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ELECTROMAGNETIC WAVES AND PHOTOACOUSTIC TRANSFORMATION IN GYROTROPIC SUPERLATTICES

Contents.

Introduction.

Over the last decade a great number of experimental and theoretical works were dedicated to the study of layered-periodic crystal structures - superlattices (see, for instance, the reviews [1, 2] and references at the same place). Superlattices (SL) do not only combine useful properties of crystal layers-components of SL, but allow for the existence phenomena radically impossible in SL constituent materials taken separately [3, 4].

SL properties are most simply described in the long wavelength approximation that corresponds to the important case of short-period SL when the lengths of various nature waves propagating in SL are significantly great compared to the period of structure [5]. In this case SL can be considered as uniform medium characterized by a set of effective parameters. Dielectric and magnetic permeability of SL formed by isotropic layers [6, 7], tensors of dielectric permeability [5] and optical activity at arbitrary crystallographic symmetry of the layers and other effective characteristics [8-10] are specified. However boundary electrodynamic problems for short-perid SL originated by absorbing gyrotropic crystals of various classes of symmetry, as for as we know, were not solved. Characteristic properties of transmission and absorption, possibilities of transformation of electromagnetic waves by such SL have not been investigated, that is important for the practical application of the indicated structures.

·From the other side, a number of experimental works [11-13] points to high efficiency of methods of photoacoustic (PA) spectroscopy at investigation of various types of SL. This is primarily due to the fact that strong optical absorption of semiconductor materials forming SL, the presence of opaque substrates and other factors [12, 13] substantially complicate the investigation of such structures by purely optical methods. Theory of the process of PA response formation in the quoted works is absent [11], or models known from photoacoustics of continuous media, which do not present in general case specifity of optical and thermal processes in SL [12, 13], are used. Besides, taking into account known advantages of PA measurements of optical activity parameters [14, 15], that is of interest to extend a field of application of PA spectroscopy having included in consideration the important case of SL formed by gyrotropic absorbing crystals.

Here the object is to investigate theoretically optical properties, PA transformation (one-dimensional geometry, gas-microphone method of registration) and possibilities of PA measurements in short-period SL originated by non-magnetic absorbing gyrotropic crystals of various classes of symmetry. Calculations have been made at arbitrary combination of effects of optical anisotropy, absorption, gyrotropy and multibeam optical interference in plane wave approximation.

1. Dissipative properties of short-period superlattices formed from cubic crystals

Theoretical model.

We assume a monochromatic elliptically polarized light incident on the SL normally to the layers boundaries at the plane $z = 0$ (in the SL region $0 \leq z \leq l$). The SL consisting of absorbing cubic crystals is characterized by the axially symmetric complex dielectric constant tensor ϵ_e and optical activity tensor γ_e [8]. The equal principal values of these tensors are:

$$(\epsilon_e)_{11} = (\epsilon_e)_{22} = x\epsilon_1 + (1-x)\epsilon_2,$$
$$(\gamma_e)_{11} = (\gamma_e)_{22} = x\gamma_1 + (1-x)\gamma_2, \qquad (1.1)$$

Here the period D of the SL consists of two layers with relative thicknesses $x = d_1/D$ and $1 - x = d_2/D$ $(d_1 + d_2 = D)$. The quantities with indexes "e, 1, 2" concern the effective medium, first and second component of the SL correspondingly. Circular dichroism is described by imaginary parts of the optical activity tensor components which will be designated γ_e'', γ_1'', γ_2'' [16].

Optical properties of the axially symmetric gyrotropic crystal in the direction of the optical axis are equivalent to the ones for the optically active isotropic medium with the complex parameters $\epsilon_e = (\epsilon_e)_{11}, \gamma_e = (\gamma_e)_{11}$ [17]. So the dissipation of the light energy in SL can be described by the familiar relations [18, 19], with taking into account Eqs. (1.1):

$$Q_e = Q_+ + Q_-, \tag{1.2}$$

$$Q_\pm = N_0 I_0 \alpha_\pm [N_+ T_\pm \exp(-\alpha_\pm z) + N_- T_\mp \exp(\alpha_\pm z - 2\beta l)],$$

where

$$N_0 = n_0' n_1^2/\zeta, \;\; N_\pm = | n_0 \pm n_2 |^2, \;\; T_\pm = (1 \pm \tau)^2/(1+\tau^2),$$

$$\beta = (4\pi/\lambda) n_0'', \;\; \alpha_\pm = (4\pi/\lambda)\; (n_0'' \pm \gamma_e''),$$

$$\zeta = \zeta_1 + [\zeta_2 \sin(\kappa l) + \zeta_3 \cos(\kappa l)] \exp(-\beta l) + \zeta_4 \exp(-2\beta l),$$

$$\kappa = (4\pi/\lambda) n_0', \;\; \zeta_1 = | n_0 + n_1 |^2 N_+, \;\; \zeta_2 = 4 n_0'' (n_1 + n_2)\; (| n_0 |^2 - n_1 n_2),$$

$$\zeta_3 = 8 n_1 n_2 n_0''^2 - 2(| n_0 |^2 - n_1^2)\; (| n_0 |^2 - n_2^2), \;\; \zeta_4 = | n_0 - n_1 |^2 \;\; N_-.$$

Here I_0 and τ are incident light intensity and ellipticity ($\tau \leq 0$ at left polarization), $n_0 = \epsilon_e^{1/2} = n_0' + i n_0''$ ($i^2 = -1$), and quantities with indexes "$\pm$" correspond to the left and right circular polarized waves superposition of which describes the field in the effective medium. We assume non-absorbing nongyrotropic media behind and in front of the SL to have real refractive indexes n_2 and n_1 correspondingly.

Eqs. (1.2) are rather complicated for the analysis. Even neglecting the SL components dichroism and reflected waves we obtain the equation of degree 5/2 from the one $dQ_e/dz = 0$. At $l \gg 1/\beta$ Eqs. (1.2) are simplified

$$Q_\pm \simeq N_0 I_0 \alpha_\pm N_+ T_\pm \exp(-\alpha_\pm z), \quad \zeta = \zeta_1 \tag{1.3}$$

that corresponds to the semi-infinite SL case.

It is seen from Eqs. (1.2) that described by the quantity ζ multibeam interference takes effect at $l \leq 1/\beta$. In this case at usual assumptions $(\epsilon_e')^{1/2}$, n_1, n_2, $(\epsilon_e')^{1/2} \pm n_1$, $(\epsilon_e')^{1/2} \pm n_2 \gg \epsilon_e''/2(\epsilon_e')^{1/2}$ Eqs.(2) give

$$\zeta = \zeta_+^2 + \zeta_-^2 - 2\zeta_+\zeta_- \exp(-\beta l)\cos(\kappa l), \tag{1.4}$$

where $\zeta_\pm = (a \pm n_1)\; (a \pm n_2)$, $a = (\epsilon_e')^{1/2}$. So the optical interference effect on the SL dissipation is characterized by the parameter $\cos(\kappa l)$, where $\kappa =$

$(4\pi/\lambda)\ [x\epsilon_1' + (1-x)\epsilon_2']^{1/2}$.

To compare the SL and its components dissipative properties we used the parameters: $\eta_j = Q_e/Q_j$, $\rho_j = \delta Q_e/\delta Q_j$, $j = 1, 2$, where $\delta Q_i = Q_i(+\tau) - Q_i(-\tau)$, $i = e, 1, 2$ and $Q_1 = Q_e\mid_{x=1}$, $Q_2 = Q_e\mid_{x=0}$. Here η_j characterises the dissipation and ρ_j - the difference in dissipation for the right and left polarized light in the SL relatively to the same quantities in the SL component j (at $z = const$).

Graphical analysis and discussion.

The following quantities were assigned constant values: $I_0 = 0.15W/sm^2$, $n_1 = 1$, $n_2 = 1.5$, $z = 1\mu m$ (wide limits varying of z did not change the form of the dependencies reported here). The parameters l, x, λ, τ and SL components properties were changed. The $Q_e(x)$ dependence at various parameters

$$curve\ 1:\ \epsilon_1 = (7 + 3\cdot 10^{-2}i),\ \epsilon_2 = (4 + 10^{-2}i),\ l = 60\mu m,$$

$$curve\ 2:\ \epsilon_1 = (4 + 10^{-2}i),\ \epsilon_2 = (7 + 3\cdot 10^{-2}i),\ l = 60\mu m,$$

$$curve\ 3:\ \epsilon_1 = (7 + 3\cdot 10^{-2}i),\ \epsilon_2 = (4 + 10^{-2}i),\ l = 1\mu m,$$

$$curve\ 4:\ \epsilon_1 = (5 + 1.8\cdot 10^{-2}i),\ \epsilon_2 = (2 + 10^{-2}i),\ l = 60\mu m,$$

$\gamma_1'' = 10^{-5}$, $\gamma_2'' = 3\cdot 10^{-5}$, $\lambda = 0.55\mu m$, $\tau = 1$ is illustrated by Fig. 1. The $Q_e(x)$ form mainly described by Eqs. (1.1) is near linear and symmetric at the transposition of layers $1 \longleftrightarrow 2$ (curv. 1, 2). $Q_e(x)$ oscillates with parameter κl at $l \le 1/\beta$ (curv. 3). At the data the SL dissipation have practically no dependence on the components mass parts(curv.4).

The effect of incident light ellipticity on the gyrotropic SL dissipation is characterized by Fig. 2. Here $\epsilon_1 = (3+6\cdot 10^{-3}i)$, $\epsilon_2 = (5+10^{-3}i)$, $\gamma_1'' = 6\cdot 10^{-5}$ (curv.1, 4, 5), $-6\cdot 10^{-5}$ (2, 3), $\gamma_2'' = 5\cdot 10^{-6}$ (1, 2, 4, 5), $6\cdot 10^{-5}$ (3), $l = 5\mu m$, $\lambda = 0.55\mu m$, $x = 0.1$ (5), 0.5 (2, 3, 4), 0.9 (1). The weak $Q_e(\tau)$ dependence at $\gamma^{\cdot} \le 10^{-6}$ with growth of the $\gamma_e^{\cdot}$ becomes nonlinear (1, 4, 5) especially at near-circular polarization. The data of Fig. 2 show too that variation of the geometry and optical constants of the components gives the opportunity to gain the SL with designed dichroic properties (2, 3, 4).

The $\eta_2(\lambda)$ dependence at $\epsilon_1 = (3+1.5\cdot 10^{-2}i)$, $\epsilon_2 = (5+2\cdot 10^{-2}i)$, $x = 0.2$, $l = 3\mu m$ (curv. 1), $40\mu m$ (2), and the same values of γ_1'', γ_2'', τ as in Fig.1 is shown in Fig. 3. One can note a characteristic beats form well described by Eq. (1.4) and that $\eta_2 > 1$ at the definite λ (though here $\beta_1 < \beta_e < \beta_2$ for absorptivities). It is interesting that $\rho_j(\lambda)$ dependencies are practically the same shown in Fig. 3. So at the definite parameters the SL dissipative properties including dichroic ones will not be intermediate between the same components properties. Strong oscillations

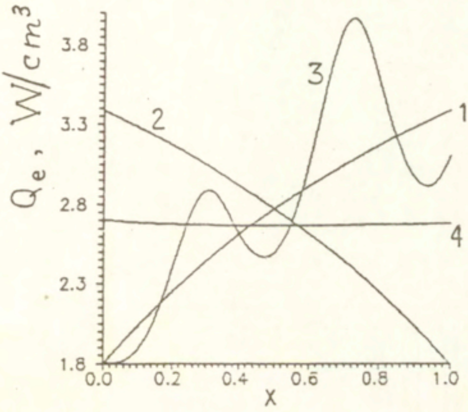

Fig. 1. Dependence of light energy dissipation Q_e on relative thickness of the SL x.

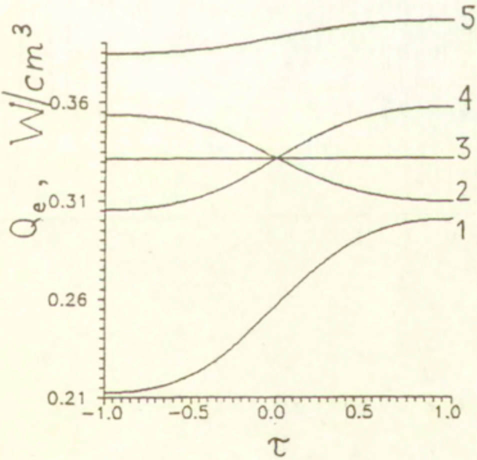

Fig. 2. Light energy dissipation Q_e depending on ellipticity τ.

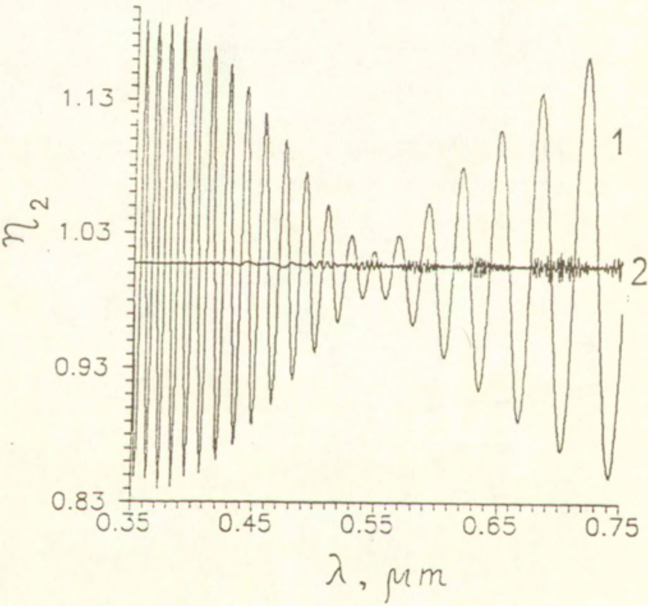

Fig. 3. Relative dissipation η_2 depending on wavelength λ.

of light absorbtion in the SL relatively to absorbtion in the components appear at $l \leq 1/\beta$.

The data reported can be used for the control and determination of the SL parameters by photothermoacoustic methods where the signal measured is proportional to the value of absorbed light energy. For example, as it is seen from Eqs. (1.1) and Fig. 1 when $x = 0.5$ the signal must not change at the radiation from the SL opposite sides (with taking into account the backing effect). At arbitrary x having determined the wavelengths for two neighbour maxima of the $Q_e(\lambda)$ one can gain from Eq. (1.4) with taking into account the dispersion $\epsilon_1(\lambda), \epsilon_2(\lambda)$ the quadratic equation in the unknown x (see Section 3). At the known x the SL components optical constants can be determined.

2. Optical properties of superlattices originated by crystals of rhomb syngony.

By now SL formed from crystals of cubic syngony [3, 4] have been much studied, whereas SL originated by absorbing crystals of middle and lower singonies worse studied [8]. The section under discussion is devoted to investigation of optical characteristics of short-period SL formed from absorbing gyrotropic non-magnetic crystals of rhomb syngony (class 222) and possibility of the employment of such structures for transformation of electromagnetic radiation characteristics.

Theoretical model.

Consider SL formed from plane-parallel layers of two absorbing gyrotropic crystals of class 222 with period $D = d + d'$ and relative layer thicknesses $x = d/D$ and $1 - x = d'/D$ (in this section the primed symbols indicate quantities which correspond to the second component of SL). According to [16] the crystals in question are characterized by the complex tensors of dielectric permeability ϵ, ϵ' and optical activity α, α' of the form

$$\epsilon = \Sigma \epsilon_q \mathbf{c}_q \cdot \mathbf{c}_q, \quad \epsilon' = \Sigma \epsilon'_q \mathbf{c}'_q \cdot \mathbf{c}'_q,$$

$$\alpha = \Sigma \alpha_q \mathbf{c}_q \cdot \mathbf{c}_q, \quad \alpha' = \Sigma \alpha'_q \mathbf{c}'_q \cdot \mathbf{c}'_q, \tag{2.1}$$

where the summation is performed by index $q = 1, 2, 3$, ϵ_q, ϵ'_q, α_q, α'_q are the complex scalars, $\mathbf{c}_q$, $\mathbf{c}'_q$ are the unit vectors directed along the axes of the second order, mutually orthogonal in the crystals investigated and the point denotes the dyadic product between the vectors. Let us consider (Fig. 4), that SL components have one axis of the second order in common which is normal to the layers boundaries and parallel to the wave normal $\mathbf{n}$ of the radiation incident on the

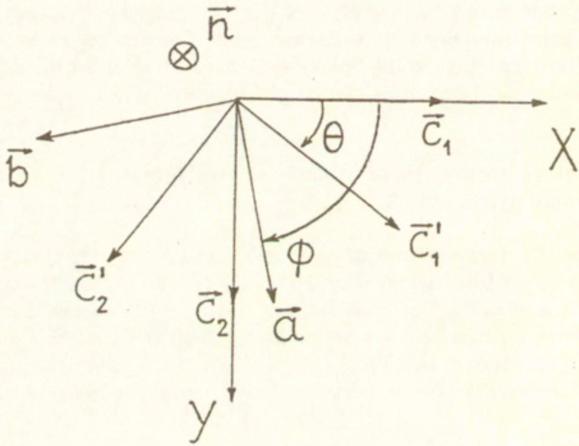

Fig. 4. Geometry of light incident on the SL originated by gyrotropic crystals of class 222 (explanations are in Section 2).

SL: $\mathbf{c}_3 = \mathbf{c}'_3 = \mathbf{n}$; the angle between vectors $\mathbf{c}_1$ and $\mathbf{c}'_1$ symbolized by θ. To solve a boundary electrodynamics problem it is necessary to choose a coordinate system with vectors $\mathbf{c}_q$ ($\mathbf{c}_3 = [\mathbf{c}_1\ \mathbf{c}_2]$) in the X-, Y- and Z-directions.

Then the electric field strength of electromagnetic plane monochromatic wave with elliptical polarization incident on the plane $z = 0$ (in the SL domain coordinate $0 \leq z \leq l$) is represented as follows [18, 20]

$$\mathbf{E}_0 = (A_0\mathbf{c}_1 + B_0\mathbf{c}_2)\exp(\psi_0) = pE_0(\mathbf{a} + i\tau_0\mathbf{b})\exp(\psi_0), \tag{2.2}$$

where A_0, B_0, E_0 are the complex scalars, $\psi_0 = ik_0nz$, $k_0 = \omega/v$ is the wave number for vacuum, $p = (1+\tau^2)^{-1/2}$, τ_0 is the ellipticity of incident light, $i^2 = -1$, $\mathbf{a}$ and $\mathbf{b}$ are the unit vectors of major and small axes of the polarization ellipse. Here and below we will omit the time phase factor $\exp(-i\omega t)$ in the formulae for electromagnetic fields, i. e., we will use vector amplitudes [16] of the corresponding fields. It is anticipated that non-absorbing nongyrotropic media in front of and behind SL have real reflective indexes n and n_3 correspondingly. It is not difficult to indicate that $A_0 = pE_0(\cos\phi - i\tau_0\sin\phi)$, $B_0 = pE_0(\sin\phi + i\tau_0\cos\phi)$, where ϕ is the angle between the vectors $\mathbf{c}_1$ and $\mathbf{a}$ (Fig. 4), and that intensity of the incident light $I_0 = vn(|A_0|^2 + |B_0|^2)/(8\pi)$ does not depend on quantities τ_0 and ϕ.

Using the procedure for calculation of effective tensors of dielectric permeability ϵ_e [5] and optical activity α_e [8], in view of relations (2.1) and given geometry of the problem, one can get

$$\epsilon_e = \begin{pmatrix} L & R & 0 \\ R & N & 0 \\ 0 & 0 & C \end{pmatrix}, \qquad \gamma_e = \begin{pmatrix} F & P & 0 \\ P & Q & 0 \\ 0 & 0 & H \end{pmatrix} \tag{2.3}$$

where the following designations are adopted

$$L = x\epsilon_1 + (1-x)(\Delta\cos^2\theta + \epsilon'_2),\ N = x\epsilon_2 + (1-x)(-\Delta\cos^2\theta + \epsilon'_1),$$

$$C = [x/\epsilon_3 + (1-x)/\epsilon'_3]^{-1},\ R = (1/2)(1-x)\Delta\sin(2\theta),$$

$$H = C[x\alpha_3/\epsilon_3 + (1-x)\alpha'_3/\epsilon'_3],\ \Delta = \epsilon'_1 - \epsilon'_2,$$

and relations for components F, Q and P of tensor α_e result from the formulae for quantities L, N and R at substitution of parameters ϵ_1, ϵ_2, ϵ'_1, ϵ'_2 for α_1, α_2, α'_1, α'_2 respectively. From the formulae (2.3) we notice that when $\theta \neq (\pi/2)f$ (f is an integer number), $\epsilon'_1 \neq \epsilon'_2$, $\alpha'_1 \neq \alpha'_2$ tensors ϵ_e, α_e do not result in diagonal view in real major system of coordinates.

Maxwell equations and material equations in the form [16] ($\mathbf{m} = n\mathbf{n}$ is the refraction vector)

$\mathbf{D} = -[\mathbf{mH}]$, $\mathbf{B} = [\mathbf{mE}]$,

$$\mathbf{D} = \epsilon_e \mathbf{E} + i\alpha_e \mathbf{H}, \quad \mathbf{B} = \mathbf{H} - i\alpha_e^t \quad \mathbf{E}, \tag{2.4}$$

and the following from Eqs. (2.4) wave equation [16]

$$(\epsilon_e - \alpha_e \alpha_e^t + \mathbf{m}^{\times 2} + i\beta^{\times})\mathbf{E} = 0, \tag{2.5}$$

(here $\beta = (Tr(\alpha_e) - \alpha_e^t)\mathbf{m}$, and symbols "$t$", " $\times$ ", "Tr" denote transposition, tensor, which is dual to vector and trace of tensor, multiplied by unit tensor) allow to determine the components of the refracted $\mathbf{E}_1$, $\mathbf{E}_2$, $\mathbf{H}_1$, $\mathbf{H}_2$ and reflected from the boundary $z = l$ $\mathbf{E}_3$, $\mathbf{E}_4$, $\mathbf{H}_3$, $\mathbf{H}_4$ proper waves in the SL in the chosen basic set $(\mathbf{c}_1, \ \mathbf{c}_2)$ (there are no components of the fields alone axis Z at the given geometry):

$$\mathbf{E}_1 = A_1 \exp(\phi_1)\ (1, k_1), \quad \mathbf{E}_2 = A_2 \exp(\phi_2)\ (k_2, 1),$$

$$\mathbf{E}_3 = A_3 \exp(-\phi_1)\ (1, k_3), \quad \mathbf{E}_4 = A_4 \exp(-\phi_2)\ (k_4, 1), \tag{2.6}$$

$$\mathbf{H}_1 = A_1 \exp(\phi_1)\ (k_5, \ k_6), \quad \mathbf{H}_2 = A_2 \exp(\phi_2)\ (k_7, \ k_8),$$

$$\mathbf{H}_3 = A_3 \exp(-\phi_1)\ (k_9, \ k_{10}), \quad \mathbf{H}_4 = A_4 \exp(-\phi_2)\ (k_{11}, \ k_{12}),$$

Here A_1, A_2, A_3, A_4 are the complex coefficients, $\phi_j = ik_0 n_j z$, $j = 1, 2$, and the expressions for quantities k_s may be presented in the form

$$k_{1,3} = \eta_1 \pm \eta_2, \ k_{2,4} = \eta_3 \pm \eta_4, \ k_{5,9} = i(F + \eta_1 P) \mp n_1 k_{1,3},$$
$$k_{6,10} = i(P + \eta_1 Q) \pm n_1, \ k_{7,11} = i(P + \eta_3 F) \mp n_2,$$
$$k_{8,12} = i(Q + \eta_3 P) \pm n_2 k_{2,4},$$
$$\eta_1 = R/(n_1^2 - B), \ \eta_2 = in_1(F + Q)/(n_1^2 - B),$$
$$\eta_3 = R/(n_2^2 - A), \ \eta_4 = in_2(F + Q)/(A - n_2^2),$$

choosing indexes standing only to the left (right) of the comma, with upper sign corresponding to the left indexes.

In the relations (2.6) complex indexes of refraction n_j can be determined from Eq. (2.5) and are of the form $n_1 = n_+$, $n_2 = n_-$, where

$$n_\pm^2 = (1/2)\{L + N + G_1 \pm [(L - N)^2 + 4R^2 + G_2]^{1/2}\}, \tag{2.7}$$

and

$$G_1 = 2(FQ - P^2), \ G_2 = 4(F + Q)\ (LQ + NF - 2RP).$$

The approximation, frequently used due to small values of the optical activity tensors components, is used above: in the expression for fields the terms not higher than the first order by parameters of gyrotropy $(F, \ P, \ Q)$ are remained, and in the relations for refractive indexes - the terms not higher than the second order. It is seen from Eq. (2.7), that without taking into account second order of quantities F, Q, P refractive indexes are determined only by components of the tensor ϵ_e.

Wave $\mathbf{E}_r$ reflected from the boundary $z = 0$ and $\mathbf{E}$ transmitted behind SL let us represent as follows

$$\mathbf{E}_r = \exp(-\psi_0)\ (A_r, B_r), \quad \mathbf{E} = \exp(\psi)\ (A, B), \tag{2.8}$$

where A, A_r, B, B_r are the complex scalars, $\psi_. = ik_0 n_3 z$. Defining expressions for magnetic field strengths outside the SL according to Eqs. (2.4) and solwing boundary electrodynamic problem in a traditional way [16, 20], we would obtain

$$\begin{aligned}
&A_4 = [(\kappa_1\kappa_6 - \kappa_3\kappa_5)A_0 + \kappa_2\kappa_6 B_0]/(\kappa_3\kappa_7 - \kappa_4\kappa_6),\\
&A_2 = (-1/\kappa_6)\ (\kappa_7 A_4 + \kappa_5 A_0),\\
&A_3 = (-1/\lambda_7)\ (\lambda_{12} A_0 + \lambda_6 A_2 + \lambda_8 A_4),\\
&A_1 = [(nk_3 - k_9)A_3 + (n - k_7)A_2 + (n - k_{11})A_4 - 2nB_0]/(k_5 - nk_1),\\
&A_r = A_1 + A_3 + k_2 A_2 + k_4 A_4 - A_0,\\
&B_r = k_1 A_1 + k_3 A_3 + A_2 + A_4 - B_0,\\
&A = \exp(-\psi_l)\ (A_1 \exp(\psi_1) + A_3 \exp(-\psi_1) + k_2 A_2 \exp(\psi_2) + k_4 A_4 \exp(-\psi_2)),\\
&B = \exp(-\psi_l)\ (A_1 k_1 \exp(\psi_1) + A_3 k_3 \exp(-\psi_1) + A_2 \exp(\psi_2) + A_4 \exp(-\psi_2)),
\end{aligned} \tag{2.9}$$

where the following designation are used ($\psi_j = ik_0 n_j l, j = 1, 2,\ \psi_l = ik_0 n_3 l$)

$$\begin{aligned}
&\kappa_1 = \lambda_7\lambda_9 - \lambda_1\lambda_{12},\ \kappa_2 = \lambda_7\lambda_{10},\ \kappa_3 = \lambda_0\lambda_7 - \lambda_1\lambda_6,\ \kappa_4 = \lambda_2\lambda_7 - \lambda_1\lambda_8,\\
&\kappa_5 = \lambda_7\lambda_{11} - \lambda_4\lambda_{12},\ \kappa_6 = \lambda_3\lambda_7 - \lambda_4\lambda_6,\ \kappa_7 = \lambda_5\lambda_7 - \lambda_4\lambda_8,
\end{aligned}$$

$$\begin{aligned}
&\lambda_0 = N_5 N_6 - N_1(k_7 - n),\ \lambda_1 = N_5 N_7 - N_1(k_9 - nk_3),\\
&\lambda_2 = N_5 N_4 - N_1(k_{11} - n),\ \lambda_3 = N_6 N_2 \exp(\psi_1) - N_1(n_3 k_2 - k_8)\exp(\psi_2),\\
&\lambda_4 = N_7 N_2 \exp(\psi_1) - N_1(n_3 - k_{10})\exp(-\psi_1),\\
&\lambda_5 = N_4 N_2 \exp(\psi_1) - N_1(n_3 k_4 - k_{12})\exp(-\psi_2),\\
&\lambda_6 = N_6 N_3 \exp(\psi_1) - N_1(n_3 + k_7)\exp(\psi_2),\\
&\lambda_7 = N_7 N_3 \exp(\psi_1) - N_1(n_3 k_3 + k_9)\exp(-\psi_1),\\
&\lambda_8 = N_4 N_3 \exp(\psi_1) - N_1(n_3 + k_{11})\exp(-\psi_2),\ \lambda_9 = -2nN_5,\\
&\lambda_{10} = -2nN_1,\ \lambda_{11} = -2nN_2 \exp(\psi_1),\ \lambda_{12} = -2nN_3 \exp(\psi_1),
\end{aligned}$$

$$\begin{aligned}
&N_1 = n + k_6,\ N_2 = n_3 - k_6,\ N_3 = n_3 k_1 + k_5,\ N_4 = nk_4 + k_{12},\\
&N_5 = k_5 - nk_1,\ N_6 = k_8 + nk_2,\ N_7 = n + k_{10}.
\end{aligned}$$

The intensity of the light behind the SL is equal to

$$I = cn_3 \mid \mathbf{E} \mid^2 / 8\pi = cn_3(\mid A \mid^2 + \mid B \mid^2)/8\pi. \tag{2.10}$$

Ratios of the complex coefficients at unit vectors $\mathbf{c}_1$, $\mathbf{c}_2$ in the expresssions for fields $\zeta = B/A$, $\zeta_1 = k_1$, $\zeta_2 = 1/k_2$ by [16] completely determine ellipticities of τ, τ_1, τ_2 and polarization azimuthes of χ, χ_1, χ_2 (the angles between the major axes of polarization ellipses and vector $\mathbf{c}_1$) respectively of the wave behind the SL and proper refracted waves in the SL

$$\tau^2 = (1 - T^{1/2})/(1 + T^{1/2}), \; tg\chi = Re[\zeta/(1+\zeta^2)^{1/2}]/Re[1/(1+\zeta^2)^{1/2}], \tag{2.11}$$

where $T = 1 - [2Im(\zeta)/(1 + |\zeta|^2)]^2$ and left polarization ($\tau < 0$) is satified by the condition $Im(\zeta) < 0$ (for the quantities τ_j, χ_j we have similar formulae in terms of substition of ζ for ζ_j). It is not difficult to show the equivalence of expressions (2.11) to the description of polarization characteristics by Stocks parameters method [21].

By approach developed in [18] and taking into account Eqs. (2.3), (2.6) let us define the dissipation of light energy W in the unit volume of the SL

$$(8\pi/\omega)W = \sum\{\mathbf{E}_s^* Im(\epsilon_e)\mathbf{E}_s - 2Im[\mathbf{E}_s^* Im(\alpha_e)\mathbf{H}_s]\}, \tag{2.12}$$

where "$*$" denotes complex conjugation and summation is performed by index $s = 1, 2, 3, 4$.

In the absence of gyrotropy ($\alpha_e = 0$) Eqs. (2.9) are significantly simplified and for the characteristics of radiation behind the SL we have

$$A = \sigma(p_1 A_0 + p_2 B_0), \; B = \sigma(t_1 A_0 + t_2 B_0), \tag{2.13}$$

where

$$p_1 = a - b\eta_1\eta_3, \; p_2 = (b-a)\eta_3, \; t_1 = (a-b)\eta_1, \; t_2 = b - a\eta_1\eta_3,$$
$$\sigma = 4n\exp(-\psi_l)/[(1-\eta_1\eta_3)\Delta_1\Delta_2], \; a = n_1\Delta_2, \; b = n_2\Delta_1,$$
$$\Delta_j = (n+n_j)\,(n_3+n_j)\exp(-\psi_j) - (n-n_j)\,(n_3-n_j)\exp(\psi_j).$$

In this case the intensity of transmitted radiation can be represented in the form

$$I = I_1 + I_2\sin^2(\phi) + I_3\sin(2\phi), \tag{2.14}$$

where

$$I_1 = \rho[R_1 + R_2\tau_0^2 - 2Im(R_3)\tau_0],$$
$$I_2 = \rho(R_1 - R_2)\,(\tau_0^2 - 1), \; I_3 = Re(R_3)\,(1 - \tau_0^2),$$
$$R_j = |\rho_j|^2 + |t_j|^2, \quad j = 1, 2,$$
$$R_3 = t_2 t_1^* + p_2 p_1^*, \; \rho = n_3 I_0 |\sigma|^2/[n(1+\tau_0^2)].$$

In Eq. (2.14) the dependencies of the SL transmission when $\alpha_e = 0$ on the incident light polarization parameters (τ_0, ϕ) are given in an explicit form.

Graphical analysis and discussion.

At calculation the constant parameters not given in the captions took the following values:

$$\epsilon_1 = 2.55 + 3.8 \cdot 10^d i, \quad \alpha_1 = (3 + 0.05i) \cdot 10^r,$$
$$\epsilon_1 = 2.7 + 4 \cdot 10^d i, \quad \alpha_1 = (1.5 + 0.03i) \cdot 10^r,$$
$$\epsilon_1 = 2.8 + 6 \cdot 10^d i, \quad \alpha_1 = (5 + 0.06i) \cdot 10^r,$$
$$\epsilon_1 = 2.9 + 8 \cdot 10^d i, \quad \alpha_1 = (6 + 0.07i) \cdot 10^r,$$

where indexes d and r took the values from -4 to -1 and -3, -4 correspondingly, $I_0 = 0.1\ W/cm^2$, $n = 1$, $n_3 = 1.5$.

In the given SL only waves which are the superposition of the proper waves (Eqs. (2.6)) can propagate, it being known that the latter pass through the SL without changing their polarization. That's why consider at first a behaviour of the refracted proper waves (PW), $\mathbf{E}_1$, $\mathbf{E}_2$, in the SL depending on the structure geometry (θ, x) and the parameters of the absorption and gyrotropy (Fig. 5, 6). Assume that $\Delta\chi = |\chi_1 - \chi_2|$ is the angle between major axes of polarization ellipses of the waves $\mathbf{E}_1$, $\mathbf{E}_2$, then parameter $\beta = |\pi/2 - \Delta\chi|$ characterizes the value of nonorthogonality of the PW in the SL. From Eq. (2.11) it is evident that in the absense of gyrotropy the ellipses of the polarization for the waves $\mathbf{E}_1$, $\mathbf{E}_2$, are orthogonal: $\Delta\chi = \pi/2$, $\beta = 0$ (Fig. 5c, curve 9), and their ellipticities are equal: $\tau_1 = \tau_2$ (Fig. 5a, curves 2, 3, Fig. 6a, curve 3); at $R = 0$ PW are linearly polarized along unit vectors $\mathbf{c}_1$, $\mathbf{c}_2$.

In the presence of the gyrotropy $\tau_1 \neq \tau_2$ and the ellipticities of the PW have different signs (Fig. 5a, curves 1, 4, Fig. 6a, curves 1, 2, 4, 5). It is seen from Fig. 5, 6 that at values θ, x corresponding to the maximuma of the quantities $|\tau_j|$ quantities $|\partial\chi_j/\partial\theta|$, $|\partial\chi_j/\partial x|$, β are also maximal, i. e., with a rise of $|\tau_j|$ the dependecies $\chi_j(\theta, x)$ are enhanced and nonorthogonality of the PW rises.

In this case functions $\tau_j(\theta)$ have extremums at different values θ (Fig. 5a), and functions $\tau_j(x)$ - at closely spaced values of x (Fig. 6a). By relations (2.11), at $\theta = 0$ the condition $\tau_1 \simeq -\tau_2$ is true (Fig. 5a, curves 1, 4, Fig. 6a, curves 2, 4) and the dependencies $\tau_j(x)$ and $\Delta\chi(x)$ (Fig. 6c) substantially weaken.

The rise of the values $Im(\epsilon_e)$ (at varying parameter d from -4 to -2) and α_e (from $\alpha_e = 0$ to $\alpha_e \sim 10^{-5}$ at $r = -3$), characterizing optical absorption and gyrotropy, leads to significant rise of extremum values of the functions $\tau_j(\theta, x)$, $\Delta\chi(\theta, x)$ (Fig. 5a,c, Fig. 6a,c), whereas the dependencies $\chi_j(\theta, x)$ in the scale of Fig. 5b, 6b therewith do not change virtually. It is seen from Fig. 5c, 6c that quantity β may reach the values $0.2 - 0.3\ rad$, that is comparable with the value of nonorthogonality of PW in crystals of rhomb group for directions close to optical axes [22]. The influence of gyrotropy parameters on the

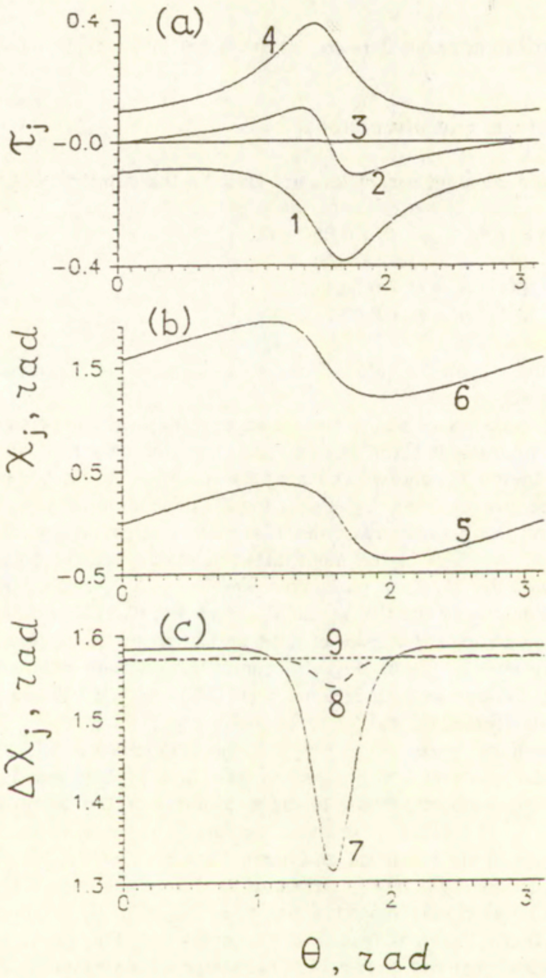

Fig. 5. Effect of parameter θ on PW polarization characteristics: $\tau_1=\tau_2$ (curves 2,3), τ_1 (1), τ_2 (4), χ_1 (5), χ_2 (6) at $x = 0.5$, $d = -2$ (1,2,4-9), -4 (3), $r = -3$ (1, 4-7), -4 (8), $\alpha_e = 0$ (2, 3, 9).

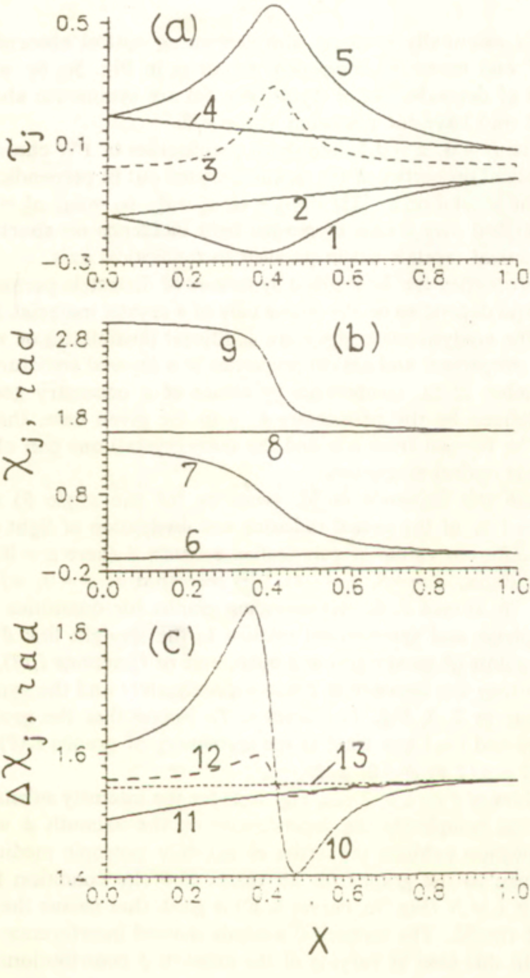

Fig. 6. Effect of parameter x on PW polarization characteristics: $\tau_1=\tau_2$ (curve 3), τ_1 (1, 2), τ_2 (4, 5), χ_1 (6,7), χ_2 (8, 9) at θ (in rad.) = 0 (2,4,6,8, 11,13), 1.4 (1,3,5,7,9, 10,12), d=-2, r = -3 (1,2, 4-11) -4 (12,13), α_e=0 (3).

PW nonorthogonality essentially weakens with decreasing optical absorption: at $Im(\epsilon_\epsilon) \sim 10^{-3} - 10^{-4}$ and tensor α_ϵ component values as in Fig. 5c, 6c we have $\beta \sim 10^{-2} rad$. Graphs of dependencies of $\Delta\chi(\theta)$ (Fig. 5c) are symmetric about the straight line $\theta = \pi/2$ and have the minimum at $\theta = \pi/2$.

In a particular case $R = 0$, $x = 0,1$, considered peculiarities of PW characteristics correspond to optical properties of the rhombic crystal cut in perpendicular to one of the axes of the second order [22]. At $\epsilon_2 = \epsilon_3$, $\epsilon_2' = \epsilon_3'$, $\alpha_2 = \alpha_3$, $\alpha_2' = \alpha_3'$ the proposed model described also a case of normal light incidence on short-period SL originated by uniaxial crystals cut in parallels to the optical axis.

In a crystal PW properties are determined by tensors of dielectric permeability and optical activity and depend so on the choice only of a crystal material. In case of SL according to the analysis made there are additional possibilities of varying in a wide range PW properties, and optical properties of a layered structure then. Even at a small number of SL components by choice of a necessary geometry of layers (what is defined by the parameters θ, x in the given case, therewith at $\theta \neq 0$ layers may be formed from one and the same crystal) one can obtain a structure with various optical properties.

Fig. 7a,b illustrate the influence of SL geometry (of the angle θ) on the relative intensity $I_r = I/I_0$ of the passed radiation and dissipation of light energy W inside the SL at different values of polarization azimuth ϕ (here $x = 0.5$, $\lambda = 0.55 \mu m$, $\tau_0 = 0$, $l = 20 \mu m$, $d = -3$, $r = -4$). It is seen that at $\phi = 0$, $\pi/2$ (Fig. 7a, curves 1, 4, Fig. 7b, curves 5, 8) corresponding graphs for quantities I_r and W are opposite in phase and symmetrical relative to the straight line $\theta = \pi/2$ passing through the points of maximuma and minimuma of functions $I_r(\theta)$, $W(\theta)$. At other values of ϕ they are opposite in phase approximately and the symmetry is absent (Fig. 7a, curves 2, 3, Fig. 7b, curves 6, 7). Notice that the growth of gyrotropy parameters and $|\tau_0|$ also leads to the asymmetry of graphs $I_r(\theta)$, $W(\theta)$ relative to the axis $\theta = \pi/2$ at $\phi = 0$, $\pi/2$.

At the definite values of θ ($\simeq 1.2$, $2\ rad$, Fig. 7a,b) for the intensity substantially and for the dissipation completely the dependencies on the azimuth ϕ weaken, i. e., structure in question exhibits properties of optically isotropic medium. As well as Fig. 7a,b given to the graphs for all values of θ the condition for the tensor ϵ_ϵ components: $L \neq N$ (Fig. 7c, curves 9, 10) is good, that means the strong optical anisotropy of the SL. The numerical analysis showed interference nature of the given effect. In this case at varying of the azimuth ϕ contributions to the dissipation and the intensity of passed radiation from the waves inside the SL: 1) propagating to the boundary $z = l$, 2) reflected from the boundary $z = l$, are changed on values close by modulus and opposite in sign, that leads to compensation of the optical anisotropy influence. For the simplification of calculations let us illustrate this for intensity of passed radiation in the case of nongyrotropic SL (at $\alpha_\epsilon = 0$). Then according to Eq. (2.14), (2.13) dependence $I(\phi)$ will be absent at (evidently, that $|\tau_0| \neq 1$)

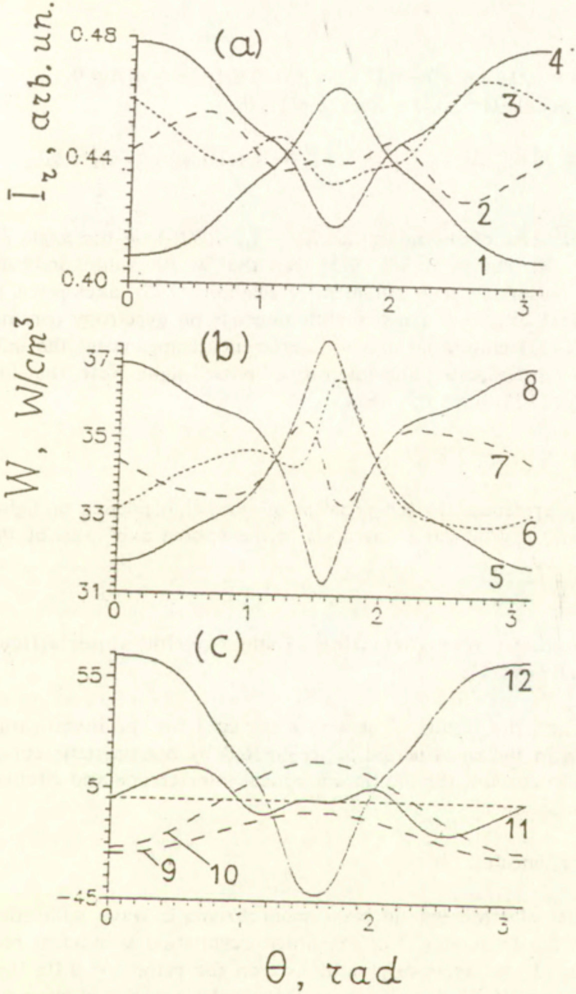

Fig. 7. Light intensity behind the SL (a), dissipation (b, z = 1 μm) and quantities $R_2 - R_1$ (curve 12), $Re(R_3)$ (11), $Im(L-N)\cdot 2\cdot 10^4$ (10), $Re(L-N)\cdot 2\cdot 10^2$ (9) depending on parameter θ. ϕ (in rad.) = 0 (4,5), π/4 (2,7), π/2 (1,8), 2.6 (3,6).

$$R_2 - R_1 = q_1(1-|\eta_3|^2) - q_2(1-|\eta_1|^2) - 2Re[q_3(\eta_1 - \eta_3^*)] = 0, \quad (2.15)$$
$$Re(R_3) = Re[q_3(1+\eta_1\eta_3^*) - q_1\eta_3 - q_2\eta_1^*] = 0,$$

where $q_1 = |a|^2(1+|\eta_1|^2), q_2 = |b|^2(1+|\eta_3|^2), q_3 = ba^*(\eta_1^* + \eta_3)$.

The dependencies of the quantities $R_2 - R_1$, $Re(R_3)$ on the angle θ are presented of Fig. 7c (curves 11, 12). It is seen that at the values indicated above $\theta \simeq 1.2$, $2rad$ reasonable true fulfilment of relations (2.15) takes place. In such a matter the effect discussed above slightly depends on gyrotropy parameters and at conditions (2.15) multibeam optical interference compensates the influence of SL anisotropy on dissipation and intensity of passed light. Note, that in the case $\eta_1 = \eta_3 = 0$ Eqs. (2.15) have the form

$$|n_1\Delta_2|^2 = |n_2\Delta_1|^2, \; Re(R_3) = 0, \quad (2.16)$$

and at $z = 1$ correspond to the problem of normal incidence of light on uniaxial (or rhomb) crystal cut in parallels to the optical axis (axis of the second order) [20, 23, 24].

3. Photoacoustic transformation in short-period superlattices formed from cubic crystals

In this Section the results of Section 1 are used for the investigation of PA transformation in the short-period SL originated by nonmagnetic cubic crystals with taking into account the multibeam optical interference and circular dichroism of SL components.

Theoretical model.

Assume, that electromagnetic plane monochromatic wave with elliptical polarization and the frequency Ω of amplitude modulation is incident normally to the boundaries of the layers originating SL, on the plane $z = 0$ (in the SL field coordinate $0 \leq z \leq l$). SL including absorbing cubic crystals is characterized by the axial complex tensors of dielectric permeability (ϵ_e) and optical activity (γ_e) [8]. The media in front and behind SL will be considered non-absorbing and nongyrotropic with real reflectivities n_1 and n_2 correspondingly.

In the often used short-period SL case [5] the SL period D takes the values $D \ll \lambda$, λ_t, where λ and λ_t are the optical and thermal wavelengths. The electromagnetic waves propagation in SL is described by well-known Hill's equation from the solution of wich it follows, that short-period SL can be considered as homogeneous media with some effective parameters [5, and Refs.in 8]. It is simply to show that at the harmonic thermal sources used in photoacoustics the thermal diffusion equation describing thermal waves in SL has the same form as Hill's equation (with accuracy to inhomogeneity). So we can assume the thermal effective parameters to be described by the equations [5, 8] derived for the components of tensors (ϵ_e), (γ_e)

$$a_e = xa_1 + (1-x)a_2, \tag{3.1}$$

where $a = \epsilon, \gamma, \rho, k$; ϵ_e and γ_e are the coincident main values of tensors (ϵ_e) and (γ_e), ρ and k are the thermal diffusivity and conductivity correspondingly. As in Section 1, it is assumed that the SL period consists of two layers with relative thiknesses $x = d_1/D$ and $1-x = d_2/D$ $(d_1 + d_2 = D)$. The quantities with indexes "e, 1, 2" concern the effective medium, first and second component of the SL correspondingly. Circular dichroism is described by imaginary parts of the optical activity tensors, which will be designated γ''_e, γ''_1, γ''_2. Eqs. (3.1) can be also derived from the averaging SL parameters over the period D.

Note that only at satisfying for SL considered approximation of effective medium one can use the models known from photoacoustics of homogeneous media for description of PA transformation. In this case the homogeneous medium characteristics can be replaced by the effective parameters describing optical and thermophysical processes in SL.

At given interaction geometry optical properties of axial gyrotropic crystal in the optical axis direction are equivalent to ones for the isotropic-gyrotropic medium with the complex parameters ϵ_e, γ_e [17]. So using Eq. (1.2) for the quantity of light energy dissipation with taking into account Eq. (3.1), on the basis of Rosencwaig-Gersho model [25] one can gain the relations for PA amplitude $q_e = |\theta|$ and phase $\psi_e = arctg(Im\theta/Re\theta)$, $\theta = \theta_+ + \theta_-$,

$$\theta_\pm = Y\alpha_\pm \zeta^{-1} k_e^{-1}/(\alpha_\pm^2 - \sigma_e^2)\ [A_\pm F(\alpha_\pm) + B_\mp F(-\alpha_\pm)\exp(-2\beta_e l)], \tag{3.2}$$

and

$$A_\pm = N_+ T_\pm,\ B_\mp = N_- T_\mp,\ T_\pm = (1\pm\tau)^2/(1+\tau^2),\ \alpha_\pm = \beta_e \pm (4\pi/\lambda)\gamma''_e,$$

$$N_\pm = n_1 \mid \epsilon_e^{1/2} \pm n_2 \mid^2 Re(\epsilon_e^{1/2}),$$

$$\zeta = \zeta_1 + [\zeta_2 \sin(\kappa_e l) + \zeta_3 \cos(\kappa_e l)]\exp(-\beta_e l) + \zeta_4 \exp(-2\beta_e l),$$

$$\kappa_e + i\beta_e = (4\pi/\lambda)\epsilon_e^{1/2},\ i^2 = -1,$$

$$F(p) = [(r-1)\ (b+1)\exp(\sigma_e l) - (r+1)\ (b-1)\exp(-\sigma_e l) + 2(b-r)\exp(-pl)]/D,\ r = p/\sigma_e,$$

$$D = \exp(\sigma_e l)\ (b+1)\ (g+1) - \exp(-\sigma_e l)\ (b-1)\ (g-1).$$

In Eqs. (3.2) $Y = \gamma_0 P_0 I_0/(2^{3/2} l_g a_g T_0)$, where γ_0, P_0, T_0, l_g, a_g are characteristics of detector gas [25]; I_0 and τ are intensity and ellipticity of incident light, $\alpha_\pm$ is absorption coefficient with taking into account dichroism. The quantities with indexes "$\pm$" concern the account of right (+) and left (-) circularly polarized waves superposition of wich describes the field in the effective medium. The relations for quantities ζ_i and σ_e, b, g, Y follow from ones given in Section 1 and [25] correspondingly (we used the same designations) with taking into account Eqs. (3.1). Note only that ζ_i are defined by optical (ϵ_e, n_1, n_2), and σ_e, k_e, b, g, Y - by thermal constants of the SL and boundaries media.

According to [25] from Eqs. (3.2) one can gain the relations for special cases. For optically thin samples ($l < l_\beta$, $l_\beta = 1/\beta_e$)

$$q_e = 2^{1/2}(C^e_+ + C^e_-) l \mu_b / k_b, \quad \mu_e \gg l; \ \mu_e > l_\beta, \quad \mu_e < l_\beta, \tag{3.3}$$

$$q_e = (C^e_+ + C^e_-)\mu_e^2/k_e, \quad \mu_e < l; \quad \mu_e \ll l_\beta; \tag{3.4}$$

where

$$C^e_\pm = (1/4) Y \alpha_\pm \zeta^{-1} [A_\pm + B_\mp (1 - 2\beta_e l)], \ \mu_e = (2\rho_e/\Omega)^{1/2},$$

and quantities μ_b, k_b are the thermal diffusion length and thermal conductivity correspondingly for the backing [25].

In the case of optically thick samples ($l_\beta \ll l$)

$$\theta_\pm = (1-i) M_e T_\pm [1 + (\alpha_\pm - \beta_e)\ (\partial R/\partial \alpha_\pm)_{\beta_e}] \mu_b / k_b, \ \mu_e \gg l, \ \mu_e \gg l_\beta, \tag{3.5}$$

$$\theta_\pm = (1-i) M_e T_\pm [1/(1 + \sigma_e/\beta_e) + (\alpha_\pm - \beta_e)\ (\partial R/\partial \alpha_\pm)_{\beta_e}] \mu_e / k_e, \tag{3.6}$$

$$\mu_e < l, \ \mu_e > l_\beta,$$

$$q_e = M_e(\alpha_+ T_+ + \alpha_- T_-)\mu_e^2/k_e, \ \mu_e \ll l. \ \mu_e < l_\beta, \tag{3.7}$$

where $M_e = (1/2) Y n_1 Re((\epsilon_e)^{1/2}) / \mid (\epsilon_e)^{1/2} + n_1 \mid^2$, $R(\alpha_\pm) = \alpha_\pm/(\alpha_\pm + \sigma_e)$. Eqs. (3.5), (3.6) are the higher order approximations derived at using Taylor series for $\theta_\pm(\alpha_\pm)$ and that usually $\beta_e \gg \mid \alpha_\pm - \beta_e \mid$. Such approach is preferable because Eqs. (3.5), (3.6) describe, unlike analogical relations following from [25], the linear $q_e(\gamma_e'')$ dependence, as it will be shown further.

It is obvious that Eqs. (3.2) - (3.7) include as special cases the relations for PA response of nongyrotropic short-period SL (at $\gamma_e'' = 0$) and layer (at $x = 0, 1$) in the frames of the theory [25] at presence or absence of circular dichroism and multibeam interference in the sample.

Discussion and graphical analysis.

Let us consider the main distinctions of the derived relations compared to ones given in [25]. The account of multibeam reflections at boundaries $z = 0, l$ is described by the terms with multiplier $B_{\mp}$ (the contribution in absorption of the radiation, reflected at boundary $z = l$) and by the parameter ζ, describing the multibeam interference. It is seen that interference contribution can be neglected at $\beta_e l \gg 1$, and at $\beta_e l \leq 1$ PA signal amplitude will be oscillating function of parameter $\kappa_e l$. Circular dichroism of SL components leads to PA response dependence on parameters γ_1'', γ_2'', τ. Note, that for gyrotropic SL the circular dichroism disymmetry factor [26] $g_{cd} = 2(\alpha_+ - \alpha_-)/(\alpha_+ + \alpha_-) = 2\gamma_e''/Im((\epsilon_e)^{1/2})$ has rather complicated dependence on parameter x. But from Eqs. (3.3)-(3.7) it follows that in considered cases the PA signal amplitude dependencies on γ_e'', g_{cd} are linear. So at various x measuring PA signal $q_e' =| \theta_+ - \theta_- |$ taking place at additional polarization modulation ($\pm\tau$) [26] with frequency Ω of incident light let us define the parameters γ_e'', g_{cd}.

It is obvious that distinctions concerned effective character of SL parameters will be practically the same as well as in dichroic as in non-dichroic SL (due to condition $\gamma_e'' \ll \epsilon_e''$ wich usually takes place). So to concretize the calculation let us consider PA transformation in grown along axis $< 001 >$ system $GaAs/GaP$ which is one of the classic SL and originated by the cubic crystals of class $43\overline{m}$. It was assumed that $I_0 = 0.15\ W/cm^2$, $\Omega = 300\ Hz$, $\lambda = 0.55\ \mu m$ and gas column length $l_g = 1cm$ (besides the Fig.10 data where $I_0 = 1.5\ W/cm^2$, $\Omega = 100\ Hz$, $l_g = 0.5cm$). The values of the SL parameters were taken from [27, 28], detector gas characteristics: $\gamma_0 = 1.4$, $\rho_g = 0.2\ cm^2/s$, $k_g = 2.5 \cdot 10^{-4}\ J/(cm \cdot s \cdot K)$, $T_0 = 290K$, $P_0 = 10^5 Pa$, $n_1 = 1$ corresponded to air at normal conditions and backing parameters took the values:$\rho_b = 10^{-2}\ cm^2/s$, $k_b = 10^{-2}\ J/(cm \cdot s \cdot K)$, $n_2 = 1.5$.

As Fig. 8 shows $q_e(x)$ dependence is defined by competitive influence of light absorption and heat transport processes. For optically thin samples, that takes place here at small values of x, the PA signal is mainly defined by absorption (for curve 2 it holds at all x due to satisfying condition (3.3)). With growth of x the sample becomes optically thick that leads to dominating role of thermal processes in PA signal formation: the signal decreases at rising the absorption coefficient (curve 3). Note that according to Eqs. (3.1) at the transposition of layers $1 \longleftrightarrow 2$ we have the symmetric relatively to straight line $x = 0.5$ curves. The late also holds for phase dependencies $\psi_e(x)$ wich are very weak and monotonous (at $x = 0 - 1$ phase characteristics change takes the value of order 10^{-2} rad).

The multibeam optical interfernce effect on PA response in SL $GaAs/GaP$ is illustrated by Fig. 9. At $l < l_\beta$ the $q_e(l)$ dependence is strong-oscillating and can have a characteristic beats form well described by Eqs. 3.2 (curve 2). The $q_e(l)$

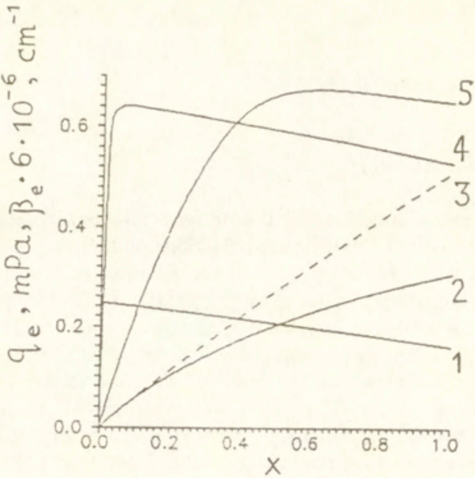

Fig. 8. PA amplitude and absorption coefficient (curve 3) dependencies on x for GaAs/GaP at l (μm) = 100 (1), 10 (4), 0.5 (5), 0.1 (2).

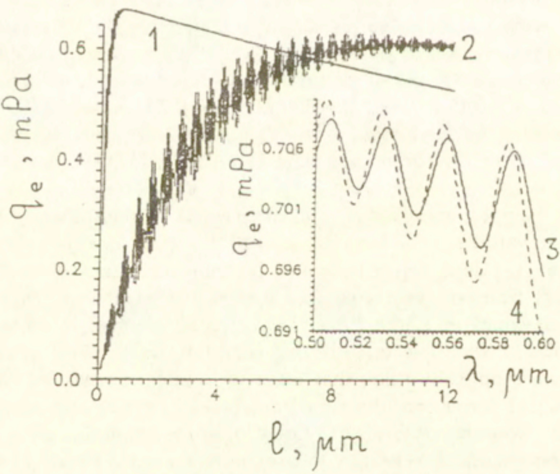

Fig. 9. PA amplitude depending on l and λ (insert) for GaAs/GaP at x = 0.85 (1), 0.03 (2), 0.33 (3), 0.30 (4), l = 1.5 μm (3, 4).

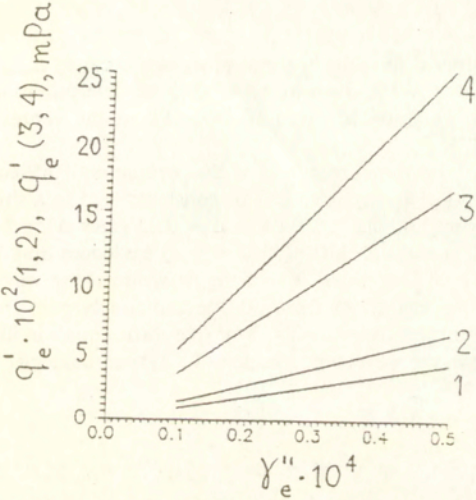

Fig. 10. PA differential amplitude depending on γ''_e at x=0.1 (2,4), 0.5 (1,3), l (μm) = 0.5 (3,4), 5 (1,2).

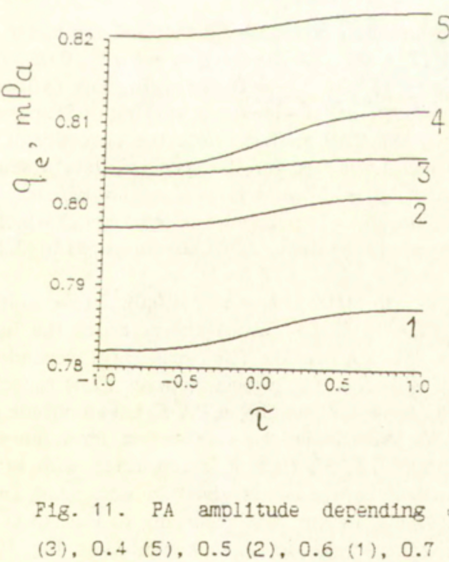

Fig. 11. PA amplitude depending on τ at x = 0.3 (3), 0.4 (5), 0.5 (2), 0.6 (1), 0.7 (4).

maxima positions are mainly defined by thermal processes because $l_{max} \gg l_\beta$ at various parameters. So sensitive PA measurements such as determination of SL energy levels [11-13] require account of interference in SL at the values l up to $l \gg l_\beta$.

Curves 3,4 also characterize the opportunity of SL parameters PAS control at $l > l_\beta$. Small changes of optical and geometrical SL constants lead to a shift $\Delta\lambda$of the $q_e(\lambda)$ dependence maxima. At the Fig. 9 data $\Delta x = 0.03$ gives $\Delta\lambda = 2nm$ that can be simply determined. A vertical shift of curves $q_e(\lambda)$ evidences mainly about changes of thermophysical parameters $\rho_i,\ k_i$. Having determined the wavelengths $\lambda_1,\ \lambda_2$ for two neighbouring maxima of the $q_e(\lambda)$ one can simply gain from Eqs. (3.2) with taking into account the dispersion $\epsilon_e(\lambda)$ the quadratic equation in the unknown x. If the dispersion in the wavelengths region $(\lambda_1,\ \lambda_2)$ can be neglected then

$$x = (\epsilon_1' - \epsilon_2')^{-1}\{[2l(1/\lambda_2 - 1/\lambda_1)]^{-2} - \epsilon_2'\}, \tag{3.8}$$

which follows from Eqs. (3.2) at usual conditions $(\epsilon_e')^{1/2},\ n_j,\ (\epsilon_e')^{1/2} \pm n_j \gg \epsilon_e''(\epsilon_e')^{-1/2},\ j = 1,2$.

At $l_\beta \ll l$ for SL geometry control the measurements at various modulation frequencies can be used. When changing Ω for the sample the conditions (3.5)-(3.7) can be realized. Having determined the quantity $q_e^{(3.5)}/q_e^{(3.6)} \sim \rho_e^{1/2}/k_e$ (indexes correspond to the formula numbers) we also have the quadratic equation for parameter x.

The conditions of the determination of circular dichroism parameter γ_e'' are illustrated by Fig. 10 (here $\epsilon_1 = (7+0.8i)$, $\epsilon_2 = (5+0.4i)$, $k_1 = k_2/2 = 0.03\ J/(cm \cdot s \cdot K)$, $\rho_1 = \rho_2/2 = 0.3\ cm^2/s$, $\gamma_1'' = \gamma_2''/5 = 10^{-5}$, $\tau = 1$). According Eqs. (3.3)-(3.7) the $q_e'(\gamma'')$ dependence is directly proportional at wide limits varying of SL parameters that allows to determine γ_e'' by the PAS method. Note the necessity of rather high light intensity for such measurements: for the specified data a sensitivity evaluation $10^{-5}Pa$ at $\gamma_e'' \sim 10^{-5}$, $\beta_e = 10^4 cm^{-1}$ gives $I_0 = 1.5\ W/cm^2$. At the conditions (3.5), (3.6) the $q_e'(\gamma'')$ dependence is very weak (curves 1,2) which is defined by the higher order of the approximations (3.5), (3.6) compared to (3.3), (3.4).

Fig.11 (here $\epsilon_1 = (5+0.01i)$, $\epsilon_2 = (6+0.02i)$, $k_1 = k_2/2 = 0.02\ J/(cm \cdot s \cdot K)$, $\rho_1 = \rho_2/2 = 0.03\ cm^2/s$, $\gamma_2'' = \gamma_1''/5 = 10^{-5}$, $l = 30\mu m$) characterizes the light polarization effect on gyrotropic SL PA signal. The weak $q_e(\tau)$ dependence at $\gamma_e^{"} \leq 10^{-6}$ with growth of the $\gamma_e^{"}$ becomes non-linear (curves 1,2,4) especially at near-circular polarizations. The main contribution in PA signal amplitude change $\Delta q_e(\tau, x) = (\partial q_e/\partial\tau)\Delta\tau + (\partial q_e/\partial x)\Delta x$ can be due to the first term (curves 3,4) as well as the second one (curves 1-3, 5). Here it is connected with satisfying conditions which are intermediate between ones given in Eqs. (3.3) and (3.5) ($l_\beta = 12 - 15\mu m,\ \mu_e = 160 - 180\mu m$). In this case according to Eqs. (3.2) optical interference leads to oscillating $q_e(x)$ dependence, that exhibits in Fig. 11. Note, that PA signal phase has practically no dependence on the ellipticity τ.

Conclusion.

So at typical parameters the models advanced predict some characteristic optical properties of the gyrotropic SL satisfying the long wavelength approximation. It is shown that photoacoustic transformation in short-period SL originated by cubic gyrotropic crystals has the peculiarities connected with the effect on PA response of multibeam optical interference, SL constants effective character, circular dichroism and exciting radiation polarization. The analysis made lets to define the conditions of experimental investigation and control of SL optical, thermal and geometrical properties by the PA spectroscopy method.

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