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ANISOTROPY OF ACOUSTIC PROPERTIES IN PARATELLURITE[1]

Vladimir N Parygin
Department of Physics, Moscow State University 119899, Moscow, Russia

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One of the peculiarities of the TeO_2 crystal consists of its strong acoustic anisotropy. This anisotropy demonstrates itself by acoustic energy walk-off and anisotropic distortion of an acoustic beam. Four constants completely characterise the acoustic anisotropy of the medium. In this paper these constants are calculated for various directions of the acoustic beam in crystal.

The tellurium dioxide (TeO_2) crystal is one of the most interesting objects for acousto-optics and its application. Many types of modulators, deflectors, tuneable filters and other devices have been designed and constructed based on this crystal [1]. Theoretical analysis of the device operation was usually performed using a plane-wave approximation method. However, the using of the plane-wave approximation of these devices is inadequate to describe experimental results.

The theory of slightly divergent acoustic beams can be utilized for the investigation of the majority of acousto-optical devices [2]. The beams are generated by planar piezzotransducers, the transversal dimensions of which are considerably larger than an acoustic wavelength λ. If x–direction is orthogonal to the transducer surface then one can describe the acoustic beam in the form

$$a(x, y, z, t) = A_0(x, y, z)\cos(Kx - \Omega t). \qquad (1)$$

Here K is the average wave-number of the acoustic beam, Ω is its frequency, and A_0 is the slowly varying amplitude of sound in the point (x, y, z).

A variation of the amplitude occurs on distances which are large in comparison with the sound wavelength λ. The TeO_2 crystal peculiarity consists in its strong acoustic anisotropy. For slightly divergent acoustic beam, this anisotropy is expressed by the acoustic energy walk-off and by the anisotropic distortion of the beam. The acoustic energy walk-off means that the direction of the acoustic beam energy propagation may be different considerably from the wave-vector **K** direction. The angle between directions of group and phase velocities in tellurium dioxide can reach tens of degrees.

Another strong effect observed in TeO_2 crystal is the anisotropic distortion of an acoustic beam. In an isotropic medium, the distortion is always proportional to the

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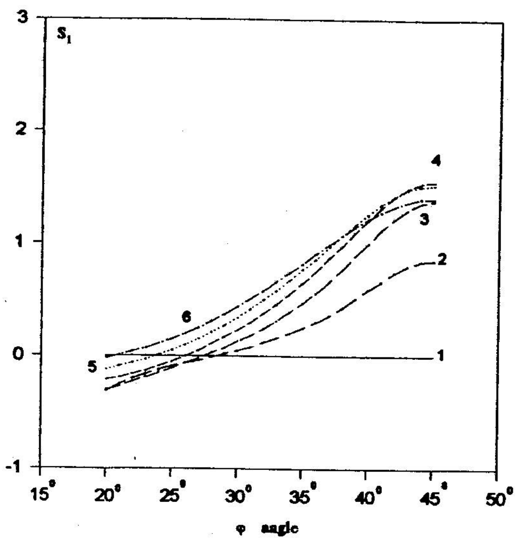

Fig.1 Walk-off coefficient S_1 dependence on φ in (x, y) plane for various values of θ: $\theta = 90°$ (1); $\theta = 85°$ (2); $\theta = 80°$ (3); $\theta = 75°$ (4); $\theta = 70°(5)$; $\theta = 65°(6)$.

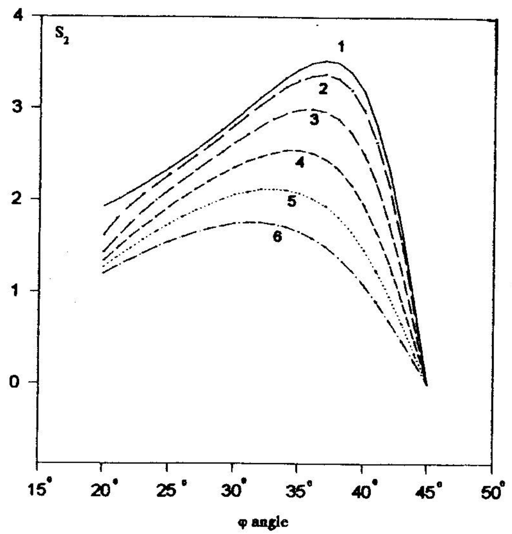

Fig.2 Dependence of walk-off coefficient S_2 on φ in (x,z) plane: $\theta = 90°(1)$; $\theta = 85°(2)$; $\theta = 80°(3)$; $\theta = 75°(4)$; $\theta = 70°(5)$; $\theta = 65°(6)$.

squared beam radius and does not depend on the propagation direction. On the contrary, in an anistotropic crystal the distortion depends strongly on the beam propagation

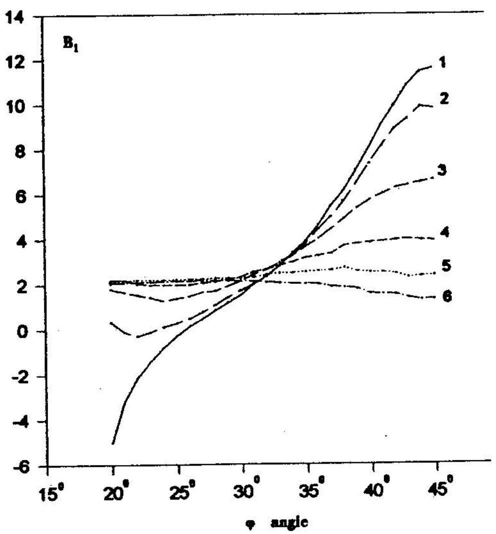

Fig.3 Dependence of distortion factor B_1 on φ for various values of θ: $\theta = 90°(1)$; $\theta = 85°(2)$; $\theta = 80°(3)$; $\theta = 75°(4)$; $\theta = 70°(5)$; $\theta = 65°(6)$.

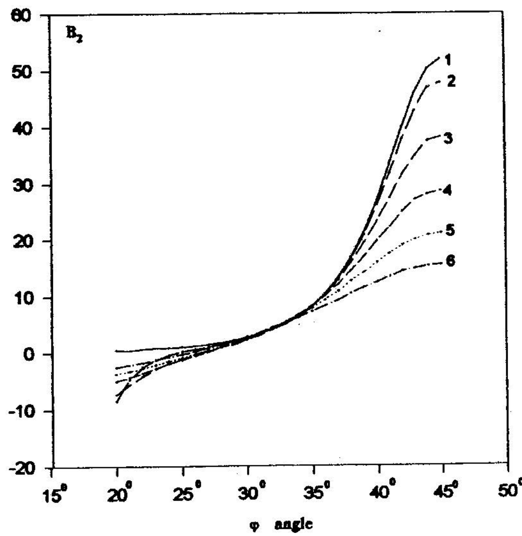

Fig.4 Dependence of distortion multiplier B_2 on φ for various values of θ: $\theta = 90°(1)$; $\theta = 85°(2)$; $\theta = 80°(3)$; $\theta = 75°(4)$; $\theta = 70°(5)$; $\theta = 65°(6)$.

direction corresponding to eigen-vectors of a distortion tensor.

A piezzotransducer oscillations amplitude distribution can be described in the Gaussian form

$$U(y,z) = U_0 \exp(-y^2/R_1^2)\exp(-z^2/R_2^2), \quad (2)$$

where R_1 and R_2 are the dimensions of the transducer in y and z directions, respectirely.

It can be shown that in this case the amplitude distribution across the acoustic beam in an anisotropic medium can be written as

$$A(x,y,z) = \frac{A_0 \exp[-\frac{(y-S_1x)^2}{R_1^2(1+jB_1D_1x')} - \frac{(z-S_2x)^2}{R_2^2(1+jB_2D_2x')}]}{\sqrt{(1+jB_1D_1x')(1+jB_2D_2x')}}. \quad (3)$$

Here S_1 and S_2 are the coefficients which correspond to the energy walk-off in (x,y) and (x,z) planes, respectirely. The y and z directions coincide with the eigen-vectors of the acoustic beam distortion tensor. The direction x is chosen as the direction of **K** vector. In addition to the non-normalized coordinate x we use in Eq. (3) also the normalized coordinate $x' = x/L$, were L is the crystal size in the x direction. So, inside the crystal, x' varies from 0 to 1. The introduction of the normalized coordinate x makes it possible to use the dimensionless parameters D_1, D_2, B_1 and B_2. Here $D_1 = 2L/KR_1^2$ and $D_2 = 2L/KR_2^2$ are the isotropic wave-parameters of the beam. In an anisotropic medium the additional B_1 and B_2 coefficients appear. These coefficients characterize the additional wave front bend in the crystal. The anisotropy can increase $(B > 1)$ or decrease $(B < 1)$ the diffractional divergence of the beam in comparison with an isotropic medium case. As a rule, the divergence of the beam for various directions is different.

Therefore, there are four constants S_1, S_2, B_1, B_2 which completely characterize the medium anisotropy for slightly divergent acoustic beam. These coefficients may be calculated for an arbitrary crystal. In the paper these calculations are carried out for TeO_2 as follows. In a plane-wave approximation one can get the phase velocity value of the slow quasitransverse wave and the two-dimensional function $V(\theta,\varphi)$ of the Euler's angles θ and φ in TeO_2 crystallographic coordinate system can be calculated to define the acoustic beam average wave-vector direction by

$$K_0(\theta,\varphi) = \Omega/V(\theta,\varphi). \quad (4)$$

We can approximate the acoustic beam wave-vector surface in the coordinate system of piezzotransducer by a paraboloid:

$$K_x = K_0(\theta,\varphi) - S_1(\theta,\varphi)K_y - \frac{B_1(\theta,\varphi)}{2K_0}K_y^2 - S_2(\theta,\varphi)K_z - \frac{B_2(\theta,\varphi)}{2K_0}K_z^2, \quad (5)$$

where S_1, S_2, B_1, B_2 are the earlier defined parameters of the acoustic beam walk-off distortion, respectively. Their magnitudes may be calculated applying coefficients of the parabola based on three points for $y = 0$ or $z = 0$ planes.

In the case of the $z = 0$ plane we have the following parabola

$$K_x = K_0(\theta,\varphi) - S_1(\theta,\varphi)K_y - B_1(\theta,\varphi)K_y^2/2K_0. \quad (6)$$

The coordinates $K_0(\theta+\delta\theta,\varphi)$, $K_0(\theta,\varphi)$ and $K_0(\theta-\delta\theta,\varphi)$ where $\delta\theta$ is small change of θ, are used then as three reference points of this plane. Values S_1 and B_1 can be determined from two equations corresponding to these points. The similar procedure in the $y = 0$ plane yields the expression for S_2 and B_2 values.

Figures 1 and 2 demonstrate the dependence of the walk-off coefficients on φ for various values of θ. One can see that the walk-off coefficient S_2 is larger than S_1.

Figures 3 and 4 show the dependence of the acoustic beam distortion coefficients B_1 and B_2 on φ for various values of θ. The presented data demonstrate that the maximal distortion takes place at θ angle close to 90°. The coefficient B_2 reaches the magnitude 52 in this case. It means that the beam divergence is higher by two orders than in an isotropic medium. The distortion in the orthogonal direction is 5 times lower in comparison with (001) plane.

The presented results of calculations may be used at the design of acousto-optic devices based on the tellurium dioxide crystal.

References

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