Impact of piezoelectric and flexoelectric effects on the wave mixing in photosensitive crystals

S M Shandarov[1] and V V Shepelevich[2]

[1]Tomsk State University of Control Systems and Radioelectronics, 40 Lenin Ave., Tomsk 634050, Russia
[2]I.P. Shamyakin Mozyr State Pedagogical University, 28 Studencheskaya Str., Mozyr 247760, Belarus

E-mail: stanislavshandarov@gmail.com

Abstract. We consider the main phenomena relating to elastic fields accompanying through the converse piezoelectric and flexoelectric effects the electric ones created in photosensitive crystals by inhomogeneous distributions of light intensity as a results of dynamic hologram formation.

1. Introduction

The non-uniform electric fields of photorefractive holograms 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 describe the main 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.

2. General equations

The elastic fields induced in the crystal by the space-charge field of photorefractive grating should satisfy the elastostatic equation [3]

$$\frac{\partial}{\partial x_j} T_{ij} = 0, \tag{1}$$

where T_{ij} are the tensor components of elastic stress. 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 in the general case can be represented from equations taking into account the nonlocality of response [4] as

$$T_{ij} = C_{ijkl}^{E} S_{kl} - e_{mij} E_m + f_{ijmr} \frac{\partial E_m}{\partial x_r}, \tag{2}$$

$$D_n = e_{nkl} S_{kl} + \varepsilon_{nm}^{S} E_m + f_{klnr} \frac{\partial S_{kl}}{\partial x_r}, \tag{3}$$

where S_{kl} are the tensor components of elastic strain, E_m and D_n are the vector components of the

electric field and electric displacement, and C_{ijkl}^{E}, ε_{nm}^{S}, and e_{mij} are the tensor components of the elastic modulus, the static dielectric permittivity and the piezoelectric constant of the crystal, respectively. The last gradient terms in Eqs. (2) and (3) define respectively the converse and direct flexoelectriceffects describable by fourth-rank flexoelectric tensor with components f_{ijmr}.

The solution for elastic fields of a photorefractive grating formed by continuous light pattern in boundless crystals can be obtained, as in [3] 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 [3], whereas the converse flexoelectricity produces the similar distribution, but shifted by π/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, 3]. By contrast, the magnitude of flexoelectrically induced elastic fields varies inversely with Λ and can be different from zero in centrosymmetrical photosensitive media also [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 [3]. This renormalized permittivity satisfies the inequality $\varepsilon^{S} \leq \varepsilon' \leq \varepsilon^{T}$, 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.

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 [5]), may even overtop the electro-optic one for certain directions of the grating vector in ferroelectric photorefractive crystals such as BaTiO$_3$.

In the case of the electric and elastic fields of photorefractive gratings in semi-bounded piezoelectric crystals, the relevant boundary conditions must be taking into account [6].

3. Conclusions
We have considered the main phenomena related to the elastic fields accompanying the electric ones created by inhomogeneous distributions of light intensity in photosensitive and photorefractive crystals owing to the converse piezoelectric and flexoelectric effects.

References
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