THE OPTICAL PROPERTIES OF Fe:LiNbO$_3$

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The present paper is the continuous of publications of complex of optical properties investigations, which are perspective for the practical additions of nonlinear crystals of LiNbO$_3$+0,03%Fe with the aim of the usage in the systems of transmission, reception, treatment and storage of the optical information.

After the recording of the interference figure of the interaction of two plane waves in lithium niobate, he can be considered as a crystal, the index of refraction of which is periodic function.

$$n^2(z) = n_0^2\left(1 + 2\sum_{m=1}^{\infty} x_m \cos\left(\frac{2\pi}{\Lambda} mz\right)\right) \tag{1}$$

If the crystal thickness us more than the sizes of the recorded interference figure, so the hologram will have the properties of three-dimensional diffraction grating. Thus, the plane wave propagation along the trajectory is in the conditions of the periodic modulation of the lateral component of wave vector k_x and consequently, the longitudinal component k_z, connected with it by ratio $k_x^2+k_z^2=k_0^2n^2$. The TE-wave amplitude, propagating in the medium, the index of refraction of which is defined by the expressions (1), satisfies to the Hill equation [5]:

$$\frac{d^2u}{d\varsigma^2} + \left(\theta_0 + 2\sum_{m=1}^{\infty}\theta_m \cos(2m\varsigma)\right)u = 0,$$

the solution of which, according to Flow theorem, can express in the form $u(\varsigma) = Ae^{-\frac{i\delta\varsigma}{n}} f(\varsigma) + Be^{\frac{i\delta\varsigma}{n}} f(-\varsigma)$, where δ is the some characteristic constant, $f(\zeta)$ is the periodic (with period π) function and $\varsigma = \left(\frac{\pi z}{\Lambda}\right), \theta_0 = \left(\frac{2\Lambda}{\lambda}\right)^2, \theta_m = X_m\theta_0$.

After substitution of the decomposition $f(\zeta)$ in Fourier series in (2), the characteristic constant δ is defined from the solutions of equations $\Delta(\delta)=0$ or

$$\sin\left(\frac{\delta}{2}\right) = \pm\sqrt{\Delta(0)}\sin\left[\left(\frac{\pi}{2}\right)\sqrt{\theta_0}\right],$$ in which

$$\Delta(\delta) = \frac{1}{\theta_0 - 4n^2}\left[\left(2n - \frac{\delta}{\pi}\right)^2 f_n - \sum_{m=\infty}^{\infty}\theta_m f_{n-m}\right] = 0,$$

$\Delta(\delta)$ is Hill determinant. It is easy to note, that in the general case at δ=0, the necessity in the calculations of the determinant of infinite dimension matrix. However, for the case $\theta_0 \approx 1$ the approximated solution (6) shows that periodic medium under the condition $\left|\lambda - \lambda_0\right| < \frac{2\left(\left[\Delta_0(0)\right]^{1/2} - 1\right)\lambda_0}{\pi}$ behaves itself as Bragg reflector and diffraction, propagating in wave crystal, will be described by Bragg reflective angles, correspondingly. It is noted, that z axis situates parallel to vector difference vector (***k$_1$* - *k$_2$***), where ***k$_1$*** and ***k$_2$*** are the wave vectors of two plane waves.

From the other side, the effects, connected with the attenuation of the luminous radiation, which is caused by the scattering, caused by the density fluctuations on the microscopic and atom levels, and absorption, and geometrical distortions of form, thickness and etc. also. For example, in the case of lithium niobate crystals, the space-time changes of the coefficient of refraction, appearing under the action of incident light, depending on its wavelength and intensity, lead to the trajectory change of the luminous beam propagation, geometrical sizes and form of output light spot. The last circumstance is demonstrated in the fig.2 by the intensity propagating in the region of output light spot, the maximum of which in the limits of general accuracy, should be situated in the center. It is clear, that all characteristics of incident light on crystal, were stable during the time of experiment carrying out, the influence of external factors, which can influence on the investigation results, is equal to zero. Thus, it is followed from the figures 1,2,3 and, 4 the consideration of space-time changes of index of refraction, kinetics of scattering and transmission processes, is the obligatory condition in the optical experiments with given crystal. It is need to note, that change of angle of incidence of light from 0 till $\pi/3$, leads to the decrease of the scattered light intensity, at the same moment as scattering indicatrix doesn't change. This statement is stable till the crystal thickness is less than $3\text{-}4\mu$. In the other case, maximums of intensity of scattered light to 0 and π and scattering indicatrix becomes more diffusive.

As forms of curves of coefficient of refraction change are close to Gaussian profile, so it can be proposed that

$$n^2(\rho, z, t) = n_z^2 f(t) e^{-\frac{bp^2}{n_0}} \tag{2}$$

where $\rho = x^2+y^2$, $f(t)$ is function on time, b is some constant, n is coefficient of refraction.

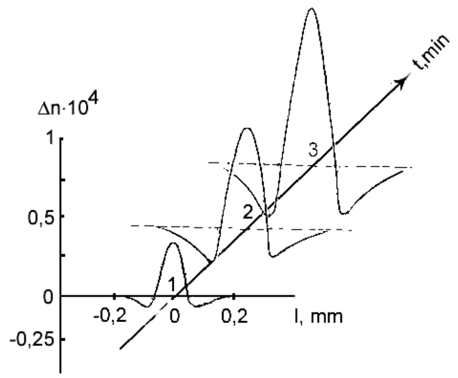
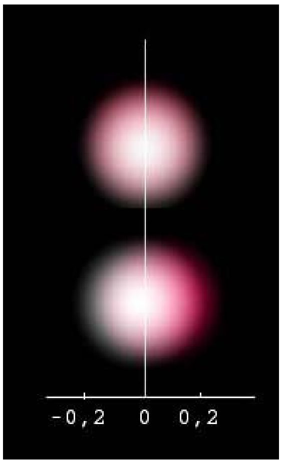


Fig.1. Space and time dependencies (t=1,2,3 min.) of the change of coefficient of refraction in lithium niobate crystals.



a

b

Fig.2. The time changes of the form and distribution of the intensity in the output light spot region in lithium niobate crystals (a – t=0; b – t = 2 min).

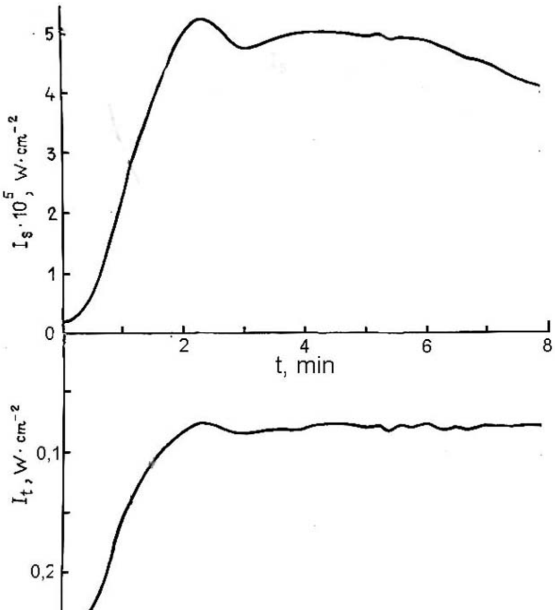


Fig.3. The time changes of transmission (I_t) and scattering (I_t) of the light in $LiNbO_3$ +0,03%Fe ($L=2\mu$, thickness of the sample is 2mm, λ = 440 nm).

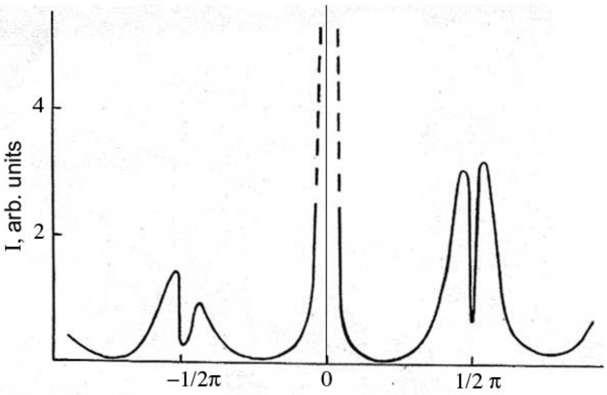


Fig.4. The scattering indicatrix (I_s) for $LiNbO_3$ +0,03%Fe ($L=2\mu$, the thickness of the sample is 2mm).

Taking into consideration, that the index of refraction of crystal doesn't depend on x and y, i.e. we consider unlimited layered medium, and at z =-∞ $u_i = e^{-i\vec{k}_0 n_0 (z\cos\theta + x\sin\theta)}$ also, the field has the form of plane wave u_i, propagating under the angle θ to z axis: $x = x_0 + \int_{z_0}^{z} \frac{a\,dz'}{\sqrt{n^2(z) - a^2}}$. The trajectory of any beam in the Cartesian coordinates for the considered case can be recorded in the form, where z_o and x_o are coordinates of the trajectory point, $a = n_0 \sin\theta$ .The observable inclinations are well described by the given approach till the crystal thickness isn't so bigger, than the sizes of recorded interference figure. From the other side, such approach doesn't take into consideration this fact at all, that as of light propagation in the crystal, the intensity of the interacted pencils of light change because of the their interaction with the recorded holographic lattice by them. Such dynamic process leads to the essential coordinate dependence of amplitude and phase of the recorded lattice. According to the ref [2], the phase difference of two interacted pencils change thus, that surfaces of maximal and minimal change of the index of refraction generally stop to be the planes. However, if phase shift is equal to 0 and π, inspite of the unequal to 0 value of the diffraction efficiency, the intensity of the recorded pencils on the crystal output doesn't change. For the case of phase shift, which is equal to $\pi/4$, the recorded lattice has the alternating contrast on the crystal thickness. In many cases, after the recording of the interference figure in lithium niobate crystals (by the thickness, satisfying the condition $(2\pi\lambda z)/(nL^2)>10$ [1], where L is the constant of holographic lattice), the obtained holographic lattice can be related to the phase volume one. The limiting recording density for the volume holograms is estimated by the dependence of the diffraction efficiency on the inclination from Bragg angle. At the small intensities, this dependence well coincides with the estimate, given in the ref [1], $\Delta\theta \approx L/z$. The further increase of the diffraction efficiency is accompanied by the broadening, connected with the presence of the efficiency nonhomogeneous on the crystal thickness. The more big the z value, the more big the nonhomogeneous and the broadening also. In the case of the $LiNbO_3$ +0,03%Fe crystal ($L=2\mu$, sample thickness-2mm) the reason of the nonhomogeneous can be energy exchange [3,10] between recorded beams, at which the contrast of interference figure changes (because of the change of phase F and oscillating character η).From the other side, as it is followed from the analysis of time changes of transition and scattering. The big value has the exposition time of recorded hologram on this crystal. The value of crystal absorption at the above mentioned parameters, in the region 440nm near 1,5 sm^{-1} and the peculiarities of angular selectivity of diffraction efficiency also weak dependence from this process. The obtained experimental dependencies of the diffraction efficiency on the value of phase shift and angle of reading information for $LiNbO_3$+0,03%Fe are presented on the fig.5,6.

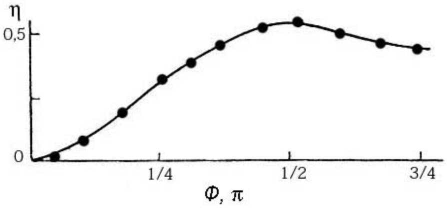


Fig.5 Dependence of diffraction efficiency η on phase displacement angle.

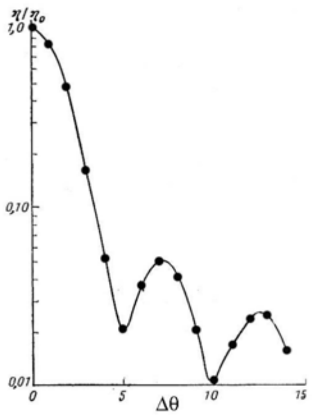


Fig.6 Dependence of diffraction efficiency η/η_0 on angle of reeding information of holographic lattice in the crystal $LiNbO_3$ +0,03%Fe ($L=2\mu$, sample thickness is 2mm, η_0=20%).

They are well accord to the results of the ref [3].

The theoretic model, taking into consideration the nonlinear dynamic processes at the recording of the stationary holographic lattices with the taking into consideration of diffusion and drift of photocarriers, change of crystal dipole moment in the result of the elimination, was introduced in the ref [4]. The change of crystal ΔP, dipole moment, appearing in the generation and recombination processes of current carriers, was taken into consideration phenomenologically in the prediction, that it is proportional to the concentration change of the charged centers, i.e. in the form: $\Delta\vec{P} = \vec{d}(N_D^+ - N_A)$. The connection of dipole moment change only with the change of the charge impurity state, probably doesn't correct at all. It is possible to show, that absence of the consideration of ion arrangement relatively each other changes neglible few the value of sum crystal dipole moment. The questions, connected with the change nature of crystal dipole moment, were discussed in refs [5,6] and as analysis of the given experimental results show, the nature of these changes for the pure crystals and crystal with impurity is different. In our case we consider $LiNbO_3$ with impurity 0,03%Fe, and the expression application (fP_s), where $\alpha^*(fP_s)$ -is impurity polarizability; f- is Lorentz factor; (fP_s) is the macroscopic field; &(*)(fP_s) is the impurity dipole moment. For the case of shallow impurities: $f=0$. Thus, deposit in the polarizability change will be put by the deep levels. As at the homogeneous elumination of short-circuit crystal the macroscopic field has tendency to the zero, so dipole moment changes connect with the change of the polarizability and deformation of the space region near impurity atom. Experimentally, the dipole moment value can be defined, measuring the polarization currents [8]. The obtained results are well correspond with the ones, given in the ref [6] and P_s value is equal to 0,71 cm^{-2}. All above mentioned allows to take into consideration the time changes of dielectric constant. They can be easily obtained from the experiments, given not only in the present publication, but in the refs [3,5,6,7] also.

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Fe:$LiNbO_3$-ÜN OPTİK XÜSUSİYYƏTLƏRİ

Təklif olunan iş praktik tətbiqlərdə böyük perspektivi olan qeyri-xətti $LiNbO_3$+0,03%Fe kristallarının optik xassələrinin kompleks tədqiqinə həsr olunmuş işlərin davamıdır.Tətqiqatlar optik məlumatı xaricə yayan, qəbul edən, yenidən işləyən və özündə saxlayan sistemlərdə istifadə oluna bilmək məqsədini daşıyır.

Талат Р. Мехтиев

ОПТИЧЕСКИЕ СВОЙСТВА Fe:$LiNbO_3$.

Настоящая работа является продолжением публикаций комплекса исследований оптических свойств перспективных для практических приложений нелинейных кристаллов $LiNbO_3$+0,03%Fe с целью использования в системах передачи, приема, обработки и хранения оптической информации.

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