Application of Acoustical Activity for Measurement of Acoustic Wave Frequency

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Abstract— **the new technology is offered for measurement of acoustic wave frequency. The method is based on using the Bragg light diffraction on the hypersonic transversal acoustic wave in a gyrotropic crystal. Measurements have been carried out with help of $LiNbO_3$ crystal oriented along the crystallographic axis of the third order at the average frequency 1.0 GHz. The dependence of the diffracted light intensity from the quantity of specific rotation was used for determination of the acoustic wave frequency by the appropriate model equation accurate within 0.1 %.**

I. Introduction

The interaction of light and acoustic waves in crystals gives rise to light scattering by these waves. It is Bragg diffraction in the case of coherent acoustic waves, excited by external sources, and Mandelstam-Brillouin scattering in the case of thermal elastic waves. The Bragg diffraction method is especially promising as the acoustic power of coherent elastic waves can be controlled. As a consequence, the intensity of Bragg diffraction is several orders of magnitude higher than that of Mandelstam-Brillouin scattering. If the crystal is optically anisotropic (biaxial or uniaxial) for successful use Bragg diffraction method in the acoustic-optical study of crystals it is necessary to know the peculiarities of diffraction in optically anisotropic media. The proposed method is based on using the Bragg light diffraction on the hypersonic acoustic wave in gyrotropic crystals. To understand the proposed technology below is briefly described the phenomenon of acoustical activity without theoretical details.

II. THE CONCEPT OF ACOUSTICAL ACTIVITY IN CRYSTALS

It is well known that the acoustical activity is the mechanical analogue of optical activity. Its simplest manifestation is the progressive rotation of the polarization plane of a transverse acoustic wave propagating in a crystal along some special directions [1-7]. Although the phenomenon of the acoustical activity has been discovered relatively long ago, its direct experimental investigation is considerably more difficult as compared with the optical analogue. Because of that, the acoustical activity has been experimentally investigated in a limited number of crystals [8-14].

Unlike the optical activity, the acoustical activity can occur in all of the 21-acentric crystal point groups of the symmetry [11]. Moreover, the acoustical activity has been explained in terms of first order spatial dispersion: a strain ε created at time τ at a point r' gives the rise to a stress δ at another point r at a later moment of time. Thus, taking into account the spatial dispersion the complex elastic constants C_{ijkl} are equal [11]:

$$C_{ijkl}(\omega, q) = C_{ijkl}(\omega) + i \cdot \gamma_{ijklm}(\omega) \cdot \mathbf{q} \cdot \mathbf{m}, \qquad (1)$$

where γ_{ijklm} is the tensor of acoustical activity, ω is the frequency of acoustic wave, **m** is the normal vector and **q** is the wave vector of acoustic wave.

It is known also that the propagation of real acoustic waves is accompanied by decreasing of energy. The reasons are different dissipation processes including phonon-phonon and electron-phonon mechanisms [15]. In piezoelectric crystals, an appreciable contribution into the sonic attenuation can be made by dielectric losses by means of the piezoelectric effect [16].

III. BRIEF DESCRIPTION OF THE EXPERIMENTAL METHOD FOR MEASUREMENT OF ACOUSTIC WAVE FREQUENCY

In present work acoustical activity and Bragg light diffraction on hypersonic waves in ferroelectrics crystal $LiNbO_3$ have been used for control and measuring of the acoustic wave frequency at home temperature. The applied sample of $LiNbO_3$ was cut from optically clear single crystal and oriented along the crystallographic axis of the third order with the accuracy of 10'. Piezoelectric transducers of Lithium Niobate of appropriate cuts are used to excite the plane-polarized transverse acoustic waves in the frequency range from 0.9 to 1.1 GHz.

The acoustic-optical cell for control and measurement of light intensity is shown in Fig. 1. The observation of diffracted light beam is shown for the time moment when the acoustic

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pulse is moved through the area of the acoustic-optical interaction. The light waves with wave length 632.8 nm were generated by He-Ne laser.

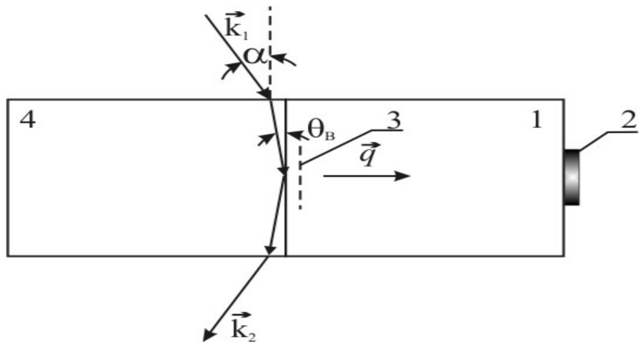

FIGURE 1. Block diagram of acoustic-optical system for control of light intensity.

Here: 1 – sample of $LiNbO_3$ crystal, 2– piezoelectric transducer, 3 – acoustic wave front, 4 – back of sample; k_1 and k_2 are wave vectors of incident and diffracted light, accordingly, q is wave vector of acoustic wave, α and θ_B are outside and inside angles of the incident light beam.

Measurements of the dependence of the scattered light intensity from the distance to the piezoelectric transducer along the direction of the acoustic wave propagation were carried out in automatic regime by using the computer, which worked under the control of the software developed specially for solving this problem.

In common case, the light intensity is the function from some parameters including the attenuation coefficient of acoustic wave (α) and the specific rotation of polarization vector (β) [13]:

$$I = I_0 \cdot [\exp(-\alpha \cdot z)] \cdot \mathrm{Cos}^2 (\beta \cdot z + \varphi), \qquad (2)$$

where I_0 is the incident laser light intensity; φ is initial phase of acoustic wave.

In the experiment first were determined the specific rotation of polarization vector and the attenuation coefficient of the acoustic wave by the appropriate model (2), when the acoustic wave frequency has not been changed.

The values of the specific rotation of polarization vector (β) of the transverse acoustic waves were estimated from the measurements of the dependence of the diffracted light intensity (*I*) from the distance (*z*) to the piezoelectric transducer along the direction of the acoustic wave propagation.

The typical experimental results for Lithium Niobate crystals at the frequency 1.0 GHz are shown by Fig. 2. We can see at the picture that the direction of rotation of the polarization vector changes at the both boundaries of sample. This effect is lightly explained because the acoustic wave is reflected at the boundary and accordingly the direction of the rotation changes to the straight contrary direction.

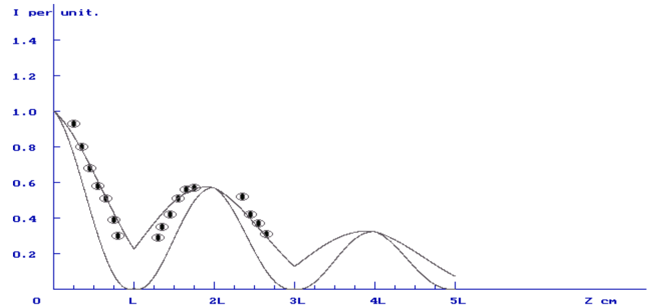

Fig 2 Dependence of Bragg diffraction light intensity I on the distance Z from piezo-transducer along the direction of propagation of transverse acoustic wave with frequency 1.0 GHz.

The points at the picture are the experimental results, the first curve is the calculation by equation (2). L is the length of real sample. The second curve is the calculation for absract sample having the same attenuation coefficient and the specific rotation angle exactly equal π/2L.

Then the main experiment has been realized. The frequency of investigated acoustic wave was changed by modification of generator frequency by which the acoustic wave is excited. As a result, the increase or decrease of the light intensity was provided electronically, fluently and with high accuracy. The measurements of the light intensities were carried out by using the standard calibration of the photo receiver as that was used the industrial photomultiplier. These intensities were used for determination of acoustic wave frequency by (2) at assumption that the attenuation coefficient and the specific rotation are dependent from frequency by quadratic law [3-7}.

The comparison of the measuring values of frequency with the used generator frequencies has shown that the proposed method allows to control and measure the acoustic wave frequency. The method can also be useful for control of the frequency of acoustic wave propagating in a gyrotropic media.

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