acta physica slovaca vol. 46 No. 6, 733 – 738 December 1996

ACOUSTO-OPTIC MEASUREMENTS OF ULTRASOUND ATTENUATION IN TELLURIUM DIOXIDE CRYSTAL [1]

V.B. Voloshinov, E.A. Lemyaskina
Department of Physics, Moscow State University, 119899 Moscow, Russia

Received 15 May 1996, accepted 23 September 1996

The paper is devoted to experimental investiation of ultrasound propagation in tellurium dioxide monocrystal. In particular, attenuation of slow shear acoustic modes in the crystal was measured. The measurements were performed by acousto-optic methods using probing of acoustic column by a laser beam. The paper describes measurements of acoustic attenuation coefficient for slow shear ultrasonic waves propagating at an angle $\varphi = 4.5°$ with respect to the [110] direction in the $(1\bar{1}0)$ plane. The investigation was made at acoustic frequency $f = 100$ MHz with pulsed acoustic waves and with an optical beam of a He-Ne laser. It is found that the attenuation coefficient is $\alpha = 0.57\mathrm{cm}^{-1} \pm 15\%$. The attenuation at acoustic frequencies $f \geq 100$ MHz influences performance characteristics of acousto-optical devices based on tellurium dioxide. As proved, spectral resolution of a quasi-collinear acoustooptic filter decreases by a factor of 2 compared to a case of the attenuation absence.

1. Introduction

Tellurium dioxide (paratellurite, TeO_2) is a well-known material in acousto-optics. The crystal is used in optoelectronic devices such as acousto-optic modulators, deflectors, and tunable filters [1-3]. The anomalously slow acoustic shear velocity in the [110] direction leads to a favourable acousto-optic value of merit value. As a result, acousto-optic instruments on base of tellurium dioxide provide efficient diffraction of light on ultrasound at relatively low drive acoustic and electric power levels.

Acousto-optical devices on base of tellurium dioxide known so far use slow shear acoustic waves propagating along the [110] direction or at an angle φ (usually $\varphi \leq 20°$) relative to the [110] axis in the $(1\bar{1}0)$ plane [6]. Unfortunately, the acoustic waves are characterized by relatively high acoustic attenuation which influences performance parameters of the devices. This influence becomes intorelable especially in the case of acousto-optic deflectors and tunable acousto-optic filters. The paper is devoted to

---

[1] Presented at the 14th International Conference on Utilization of Ultrasonic Methods in Condensed Matter, August 30 - September 2, 1995, Žilina, Slovakia

0323-0465/96

experimental evaluation of the attenuation in TeO_2 single crystals for a crystal cut typical of a high-resolution quasi-collinear filter [7]. The measurement of the attenuation was performed using probing of an acoustic column in a cell by a laser beam.

2. Experiment

Experimental investigation of ultrasound attenuation was made with the help of an acousto-optic cell shown in Fig.1. The cell was fabricated of a TeO_2 monocrystal in a form of a prism with a lithium niobate piezotransducer generating shear acoustic waves in the volume. Cold indium welding technology was used during the fabrication of the cell. The transducer launched slow shear acoustic waves in the $(1\bar{1}0)$ plane of the crystal at an angle $\varphi = 4.5°$ relative to the [110] direction. Acoustic anisotropy of the crystal resulted in a strong "walkoff" of acoustic energy in the sample so that the angle between the phase and the group velocities was $\psi = 38°$ [7]. The length and the width of the transducer in $(1\bar{1}0)$ and (001) planes were correspondingly equal to $l = h = 0.25$ cm. The transducer was polished so that a fundamental tone of the piezoelectric plate was $f = 100$ MHz. All measurements were made at this acoustic frequency in a pulse regime of operation. Pulsed ultrasound was used in order to avoid undesirable reflections of acoustic waves in the cell.

An optical beam of a He-Ne laser with a diameter $a = 0.1$ cm and wavelength $\lambda = 633$ nm was incident on ultrasound at a Bragg angle in the $(1\bar{1}0)$ acousto-optic interaction plane. Position of the laser beam relative to the transducer was varied. The beam was shifted step by step along ultrasonic phase velocity propagation direction (axis ξ in Fig. 1), i.e. approximately along the [110] axis, and in the orthogonal direction (axis η) along the width of the transducer h.

A process of light diffraction by a travelling ultrasonic wave was observed in the cell if a pulsed RF electric signal was applied to the transducer terminals. It is known that intensity of a diffracted optical beam I_d is proportional to acoustic power P [1-3]. Therefore, measurements of diffracted light intensity at various distances from the transducer along ξ axis provided evaluation of the required attenuation value [5]. The diffracted light intensity was measured in the experiments by a photomultiplier positioned at the cell output.

A spreading of acoustic energy in (001) plane, i.e. along the η axis, was observed in the cell. Figure 2 illustrates measured dependencies of diffracted light intensities I_d on the η coordinate. The presented dependencies were measured at the following distances from the transducer: $\xi_1 = 0.3$ cm (curve 1) and $\xi_2 = 1.0$ cm (curve 2). It is seen in Fig. 2 that the diffracted intensity I_d is decreasing with the growth of ξ parameter. The decrease originates from two factors: ultrasound attenuation and spreading of acoustic energy in the cell. Comparison of the two curves in Fig. 2 proves that a linear aperture of the acoustic column in the cell is increasing with the distance ξ. Therefore, the observed divergence of ultrasonic waves should be taken into account during the analysis. On the other hand, divergence of ultrasound in the $(1\bar{1}0)$ plane may be neglected because it is a few times lower than in (001) plane [6].

In order to determine attenuation coefficient, measurements of diffracted light intensity on η coordinate were made. The measurements of $I_d(\eta)$ were performed at ξ values

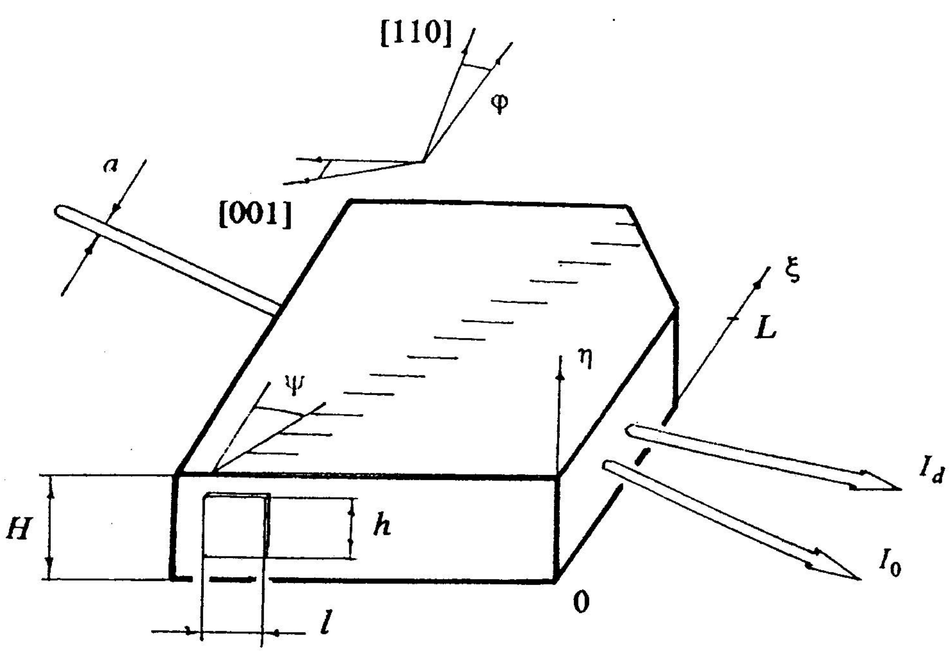

Fig. 1. Scheme of the experimental investigations

varying in series from $\xi = 0.3$ cm to $\xi = 1.2$ cm with a step $\Delta\xi = 0.1$ cm. Bragg angle of light incidence on ultrasound was adjusted during the probing of the acoustic column. On base of the obtained $I_d(\eta)$ dependencies, the following integrals were calculated for each of the twelve cross-sections of the acoustic beam

$$S = \frac{1}{I_0} \int_0^H I_d(\eta) \mathrm{d}\eta \,, \tag{1}$$

where I_0 is intensity of the incident light, and H is dimension of the crystal along the η axis. In the experiments the size of the crystal was equal to $H = 0.6$ cm. It is clear that the value of the integral in Eq.(1) is proportional to the total amount of acoustic power in a cross-section of the acoustic column at a chosen distance ξ from the transducer.

3. Attenuation coefficient evaluation

Experimental results on laser probing of the acoustic column are summarized in Fig. 3. The figure presents dependency of acoustic power in the cell P on ξ value, i.e. on the path of ultrasound in the crystal. As mentioned, the acoustic power was determined from the known values of S integrals Eq.(1). It is seen in the picture that the acoustic power is decreasing with the distance ξ. Therefore, it was reasonable to approximate the experimentally obtained dependence of the power on ξ by the following exponential

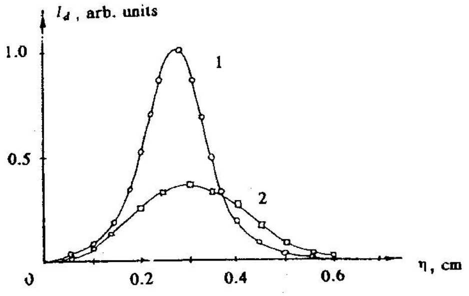

Fig. 2. Distribution of acoustic energy over acoustic column cross-section, where curve 1 stands for $\xi = 0.3$ cm and curve 2 for $\xi = 1.0$ cm.

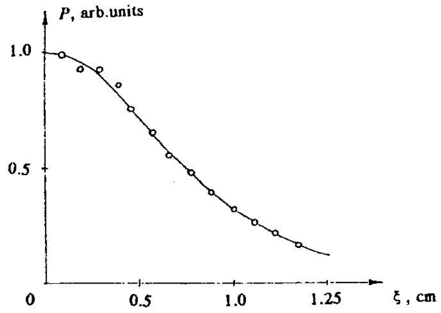

Fig. 3. Dependence of acoustic power on the distance of ultrasound propagation.

function

$$P(\xi) = P_0 \exp(-\alpha\xi)\ , \tag{2}$$

where P_0 is the intensity of ultrasound in the neighbourhood of the transducer at $\xi = 0$. This approximation was performed with the help of a computer. Computer processing of the experimental results provided determination of the attenuation coefficient. The coefficient at acoustic frequency $f = 100$ MHz was equal to $\alpha = 0.57\mathrm{cm}^{-1} \pm 15\%$ or 2.5 ± 0.3 dB/cm. The value of the attenuation coefficient obtained by means of acousto-optics is in good agreement with data presented in reference [5] for the [110] direction of ultrasound propagation in the crystal.

4. Influence of attenuation on acousto-optic filter parameters

It is known that attenuation of ultrasound influences operation parameters of acousto-optic devices, e.g. tunable filters [1]. The influence of the attenuation on the parameters of a quasi-collinear TeO_2 filter [7] may be evaluated if the attenuation coefficient value is known [8]. Spectral resolution of a filter $R = \lambda/\Delta\lambda$ in case of negligible ultrasound attenuation is determined by a number of periods of a diffraction grating intersected by an optical beam [1,7]

$$R \approx \frac{fL}{V}, \tag{3}$$

where L is the length of the acoustic column along phase velocity of ultrasound. This length is usually determined by a size of a crystal used in the filter. However, presence of acoustic attenuation decreases an effective length of light and sound interaction in the cell. Therefore, the resolution value becomes lower than proposed by Eq.(3) and determined by dimensions of the crystal.

The spectral bandwidth of a quasi-collinear filter on base of TeO_2 was calculated using methodics presented in paper [8]. Calculations were performed for a crystal with $L = 5.0$ cm and ultrasound propagation direction in the $(1\bar{1}0)$ plane described by a

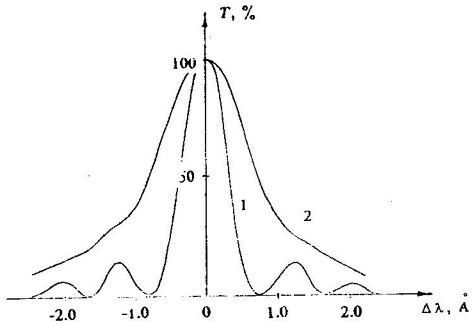

Fig. 4. Filter transmission coefficient dependence on optical wavelengths. Here, curve 1 is without ultrasound attenuation and 2 is with attenuation of acoustic waves

tilt angle of acoustic wave vector $\varphi = 4.5°$. Analysis shows that spectral bandwidth of the filter in case of the attenuation absence is equal to $\Delta\lambda = 0.8$ Åat $\lambda = 633$ nm corresponding to the resolution value $R = 8000$. On the other hand, calculation of spectral resolution of a real instrument with attenuated acoustic waves predicts the resolution value about 2 times lower compared to the ideal case without attenuation. The attenuation leads to the spectral bandwidth broadening up to $\Delta\lambda = 1.3 - 1.5$ Å. Figure 4 illustrates calculated transmission coefficient dependencies on optical wavelengths for two cases: without the attenuation (curve 1) and the ultrasonic attenuation (curve 2). The second spectral curve in Fig. 4 should be considered as a more correct and realistic one.

5. Conclusion

Crystal cuts of tellurium dioxide commonly used in acousto-optics are characterized by relatively high acoustic attenuation. Experimental investigation of the attenuation at acoustic frequencies about $f = 100$ MHz demonstrates that attenuation coefficient for slow shear acoustic waves propagating in $(1\bar{1}0)$ plane close to [110] axis is equal to $\alpha = 0.57\mathrm{cm}^{-1} \pm 15\%$ or 2.5 ± 0.3 dB/cm. The attenuation influences operational parameters of acousto-optical devices based on the examined crystalline cut of tellurium dioxide. For example, spectral resolution of quasi-collinear filters on base of TeO_2 crystals is considerably decreased compared to cases of the attenuation absence.

References

[1] E. Dieulesaint, D. Royer: *Ondes Elastiques dans les Solides*. Maison, Paris 1974;
[2] V. Balakshy, V. Parygin, E. Chirkov: *Physical Principles of Acoustooptics*. Radio and Communication, Moscow 1985;
[3] A. Korpel: *Acousto-Optics*. Marcel Decker, N.Y. 1990;
[4] N. Uchida: *J. Appl. Phys.* **43** (1972) 2915

[5] S. Antonov, E. Kuznetzova, V. Mirgorodsky, V. Proklov : *Sov. Journ. of Acoustics* **4** (1982) 433

[6] V. Voloshinov: *Ultrasonics* **31** (1993) 333

[7] V. Voloshinov: *Opt. Engineering* **31** (1992) 2089

[8] V. Voloshinov, V. Parygin: *Moscow University Physics Bulletin* **35** (1980) 98