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Propagation of linearly polarized light in a heated uniaxial CdS crystal

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Abstract. It has been shown that the intensity of linearly polarized light transmitted through CdS single crystal depends on its temperature. It has been found that the temperature of crystal does not affect the linearity of light polarization at the exit of crystal, but leads only to rotation of the polarization plane. It has been ascertained that in the range between 11 to 170 °C, the temperature dependence of the linear expansion coefficient and the difference between the refractive indices of unusual and ordinary beams can be neglected.

Keywords: polarizer, analyzer, temperature, CdS single crystal.

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1. Introduction

Operation of optical polarization devices is based on the possibility to change the magnitude of the phase delay

$$\delta = 2\pi(n_e - n_o)d\lambda^{-1} \quad (1)$$

between light components in uniaxial crystals under the influence of external factors. In (1) d is the single crystal thickness, λ – wavelength, n_e and n_o are the refractive indexes of unusual and ordinary rays. In existing polarization devices, δ most often changes under the action of electric (devices based on using the Pockels or Kerr effects [1]) or magnetic (Faraday effect devices [2]) fields. In these devices, under the influence of these fields, $\Delta n = n_e - n_o$ changes, and it is assumed that d is a constant value. However, d, n_e and n_o are temperature-dependent parameters. If the external factor is the temperature, then, d, n_e, and n_o are temperature dependent parameters. In particular, when the temperature of crystalline quartz changes at 1 °C, the phase delay is approximately 0.01% [3]. If optical polarization devices operate in the presence of field, then the influence of temperature on their parameters must be taken into account [4].

In this paper, the character of the temperature influence of monocrystalline CdS on the magnitude of angle onset of the phase, the difference between refractive indices of the unusual and ordinary light beams occur, which allow one to investigate the possibility of creating a temperature-controlled light polarization rotator.

2. Peculiarities of the polarization of light propagating in a uniaxial crystal

During our experiments, the light flux passed through the polarizer, monocrystalline CdS, and analyzer. The optical axis of the crystal was parallel to the entrance surface of the crystal. From the polarizer, the beam of linearly polarized light emerged, which fell along the normal to a flat parallel crystalline plate of CdS with the thickness d. For better understanding the influence of temperature of a uniaxial crystal on the light polarization, we briefly consider peculiarities of changing the polarization of light, when the latter passes through a uniaxial crystal, guided by information given in many monographs (see, for example, [5-7]), devoted to the basics of optics.

The components of the amplitude of the light wave incident on the plate (Fig. 2, vector $\mathbf{0E_0}$) are

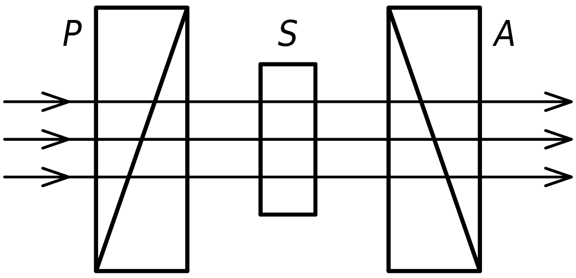

Fig. 1. Light passage through a polarizer (P), a uniaxial crystal (S) and an analyzer (A).

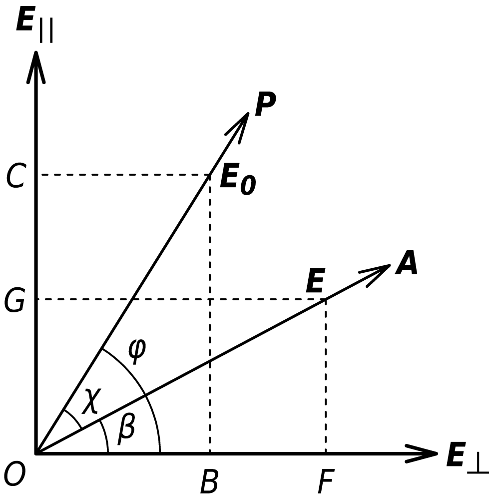

Fig. 2. To determine the oscillation component of the vector of polarization of light passing through the polarizer and analyzer.

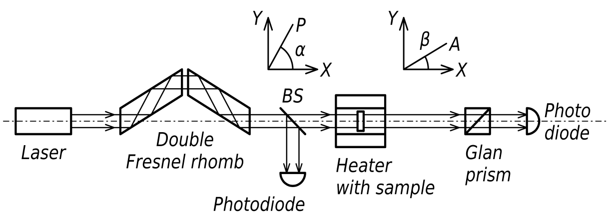

Fig. 3. A simplified scheme for studying the influence of external factors on the state of polarization of light propagating in a uniaxial crystal. α and β are the angles between the optical axis and the light vector at the input and output from the sample, respectively. FD-24K is a silicon photodiode.

$$OB = E\cos\alpha\,,\ OC = E\sin\alpha\,, \tag{2}$$

where α is the angle between the optical axis C of the crystal and vector **E** of the light wave.

Entering to the plate, each beam is separated by two rays. Each ray propagates with a different speed, and their vectors $\mathbf{E}_\perp$ and $\mathbf{E}_{||}$ oscillate in two mutually orthogonal directions perpendicular to the direction of the normal to the plate (Fig. 2). The components of the rays emerge from a plate with a certain phase difference δ, Eq. (1).

The corresponding amplitudes of the light wave (vector **0E**, Fig. 2) are

$$OF = E\cos\varphi\cos(\varphi-\chi)\,,\quad OG = E\sin\varphi\sin(\varphi-\chi)\,, \tag{3}$$

where χ is the angle at which the light wave vector rotates as a result of the light passage through the uniaxial crystal (Fig. 1).

According to [7], the intensity of light I obtained as a result of interference of the components of light emerging from a plane-parallel plate of the uniaxial crystal is as follows

$$I = I_0\cos^2(\alpha-\beta) - I_0\sin 2\alpha\sin 2\beta\sin^2(\delta/2)\,, \tag{4}$$

where α is the angle between the vector $\mathbf{E_0}$ of the light wave incident along the normal to the input surface of the crystal, and the optical axis C, β – angle between the vector **E** of the light wave and the optical axis C at the exit from the crystal, I_0 – intensity of the light incident on the input surface of the plane-parallel CdS plate.

It must be remembered that n_e, n_o and

$$d = d_0(1+\gamma\cdot\Delta T) \tag{5}$$

are temperature dependent. In (5), $\Delta T = T - T_0$, γ is the linear expansion coefficient. T and d are the final temperature and crystal thickness, T_0 and d_0 are their initial values.

3. Method of investigation

A simplified scheme of analyzing the state of light polarization, when light propagates in the plane-parallel CdS plate, is shown in Fig. 3. The helium-neon laser (λ = = 632.8 nm) was used as the source of linearly polarized light. The flow of this light passes through a double Fresnel rhombus, by turning which we set the desired value of the angle α. The analyzer was Glan's prism. The intensity of light coming out from the polarizer or the analyzer was controlled using FD-24K photodiodes. The temperature of the sample was controlled by heating it with an electro-furnace and monitored using a thermocouple.

4. Features of the polarization of light during its propagation through the heated CdS single crystal

The polarization planes of polarizer and analyzer were oriented in parallel. We place the uniaxial crystal between the polarizer and analyzer. The value α = 70° was settled by turning the double Fresnel rhomb.

To determine peculiarities of changing the polarization of light during its propagation in the heated CdS single crystal, the values I_0 and α were fixed, and for each temperature dependence I on the angle of analyzer rotation the intensity was measured (Fig. 4, points).

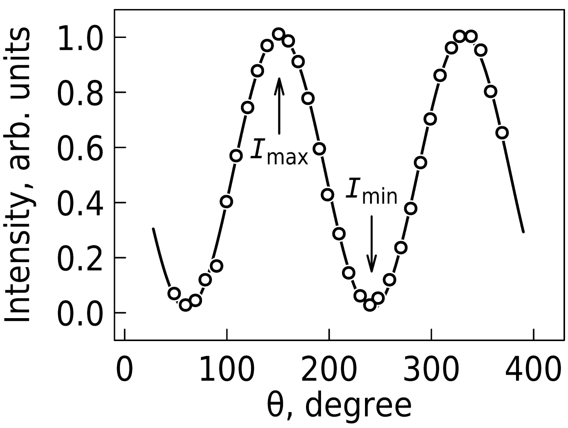

Fig. 4. Dependence of the intensity I at the output from the analyzer on the angle of analyzer rotation θ, $\alpha = 70°$. The sample temperature is 150 °C. The maximum (I_{max}) and minimum (I_{min}) values of the intensity correspond to 203 and 150 °C. Experiment (points) and sinusoid approximation (solid curve).

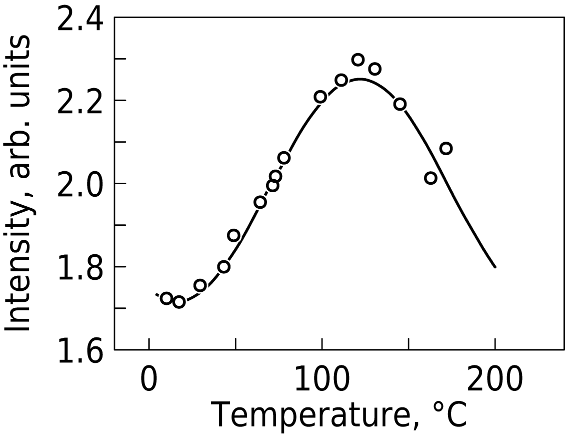

Fig. 5. Dependence of the light intensity at the exit from the analyzer on the temperature of the plane-parallel plate of CdS single crystal. Points stand for the experimental data, the solid line corresponds to calculation with Eq. (4).

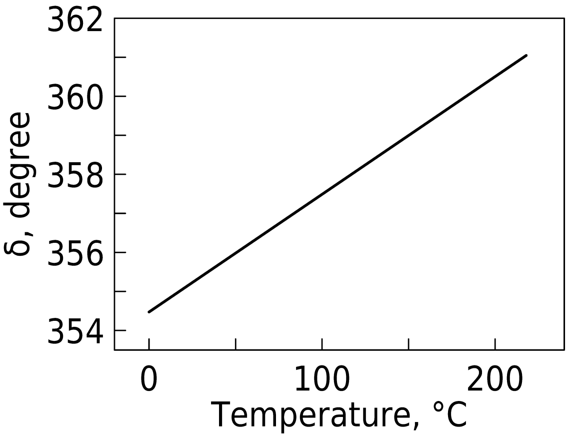

Fig. 6. Phase delay angle δ *vs* temperature *T*.

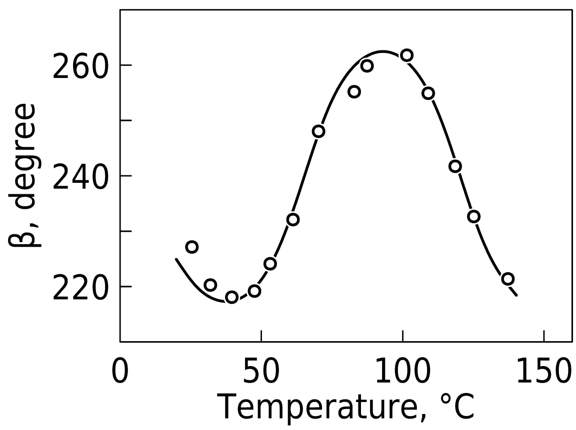

Fig. 7. Temperature dependence of the angle of rotation of the plane of polarization by a sample of CdS (thickness is 0.21 cm). Experiment, solid curve is calculation by equation (4).

The experimentally obtained dependence was approximated by a sinusoid (Fig. 4, solid curve). With a mean square error of less than 10%, the calculated curve described the experimental dependence. This allowed us to estimate the value θ that provides achievement of the maximum (I_{max}) and minimum (I_{min}) values (Fig. 6). When I reaches a magnitude I_{max}, the value of θ is taken to be equal to β. Thus, the plane of light polarization at the exit of CdS single crystal was determined.

Then, the dependence of light intensity at the output of the analyzer on the temperature of CdS plate was determined (Fig. 5). Using the formulae (2), (4), (5), the dependence of light intensity I on the sample temperature T (Fig. 5, solid curve) was calculated. During calculations of I on T, it was considered that $\Delta n = n_e - n_o$ and γ are temperature-independent parameters. As can be seen from the data shown in Fig. 5, the experimental and calculated dependences I on T are in perfect agreement with each other. It means that within the range 11…170 °C one can exclude temperature dependences of CdS.

Further, using the known values Δn and γ, let us calculate the temperature dependence of the phase delay angle δ (Fig. 6). The presence of this dependence indicates that heating the plate can affect the shape of ellipse for light polarization and leads to a temperature dependence of rotation of the angle β for the polarization azimuth.

Using the known values for each sample temperature, the degree of polarization was found [6]

$$P = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} . \qquad (6)$$

From the analysis of the set of data, similar to those shown in Fig. 4, it was ascertained that $I_{min} \approx 0$ for all the fixed values of CdS temperature. It means that heating the CdS samples does not lead to ellipticity, and at the output of them the light beam remains linearly polarized, since the light polarization degree is $P = 1$.

4.1. The angle of rotation of light polarization plane

According to the data adduced in Fig. 4, for each temperature of the CdS plate, one can find such an angular position of the analyzer when it provides the equality $I = I_{\max}$. In this case, the plane of light polarization at the output of the sample coincides with the position of the polarization plane at the output of the analyzer, *i.e.*, in this case, the plane of light polarization at the output of the sample coincides with the position of the polarization plane at the output of the analyzer, *i.e.* $\theta = \beta$. We carried out this procedure for a set of fixed temperatures. It allowed us to find the temperature dependence of the azimuth of light polarization (Fig. 7, points). To find the respective function necessary to approximate the obtained dependence, we equate the derivative $dI/d\beta$ to zero. After simple transformations, we get the relation β with ΔT:

$$\mathrm{tg}2\beta \cdot \mathrm{ctg}2\alpha = \cos\{[\pi(n_e - n_o)/\lambda]\cdot[d_0(1+\gamma\Delta T)]\}. \qquad (7)$$

The dependence of the angle of rotation of the polarization plane on temperature (Fig. 7, solid curve) calculated using the formula (7) is in good agreement with the experimental data (Fig. 6, points).

5. Conclusions

It has been shown that the intensity of linearly polarized light successively passing through the polarizer, CdS plane parallel plate, and analyzer depends on the plate temperature. The temperature dependences of the intensity of light at the exit from the CdS plate and the angle of rotation for the light polarization plane has been determined. It has been established that, at the output of the CdS single crystal, the light remains linearly polarized, when the temperature of the sample changes within the range 11…170 °C. It has been found that in the mentioned temperature interval the temperature dependence of the coefficient of temperature expansion and refractive index difference can be neglected. It can be assumed that these polarization properties are due to the change in the thickness of the plate of CdS single crystal when heated.

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