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ANISOTROPY OF ATTENUATION OF ACOUSTIC WAVES IN PHOTOREFRACTIVE BSO AND BGO CRYSTALS

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Висмут силикати ва висмут германати кристалларда акустик тўлқинларнинг сўниш анизотропияси 0.4–1.6 ГГц частотавий диапазонида тадқиқот қилинди. Ушбу кристалларда мавҳум константалар бўйича аниқланган анизотропия параметри қиймати 0.58 ва 0.52 сонларга тенг бўлганлиги кўрсатилди. (001) текисликда тарқалаётган пьезоактив кундаланг тўлқинлар учун диэлектрик йўқотишларнинг ҳисаси кузатилди ва шу тўлқинларнинг акустик сўниш анизотропияси енг катта бўлиши кўрсатилди.

Изучена анизотропия затухания акустических волн в кристаллах силиката висмута и германата висмута в частотном диапазоне 0.4–1.6 ГГц. Параметр анизотропии, определенный по мнимым константам кристаллов BSO и BGO, оказался равным 0.58 и 0.52 соответственно. Показано, что наибольший вклад диэлектрических потерь в затухание акустических волн наблюдается для пьезоактивных поперечных волн, распространяющихся в плоскости (001).

Anisotropy of attenuation of acoustic waves in photorefractive BSO and BGO crystals has been studied in the frequency range of 0.4–1.6 GHz. The anisotropy parameters determined by the imaginary constants of BSO and BGO crystals are equal 0.58 and 0.52, respectively. It is shown that the most contribution of dielectric loss to the attenuation of acoustic waves is observed for the piezoactive transversal waves propagating in the (100) plane.

I. INTRODUCTION

The photorefractive crystals of bismuth silicate $Bi_{12}SiO_{20}$ (BSO) and bismuth germanate $Bi_{12}GeO_{20}$ (BGO) are widely used as an active medium in different optic and acoustooptical devices [1-3]. One of the main parameters of these devices is the attenuation coefficient of the acoustic waves, which can be calculated using the real and imaginary components of the elasticity tensor [4, 5]:

$$c_{ijkl} = c'_{ijkl} + ic''_{ijkl}, \tag{1}$$

which enter into the expression of effective elastic constant:

$$c_{eff} = c'_{eff} + ic''_{eff} = c'_{ijkl}\kappa_j\kappa_l\gamma_i\gamma_k + ic''_{ijkl}\kappa_j\kappa_l\gamma_i\gamma_k, \tag{2}$$

where κ_j and γ_i are the direction cosines of the wave vector and the displacement vector, respectively. The real components of the elastic constant tensor c'_{ijkl} for these crystals were measured in a number of papers [6, 7]. As for the imaginary components c''_{ijkl} which describe the attenuation of acoustic waves, they were practically not investigated. In the present paper, the detailed study of the complex tensor of elastic constants of BSO and BGO crystals was carried out to determine the anisotropy of attenuation of high-frequency acoustic waves at room temperature. On the whole, the study of the anisotropy of the elastic properties of these crystals seems to be important for solution of many problems of nonlinear acoustics and nonlinear optics.

II. EXPERIMENTAL METHODS

The crystals $Bi_{12}SiO_{20}$ and $Bi_{12}GeO_{20}$ were grown by the Czochralski technique on a Donets-1 setup. The crystals were prepared in the form of a parallelepiped with sides 16×8×4 mm. The faces of samples have been oriented with accuracy no worse than 1° along the <001>, <110> and <111> crystallographic directions. All faces of the parallelepipeds were processed by mechanical polishing and polishing with optical accuracy.

The velocity and attenuation of acoustic waves were investigated with the help of Bragg diffraction of light on acoustic waves in frequency range 0.4–1.6 GHz. Longitudinal and transverse acoustic waves were excited by piezoelectric transducers of quartz, accordingly of the X-cut or Y-cut. The helium-neon laser with a wavelength of 632.8 nm was used as a light source. The intensities of diffracted light were measured with the help of photoelectric multiplier.

The acoustic wave velocity V was determined from the Bragg diffraction angle with the accuracy of 0.2% [5]:

$$V = \lambda\nu / 2\sin\theta_B , \tag{3}$$

where ν is the linear frequency of acoustic wave, θ_B – the external Bragg angle.

The anisotropy of the attenuation has been investigated for longitudinal and transverse acoustic waves propagating in the plane of symmetry (001) of these crystals. The attenuation coefficient was calculated with the accuracy ~ 5% by the formula:

$$\alpha = 10\lg\left(I_1/I_2\right) / 2L_0 . \tag{4}$$

Here L_0 is the length of the sample, I_1 and I_2 are the intensity of the light diffracted on the direct acoustic wave and the intensity of the light diffracted on the wave, reflected from the free end of the sample, respectively. These measurements were carried out at the same point of the sample along the wave propagation direction.

III. RESULTS OF EXPERIMENTS AND DISCUSSION

The experimental values of the velocity and the attenuation of acoustic waves along the <001>, <110> and <111> directions were used to determine all the independent components of the complex tensor of elastic constants c_{ijkl}, which define effective elastic constant in equation (2). Anisotropy of the velocity and attenuation of acoustic waves in BGO and BSO crystals was considered for the (001) plane, which is orthogonal to the symmetry axis of the second order. The direction cosines of the wave vector of waves propagating in this plane are equal to $\kappa_1=\cos\psi$, $\kappa_2=\sin\psi$, $\kappa_3=0$. Then the components (respectively real or imaginary) of the Green-Christoffel tensor can be written in the form [1, 4]:

$$\Gamma_{11}=c_{11}(\cos\psi)^2+c_{44}(\sin\psi)^2$$
$$\Gamma_{22}=c_{44}(\cos\psi)^2+c_{11}(\sin\psi)^2$$
$$\Gamma_{33}=c_{44}$$
$$\Gamma_{12}=\Gamma_{21}=(c_{12}+c_{44})\cos\psi\sin\psi$$
$$\Gamma_{13}=\Gamma_{31}=\Gamma_{23}=\Gamma_{32}=0$$

In these expressions, the angle ψ is the angle between the direction of the wave vector and the second-order symmetry axis [100]. Components $c_{\alpha\beta}$ are substituted real or imaginary, respectively. In particular, the real part of the effective elastic constant will be written as:

$$c'_{eff} = \frac{\Gamma'_{11} + \Gamma'_{22}}{2} \pm \frac{1}{2}\sqrt{(\Gamma'_{11} - \Gamma'_{22})^2 + 4\Gamma'^2_{12}} \,. \tag{5}$$

As a result, the phase velocities of the longitudinal and one of transverse waves polarized in the (001) plane of the BSO and BGO crystals are determined in terms of the real components of the elastic constants tensor by the expression:

$$V^2_{1,2} = \frac{c'_{11} + c'_{66} \pm \sqrt{(c'_{11} - c'_{66})^2 \cos^2 2\psi + (c'_{12} + c'_{66})^2 \sin^2 2\psi}}{2\rho} \,. \tag{6}$$

Relation (6) determines the values of the velocities of two waves, the polarization of which lies in the (001) plane. In this case, the [100] and [010] axes are equivalent. The expression for imaginary effective elastic constant is obtained, if in expressions (5) and (6) change the real components of the elastic constants tensor into suitable imaginary elastic constants.

The obtained values of effective elastic constants were used for calculation of the anisotropy of the attenuation of longitudinal and transverse waves in the (001) plane by the equation [4, 5]:

$$\alpha = \pi\nu \frac{c''_{eff}}{c'_{eff}} \,. \tag{7}$$

The results of calculation are shown in Fig. 1 in the form of cross-section of characteristic surfaces of attenuation of acoustic waves by plane (001). It is seen that the strongest anisotropy of transversal waves is observed in BGO crystals.

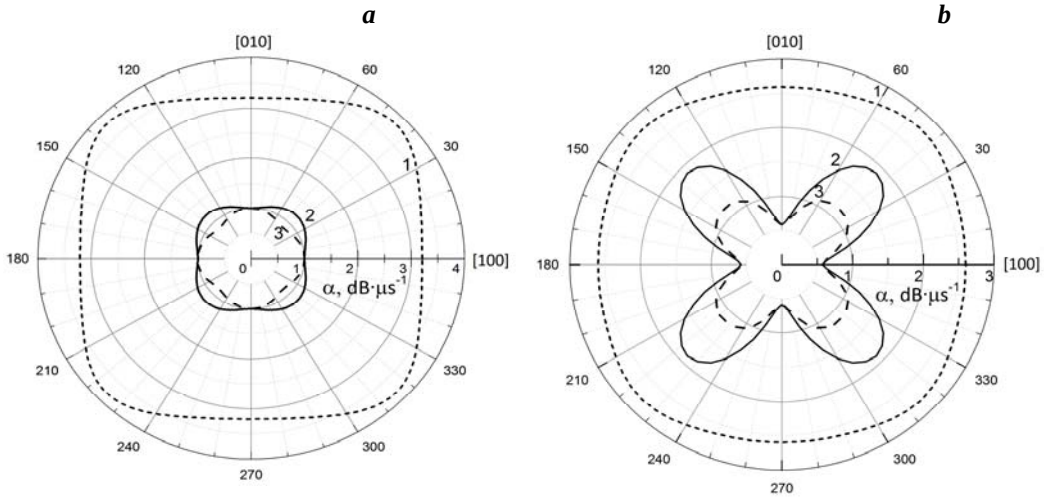


Fig. 1. Anisotropy of the attenuation of quasilongitudinal (*1*), quasitransverse (*3*) and pure transverse (*2*) waves in BSO (*a*) and BGO (*b*) crystals.

In crystals of bismuth silicate and bismuth germanate longitudinal waves along [111] and slow transverse waves along [110] are piezoactive and for them it is necessary to take into account the contribution of dielectric losses to attenuation [8]. For slow transverse waves along [110] the imaginary effective elastic constant is written in the form [5]:

$$c''_{eff} = c''_{44} + (e^2_{14} / \varepsilon_0 \varepsilon) \mathrm{tg}\delta \,. \tag{8}$$

Here e_{14} is the piezoelectric coefficient, ε – the dielectric constant, and tgδ – the tangent of the dielectric loss angle. The calculations with help of equations (7) and (8) have shown that this contribution is most significant in crystals of bismuth germanate and it is about 45%.

By analogy with the anisotropy factor of the real parts of the elastic module A^{Re} [9], one can introduce the anisotropy factor of imaginary modules [10]:

$$A^{\mathrm{Im}} = \frac{2c''_{44}}{c''_{11} - c''_{12}}. \tag{9}$$

The A^{Im} factor in BSO crystals is 0.58 and it is close to $A^{\mathrm{Re}} = 0.49$. At the same time, in BGO crystals these factors are very different (0.52 and 0.26, respectively), that can be due to the anisotropy of the Grüneisen parameter [11], which leads to a noticeable anisotropy of the acoustic attenuation.

IV. CONCLUSION

It is shown that the anisotropy of attenuation of acoustic waves is right described by the proposed equations. The results of the calculations coincide with the experimental results with good accuracy. It can be seen that in the considered crystallographic plane the longitudinal acoustic waves have the greatest attenuation value. A relatively strong anisotropy of the attenuation of acoustic waves is observed in BGO crystals that can be explained by the contribution of dielectric loss to the attenuation. The obtained results can be useful in the development of acousto-optical devices used for the transformation or dynamic control of signals in optical and fiber-optic communication lines.

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