$$

$$c^E_{11} = c^E_{22} = c^E_{33} \equiv c_1,$$

$$c^E_{12} = c^E_{13} = c^E_{23} = c^E_{21} = c^E_{31} = c^E_{32} \equiv c_2,$$

$$c^E_{44} = c^E_{55} = c^E_{66} \equiv c_3, \ p^E_{11} = p^E_{22} = p^E_{33} \equiv p_1,$$

$$p^E_{12} = p^E_{23} = p^E_{31} \equiv p_2, \ p^E_{13} = p^E_{21} = p^E_{32} \equiv p_3,$$

$$p^E_{44} = p^E_{55} = p^E_{66} \equiv p_4.$$

The index S for the component of tensor of linear electrooptic effect means that they were measured for the clamped crystal; for components of tensors of the elasticity and photoelasticity the index E means that they were measured at a constant electric field. The elastic and photoelastic properties of crystals are described by tensors of the fourth rank (c^E_{ijkl} and p^E_{ijkl}), but in the given expressions the components of these tensors have two indices, since they are written using abbreviated matrix notation [23]. Parameters n_1, n_2, n_3 are the guides of the unit vector **n** in the crystallographic coordinate system, which is parallel to the vector **K**. In the given expressions, the tensor $\hat{\gamma}$ is inverse of the tensor $\hat{\Gamma}$ with components: $\Gamma_{ik} = c^E_{ijkl}n_jn_l$, where c^E_{ijkl} — components of the elasticity tensor.

When solving the equations of coupled waves (1) and (2), we used GaAs crystal parameters taken from [7,24] for $\lambda = 1.064\,\mu$m, which corresponds to wavelength of the radiation of solid-state Nd:YAG laser: refraction index of unperturbed crystal $n_0 = 3.48$ [7]; electrooptical coefficient $r_{41} = -1.43 \cdot 10^{-12}$ m/V [7]; elasticity coefficients $c_1 = 11.88 \cdot 10^{10}\,\text{N/m}^2$, $c_2 = 5.38 \cdot 10^{10}\,\text{N/m}^2$, $c_3 = 5.94 \cdot 10^{10}\,\text{N/m}^2$ [7]; photoelasticity coefficients $p_1 = -0.165$, $p_2 = p_3 = -0.14$, $p_4 = -0.072$ [24]; piezoelectric coefficient $e_{14} = 0.154\,\text{C/m}^2$ [7].

The following methodology is used for calculations. In the crystallographic coordinate system the direction of the vector **K** is fixed, and taking into account the given analytical expressions the components of the inverse dielectric permittivity tensor of GaAs crystal are calculated. Based on expression (3), the normal components χ for various directions of the vector **e** are found, and the maximum value $\chi^{\max}$ is determined, which is assigned to the vector **K**. Next, the procedure is repeated for other directions of the vector **K**, resulting in the formation of an array of numerical values $\chi^{\max}$, each of which corresponds to specifically oriented vector **K**. Based on the data obtained, a surface is then constructed, it displays the dependence $\chi^{\max}(\mathbf{K})$.

Depending on the direction of the vector **K** the normal component χ can take both positive and negative values. A positive value χ means that under the influence of linear electrooptical, photoelastic and inverse piezoelectric effects the amplitude value n of the refraction index of the phase grating will exceed the refraction index of the unperturbed crystal n_0: $n = n_0 + \Delta n$, where Δn — amplitude of the phase grating. In the opposite case, with negative value of the normal component χ the equality $n = n_0 - \Delta n$ is satisfied, i.e., the amplitude value n of the phase array is less than n_0. The difference in the signs before Δn is significant, since it determines the direction of energy exchange during two-wave mixing on the phase grating. The equality to zero of the normal component χ means that for the given direction of the vector **K** in GaAs crystal, as a result of the interference of light waves, the phase grating is not formed.

Since the normal component χ can take both positive and negative values, its maximum values $\chi^{\max}$, accordingly, can also have different signs. In this case, to construct the surface $\chi^{\max}(\mathbf{K})$ you should use two independent spatial shapes corresponding to the values $\chi^{\max}$ with different signs. The method for constructing such surfaces is as follows. In all possible directions of the vector **K** exiting from the origin of the crystallographic coordinate system the segments equal in length to the corresponding numerical value $\chi^{\max}$ are plotted. The following rule is used: if the parameter $\chi^{\max}$ has a positive sign, then the corresponding surface point is painted in light gray color, and if $\chi^{\max}$ has a negative value — in dark gray color (Figure 1). When the ends of these segments are connected together, two surfaces are formed, painted in different colors. As a result of the superposition of these figures in the crystallographic coordinate system a surface is formed that can be used to display the dependence $\chi^{\max}(\mathbf{K})$. Some parts of the surfaces of light and dark gray shapes will be in the geometric shadow of each other, therefore, to study them the shapes should be considered separately, as well as sections of the surface $\chi^{\max}(\mathbf{K})$ with planes oriented in a certain way shall be analyzed.

3. Results and discussion

Figure 1 shows a surface in the crystallographic coordinate system, the surface illustrates the dependence $\chi^{\max}(\mathbf{K})$ and is calculated for GaAs crystal based on formula (3).

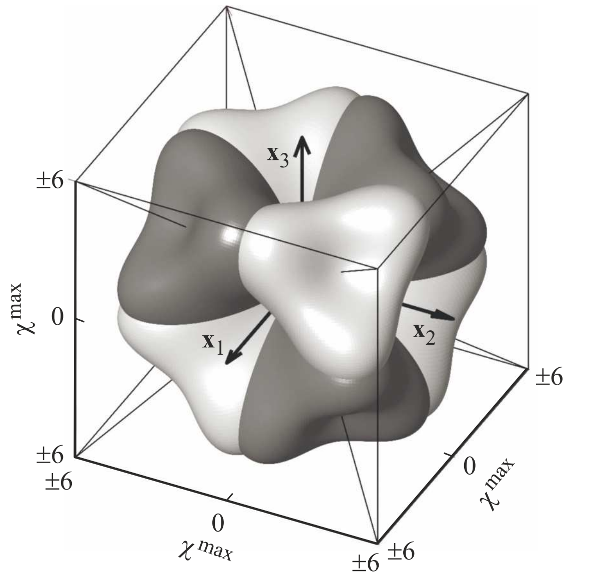

Figure 1. Dependence χ^{max} on direction of grating vector $\mathbf{K}$ in the crystallographic coordinate system.

Vectors $(\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3)$ form orthogonal basis and coincide in direction with [100], [010] and [001] axes, respectively. The cube visible in Figure 1 is an additional construction, the edges of which are parallel to the vectors $(\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3)$ and are used to set the parameter change interval χ^{max}. When considering the light gray part of the surface $\chi^{max}(\mathbf{K})$, it should be taken into account that the numbers plotted along the coordinate axes correspond to positive values of the parameter χ^{max}, since the refraction index of the crystal increases in these directions. For the dark gray part of the surface $\chi^{max}(\mathbf{K})$ the numbers plotted along the edges will correspond to negative values of the parameter χ^{max}, since in this case the amplitude value of the grating of refraction index will be smaller n_0.

As can be seen from Figure 1, the surface $\chi^{max}(\mathbf{K})$ is a complex figure, which consists of eight symmetrically located areas, equal to each other and painted in light and dark gray colors. If we do not take into account the color of the shape, then the elements of external symmetry of the surface in accordance with the Neumann principle [23] include elements of the point group of the crystal of symmetry class $\bar{4}3m$: directions $\langle 100 \rangle$ correspond to three rotation axes of the fourth order, and the directions $\langle 111 \rangle$, which in Figure 1 coincide with the diagonals of the cube, correspond to four rotation axes of the third order. If the shape in Figure 1 is considered taking into account the color, then we can say that the symmetry class of the surface $\chi^{max}(\mathbf{K})$ is reduced and corresponds to the point group 23, since in this case the directions $\langle 100 \rangle$ correspond to the rotation axes of second order. The change in the symmetry of the shape can be explained by the Curie superposition principle [23], according to which the properties of the crystal subjected to external influence are determined.

When considering the surface $\chi^{max}(\mathbf{K})$, one can first see that the highest values of the normal component will be achieved for such orientations of the vector $\mathbf{K}$ when they will be deviated by a small angular distance from the directions $\langle 110 \rangle$. The minimum values χ^{max} will correspond to directions in the vicinity of the axes $\langle 100 \rangle$.

The light and dark gray shapes, which combination form the surface $\chi^{max}(\mathbf{K})$, individually represent surfaces similar to each other, which consist of four symmetrically located tetrahedron-like convexities. Each of the shapes includes elements of point group 23: the directions $\langle 100 \rangle$ correspond to three rotation axes of the second order, and the directions $\langle 111 \rangle$ — to four rotation axes of the third order. Shapes can coincide to each other by their rotation about the axes $\langle 100 \rangle$ on 90°. It is important to note that the values of the parameter χ^{max} along the directions $\langle 111 \rangle$ for light and dark gray shapes are significantly different. For example, if along the [111] direction the parameter χ^{max} for light gray shape takes a value that is comparable to the largest, then for dark gray shape the parameter χ^{max} will be approximately equal to zero.

The largest (extreme) value of the normal component χ^{extr} for crystal with GaAs parameters cannot be achieved when the vector $\mathbf{K}$ is oriented along the known directions $\langle 100 \rangle$, $\langle 110 \rangle$ and $\langle 111 \rangle$ — there are vector directions different from those indicated $\mathbf{K}$ (hereinafter — extreme directions $\mathbf{K}^{extr}$), along which χ^{max} reaches its extreme value ($\chi^{max} = \chi^{extr}$). Due to the high symmetry of the surface $\chi^{max}(\mathbf{K})$, the extreme directions $\mathbf{K}^{extr}$ will also be symmetrically equivalent.

Let us consider a section of the surface $\chi^{max}(\mathbf{K})$ by plane parallel to (100) and passing through the origin of the coordinate system. Figure 2, *a* shows the relative position of the surface and the cutting plane. In Figure 2, *b* the dark solid line represents the section trace, and also shows the vectors $\mathbf{x}_2, \mathbf{x}_3$ and the direction [011]. The dashed circle is an additional construction and its radius corresponds to the largest value for the given section $\chi^{max} = 6.75$.

The dashed circle touches the surface $\chi^{max}(\mathbf{K})$ in the cutting plane along the directions $\langle 110 \rangle$. Thus, if the vector $\mathbf{K}$ lies in one of the planes of type $\{100\}$, then the greatest value χ^{max} can be achieved when it is directed along direction $\langle 110 \rangle$ lying in this plane. From a practical point of view, this suggests that when writing the transmission grating in GaAs crystal with (100) cut, the maximum diffraction efficiency can be achieved at an orientation angle for which the condition is satisfied: $\mathbf{K} \parallel \langle 110 \rangle$. The smallest value χ^{max} in the cut plane, equal to 0.43, is achieved when the vector $\mathbf{K}$ is oriented along the directions $\langle 100 \rangle$. For other orientations of the vector $\mathbf{K}$ in the section plane, the value χ^{max}varies from 0.43 to 6.75.

Note that in Figure 2, *b* the traces of contact of the cut plane with the light and dark gray shapes coincide with each other, and therefore they are not highlighted in color, but are designated uniformly with dark solid line. In the general case, the traces of contact of the cut plane with these shapes do not coincide, and in the future we will

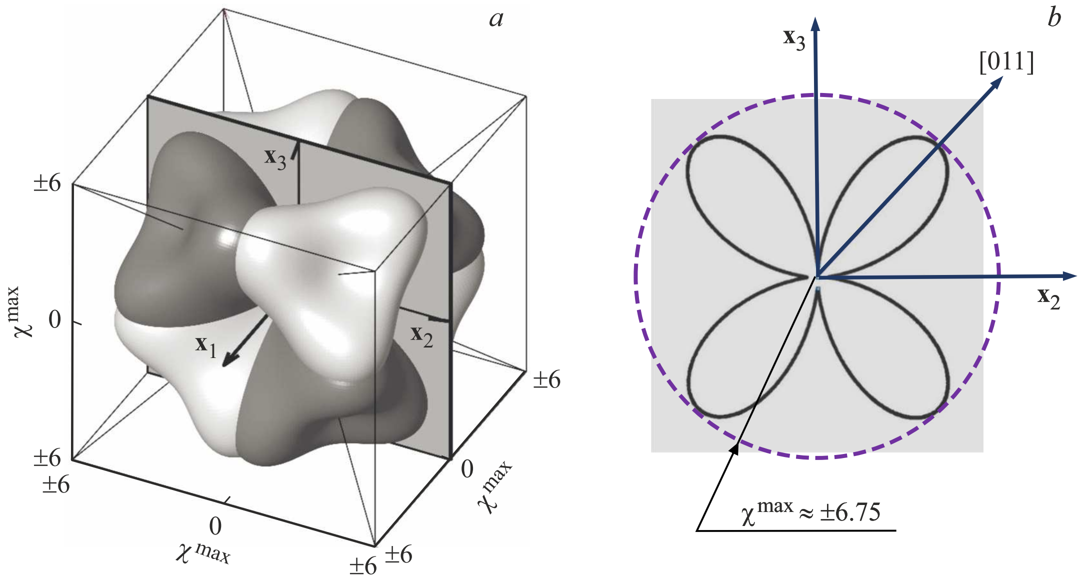

Figure 2. Section of the surface $\chi^{max}(\mathbf{K})$ by a plane parallel to (100) and passing through the origin of coordinates.

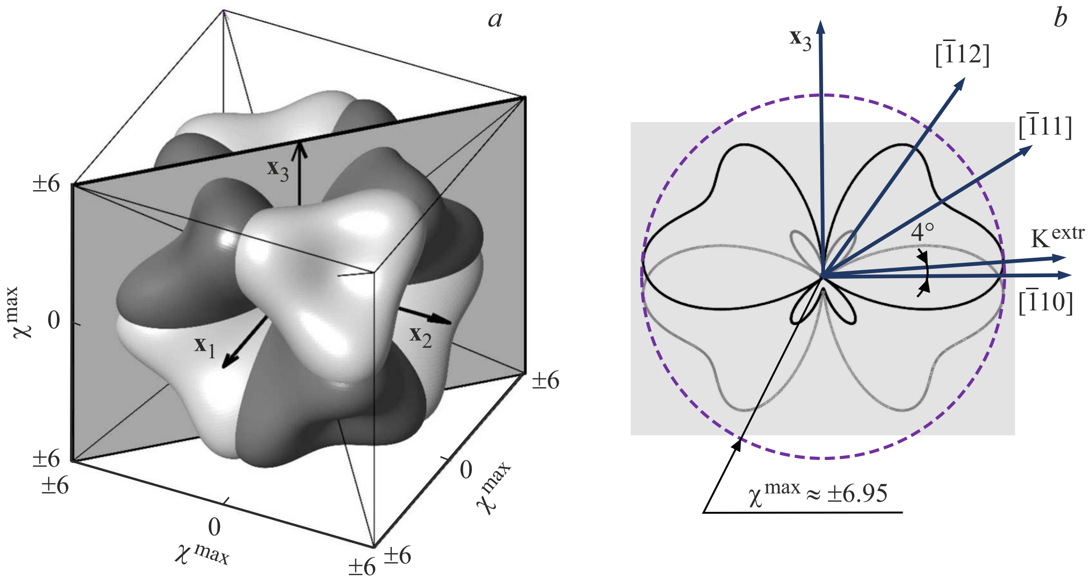

Figure 3. Section of the surface $\chi^{max}(\mathbf{K})$ by the plane parallel to (110) and passing through the origin of coordinates.

mark the sections of light and dark gray surfaces with gray and black lines, respectively.

Let us analyze the section of the surface $\chi^{max}(\mathbf{K})$ by the plane parallel to (110) and passing through the origin of coordinates (see Figure 3). The radius of the dashed circle is $\chi^{max} = 6.95$. The sections of the light and dark gray shapes are symmetrical curves and can be aligned with themselves by rotating by 180° about x_3 axis, and by similar rotation relative to direction $[\bar{1}10]$.

The points of tangent of the dashed circle with the surface section $\chi^{max}(\mathbf{K})$ in Figure 3 correspond to such orientations of the vector $\mathbf{K}$ at which in the section plane it forms angle 4° with the directions $[\bar{1}10]$ and $[1\bar{1}0]$. Since in this case the radius of the circle is equal to the extreme value χ^{extr}, we can say that such directions are extreme, for which the equality $\chi^{max} = \chi^{extr} = 6.95$ is satisfied. For clarity, in Figure 3, *b* one of the extreme directions is marked with the vector $\mathbf{K}^{extr}$. Taking into account the symmetry of the surface $\chi^{max}(\mathbf{K})$, we can state that when the vector is oriented $\mathbf{K}$ along any direction lying in the planes $\{110\}$, which makes an angle 4° with directions like $\langle 110 \rangle$ the parameter χ^{max} will reach its extreme value χ^{extr}.

Among the directions $\langle 100 \rangle$, $\langle 110 \rangle$, $\langle 111 \rangle$, $\langle 112 \rangle$ the value χ^{max}, closest to χ^{extr}, can be achieved at $\mathbf{K} \parallel \langle 110 \rangle$. In this case, the value $\chi^{max} = 6.74$ and is 97% of χ^{extr}. Along the directions $\langle 112 \rangle$ the value χ^{max} in the section

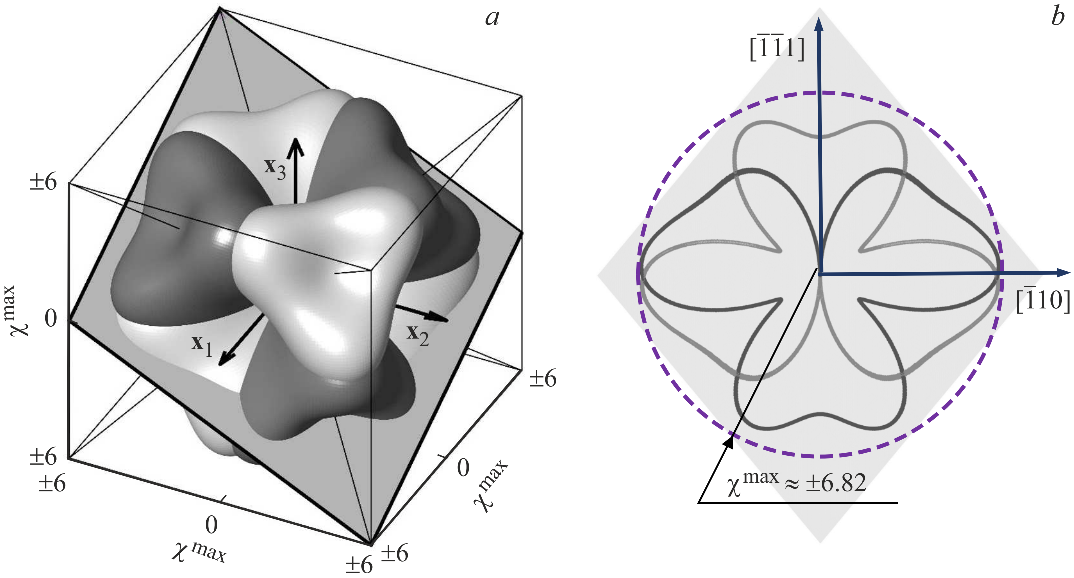

Figure 4. Section of the surface $\chi^{max}(\mathbf{K})$ by the plane parallel to (112) and passing through the origin of coordinates.

plane is approximately 6.07, which is 88% of χ^{extr}. Note that for the light and dark gray shapes the values χ^{max} along the directions $\langle 112 \rangle$ are noticeably different. For example, along the direction [$\bar{1}12$] χ^{max} reaches 6.07 for dark gray shape and 2.1 — for light gray one, and in the direction [$11\bar{2}$] the situation is reversed. For the direction [$\bar{1}11$] the achieved value χ^{max} is 5.36, which is by 25% lower than χ^{extr}. In the section plane along directions of the type $\langle 100 \rangle$ and $\langle 110 \rangle$ values of χ^{max} due to the symmetry of the surface $\chi^{max}(\mathbf{K})$ reach the same values as in Figure 2.

Figure 4 shows section of the surface $\chi^{max}(\mathbf{K})$ by the plane parallel to (112) and passing through the origin of coordinates. Interest in studying such section is due to the fact that in the literature analyzes cases when either the wave vector $\mathbf{K}$ is directed along [112] direction, or the working facet of the crystal is cut parallel to (112) plane. For example, in the paper [25] the dependence of the two-wave gain for non-unidirectional energy exchange by reflection hologram on the angle of rotation of polarization of the signal wave is analyzed for the case when the wave vector $\mathbf{K}$ is directed along the direction [$11\bar{2}$]. In the paper [17], when studying the orientation dependence of the signal wave gain and the diffraction efficiency of the transmission hologram during a codirectional two-wave mixing in cubic crystal of cut (111), the case is analyzed when, upon rotation in the cut plane, the wave vector $\mathbf{K}$ is oriented along the direction [$\bar{1}12$].

Planes of the type $\{112\}$ do not contain extreme directions since the largest value χ^{max} in the section plane is 6.82, which is less than the extreme value $\chi^{extr} = 6.95$. The dashed circle touches the section of the surface $\chi^{max}(\mathbf{K})$ for such vector orientations $\mathbf{K}$ at which they form small angles ($\sim 2^\circ$) with the directions [$\bar{1}10$] and [$1\bar{1}0$]. Since along the directions $\langle 110 \rangle$ the parameter χ^{max} takes value of 6.74, it can be stated that when using GaAs crystal to record phase hologram, the value close to the maximum value of modulation refraction index in (112) plane is achieved when the vector $\mathbf{K}$ coincides or makes a small angle with the directions $\langle 110 \rangle$. Along the direction [$\bar{1}\bar{1}1$] the achieved value χ^{max} is 5.36, which corresponds to the data in Figure 3.

4. Conclusion

Increasing the signal wave gain and the diffraction efficiency of hologram during two-wave coherent mixing in the photorefractive crystal is a complex task that requires joint consideration of a number of factors. The amplitude control of phase holographic grating by choosing the optimal orientation of the wave vector of the hologram in the crystallographic coordinate system is one of the main ways by which it is possible to increase the diffraction efficiency of light waves.

The paper shows that extremely large values of the modulation amplitude of the refraction index of photorefractive GaAs crystal when recording phase hologram can be achieved if the wave vector of the grating lies in one of the planes of type $\{110\}$ and makes an angle 4° with direction of type $\langle 110 \rangle$ lying in this plane. The modulation refraction index value close in magnitude to the extreme value can be achieved when the grating wave vector is oriented along the directions $\langle 110 \rangle$. In this case, the amplitude of the phase hologram can reach 97% of the extreme value. When the grating vector is oriented along the directions $\langle 112 \rangle$ and $\langle 111 \rangle$, the maximum achievable amplitude of the phase hologram will be less by approximately 12 and 25%, respectively. The minimum modulation of the refraction index amplitude among the cases considered will be achieved when the grating vector is oriented along the directions ⟨100⟩. When calculating the inverse dielectric permittivity tensor of GaAs crystal the linear electrooptical, photoelastic and inverse piezoelectric effects were taken into account.

The results obtained can be used to select the optimal orientation of the crystalline sample when conducting experiments on holographic recording in the photorefractive GaAs crystal. Also, the data obtained can be useful for improving the efficiency of use of holographic interferometry devices, optical filtering and other applications that use gallium arsenide crystals.

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Conflict of interest

The author declares that he has no conflict of interest.

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