# Combined Piezoelectrooptical Effect in $LiNbO_3$ and $LiTaO_3$ Crystals

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## Abstract

The paper is devoted to the study of the combined piezoelectrooptical effect in $LiNbO_3$ and $LiTaO_3$ crystals induced by the mutual influence of the electric field and mechanical strain. The coefficients of the combined piezoelectrooptical effect were determined as $N_{313}$=3.6×10$^{-18}$m$^3$/NV for lithium niobate crystals and $N_{313}$=4.8×10$^{-18}$m$^3$/NV obtained from dependence of piezooptical coeffecients on the electrical field as well as $N_{313}$=4.32×10$^{-18}$m$^3$/NV obtained from dependence of electrooptical coefficients on the mechanical strain for $LiTaO_3$ crystals. It was shown that at the bias field $E_3$≈1.2×10$^6$V/m the piezooptical coefficient $\pi_{31}$=0 changes the sign for $LiNbO_3$ crystals as well as in $LiTaO_3$ crystals at $E_3$≈1.6×10$^6$V/m $\pi_{31}$=0 and at $\sigma_1$≈2.5×10$^7$N/m$^2$ the electrooptical coeffecient $r_{33}$=0. It is shown that the change of electrooptical coefficients under the mechanical strain and that of piezooptical coefficients under the electrical field are interchangeable effects.

**Key words:** piezoelectrooptical effect, lithium niobate, lithium tantalate, combined effect.

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## Introduction

As it was shown in our previous reports [1, 2] the change of piezooptical coefficients at ferroelectrical phase transitions in $Ca_2Pb(C_2H_5CO_2)_6$ and $Pb_5Ge_3O_{11}$ crystals is linearly or quadratically proportional to the spontaneous polarization. It means that piezooptical coefficients can be changed by the polarization or bias electrical field

$$\Delta\pi_{ijkl}=N_{ijklm}E_m+L_{ijklmn}E_mE_n, \qquad (1)$$

where $\Delta\pi_{ijkl}$ - change of piezooptical coefficients, $N_{ijklm}$, $L_{ijklmn}$ - fifth and six rank polar tensors and $E_m$, $E_n$ - electrical field. On the other hand this effect can be interpreted as a combined piezoelectrooptical effect, i.e. an effect that consists in the change of refractive indices $n=1/(a_{ij})^{1/2}$ at mutual influence of the electric field and mechanical strain and described as

$$\Delta a_{ij}=N_{ijklm}\sigma_{kl}E_m+L_{ijklmn}\sigma_{kl}E_mE_n. \qquad (2)$$

It is interesting to note that the linear piezoelectrooptical effect can exist only in noncentrosymmetrical crystals as well as quadratic ones - in media with any point group of symmetry.

The present paper is devoted to the study of the piezoelectrooptical effect induced by an external mechanical strain and electrical field. For this we chose the $LiNbO_3$ and $LiTaO_3$ crystals as well known electrooptical and acoustooptical materials [3,4].

## Experimental

The induced piezoelectrooptical effect in the $LiNbO_3$ and $LiTaO_3$ crystals was studied by the Senarmon method. As a light source the He-Ne laser was used with the wavelength of radiation 632.8 nm. The experimental setup (Figure 1)

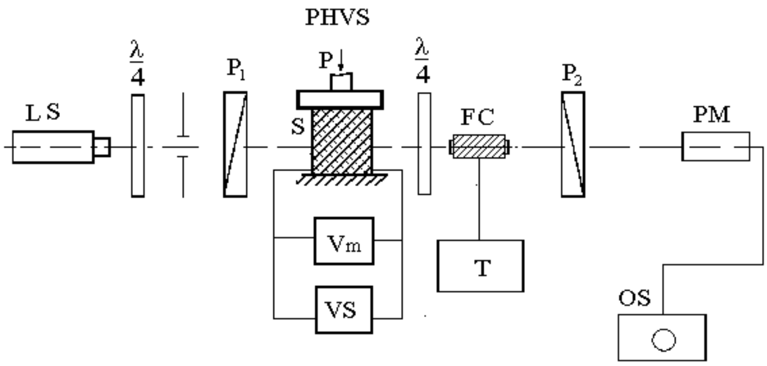


**Fig1.** Experimental setup for the measurement of the optical birefringence on the applied electrical field and mechanical strain.

consisted of a laser (LS), a quarter-wave plate (λ/4), a polarizator ($P_1$), the sample (S) that was placed in the pressure-high-voltage setup (PHVS), a compensator (λ/4), a Faraday cell (FC), a polarizator with angle scale ($P_2$), a photomultiplayer (PM), an oscilloscope (OS), a voltage transformator (T), a kilovoltmeter (Vm) and a voltage source (VS). The accuracy of determination of the polarization plane rotation was not worse than 0.05°. The electrical field and mechanical compressive strain were applied along $Z$ and $X$ - directions, respectively. The optical radiation was propagated along the principle crystallophysical direction, perpendicular to the optical axis.

## Results and discussion

As it is visible from Figure 2 the linear dependencies of induced birefringence on the mechanical strain at different electrical fields in $LiNbO_3$ crystals possesses a different inclination to the coordinate axis. It means that the piezooptical coefficient changes its value under a bias electrical field. The dependence of the change of the piezooptical coefficient on the electrical field is presented on Figure 3. This dependence is linear and on the base of this dependence it is possible to estimate the magnitude of the electrical field ($E_3 \approx 1.2\times10^6$V/m) at which the piezooptical coefficient $\pi_{31}=0$ and changes the sign.

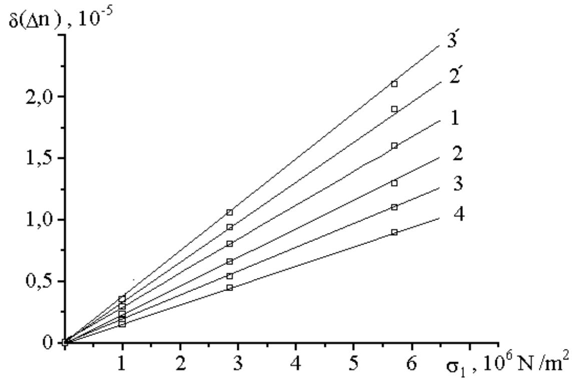


**Fig.2.** The dependencies of the change of birefringence on the mechanical strain $\sigma_1$ at different magnitudes of electrical field $E_3$ in $LiNbO_3$ crystals ((1)-$E_3$=0; (2)-$E_3=2.7\times10^5$V/m; (3)-$E_3=4.0\times10^5$V/m; (4)-$E_3=5.7\times10^5$V/m; λ=632.8nm; T=20°C).

Similar dependencies were obtained for $LiTaO_3$ crystals for the piezooptical change of birefringence at a bias electrical field (Figure 4) as well as for the electrooptical change of birefringence on external mechanical strain (Fig. 5). From these dependencies it is also possible to estimate the magnitude of the electrical field at which the piezooptical coefficient ($E_3 \approx 1.6\times10^6$V/m) $\pi_{31}=0$ and the magnitude of mechanical strain ($\sigma_1 \approx 2.5\times10^7$N/m$^2$) at which electrooptical coeffecient is $r_{33}=0$ (Fig. 6, 7).

Let us consider the equation of the optical indicatrix at the applied electrical field $E_3$ and mechanical strain $\sigma_1$ for the crystal with a point group of symmetry 3m:

$$(a_1+r_{13}E_3+\pi_{11}\sigma_1)x^2+(a_1+r_{13}E_3+\pi_{21}\sigma_1)y^2 +(a_{33}+r_{33}E_3+\pi_{31}\sigma_1+N_{313}\sigma_1E_3)+2\pi_{41}\sigma_{11}zy=1$$

Were we to neglect the turning of the optical indicatrix, the change of induced birefringence can be written as

$$\delta(\Delta n)_{zx}=\delta(\Delta n)^E_{zx}+\delta(\Delta n)^\sigma_{zx}+\delta(\Delta n)^{\sigma E}_{zx}=\{(n^3_3r_{33}-n_1^3r_{13})E_3+(n_1^3\pi_{11}-n_3^3\pi_{31})\sigma_1+n_3^3N_{313}\sigma_1E_3\}/2.$$

The exception of the the piezooptical and electrooptical effect lead to the relations for the coefficients of the combined effect

$$N_{313}=2\delta(\Delta n)^{\sigma E}_{zx}/n_3^3\sigma_1E_3.$$

As it follows from calculations $N_{313}$=3.6×10$^{-18}$m$^3$/NV for $LiNbO_3$ crystals. For $LiTaO_3$ crystals - $N_{313}$=4.8×10$^{-18}$m$^3$/NV, obtained from the dependence of piezooptical coeffecients on the electrical field and $N_{313}$=4.32×10$^{-18}$m$^3$/NV, obtained from the

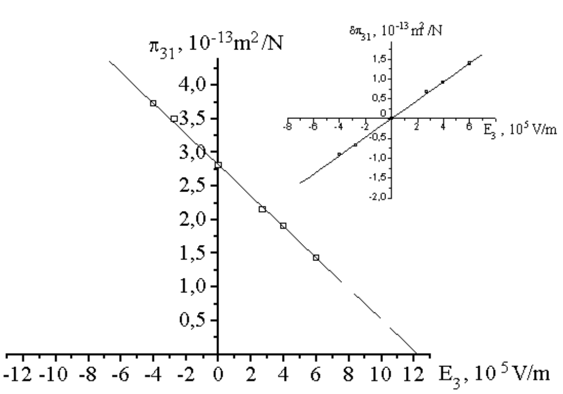


**Fig.3.** The dependence of the piezooptical coefficients $\pi_{31}$ on the electricalal field $E_3$ in $LiNbO_3$ crystals (λ=632.8nm, T=20°C); insert: increament of piezooptical coefficient $\pi_{31}$ on electricalal field $E_3$

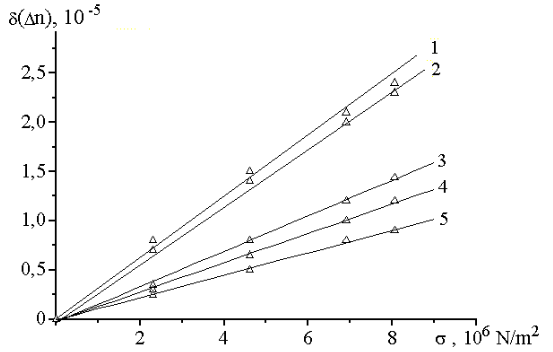


**Fig.4.** The dependencies of the change of birefringence on the mechanical strain $\sigma_1$ at different magnitudes of the electrical field $E_3$ in $LiTaO_3$ crystals ((1)-$E_3$=0, (2)-$E_3$=2.3×10$^5$V/m; (3)-$E_3$=4.6×10$^5$V/m; (4)-$E_3$=6.9×10$^5$V/m; (5)-$E_3$=8.1×10$^5$V/m; λ=632.8nm, T=20°C).

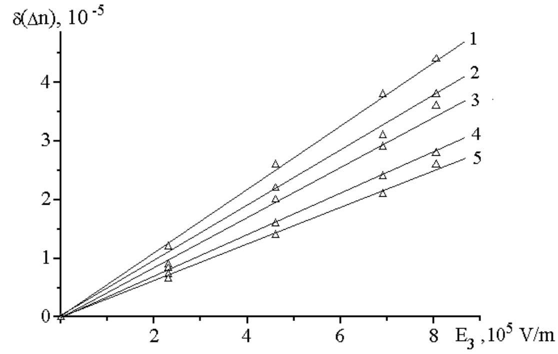


**Fig.5.** The dependencies of the change of birefringence on the electrical field $E_3$ at different magnitudes of mechanical strain $\sigma_1$ in $LiTaO_3$ crystals ((1)-$\sigma_1$=0, (2)-$\sigma_1$=2.5×10$^6$N/m$^2$; (3)-$\sigma_1$=5.1×10$^6$N/m$^2$; (4)-$\sigma_1$=7.5×10$^6$N/m$^2$; (5)-$\sigma_1$=11×10$^6$N/m$^2$; λ=632.8nm, T=20°C).

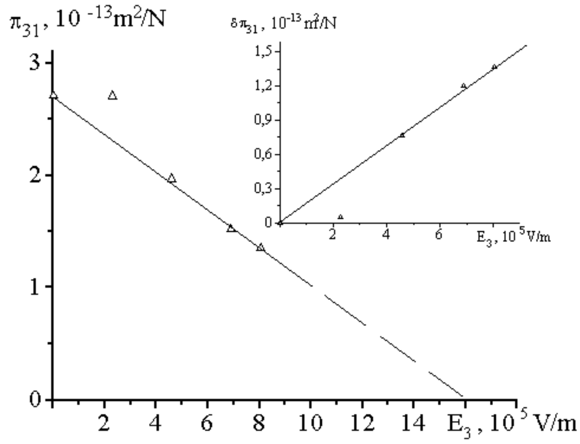


**Fig.6.** The dependence of the piezooptical coefficients $\pi_{31}$ on the electrical field $E_3$ in $LiTaO_3$ crystals (λ=632.8nm, T=20°C)

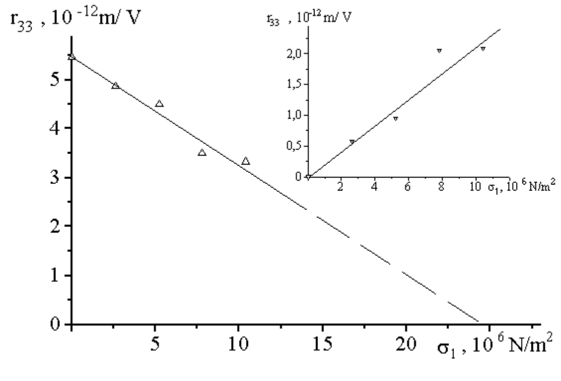


**Fig.7.** The dependence of the electrooptical coefficients $r_{33}$ on mechanical strain $\sigma_1$ in $LiTaO_3$ crystals (λ=632.8nm, T=20°C)

dependence of electrooptical coefficients on the mechanical strain. It is interesting to note that the change of electrooptical coefficients under the mechanical strain and piezooptical coefficients under the electrical field are interchangeable effects. It means that on the base of known coefficients $N_{ijklm}$, obtained for example from the dependence $\Delta r_{ijm}=N_{ijklm}\sigma_{kl}$, one can deduce the dependencies $\Delta\pi_{ijkl}=N_{ijklm}E_m$ as well as $\Delta\pi_{ijkl}/E_m=\Delta r_{ijm}/\sigma_{kl}$. As it follows from our results this conclusion is in agreement with experiment.

## Conclusions

The combined piezoelectrooptical effect in the $LiNbO_3$ and $LiTaO_3$ crystals induced by the mutual influence of the electric field and mechanical strain is experimentally studied. The coefficients of the combined piezoelectrooptical effect were determined as $N_{313}=3.6\times10^{-18}m^3/NV$ for lithium niobate crystals and $N_{313}=4.8\times10^{-18}m^3/NV$ (obtained from the dependence of piezooptical coeffecients on the electrical field) and $N_{313}=4.32\times10^{-18}m^3/NV$ (obtained from the dependence of electrooptical coefficients on the mechanical strain) for $LiTaO_3$ crystals. It was shown that at the bias field $E_3\approx1.2\times10^6V/m$ the piezooptical coefficient of $LiNbO_3$ crystals $\pi_{31}=0$ and changes the sign as well as in $LiTaO_3$ crystal coefficient $\pi_{31}=0$ at $E_3\approx1.6\times10^6V/m$ and at $\sigma_1\approx2.5\times10^7N/m^2$ $r_{33}=0$. On the base of known coefficients $N_{ijklm}$ , obtained for example from the dependence $\Delta r_{ijm}=N_{ijklm}\sigma_{kl}$, one can deduced the dependencies $\Delta\pi_{ijkl}=N_{ijklm}E_m$

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