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IMPACT OF PIEZOELECTRIC AND FLEXOELECTRIC EFFECTS ON PHOTOREFRACTION

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The non-uniform electric fields of photorefractive holograms in electro-optic crystals may be accompanied by the elastic fields owing to converse piezoelectric and flexoelectric effects (see, e.g., [1] and [2], and references therein). In this report we consider series of photorefractive phenomena connected with an occurrence of such elastic fields both in the boundless crystals with no center of symmetry and in the semi-bounded ones.

In the absence of spatial dispersion the relevant equations of state determining reciprocal relationship between quasi-static electric and elastic fields in crystals with no center of symmetry can be represented from equations taking into account the response nonlocality [3] as

$$T_{ij} = C^{E}_{ijkl} S_{kl} - e_{mij} E_m + f_{ijmr} \frac{\partial E_m}{\partial x_r}, \qquad (1)$$

$$D_n = e_{nkl} S_{kl} + \varepsilon^{S}_{nm} E_m + f_{klnr} \frac{\partial S_{kl}}{\partial x_r}, \qquad (2)$$

where T_{ij} and S_{kl} are the tensor components of elastic stress and elastic strain, E_m and D_n are the vector components of the electric field and the electric displacement, and C^{E}_{ijkl}, ε^{S}_{nm} and e_{mij} are the tensor components of the elastic modulus, the static dielectric permittivity and the piezoelectric constants of the crystal, respectively. The last gradient terms in Eqs. (1) and (2) define respectively the converse and direct flexoelectric effects describable by fourth-rank flexoelectric tensor with components f_{ijmr}.

Here the solution for elastic fields of a photorefractive grating formed by continuous light pattern in boundless crystals can be obtained, as in [4] for converse piezoelectric effect solely, from the equation of elastostatics and Eq. (1). It is significant that an elastic strain distribution determined by converse piezoelectric effect is in-phase with electric field [4], whereas the converse flexoelectricity produces the similar distribution, but shifted by $\pi/2$. The magnitude of nonshifted component of the elastic strain is independent on fringe spacing Λ of the grating and is determined by anisotropy of piezoelectric properties of the crystal [1, 4]. By contrast, the magnitude of flexoelectrically induced elastic fields varies inversely with Λ, whence it follows that such shifted fields are meaningful for reflection gratings [2].

As can be seen from Eq. (2), the elastic strains and the gradient of ones provide the additional contribution to the electric polarization of crystal, which depends on the crystal anisotropy and on the parameters of photorefractive grating. To describe the formation of space-charge field of photorefractive grating with taking into account the piezoelectric contribution, the effective static dielectric permittivity ε' can be used [4]. This renormalized permittivity satisfies the inequality $\varepsilon^S \le \varepsilon' \le \varepsilon^T$, where ε^S and ε^T are the effective static dielectric permittivity without taking into account the piezoelectric effect for clamped and unclamped crystals, respectively. Our estimations have shown that value of ε' may differ from ε^S and ε^T to several tens of percents for ferroelectric crystals $LiNbO_3$ and $BaTiO_3$ [4], whereas the additional flexoelectric contribution to the electric polarization is negligibly small for all photorefractive crystals. In the last estimations we used the data about flexoelectric coefficients of dielectric materials from Ref. 5.

The contribution of elastic fields under consideration to the perturbation of the light-frequency dielectric tensor of a crystal, which is additional to the conventional electro-optic one, is determined by elasto-optic effect [1, 2]. The nonshifted piezoelectric component of elasto-optic contribution, which was well-known formerly (see, e.g., [1] and [6]), may even overtop the electro-optic one for certain directions of the grating vector in ferroelectric photorefractive crystals such as $BaTiO_3$. Our calculations relating to the two-wave interaction on the reflection holograms in the (111)-cut $Bi_{12}TiO_{20}$ crystals are demonstrated that piezoelectric part of elasto-optic contribution to the coupling coefficient Γ_{pe} is opposite in sign to the electro-optic one Γ_{eo} and is characterized by ratio $|\Gamma_{pe}|/|\Gamma_{eo}| = 0.39$. At the similar interaction in the (100)-cut $Bi_{12}TiO_{20}$ crystals, where $\Gamma_{pe} = 0$, the coupling is provided by the electro-optic mechanism of photorefraction only.

To discuss the additional contribution of nonshifted flexoelectric component of the elastic strain to photorefractive response we have considered the results of theoretical study for contradirectional interaction of a steady-state reference wave with a phase-modulated signal wave on the reflection photorefractive holograms in samples of *X*-cut crystals of the symmetry classes 23, $\bar{4}3m$, $\bar{4}2m$, 422, 622, 222, and 3*m* [2], and the results of experimental investigations of such interaction in the (100)-cut $Bi_{12}TiO_{20}$:Ni and $Bi_{12}TiO_{20}$:Fe,Cu crystals [2, 7] as well as in the (111)-cut $Bi_{12}TiO_{20}$:Ca,Ga crystal. Here it is convenient to exploit the flexoelectric coupling coefficient Γ_f, which values were experimentally measured as 0.13 cm^{-1} [2], 0.56 cm^{-1} [7] in the (100)-cut $Bi_{12}TiO_{20}$:Ni and $Bi_{12}TiO_{20}$:Fe,Cu crystals (at $\Gamma_{eo} = 4.14$ cm^{-1} in the last case), and as 0.014 cm^{-1} in the (111)-cut $Bi_{12}TiO_{20}$:Ca,Ga crystal (at $\Gamma_{eo} + \Gamma_{pe} = 0.07$ cm^{-1}). In addition, the response caused by absorption component of the reflection gratings with coupling coefficients estimated as $\Gamma_a = -0.11$ cm^{-1} [2], $\Gamma_a = -0.18$ cm^{-1} [7], and $\Gamma_a = -0.044$ cm^{-1} was observed in the above-mentioned experiments.

In spite of small values of flexoelectric coupling its contribution to the response is successfully extracted at interaction of a steady-state reference wave with a phase-modulated signal wave on reflection grating of the diffusion type in the above-mentioned crystals as a result of qualitative difference of the one from the rest of the types of coupling. This qualitative difference consists in the realization of linear phase-demodulation at interaction of the waves with circular polarizations of the opposite signs on reflection grating of the diffusion type by virtue of flexoelectric coupling only [2, 7].

Furthermore, we consider the electric and elastic fields of photorefractive gratings in semi-bounded piezoelectric crystals, where the relevant boundary conditions must be taking into account.

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