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Influence of acoustic anisotropy in paratellurite on quasicollinear acousto-optic interaction

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ABSTRACT

The influence of paratellurite acoustic anisotropy on the quasicollinear acousto-optic diffraction characteristics was examined. In the presented case the quasicollinear geometry of acousto-optic diffraction is realized with the use of acoustic beam reflection from one of the crystal surfaces. The simulations were based on the solution of acoustic beams propagation problem for anisotropic media previously presented in Balakshy and Mantsevich (2012). It is shown that media inhomogeneity affects the distribution of the acoustic energy in the ultrasound beam and the shape of wave fronts. The acoustic beam structure influences the characteristics of quasicollinear acousto-optic diffraction causing transformation of acousto-optic device transmission function shape and reducing the diffraction efficiency.

1. Introduction

Real acousto-optic devices characteristics frequently yield those obtained by solving the acousto-optic (AO) diffraction problem in classical approach, as interaction of plane light and acoustic waves. The fact that AO interaction occurs between wave beams is the reason of such discrepancy. These beams have limited aperture and inhomogeneous structure due to the diffraction effects. Inhomogeneity of interacting beams effects mostly the AO diffraction efficiency ζ.

Large part of AO devices is being fabricated on the base of paratellurite crystal to date. It is well known that TeO_2 crystal has extremely great anisotropy of acoustic and acousto-optic properties [1–4]. The biggest difference in paratellurite acoustic properties is observed in *XY* crystallographic plane [2]. However this plane is not used in acousto-optics. Different cuts in $(1\bar{1}0)$ plane are applied for AO devices fabrication most frequently. In this case acoustic anisotropy is not so great but achieves substantial value.

The evaluation of light diffraction by an inhomogeneous acoustic field is a very complicated problem. Only lately the progress in the area of mathematical modeling computer methods caused the appearance of papers devoted to the investigation of this problem [5–15]. In [5–8] the calculations were carried considering that acoustic beam has Gaussian profile. Media acoustic anisotropy was ignored. In [10–12] the influence of acoustic field inhomogeneity produced by complicated piezoelectric transducer structure was analyzed. The investigation of quasiorthogonal light diffraction at acoustic wave in paratellurite crystal [1 1 0] direction was presented in [14,15]. It was shown that it is possible to find such distance from ultrasound exciter at which the diffraction efficiency in Bragg regime achieves almost 100% and then stays constant with acoustic power growth [16]. The collinear and quasiorthogonal light diffraction in inhomogeneous acoustic field for acoustically isotropic and anisotropic media was examined in [17].

Another type of AO interaction, namely quasi-collinear geometry in paratellurite, was examined in [18]. Recently, quasi-collinear AO devices became widely used in laser techniques [19–24]. Parameters of these devices are determined by the anisotropy of elastic properties of crystals. The asymmetry of transmission function because of acoustic anisotropy in quasicollinear AO filters was studied fragmentary [25]. Phenomena of acoustic anisotropy influence on the parameters of that devices is worthy of furthers detailed studies.

Acoustic anisotropy appearance causes the distortion of acoustic beam amplitude and phase in crystal. Such distortion affects the Bragg interaction conditions and therefore the shape of AO device transmission function [18,25,27]. There are several manifestations of transmission function shape distortion. First – pass band widening, caused by acoustic field phase inhomogeneity. Phase distribution affects the phase matching conditions for separate spectral

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components of interacting acoustic and light beams. The widening may be also accompanied with pass band shift. Second – the reduction of AO interaction diffraction efficiency. This effect is caused by acoustic energy spatial repartition in ultrasound beam. The third factor is the appearance of transmission function asymmetry and function side lobes growth. The last effect has negative consequences for the application of AO devices in spectral analysis as side lobes allows the undesirable spectral components to pass through the AO filter.

In this paper we examine the influence of inhomogeneous acoustic beams amplitude and phase structure caused by existence of strong acoustic anisotropy on the characteristics of quasicollinear AO interaction in paratellurite crystal.

The structure of the paper is the following. The examination of paratellurite crystal acoustic anisotropy is presented in Section 2. The description of quasicollinear acousto-optic interaction geometry examined is given in Section 3. The short description of acoustic field structure simulation method in anisotropic media is presented in Section 4. Sections 5 and 6 are devoted to the investigation of quasicollinear acousto-optic interaction characteristics in inhomogeneous acoustic field. The influence of acoustic wave phase shift appearing during the reflection from the AO cell optical surface on the AO interaction transmission functions is presented in Section 7.

2. Acoustic anisotropy in TeO_2 crystal $(1\bar{1}0)$ plane

Paratellurite crystal $(1\bar{1}0)$ plane is widely used in acousto-optics. It is well known that TeO_2 has high anisotropy of acoustic properties in this plane producing in particular huge acoustic energy walk-off. We will determine the magnitude of crystal anisotropy in the given direction by introducing the coefficient κ defined as a ratio of acoustic beam divergence in presence Δ and in absence δ of media acoustic anisotropy [4,28].

$$\kappa = \Delta/\delta, \tag{1}$$

where $\delta = 2\Lambda/l = 2V/fl$, Λ is the acoustic wavelength, l – piezoelectric transducer length, V – acoustic wave velocity, f – ultrasound frequency. The Δ value is defined by the half width of acoustic beam power angular spectrum [4] that corresponds to the acoustic beam structure in the far diffraction field.

Fig. 1 presents the dependences of κ coefficient and acoustic walk-off angle ψ on the polar angle θ_0 in $(1\bar{1}0)$ paratellurite crystal plane calculated for $l = 4$ mm and $f = 40$ MHz.

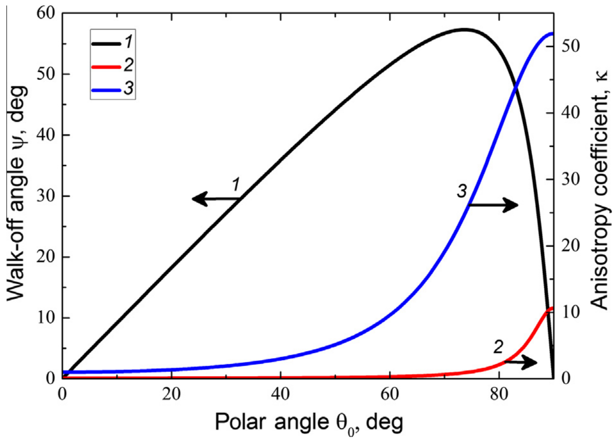

Fig. 1. The dependences of κ coefficient and acoustic walk-off angle ψ on the polar angle θ_0 in $(1\bar{1}0)$ paratellurite crystal plane.

Angle θ_0 defines the acoustic beam spatial spectrum central component propagation direction and is counted from the crystallographic axis Z. Curve 1 shows the evolution of walk-off angle in $(1\bar{1}0)$ plane. Curve 2 – anisotropy coefficient in $(1\bar{1}0)$ plane and curve 3 – anisotropy coefficient in the planes orthogonal to the $(1\bar{1}0)$ plane.

Herewith the highest values of anisotropy coefficient are observed at polar angles $\theta_0 > 70^\circ$ (cut angle $0^\circ < \alpha < 20^\circ$). This range of α angles is frequently used in AO devices fabrication on the base of TeO_2 crystal. Also we need to point out that θ_0 range with big κ corresponds to the part of $\psi(\theta_0)$ dependence where walk-off angle is changing rapidly.

As follows from (1) κ coefficient depends not only on media properties, but also on piezoelectric transducer length and ultrasound frequency that may vary. That is why the dependences of $\kappa(l,f)$ were also examined. Fig. 2 presents $\kappa(l,f)$ dependences calculated for [110] direction. Transducer length varies from 0.1 cm to 1 cm, ultrasound frequency – from 20 MHz to 100 MHz. The results are presented in mesh view for the planes (001) (Fig. 2a) and $(1\bar{1}0)$ (Fig. 2b). It is possible to notice that for most of the values $\kappa(l,f)$ stays constant except region where beam aperture and ultrasound frequencies are low (high beam divergence). These graphs dive a possibility to define the bounds of parabolic approximation [29–32] as it gives constant κ value regardless to the acoustic beam divergence δ.

3. Quasicollinear interaction in TeO_2 crystal

One of the challenges for modern acousto-optics is the creation of the devices with as high spectral resolution as possible. This means that the pass band of such devices (defined by the half width of transmission function) should be as narrow as possible. The primary method of pass band reduction is the increase of AO interaction length. It is possible to realize this variant in paratellurite by using quasicollinear geometry of AO interaction [18–21,24]

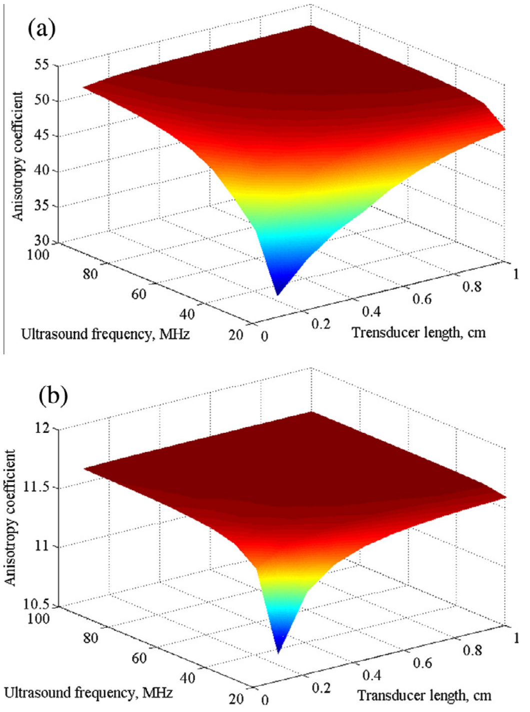

Fig. 2. The dependences of anisotropy coefficient $\kappa(l,f)$ on transducer length and ultrasound frequency in $(1\bar{1}0)$ plane (a) and in XY plane (b) for [110] direction.