Photoelectric fields in doped lithium niobate crystals

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ABSTRACT

Photoinduced light scattering (PILS) in nominally pure stoichiometric and congruent lithium niobate single crystals ($LiNbO_3$), and ones doped with B^{3+}, Cu^{2+}, Zn^{2+}, Mg^{2+}, Gd^{3+}, Y^{3+}, Er^{3+} cations was studied. All crystals have a relatively low effect of photorefraction and are promising materials for frequency conversion, electro-optical modulators and shutters. It was found that the photovoltaic and diffusion fields for some crystals have a maximum at a wavelength of 514.5 nm. All the crystals studied are characterized by a maximum of the integral intensity of the speckle structure of the PILS at a wavelength of 514.5 nm.

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1. Introduction

The ferroelectric photorefractive lithium niobate crystal ($LiNbO_3$) is characterized by a high value of spontaneous polarization, large values of the photoinduced electric fields intensity [1, 2]. The control of the photorefraction (optical damage) magnitude is usually carried out by doping of the crystal with cations of various metals [1, 2]. Photorefractive effect causes Rayleigh photoinduced light scattering, which occurs on static and dynamic (fluctuating) defects with an altered refractive index induced by laser radiation [3, 4]. In this case, the value of the electro-optical effect determines the value of the angle θ of the PILS indicatrix opening in the crystal [4].

In this paper, the angular distribution of the intensity of the speckle structure of the PILS as a function of the wavelength of the exciting laser radiation was studied. Experiments were performed in nominally pure stoichiometric ($LiNbO_{3stoich}$) and congruent ($LiNbO_{3cong}$) lithium niobate single crystals, and ones doped with B^{3+}, Cu^{2+}, Zn^{2+}, Mg^{2+}, Gd^{3+}, Y^{3+}, Er^{3+} cations. The following laser lines were used in PILS experiment: 476.5, 488.0, 514.5 and 532.0 nm. Quantitative estimation of the photovoltaic (E_{pv}) and diffusion (E_D) fields values were made using the approach described in [3].

2. Experiment setup

$LiNbO_3$ crystals were grown from the congruent melt at the "Crystal-2" installation by the Czochralski technique in air [5]. $LiNbO_{3stoich}$ crystal was grown from the melt with

58.6 mol. % of Li_2O. PILS registration was carried out using an installation, described in details in [4]. For the PILS registration the following lines of Spectra Physics (2018-RM) argon-krypton laser were used: 476.5 nm ($P = 216$ mW), 488.0 nm ($P = 98$ mW), 514.5 nm ($P = 282$ mW) and 532.0 nm ($P = 160$ mW). The value of the intensity of the photovoltaic and diffusion fields in crystals was calculated in the Mathcad 15.0 program using the approach proposed in [3]. The refractive indices of the extraordinary and ordinary rays were determined from empirical equations [6].

3. Results and discussion

The speckle structure of the PILS pattern of $LiNbO_3$ crystals is determined by the features of the secondary structure of the crystal, which depends significantly on the composition and growing technology [1, 2, 4]. The birefringence of the crystal, both intrinsic and induced by laser radiation, is also important. At a power of excitation laser radiation of 160 mW, the indicatrix of the speckle structure of the PILS in $LiNbO_3$, $LiNbO_3$: Zn (2.93), $LiNbO_3$: Gd (0.002): Mg (0.04), $LiNbO_3$: Er (3.1 wt. %) crystals is not revealed, and only circular scattering on crystal lattice defects is observed. For all other crystals investigated the indicatrix of the PILS is asymmetric with the form of a figure eight or an ellipse stretched along the polar axis.

It should be noted that for the $LiNbO_3$: Y (0.46 wt. %) crystal at $P = 160$ mW, the indicatrix of the speckle structure of the PILS is revealed very rapidly, in a time of about 1 s. For all other crystals, the opening time of the speckle structure of the PILS is about 60 s.

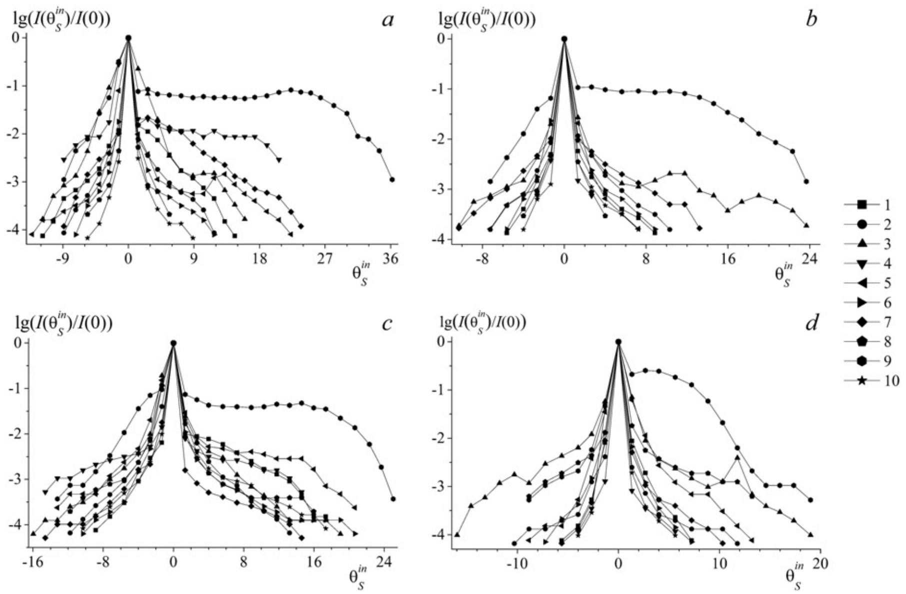

Figure 1. The angular distribution of the scattered light intensity at $\lambda = 476.5$ (*a*), 488.0 (*b*), 514.5 (*c*), 532 (*d*) nm for the following crystals: $LiNbO_3$:Zn (0.018) (1); $LiNbO_3$:Zn (2.93) (2); $LiNbO_3$:Y (0.46) (3); $LiNbO_3$:Cu (0.007):Gd (0.02) (4); $LiNbO_3$:Gd (0.05) (5); $LiNbO_3$:Gd (0.002):Mg (0.4) (6); $LiNbO_3$:B (0.08 in the reacted mixture) (7); $LiNbO_3$:Er (3.1 wt. %) (8); $LiNbO_{3stoich}$ (9); $LiNbO_{3cong}$ (10).

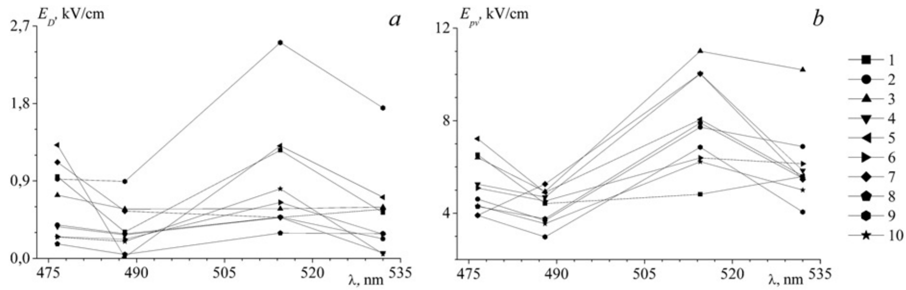

Figure 2. Dependence of E_D (*a*) and E_{pv} (*b*) on laser line wavelength for $LiNbO_3$ crystals with various composition: $LiNbO_3$:Zn (0.018) (1); $LiNbO_3$:Zn (2.93) (2); $LiNbO_3$:Y (0.46) (3); $LiNbO_3$:Cu (0.007):Gd (0.02) (4); $LiNbO_3$:Gd (0.05) (5); $LiNbO_3$:Gd (0.002):Mg (0.4) (6); $LiNbO_3$:B (0.08 in the reacted mixture) (7); $LiNbO_3$:Er (3.1 wt. %) (8); $LiNbO_{3stoich}$ (9); $LiNbO_{3cong}$ (10).

It can be seen from Figure 1 that crystals $LiNbO_{3stoich}$, $LiNbO_3$: Gd (0.05) and $LiNbO_3$: Y (0.46 wt. %) possess the greatest asymmetry and the scattered radiation angle θ in the series of crystals studied, regardless of the wavelength of the exciting line. At the same time, for a $LiNbO_{3stoich}$ crystal, the shape of the scattering curve when excited by laser lines 476.5, 488.0, and 532.0 nm is approximately the same, but differs significantly from them when excited by a 514.5 nm laser line, Figure 1.

Figure 2 shows the dependences of the E_{pv} and E_D intensities in the investigated crystals on the wavelength of the exciting radiation. For $LiNbO_3$: Zn (0.018), $LiNbO_3$: Zn (2.93), $LiNbO_3$: Gd (0.05 wt. %) crystals, a maximum in the E_D dependence at the length of the exciting laser line of 514.5 nm is observed. However, the maximum in the E_D dependence are not observed for $LiNbO_3$: Er (3.1), $LiNbO_3$: B (0.08), $LiNbO_3$: Y (0.46 wt. %) crystals.

For $LiNbO_3$: Y (0.46), $LiNbO_3$: Cu (0.007): Gd (0.02), $LiNbO_3$: B (0.08 wt. %), $LiNbO_3$: Gd (0.05), $LiNbO_3$: Zn (2.93 wt. %), $LiNbO_{3stoich}$ crystals the maximum in the E_{pv} dependence is also observed at the length of the exciting laser line of 514.5 nm. But at the same time, the maximum is absent for $LiNbO_3$: Zn (0.018), $LiNbO_3$: Gd (0.02): Mg (0.4) crystals. It is also seen from Figure 2 that the $LiNbO_{3stoich}$ crystal at wavelengths of the exciting radiation of 476.5, 488.0 and 532.0 nm and $LiNbO_3$: Zn (0.018 wt. %) at 514.5 nm possess the smallest value of the E_{pv}.

4. Summary

Photoinduced light scattering in nominally pure $LiNbO_{3stoich}$ and $LiNbO_{3cong}$ single crystals ($LiNbO_3$), and ones doped with B^{3+}, Cu^{2+}, Zn^{2+}, Mg^{2+}, Gd^{3+}, Y^{3+}, Er^{3+} cations was studied. According to the characteristics of the PILS, a quantitative estimation of the intensity of the photovoltaic and diffusion fields was made. It was found that the E_{pv} and E_D for some crystals have a maximum at a wavelength of 514.5 nm. However, for the $LiNbO_3$: Y crystal (0.46 wt. %) there is no maximum in the E_{pv} dependence, but one at a wavelength of 514.5 nm in E_D dependence.

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