WIDE BAND ANISOTROPIC DIFFRACTION OF LIGHT BY LONGITUDINAL ELASTIC WAVE IN LITHIUM NIOBATE

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1. ABSTRACT

The given work is devoted to the exposure of the peculiarities for anisotropic light diffraction by longitudinal elastic wave in lithium niobate that supposes a further frequency range raising and broadband extension. It is shown that principal possibility of realization of this kind acoustooptic interaction takes place at condition of the selection as diffraction plane *xz* and as direction of the acoustical wave movement *xz*+144° or *xz*–34°. The main merit of the anisotropic light diffraction longitudinal elastic waves in lithium niobate is the disposition of the average frequency near to 3,15 or 5,3 GHz for λ_0=0,633 micrometers.

Keywords: anisotropic diffraction, light, longitudinal waves, lithium niobate.

2. INTRODUCTION

It is known that there is so-called anisotropic (with change of light polarization) diffraction of the light by shear elastic waves in the lithium niobate crystal - the main material of for VHF acoustooptics at the choice diffraction plane as *yz* acoustical displasemend as taking place along *x*-axis. This kind of the diffraction is characterized the exclusive large efficiency (coefficient of acoustooptical quality $M_2 \approx 22 \cdot 10^{-5}$kg/c^{-3}) for elastic wave travelling along crystallophysical *yz*+120° direction. However it have essential deficiency — shear elastic waves with *x*-displacements of the medium particles in shown direction of their movement possess the raised means of linear lattice acoustic damping 16 and 25 dB·cm^{-1}, relating to frequencies near 2,5 and 3,5 GHz respectively as the centers of wide-band work at λ_0=0,633µm. On the other hand, the information about possible realization of anisotropic light diffraction by longitudinal elastic waves in lithium niobate, possessing small values of linear lattice acoustic damping on the similar frequencies, is absence in the scientific literature. Therefore the task to analyze this opportunity and to expose its features and the optimal conditions for its realization was put by us in present paper.

3. INITIAL AND WORK RELATIONS FOR ANALISIS

Let us consider meridional *xz* cross-section for indexes of refraction n_0 and n_e having in view of lithium niobate as singleaxis negative optical crystal.

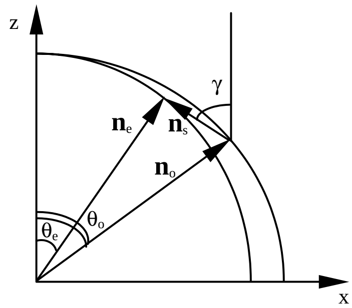

Fig. 1. Cross-section *zx* of the surfaces for indexes of refraction and vector diagram for phase (Bragg) matching of interacting waves.

Fig.1. reflects this cross-section and it contain also the closed Bragg set of three vectors $\boldsymbol{n}_0$, $\boldsymbol{n}_e$ and $\boldsymbol{n}_s$ expressing respectively ordinary optical wave, extraordinary optical wave and elastic wave all are normalized to optical wave number of vacuum $k_{oo}=2\pi/\lambda_o$. There are three angles θ_o, θ_e and γ on Fig.1 and they designate angles of directness for interacting waves in regarded case of anisotropic Bragg diffraction of light by longitudinal elastic wave in lithium niobate. The angles θ_o and θ_e count as positive ones clock wise, and angle γ count clock wise.

Grating these designations the wave numbers interacting waves have view:

$$k_e = k_{oo} n_e(\theta_e) = k_{oo} \frac{n_e n_o}{\sqrt{n_e^2 \cos^2\theta_e + n_o^2 \sin^2\theta_e}},$$

$$k_o = k_{oo} n_o (n_o = const), \; k_s = \frac{2\pi\Omega}{\upsilon_s} = k_{oo} n_s .$$

Here n_0 and n_e - principal values of indexes of refraction for ordinary and extraordinary optical waves respectively; Ω and υ_S - frequency and velocity for elastic waves in crystal (the last are considered as dependent on angle γ); n_s - normalized wave number of elastic wave. The conditions of Bragg mismatching for the waves lead to relations:

$$\frac{n_s}{n_o} = \sqrt{\left[\frac{n_e \cos\theta_e}{\sqrt{n_e^2\cos^2\theta_e + n_o^2\sin^2\theta_e}} - \cos\theta_o\right]^2 + \left[\frac{n_e \sin\theta_e}{\sqrt{n_e^2\cos^2\theta_e + n_o^2\sin^2\theta_e}} - \sin\theta_o\right]^2},$$

$$\sin\gamma = \frac{n_o \sin\theta_o - n_e(\theta_e)\sin\theta_e}{n_s},$$

$$\cos\gamma = \frac{n_e(\theta_e)\cos\theta_o - n_o\cos\theta_o}{n_s}$$

They allow to discover in particularly at preassigned values of angle θ_o required dependencies of n_s and γ on angle θ_e.

In parallel with above-mentioned dependencies the efficiency of this kind diffraction was detected by calculation of effective photoelastic sensitivity

$$q_{ef} = q_{ijkl} e_{oi} e_{ej} u_k N_l \,,$$

where $q_{ijkl} = -\varepsilon_{ii}\varepsilon_{jj} p_{ijkl}$ - tensor of photoelastic sensitivity; p_{ijkl} - tensor of photoelastic of Pokkels; ε_{ii} - diagonal tensor of dielectric permittivity $(\varepsilon_{11} = \varepsilon_{22} = n_0^2,\ \varepsilon_{33} = n_e^2)$; e_{oi} and e_{ej} - components (projections on coordinate axes) of the unit vectors of optical waves polarization; u_k - similar components of the unit vector elastic waves polarization; N_l - components of the unit vector direction of elastic waves movement.

It is appropriate to note here that well known coefficient of acoustooptical merit M_2 is expressed through above-made designations by relation

$$M_2 \cong \frac{q_{ef}^2}{n_o n_e(\theta_e)\rho\upsilon_s^3}$$

which is used for calculations by us also.

Supposing for simplicity stringent perpendicularity of the vectors ***e*** to the direction of phase movement for optical waves and stringent collinearity of the elastic displacement vector to the directional of elastic waves movement, expression for q_{ef} may be transformed to view

$$q_{ef} = q_{14}\sin 2\gamma\cos\theta_e + q_{41}\sin^2\gamma\sin\theta_e$$

which was used by us for calculations.

4. RESULTS OF CALCULATIONS AND DISCOVERED REGULARITIES

At fulfillment of calculations the next values of constants were assumed:

1) n_0=2.29, n_e=2.2, that correspond to their reference values for λ_0=0.632 micrometers.

2) q_{14}=2.06, q_{41}=3.83 that was got by calculations from known values p_{ijkl} also for λ_0=0.632 micrometers.

There are presented n_s and γ on Fig. 2 and Fig. 3 respectively as its dependencies on angle θ_0. The minimums of n_s correspond to inflection points for curves γ. The last curves have maximums and minimums that is most interesting for wide-band operation. Fig. 4 presents q_{ef} as dependencies on angle θ_e at some values of angle θ_0 also.

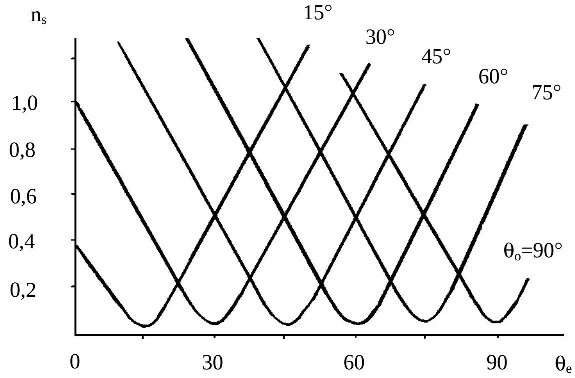

Fig.2. Behavior of the relative values for wave vector of elastic waves.

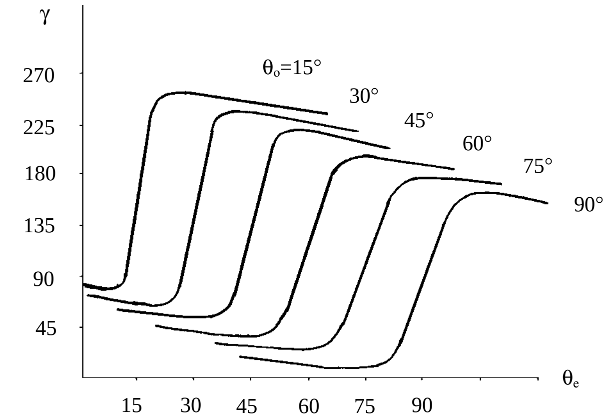

Fig.3. Angle characteristics for elastic wave.

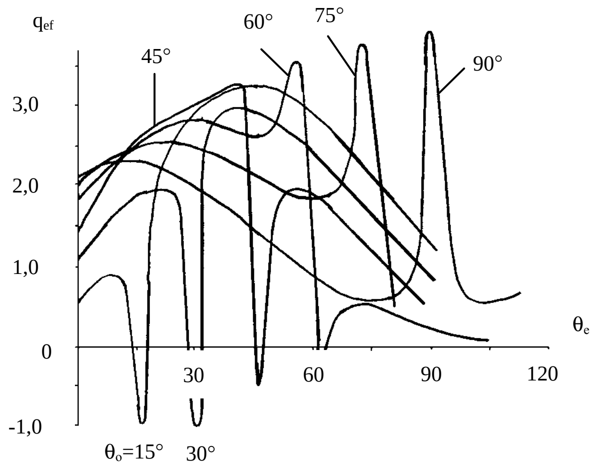

Fig.4. Behavior of effective photoelastic sensitivity.

For the obviousness it is usefull to present the values of θ_e^{min}, θ_e^{max}, n_s^{min}, n_s^{max}, γ^{min}, γ^{max} and, at last, q_{ef}^{min} and q_{ef}^{max} as the dependencies on angle θ_0.

On Fig. 5 these date are shown for θ_e^{min}, θ_e^{max}, γ^{min}, γ^{max}.

Fig. 6 by similar way present n_s^{max}, n_s^{min}, q_{ef}^{max}, q_{ef}^{min}.

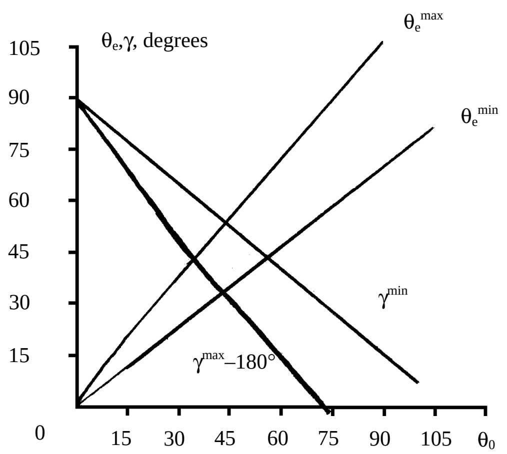

Fig. 5. Values of angles at maximums or minimums of γ.

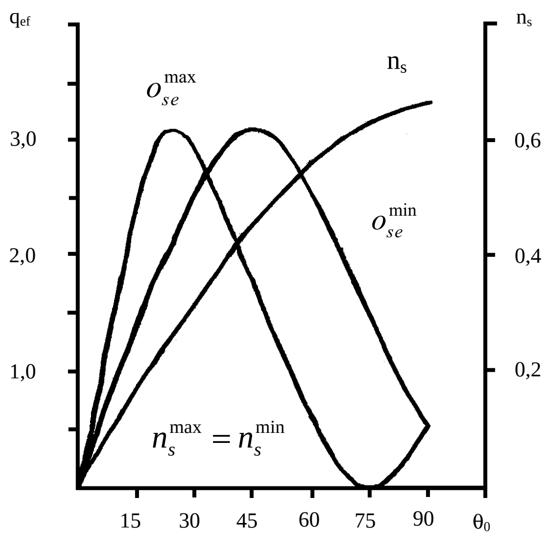

Fig. 6. Behavior of n_s and q_{ef} along angle θ_0 at maximums and minimums of γ.

5. CONCLUSION

On the base of all discovered dependencies it is possible to conclude, that there is two preferential regime for the realization of wide-band anizotropic Bragg diffraction:

a) θ_0=26°, θ_e≈32,5°,γ≈236°, n_s≈0,27, q_{ef}≈3,02

b) θ_0=45°, θ_e≈33,5°,γ≈54°, n_s≈0,457, q_{ef}≈3,02

Their preference are stipulated by maximums of numeral values of q_{ef} along with the extremals of angle γ in dependencies on angle θ_e. This fact predetermines wide-band operation near to frequencies 3,13 GHz ((case a) and 5,3 GHz (case b)) that essentially higher than in case using shear elastic waves. Coefficient acoustooptical merit M_2 here is near to value $1\cdot10^{-15}$ kg/s^3, and relatively not high its value is caused by high velocity for longitudinal elastic waves in lithium niobate v_s, which was assumed equal $7,33\cdot10^3$ m/s. Nevertheless authors expect great practical interest to kind of Bragg diffraction, considered here and unknown in scientific literature.