The Influence of Mechanical Stress on Electrooptical Coefficients r_{22} and $n_e^3r_{33}$-$n_0^3r_{13}$ in $LiNbO_3$ and $LiTaO_3$ Crystals

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Received 01.03.2003

Abstract

The combined piezo-electrooptical effect in $LiNbO_3$ and $LiTaO_3$ crystals is studied. It is shown that the mechanical stresses change notably the electrooptical (EO) coefficient r_{22} of lithium niobate and the coefficient $n_e^3r_{33}$-$n_0^3r_{13}$ of lithium tantalate crystals. The largest increment of electrooptical coefficients under the mechanical stresses is observed in $LiNbO_3$ crystals at the experimental geometry of $k||Z$, $E||Y$ and $\sigma||Y$. In case of $LiNbO_3$ crystals subjected to the compressing mechanical stress $\sigma_2 = 2.0\times10^7$N/m^2, the EO coefficient r_{22} increases approximately two times, while the half-wave voltage decreases by the same value. The obtained dependence of the angle ξ_3 of optical indicatrix rotation under the applied electric field E_1 and the mechanical compressive stress σ_1 testifies a possibility for controlling the optical indicatrix orientation in $LiNbO_3$ crystals in the range of $|0\text{-}45|$ deg.

Key words: piezo-electrooptical effect, $LiNbO_3$, $LiTaO_3$

PACS: 78.20.Hp

Introduction

$LiNbO_3$ and $LiTaO_3$ crystals are well known as efficient electrooptical (EO) materials. They are widely used in different EO devices. The EO properties of $LiNbO_3$ and $LiTaO_3$ crystals are already well studied [1,2]. On the other hand, lithium niobate and lithium tantalate crystals are rather sensitive to different external influences, e.g., temperature, optical radiation and the mechanical stresses. Concerning the influence of mechanical stresses on the optical properties of the mentioned crystals, their piezooptical coefficients have a large magnitude [1,3]. It has been shown in our recent works that the EO coefficients could be changed by application of mechanical stress due to a combined piezo-electrooptical effect [4-6]. It should mean a possibility to operate the performance characteristic of EO device, using the change of its EO coefficients induced by external mechanical stresses. Finally, we notice that the EO coefficients dealt with in the EO devices based on $LiNbO_3$ and $LiTaO_3$ crystals, are r_{22} and $n_0^3r_{13}$-$n_e^3r_{33}$, respectively.

The present paper is devoted to studies of the changes in the mentioned EO coefficients due to the applied mechanical stresses.

Experimental

All the studies were carried out with the known Senarmont technique. He-Ne laser with the wavelength of radiation 632.8 nm was used as a light source. The geometry of the experiments was $k||Y$, $E||Z$, $\sigma||X$, $\sigma||Z$ for $LiTaO_3$ crystals and $k||Z$, $E||Y$, $\sigma||Y$ for $LiNbO_3$ crystals.

The change of the birefringence $\delta(\Delta n)_{12}$ under the mutual application of the electric field E_2 and the mechanical stress σ_2 to $LiNbO_3$ crystals can be written as

$$\begin{aligned}\delta(\Delta n)_{12} &= 1/2n_0^3r_{22}E_2 + \\ &+1/2n_0^3(\pi_{12}-\pi_{22})\sigma_2 + 1/2n_0^3N_{222}E_2\sigma_2\end{aligned}, \quad (1)$$

while the corresponding change of the EO coefficient r_{22} caused by the mechanical stress is given by

$$r_{22}=N_{222}\sigma_2, \quad (2)$$

where π_{ij} are the components of piezooptical tensor and N_{ijk} the components of the piezo-electrooptical fifth-rank polar tensor. For $LiTaO_3$ crystals, the change of the birefringence $\delta(\Delta n)_{13}$ under the mutual application of the electric field E_3 and the mechanical stresses σ_3 and σ_1 can be written as

$$\begin{aligned}\delta(\Delta n)_{13}=&1/2\left(n_3^3 r_{33}-n_1^3 r_{13}\right)E_3+\\&+1/2(n_3^3\pi_{33}\text{-}n_1^3\pi_{13})\sigma_3+\\&+1/2\left(n_3^3 N_{333}-n_1^3 N_{133}\right)E_3\sigma_3\end{aligned}, \quad (3)$$

$$\begin{aligned}\delta(\Delta n)_{13}=&1/2\left(n_3^3 r_{33}-n_1^3 r_{13}\right)E_3+\\&+1/2(n_1^3\pi_{11}\text{-}n_3^3\pi_{31})\sigma_1+\\&+1/2\left(n_1^3 N_{131}-n_3^3 N_{331}\right)E_3\sigma_1\end{aligned}, \quad (4)$$

respectively, whereas the change of the EO coefficients $n_3^3 r_{33}-n_1^3 r_{13}$ under the mechanical stress is as follows:

$$\left(n_3^3 r_{33}-n_1^3 r_{13}\right)=\left(n_1^3 N_{333}-n_3^3 N_{133}\right), \quad (5)$$

$$\left(n_3^3 r_{33}-n_1^3 r_{13}\right)=\left(n_1^3 N_{131}-n_3^3 N_{331}\right). \quad (6)$$

As a consequence, one can assume that the application of mechanical strains to the $LiNbO_3$ and $LiTaO_3$ crystals would lead to changes in both the EO coefficients and the half-wave electric voltage.

Results and discussion

The change of the EO coefficient $n_3^3 r_{33}-n_1^3 r_{13}$ in $LiTaO_3$ crystals observed under the applied mechanical stress is presented in Fig.1.

As seen from Fig. 1, the influence of mechanical stress σ_3 on $LiTaO_3$ crystals does not lead to essential changes in the EO coefficient, while the influence of compressing mechanical stress σ_1 on $LiTaO_3$ crystals causes decreasing the EO coefficient $n_3^3 r_{33}-n_1^3 r_{13}$. However, in case of the compressive mechanical stress σ_3=2.0×10^{7}N/m^2 applied to $LiNbO_3$ crystals, the EO coefficient r_{22} increases approximately two times (Fig. 2). That is why one of the most important functional characteristics of EO devices based on the $LiNbO_3$ crystals, the half-wave voltage,

$$U_{\lambda/2}=\frac{\lambda}{n_0^3 r_{22}}\frac{d_y}{d_z}, \quad (7)$$

(with λ being the light wavelength, d_y the sample thickness along the direction of electric field, and d_z the sample thickness along the light propagation) can be decreased through application of mechanical stresses. Since the

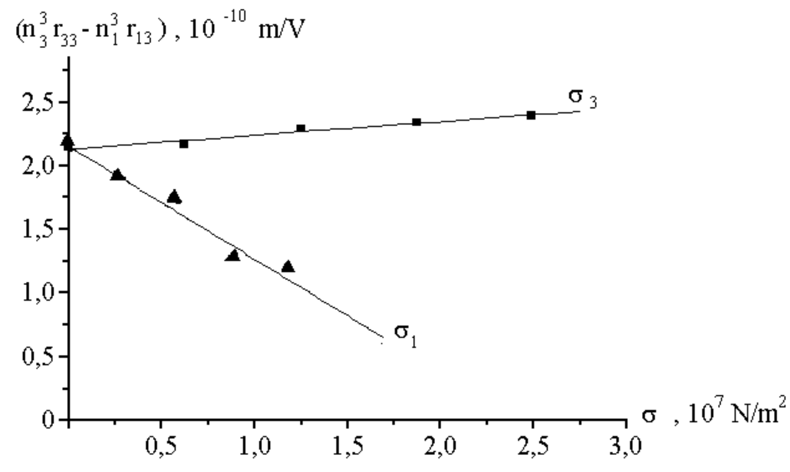

Fig. 1. The dependence of EO coefficient $n_3^3 r_{33}$-$n_1^3 r_{13}$ on the mechanical stresses σ_1 and σ_3 for $LiTaO_3$ crystals (λ=632.8nm, T=20^{0}C).

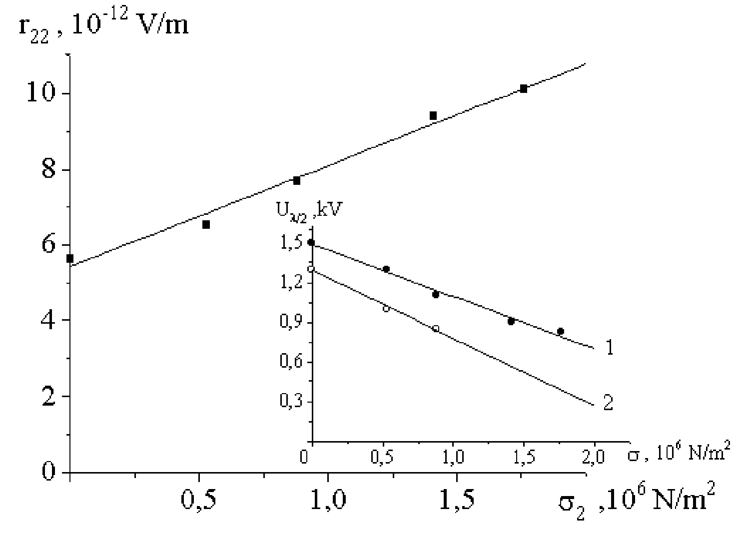

Fig. 2. The dependence of EO coefficient r_{22} on the mechanical stress σ_2 for $LiNbO_3$ crystals (λ=632.8nm, T=20^{0}C); insert: the dependence of the half-wave voltage for $LiNbO_3$ crystals subjected to the mechanical stress σ_2: 1 – the data calculated on the basis of measurements of EO coefficient, 2 – those experimentally obtained on the basis of direct measurements of the half-wave voltage (see Fig.3).

dimensions of $LiNbO_3$ crystal sample in our case were d_y=4×10^{-3} m and d_z=25×10^{-3} m, one can easily calculate the corresponding change in the half-wave voltage due to the mechanical stress (see Fig. 2, insert).

The experimental dependences of the light transmission on the electric field obtained for the $LiNbO_3$ crystal placed in the diagonal position between the crossed polarizers is presented in Fig.3. One can see that the half-wave voltage decreases when the compressive stress σ_2 is applied to $LiNbO_3$ crystals. At the same time, the modulation depth also decreases, due to the piezooptical effect.

The application of the electric field $E||X$ and the mechanical stress $\sigma||X$ to $LiNbO_3$ crystals should induce the rotation of the optical indicatrix by the angle depending on the values of both the electric field and the mechanical stress, according to the relation

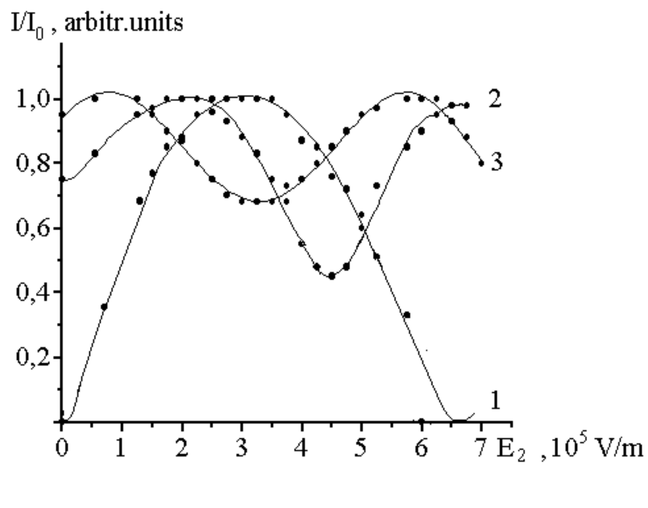

Fig. 3 The dependences of the light transmission on the electric field for $LiNbO_3$ crystals placed in the diagonal position between the crossed polarizers at different values of the mechanical stress: 1-σ_2=0 N/m^2, 2-σ_2=5.3×10^5 N/m^2 and 3-σ_2=8.8×10^{5}N/m^2 (λ=632.8nm, T=20^{0}C)

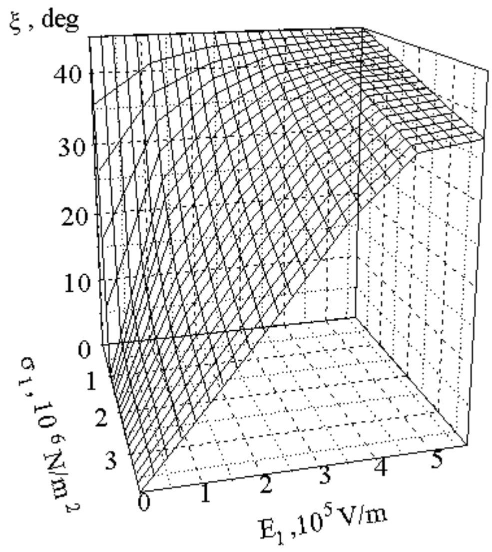

Fig.4. The dependence of the angle of optical indicatrix rotation in $LiNbO_3$ crystals under the mutual influence of the electric field E_1 and the mechanical stress σ_1 (λ=632.8nm, T=20^{0}C).

$$\tan 2\xi = \frac{2r_{22}E_1}{(\pi_{11}-\pi_{12})\sigma_1}, \qquad (8).$$

This dependence is presented in Fig. 4.

The data of Fig. 4 clearly demonstrate that a mutual influence of the electric field and the mechanical stress enables one to control the orientation of optical indicatrix in $LiNbO_3$ crystals.

Conclusions

The combined piezo-electrooptical effect in the $LiNbO_3$ and $LiTaO_3$ crystals is studied in this work. It is shown that the mechanical stresses change the EO coefficients r_{22} of lithium niobate and the coefficient $n_3^3 r_{33} - n_1^3 r_{13}$ of lithium tantalate crystals. The largest increment of EO coefficients under the application of mechanical stress was observed in $LiNbO_3$ crystals at the following experimental geometry: $k||Z$, $E||Y$ and $\sigma||Y$. It is revealed that the EO coefficient r_{22} of $LiNbO_3$ crystals increase, while the half-wave voltage decreases approximately two times, when the compressive mechanical stress σ_2=2.0×10^{7}N/m^2 is applied. The obtained dependence of the angle ξ_3 of optical indicatrix rotation due to the applied electric field E_1 and the mechanical compressive stress σ_1 testifies that it is possible to operate the optical indicatrix orientation in $LiNbO_3$ crystals in the range as large as |0-45| deg.

References

1. Kuzminov Yu.S. Lithium niobate and lithium tantalate - materials for nonlinear optics. “Nauka” Moskow (1975) 223 (in Russian).
2. Sonin A.S., Vasilevskaya A.S. Electrooptical crystals. Moscow “Atomizdat” (1971) (in Russian).
3. Vasilina Z.S., Vibluy I.F., Vlokh O.G., Romanyuk M.O., Kostecky A.M. Dielectrics and semiconductors. (1977) 3 (in Russian).
4. Vlokh R., Gotra Z., Andrushchak A., Mys O., Kaidan M. Ukr. J. Phys. Opt. **2** (2001)
5. Mys O., Vlokh R. Ukr.J.Phys.Opt. **4** (2001) 187.
6. Vlokh R., Mys O., Andrushchak A., Kostyrko M. Ukr. J. Phys. Opt. **3** (2002) 115.