DISSIPATIVE PROPERTIES OF GYROTROPIC SUPERLATTICES IN THE LONG WAVELENGTH APPROXIMATION

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The light energy dissipation in gyrotropic superlattices (SL) is calculated in the approximation for the optical wavelengths $\lambda >> D$, where D is the SL period. The determination of the SL parameters by photothermoacoustic methods is proposed.

SL optical properties are simply described in the long wavelength approximation (LWA) when the period of the SL is more less the lengths of optical waves propagating in the superstructure. Then we can consider the SL as a homogeneous medium characterized by a set of the effective parameters [1-3].

In this paper the dissipation of the electromagnetic field energy is investigated in the LWA for the SL including nonmagnetic crystals of the cubic symmetry. The one-dimensional consideration is made with taking into account the multibeam optical interference and circular dichroism of the SL components.

1. 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 [3]. The equal principal values of these tensors are:

$$(\varepsilon_e)_{11} = (\varepsilon_e)_{22} = x\varepsilon_1 + (1-x)\varepsilon_2 \, ,$$
$$(\gamma_e)_{11} = (\gamma_e)_{22} = x\gamma_1 + (1-x)\gamma_2 \, . \qquad (1)$$

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 tensors which will be designated γ_e'', γ_1'', γ_2'' .

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 $\varepsilon_e=(\varepsilon_e)_{11}$, $\gamma_e=(\gamma_e)_{11}$ [4]. So the dissipation of the energy in SL can be described by the familiar relations [5,6], with taking into account Eqs.(1):

$$Q_e = Q_+ + Q_- ,$$
$$Q_\pm = N_o I_o \alpha_\pm [N_+ T_\pm \exp(-\alpha_\pm z) + N_- T_\mp \exp(\alpha_\pm z - 2\beta l)], \qquad (2)$$

where $N_o=n'n_1^2/\xi$, $N_\pm=|n_o \pm n_2|^2$, $T_\pm=(1\pm\tau)^2/(1+\tau^2)$, $\beta=(4\pi/\lambda)n_o''$, $\alpha_\pm=(4\pi/\lambda)(n_o''\pm\gamma_e'')$, $\xi=\xi_1+[\xi_2\sin(æl)+\xi_3\cos(æl)]\exp(-\beta l)+\xi_4\exp(-2\beta l)$, $æ=(4\pi/\lambda)n_o'$, $\xi_1=|n_o+n_1|^2N_+$, $\xi_2=4n_o''(n_1+n_2)(|n_o|^2-n_1n_2)$, $\xi_3=8n_1n_2n_o''^2-2(|n_o|^2-n_1^2)(|n_o|^2-n_2^2)$, $\xi_4=|n_o-n_1|^2N_-$. Here I_o and τ are incident light intensity and ellipsity ($\tau\leqslant 0$ at left polarization), $n_o=\sqrt{\varepsilon_e}=n_o'+in_o''$ ($i^2=-1$), and quantities with indexes "±" correspond to the left and right circular polarized waves superposition of which describes the field in the effective medium. We assume non-absorbing media behind and in front of the SL to have real refractive indexes n_2 and n_1 correspondingly.

Eqs.(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 $dQ_e/dx=0$. At $l\gg 1/\beta$ Eqs.(2) are simplified

$$Q_\pm \simeq N_o I_o \alpha_\pm N_+ T_\pm \exp(-\alpha_\pm z) \ , \ \xi=\xi_1 \ , \qquad (3)$$

that corresponds to the semi-infinite SL case.

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

$$\xi = \xi_+^2 + \xi_-^2 - 2\xi_+\xi_-\exp(-\beta l)\cos(æl) \ , \qquad (4)$$

where $\xi_\pm=(a\pm n_1)(a\pm n_2)$, $a=\sqrt{\varepsilon_e'}$. So the optical interference effect on the SL dissipation is characterized by the parameter $\cos(æl)$, where $æ=(4\pi/\lambda)[x\varepsilon_1'+(1-x)\varepsilon_2']^{1/2}$

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 $Q_1=Q_e|_{x=1}$, $Q_2=Q_e|_{x=0}$. 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).

2. Graphical analysis and discussion.

The following quantities were assigned constant values: I_o= 0.15 W/sm^2, $n_1=1$, $n_2=1.5$, z=1μm (bright 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(Tab.1, $\gamma_1''=10^{-5}, \gamma_2''=3\cdot10^{-5}$, $\lambda=0.55$ μm, $\tau=1$) is illustrated by Fig.1. The $Q_e(x)$ form mainly described by Eqs.(1) is near linear and symmetric at the transposition of layers $1\leftrightarrow2$ (curv.1,2). $Q_e(x)$ oscillates with parameters $\text{æ}l$ at $l\leqslant1/\beta$(curv.3). At the data the SL dissipation have practically no dependence on the components mass parts(curv.4).

Fig.1

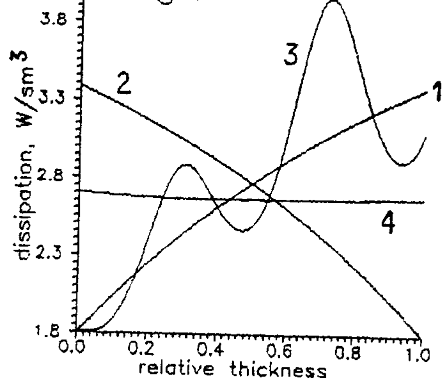


Table 1.

curve	ε_1	ε_2	l, μm
1	$(7,3\cdot10^{-2})$	$(4,10^{-2})$	60
2	$(4,10^{-2})$	$(7,3\cdot10^{-2})$	60
3	$(7,3\cdot10^{-2})$	$(4,10^{-2})$	1
4	$(5,1.8\cdot10^{-2})$	$(2,10^{-2})$	60

The $\eta_2(\lambda)$ dependence at $\varepsilon_1=(3,1.5\cdot10^{-2})$, $\varepsilon_2=(5,2\cdot10^{-2})$, $x=0.2$, $l=3$μm (curv.1), 40μm(2), and the same values of $\gamma_1'', \gamma_2'', \tau$ is shown in Fig.2. One can note a characteristic beats form well described by Eq.(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.2. So at the definite parameters the SL dissipative properties including dichroic ones will not be intermediate between the same components properties. Strong oscillations of light absorbtion in the SL relatively to absorbtion in the components appear at $l\leqslant1/\beta$.

Fig.2

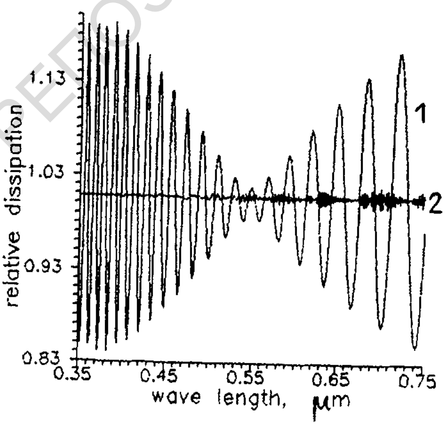
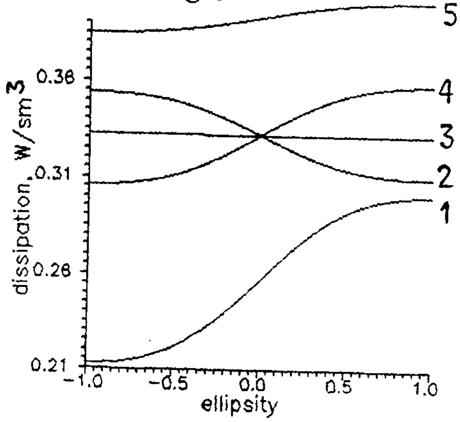


Fig.3



The effect of incident light ellipsity on the gyrotropic SL dissipation is characterized by Fig.3. Here $\varepsilon_1=(3,6\cdot10^{-3})$, $\varepsilon_2=(5,10^{-3})$, $\gamma_1''=6\cdot10^{-5}$ (curv.1,4,5), $-6\cdot10^{-5}$ (2,3), $\gamma_2''=5\cdot10^{-6}$ (1,2,4,5), $6\cdot10^{-5}$ (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 $\gamma_e''\leqslant10^{-6}$ with growth of the γ_e'' becomes non-linear(1,4,5) especially at near-circular polarization. The data of Fig.3 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 data reported can be used for the control and determination of the SL parameters by photothermoacoustic methods [7] where the signal measured is proportional to the value of absorbed light energy. For example, as it is seen from Eqs.(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.(4) with taking into account the dispersion $\varepsilon_1(\lambda)$, $\varepsilon_2(\lambda)$ the quadratic equation in the unknown x. At the known x the SL components optical constants can be determined.

So at typical parameters the simple model advanced predicts some characteristic dissipative properties of the gyrotropic SL satisfying the long optical wavelength approximation.

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