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Natural frequencies of acousto-optic TeO_2 crystals

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The optical measurements were carried out for the incident light of $\mathbf{E} \perp \mathbf{C_4}$ and $\mathbf{E} \parallel \mathbf{C_4}$, (**$C_4$** is the optical axis of crystals) in the 50 – 50000 cm^{-1} spectral range. By the Kramers -Kronig relation the calculations are made of dispersions of the real and imaginary parts of dielectric penetration, as well as of the factors of refraction and absorption, and natural frequencies are determined. Frequencies of active phonons in the IR spectrum are determined. The IR reflection spectra ($\mathbf{E} \parallel \mathbf{C_4}$) contain 4 intensive absorption bands κ(ν) and 8 bands in spectra of $\mathbf{E} \perp \mathbf{C_4}$ which were interpreted in terms of theoretical group analysis of D_4 point symmetry group of TeO_2 crystals. The natural frequencies of the TeO_2 were determined.

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1. Introduction

The interest to the study of optical properties of TeO_2 crystals is determined not only by fundamental physical mechanism present in this material ,but also by a wide spectrum of possible applications in high speed acousto-optic devices : intensity modulators, acousto-optic deflectors and tunable filters, power spectra analyzer etc.

A description is given of some experimental results of studying the optical properties of tetragonal TeO_2 (class 422) crystals.

An analysis of measurements results of reflection spectra of paratellurite TeO_2 Specific feature of frequency dependences of these value with two radiation polarizations are revealed.

An analysis of measurements results of reflection spectra of paratellurite TeO_2 crystals within the interval from 0.2 to 50 μm has been performed.

When an acoustic wave propagates in TeO_2 crystals, it produces a periodic modulation of the index of refraction .This provides a moving phase grating with may diffract portions of an incident light. This phenomenon, known as the acousto-optic (AO) diffraction, has led to a variety of optical devices that perform spatial, temporal, and spectral modulation of light. These devices have been used in optical systems for light-beam control and signal-processing applications.

The elastic-optic effect is the basic mechanism responsible for the acousto-optic interaction .It describes the change of refractive index of an optical medium due to the presence of an acoustic wave. The traveling acoustic wave sets up a spatial modulation of the refractive index which, under proper conditions, will diffract the incident beam into one or more directions (acousto-optic effect). TeO_2 crystals are very important materials in this sense.

Optical measurements have many unique and attractive features for studying crystal properties and characterizing crystal properties .There are contact less nondestructive, and compatible with any transparent ambient including high-vacuum environments and useful for in-situ analysis on processing systems.

2. Theoretical analysis

The optical properties of insulators as the semiconductors are often subdivided into these that are electronic and those that are lattice nature. The lattice properties concern processes involving vibrations of the lattice (absorption and creation of phonons).

The refractive index “n” gives the phase shift of the optical wave, and the extinction coefficient “κ” gives the attenuation of the wave.

In optics, it is frequently convenient to define a complex index “N “the square root of the complex dielectric constant $\varepsilon(\nu) = \varepsilon_1(\nu) - i\,\varepsilon_2(\nu)$;

$$N = n - i\kappa = \sqrt{\varepsilon} = \sqrt{\varepsilon_1 - i\varepsilon_2} \qquad (1)$$

and $\varepsilon_1 = n^2 - \kappa^2$, $\varepsilon_2 = 2n\kappa$ (2), where “n “is the real index of refraction and “κ ” is the index of absorption.

The reflection and transmission from a surface are given by

$$r = \frac{(\bar{n} - 1)}{(\bar{n} + 1)} = |r| \exp(i\theta) = \left| \frac{n - 1 - i\kappa}{n + 1 - i\kappa} \right| \qquad (2)$$

θ is the shift of the incident and reflected waves ,

$$R = |r^2| \qquad (3)$$

and T = 1 – R, where R and T are the reflectance and transmission.

From (2) may be obtained

$$R = |\, r^2 \,| = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2} \qquad (4)$$

and

$$\mathrm{tg}\,\theta = \frac{2n\kappa}{n^2 + k^2 - 1} \qquad (5)$$

By solved (4) and (5) follows:

$$n = \frac{1-R}{1+R-2\sqrt{R}\cos\theta} \qquad (6)$$

and

$$\kappa = \frac{2\sqrt{R}\sin\theta}{1+R-2\sqrt{R}\cos\theta} \qquad (7)$$

An expression of practical utility is one in which the experimentally measured power reflection R at normal incidence is explicitly displayed as shown

$$\theta\,(\nu) = \frac{\nu}{\pi} P\int_0^{\infty} \frac{\ln R\left(\nu^1\right) d\,\nu^1}{\left(\nu^{!}\right)^2 - \nu^2} \qquad (8)$$

and may be find by a Kramers –Kronig analysis.

If R (ν) can be measured only a limited frequency range $\Delta\nu = \nu_B - \nu_A$, but extrapolations can be made to establish reasonable values of “n” and “k”

$$\theta(\nu) = \theta_1(\nu) + \theta_2(\nu) + \theta_3(\nu) \qquad (9),$$

where:

$$\theta_1(\nu) = -\frac{\nu}{\pi} P\int_0^{\nu_A} \frac{\ln R\left(\nu^1\right) d\,\nu^1}{\left(\nu^{!}\right)^2 - \nu^2} \qquad (10)$$

$$\theta_2\,(\nu) = -\frac{\nu}{\pi} P\int_{\nu_A}^{\nu_B} \frac{\ln R\left(\nu^1\right) d\,\nu^1}{\left(\nu^{!}\right)^2 - \nu^2} \qquad (11)$$

and

$$\theta_3(\nu) = -\frac{\nu}{\pi} P\int_{\nu_B}^{\infty} \frac{\ln R\left(\nu^1\right) d\,\nu^1}{\left(\nu^{!}\right)^2 - \nu^2} \qquad (12)$$

2. Experimental results and analysis

An analysis of measurement results of reflection spectra of paratellurite TeO_2 crystals within the interval from 0.2 to 50 μm is carried out.

The Fig. 1 (a) and (b) shows the spectral variation in the reflection coefficient R and phase shift “θ “of the reflection wave for two radiation polarizations $\mathbf{E} \parallel \mathbf{C_4}$ and $\mathbf{E} \perp \mathbf{C_4}$. Frequency dependence of phase shift θ(ν) reflects a structure of vibration spectra.

In TeO_2 crystal atoms are attached by four environing “O” atoms witch are arranged in the peaks of triangular bipyramids.

A group theory analysis determines the number of the lattice vibration (natural frequencies) contributions to the dielectric constant ε(ν) of TeO_2 (class 422). In the center of Brillouin zone (wave vector $\vec{k} = 0$) there are follows [1, 2]:

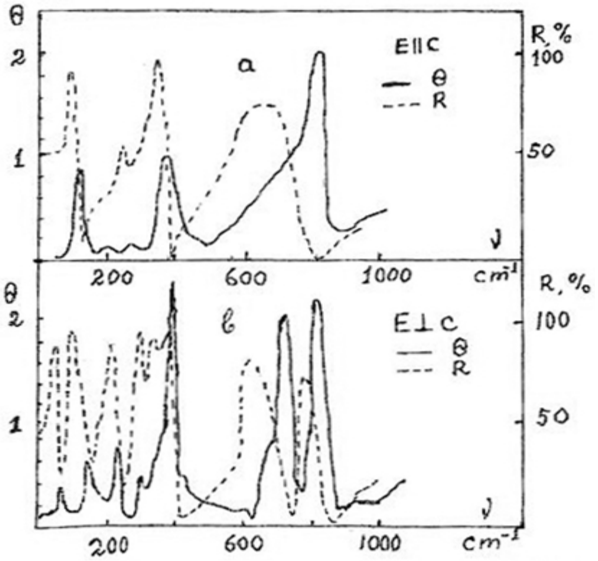

Fig. 1. Reflection spectra R and spectral variation of phase shift Θ of TeO_2: (a) $E\|C_4$ and (b) $E \perp C_4$.

$$\mathbf{\Gamma = 4A_1(R) + A_2(IR, E \parallel C_4) + 5\,B_1(R) + 4\,B_2\,(R) + 8\,E\,(IR, E \perp C_4)} \quad (13)$$

The relevant absorption peaks of the κ(ν) are listed in Table 1.

Four bands in the spectrum θ(ν) where found in $\mathbf{E} \parallel \mathbf{C_4}$ and seven bands in $\mathbf{E} \perp \mathbf{C_4}$ in accordance with position of absorption peaks mentioned by authors [3].

Position of absorption peaks are listed in Table 1.

Table 1. Peaks of absorption in TeO_2 crystals.

	$E \parallel C_4$				$E \perp C_4$							
	1	2	3	4	1	2	3	4	5	6	7	8
Peak ν cm^{-1}	81	252	315	567	123	164	205	293	-	327	623	754

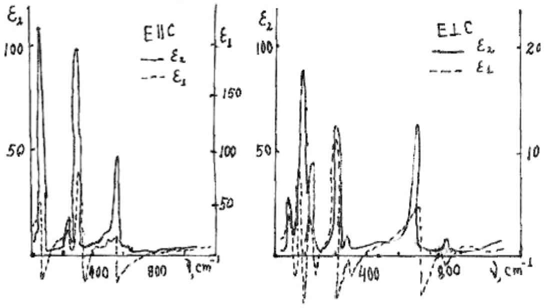

Fig. 2. Frequency dependences of $\varepsilon_1(\upsilon)$ and $\varepsilon_2(\upsilon)$ on $E \| C_4$ and $E \perp C_4$ for TeO_2.

In Fig. 2 are presented frequency dependences of $\varepsilon_1(\nu)$ and $\varepsilon_2(\nu)$ of crystals TeO_2 on $\mathbf{E} \| \mathbf{C_4}$ and $\mathbf{E} \perp \mathbf{C_4}$. Results of calculations of natural frequencies from IR spectra according (8) are shown in Table 2.

Table 2. Frequency dependence of $\varepsilon_1(\nu)$ and $\varepsilon_2(\nu)$.

$E \| C_4$			$E \perp C_4$		
ν (cm^{-1})	ε_1	ε_2	ν (cm^{-1})	ε_1	ε_2
81	- 39	141	123	- 36	
253	29	21.53	164	- 84	191
315	- 132	118	205	- 20	46
567	- 34	63.27	286	- 15	52
			303	- 19	
			623	- 63.51	30
			754	- 12.84	

3. Conclusions

In this paper the IR spectra of TeO_2 acousto-optic crystal were measured in the 50 –50000 cm^{-1} spectral ranges on two polarization of incident light $\mathbf{E} \| \mathbf{C_4}$ and $\mathbf{E} \perp \mathbf{C_4}$ Kramers-Kronig analysis of experimental spectra was made and energy of active optical phonons in $\mathbf{E} \| \mathbf{C_4}$ and $\mathbf{E} \perp \mathbf{C_4}$ polarization spectra were founded.

There was demonstrated a correlation of peaks of absorption and calculated energy of optical phonons from IR spectra TeO_2 crystals.

References

[1] D. M. Korn, A. S. Pine, G. Dresselhaus, T. Reed, Phys. Rev. **B 8**(3), 768 (1973).
[2] A. S. Pine, G. Dresselhaus, Phys. Rev. **B5**, 4087 (1972).
[3] I. C.Chang , Optical Engineering **24**, 132 (1985).
[4] M. Caraman, V. Musinschi, I. Smirnov, Sov. J. P. S **48(**5), 825 (1988).

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