OPTICAL PROPERTIES OF $LiNbO_3$

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The analysis of experimental results of some optical researches which have been carried out on pure and alloyed 0,03% Fe crystals of lithium niobate is resulted. The publication is continuation of ref. [20].

Before discussing the results of calculations in [20], we shall pay attention to the following experiments.

Thin plates of crystals $LiNbO_3$ and Fe(0.03 %): $LiNbO_3$, annealed during one hour at temperature near 500K, are positioned in the vacuum lightproof camera, in which they are anchored on a thin thread above a semitransparent metal plate. Oscillations of a crystal are checked on a diversion of an optical beam from the light pocket mirror anchored on a thread (the mass of a crystal is many times greater than mass of pocket mirror). The control of distance changes between a crystal and a plate, at appearance of a charge on a surface of a crystal, is carried out with the help of the interference microscope with the accuracy up to 0.5 micron. The temperature, during recording of a diffraction grating, is determined by measuring of an optical trajectory in dark area of a crystal.

In all cases, radiation from laser He-Ne (λ=6328Å, power of 30 Watt/cm^2) is created by the standard methodics for crystals $LiNbO_3$. Recordings of diffractograms from a crystal, in a time dependence of an exposure, have fixed changes of diffraction strips forms in the area of a light stain (fig. 1a, б), and also distribution of Δn on amplitude and section in one (fig.2.). It is necessary to note, that intensity distribution on the area of a light stain was created uniform one practically no more than 0,03%. Maximal values Δn are observed, when radiation from the laser is directed perpendicularly to an axis "C" of a crystal. The further experiments have shown that distribution Δn during lightning appreciably differs from distribution after removal of lightning. During investigations of relaxation time Δn, the quick and slow components are observed.

The observable effect is the result of appearance of an electric field in a crystal (strength about 10^5V/cm), causing Δn change and the appearance of a charge on a crystals surface depending on temperature, intensity and a wave length of laser radiation.

It is necessary to note, that there is no new effects in the obtained results, because in 1966 in paper [2] the observation of the effect of photoinduced change of the index of refraction and after that [3] on a possibility of the use this effect for the recording phase holograms with high efficiency [4-9]. Results of similar observations, but in an electric field (by electrical compass method) also have been published in paper [1]. The fact is known, that the spatial charge is formed in ferroelectrics - photoconductors, on boundaries of uniformly lightning area. Change of spontaneous polarization of crystal P_s in a place of lightning causes the appearance of depolarization electric field E which can save it self long-lived time at the low conductance of a crystal (in case of the mobility for $LiNbO_3$ is approximately equal to 10^{-4}cm$^2\cdot$s$^{-1}\cdot$V^{-1} [13]). This electric field strength is the magnitude of interatomic interactions degree and, therefore, leads to deformations of electronic configurations not only the impurity centers, but also in atoms constituting this crystal structure. This consequence is a result of observable changes of P_s and Δn. The change P_s on the other hand, causes the appearance of a depolarization electric field. Due to a photoconduction this field is screened, i.e. the electric field inside the light stain area will have zero value at long enough time of lightning. At this moment the quantity Δn can be calculated, as it has been done in paper [10].

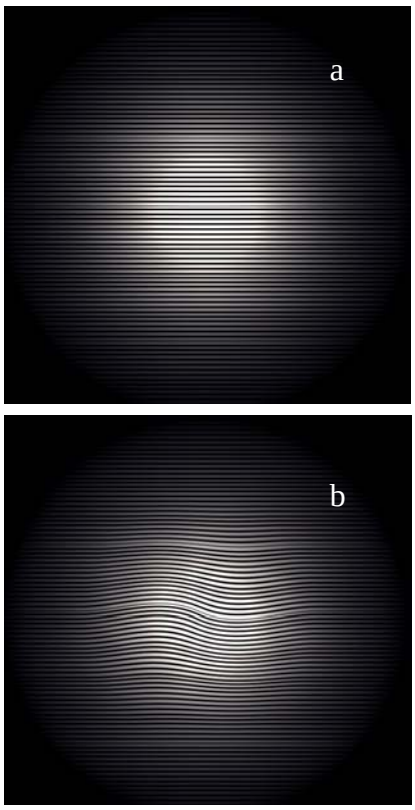


Fig.1. a. The diffraction pattern, when effect on crystal it is not observed yet;
b. Contortions of the diffraction strips in area light stain

In calculations by cluster method of electronic structure $LiNbO_3$ it has been received the data on spontaneous polarization P_s (0,77cm^{-2}) [11], taking place in the consent with the experimental results 0,71cm^{-2} [12]. Ionization or excitation of an impurity increases its polarizability in two times and so the ferroelectric impurity is polarized by a macroscopic field so the dipole moment of an impurity changes also. The deformation lattice near the impurity causes of the dipole moment change of the impurity centre [17].

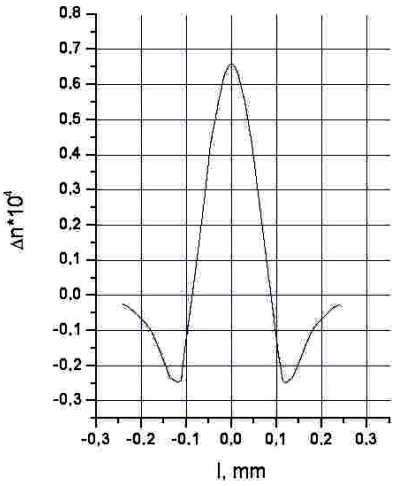


Fig.2. Distribution Δn in the area of a light stain

In [10] the expression of distribution function $P(r)$ is obtained taking into consideration [18]. From this we have the following expression

$$\Delta P_s \approx \frac{\alpha^* f P_s N}{4\pi}(f+1),$$

where f is the Lorentz factor; $E=f P_s$ is a macroscopic field; α^* is a polarizability of an impurity; $\alpha f P_s$ is change of the dipole moment of an impurity. For the case $a_B<r_c$ (shallow impurities) f is equal to zero. Thus, quantity of change ΔP_s and consequently Δn, are obtained by deep levels. The macroscopic field leads to zero at the homogeneous lightning of the short-circuited crystal. In this case the change of n is caused by change of the polarizability α of the impurity centers. The value $\Delta\alpha_0$ depends on the optical polarization of the same impurity atoms and the deformation area of the crystal. After stopping of the lightning, because of relaxation process of excited states of impurities, P_s returns to an initial equilibrium value. However, Δn does not return to an initial value. That means that the inducted field with very large relaxation time appears in the earlier lightning area (fig.3).

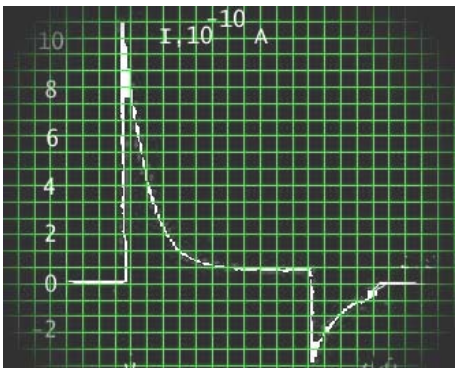
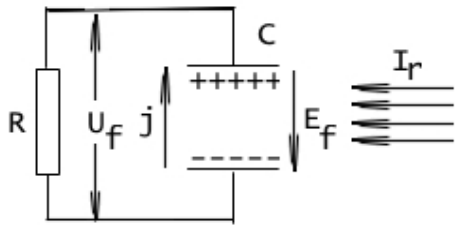


Fig.3 Changes of a photoelectric of a short circuit in crystal Fe: $LiNbO_3$.

Time of scan of a signal is 250s. The first emission of a signal corresponds to insert of light, second - to lockout.

The electric field at the non-homogeneous lightning (so it is possible for itself to present a problem on distribution of light on o a crystal taking into consideration of lightning and non-lightning areas) is determined by concentration of free electrons. It is necessary to take into account that concentration of free electrons is, less, than the trapped electrons one. Thus, the photoinduced field E is defined by the charge distribution on traps and as follows from the above mentioned, leads to the unreturning of Δn to the initial value after stopping of lightning. On the other hand, the photoinduced field can be obtained using the equivalent circuit:



where R is the loading resistor, R_c in internal resistance of a crystal ($R_c<<R$), U_f is a voltage drop on the loading resistor, I_r is the intensity light, impinging on a crystal, j is spatial component of a current $\vec{j}$, directed to normal to an face surface of the plane-parallel plate thickness d, E_f is photoinduced field strange in the capacitor C. The induced field strange is determined by charge density ρ on the capacitor plates which have arisen as a result of lightning of a crystal by light, more over $\frac{d\rho}{dt} = j - \sigma E$, σ is an admittance. As $E = \frac{4\pi\rho}{\varepsilon_l}$, where ε_l - longitudinal component of dielectric constant, then we, taking into account the time of the dielectric relaxation $t_d = \frac{\varepsilon_l}{4\pi\sigma}$, obtain $\frac{dE}{dt} + \frac{E}{t_d} = -\frac{4\pi j}{\varepsilon_l}$. It follows that $E_f = -\frac{j}{\sigma}$ and $E(t) = E_f\left(1 - exp\left(-\frac{t}{t_d}\right)\right)$. At $t>> t_d$, $j = -\sigma E_f$. Here it is possible to present σ as the total of the some two contributions: σ_f - a photoconductivity and σ_d - eigen conductivity, more over σ_f is not a small value in comparison with σ_d. Defining j as αGJ, where α is an absorption constant; G is Glass coefficient and $\sigma_f = \alpha K_f J$ where K_f is a conductivity coefficient, we have:

$$E_f = -\frac{G}{K_f\left(\frac{\sigma_d}{\sigma_f} + 1\right)}$$

and, if $\sigma_f >> \sigma_d$, then E_f is defined only by a material plate parameters, i.e. by the relation $\left(-\frac{G}{K_f}\right)$. For Fe:$LiNbO_3$ the values of Glass's constants are given by the relation in [19]:

$$G_{33}^L \approx G_{31}^L = 2-4; G_{22}^L \approx 0.1-0.3;$$
$$G_{12}^c \approx 0.1-0.5 >> G_{15}^L$$

At $t << t_d$ and the minor current j, the charge separation will be only because of photovoltaic field. In the case of niobate lithium, it is necessary to take into account also, that there is a dependence of cross spatial orientation of a polar axis of the crystal $\vec{C}$ and the current $\vec{j}$. The quantity of a photorefraction field, estimated in the experiment on $LiNbO_3$, is equal to 850 V/cm. Also the storage charge is equal to $4\cdot10^{-12}$ Q, and field of a spatial charge - 1800 V/cm. For Fe:$LiNbO_3$ value of photorefraction field is equal to $\approx1.5\cdot10^4$V/cm.

The solution of distribution problem of a spatial charge and the field near the boundary of homogeneously lighted area at the presence and absence of the external electric field is well-known [1]. The size of area of a spatial charge at presence of the external field E_o is defined by following expression:

$$l = \frac{2kT}{eE_0}\left(\sqrt{1+\left(\frac{2kT}{eE_0 l_D}\right)^2}-1\right)$$

where l_D is a screening distance of Debye which at presence of the concentration traps N, is defined by the expression $l_D = \sqrt{\frac{\varepsilon kT}{4\pi e^2 N}}$. Under conditions $E_0 > \frac{kT}{el_D}$ the character size of area of the spatial charge will be expressed from. $l = \frac{\varepsilon E_0}{4\pi eN}$. For $E_o\approx10^4$V/cm and $N\approx10^{18}$cm^3 the character size of area is approximately equal 10^{-7}cm that it is less, than the character size of area of the non-homogeneous lightning, which is equal to the wave length or more. It allows to use a quasi-neutrality condition analyzing photorefraction effect at which it can be proposed that local electron concentration is defined by the light intensity in the given point (it usually means that Δn connects with an intensity distribution weakly at the enough strong lightning and is defined only by value of an external field). The diffusion field appears usually at the external field absence at the non-homogeneous lightning, for example at recording holograms on $LiNbO_3$ in [15]. Its value is expressed by $\frac{kT}{eL}$, where L is a character length of light intensity change, for example the character wave is defined by the sinusoid wave length for the sinusoidal spatial distribution of light intensity. It is confirmed by the experimental results on hologram recording in which it is shown, that the first Fourier-component value of a diffusion field is equal to $\frac{2\pi kT}{\lambda}$ (but only it is of interest at calculations of the hologram diffraction efficiency). This value is equal to $1.5\cdot10^3$V/cm at room temperature and $\lambda\approx10^{-4}$cm.

In ref. [14] it is informed about investigations of temperature and spectral dependences of photovoltaic current in ferroelectrics, in $LiNbO_3$ particularly. It has been shown, that a photoconductivity and photovoltaic effect in $LiNbO_3$ are connected to interband or impurity to band transitions. The appearance of the photovoltaic current can be consequence of volumetric photovoltaic effect in the homogeneous and homogeneously lighted $LiNbO_3$ [19.] In this case the current direction is defined by the axes direction of spontaneous polarization, even in the absence of the electric field. At ionization of the impurity centre in a polar crystal, as it is shown in ref. [16], the free made electrons have a privaled velocity direction on spontaneous polarization direction or against one, i.e. the probability of the appearance of electrons as a result of ionization, which has the velocity direction parallel to P_s, differs from the probability of the appearance of the electron having an opposite direction of velocity. It is connected with the distortion of wave functions in an unsymmetrical field of the impurity centre. The application of this model has difficulties because of small carriers mobility in $LiNbO_3$ (conductivity must have the jump character), and the recombination time essentially exceeds 10^{-8} s, but quite agrees to Fe: $LiNbO_3$ in which the supplier of electrons is the impurity atom Fe^{2+} in a conduction band.

Thus, the expression for a current, determining the volumetric photovoltaic effect $j=\sigma E+K\alpha\Phi$ where K is the proportional coefficient of spontaneous polarization P_s, α is an absorption constant of light, is applicated completely in the case of Fe: $LiNbO_3$ and if we use the results of ref. [20], then j will explain the fact and character of changes of an absorption constant completely. On the other hand, the presence of 90°-phase shift between lattices at hologram recording on $LiNbO_3$ [15] is a necessary condition of realization of the diffusion mechanism of recording.

[1]. *V.I.Belinicher, I.F.Kanayev, V.K.Malinovskii, B.I.Sturman* Izv. AN SSSR, ser..fizicheskaya, 1977, 41, №4, p.733-739.

[2]. *A.Ashkin, G.D.Boyd et al*. Appl. Phys. Letts.1966, 9,72.

[3]. *F.S.Chen* J.Appl. Phys. 1969, 41, 3275.

[4]. *J.J. Amodei* RCA Rev., 1971,32,185.

[5]. *D.L.Staebler, J.J.Amodei* J.Appl.Phys., 1972, 43, 1042.

[6]. *M.F.Deygen, S.G.Odulov et. all.* FTT, 1974, 16, 1895.

[7]. *V.L.Vinitskii, N.V.Kuhtarev* ФТТ, 1974, 16, 3714.

[8]. *D. Von der Linde, A.M.Glass, K.F.Rodgers* Appl. Phys. Letts. 1974,25,155.

[9]. *D. Von der Linde, A.M.Glass, K.F.Rodgers* Appl. Phys. Letts. 1975,26,22.

[10]. *A.P.Levanuk, V.V.Osipov* Izv. AN SSSR, ser. fizicheskaya, 1977, 41, №4, p.753-770.

[11]. *L.Hafid, F.M.Michel-Calendini*, J.Phys. C: Solid State Phys., 1986, 19, 2907-2917.

[12]. *M.E.Lines, A.M. Glass*, in book "Principles and Applications of Ferroelectrics and Related Materials", ed. Marshal and Wilkinson, 1979, Oxford:Clarendon Press.

[13]. *A.V.Rujnikov*, Avtoreferat dissertatsii, LGPI, Leningrad, 1976.

[14]. *V.M.Fridkin, B.N.Popov, P.V.Ionov* Izv. AN SSSR ser. fizicheskaya, 1977, 41, №4, p.771-774.

[15]. *V.B.Markin, S.G.Odulov, M.S.Soskin* Izv. AN SSSR, ser. fizicheskaya, 1977,41, №4, p.822-829.

[16]. *A.M.Glass, D. Von der Linde and et.al.*, J.Electron. Mat., 1975, 4, 915.

[17]. *A.P.Levanyuk, V.V.Osipov,A.S.Sigov* Ferroelectrics, 1976, 14, 643.

[18]. *A.P.Levanuk, V.V.Osipov*. FTT, 1975,17,3595.
[19]. *B.I.Sturman, V.M.Fridkin* "The photovoltaic and photorefractive effects in noncentrosymmetric materials" 1992, Gordon&Breach Science Publishers S.A.., Amsterdam.
[20]. *Talat R..Mehdiyev* Fizika, 2002,8,n.4, p.50-56.

Tələt R. Mehdiyev

$LiNbO_3$ –NİN OPTİK XASSƏLƏRİ

Təmiz və 0.03%-li Fe-la aşqarlanmış neobat litium kristalları üzərində aparılmış bəzi optik tədqiqatların eksperimental nəticələrinin analizi verilmişdir. Bu məqalə [20] – nin davamıdır.

Талат Р. Мехтиев

ОПТИЧЕСКИЕ СВОЙСТВА $LiNbO_3$.

Приведен анализ экспериментальных результатов некоторых оптических исследований, проведенных на кристаллах ниобата лития чистого и легированного 0,03% Fe. Данная публикация является продолжением статьи [20].

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