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A method of investigations of the optical properties of anisotropic materials using modulation of the light polarization*

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A method of investigation of the optical properties of anisotropic materials using modulation of the light polarization is presented. Measuring set-up was constructed and used to examine the optical properties of interesting tetragonal semiconducting Zn_3P_2 compound.

1. Introduction

The investigation of the optical properties of anisotropic materials is usually performed by independent measurements at different orientation of the light polarization with respect to the main axes of the crystal. For example, the dichroism of the crystal is obtained by subtraction absorption coefficient measured for different polarization of the light.

The presented method makes it possible to obtain directly the values of the crystal dichroism in the examined light waverange.

2. Method of measurements

Modulation of the light polarization is made using two linear polarizers: P polarizer and PM one rotating around the optical axis of the set-up (see Fig. 1).

It can be assumed that the light after having passed through the P polarizer is linearly polarized. Its intensity I_0 is proportional to $|\boldsymbol{D}_0|^2$, where $\boldsymbol{D}_0$ – vector of electric induction. The polarization state of light passing through PM modulator will undergo the variation with a frequency twice as great as that of the modulated rotation. The intensity of this light will vary according to $I_0 \cos^2\gamma$, where $\gamma = \Omega t$ (Ω – frequency of the modulator rotation).

In a birefringent sample the wave is splitted into two parts in the main direction of the crystal. Figure 2 presents the decomposition of the electric in-

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duction vector $\boldsymbol{D}$. These two components of orthogonal polarization states will interfere with each other, after the light passed through the sample. For $\boldsymbol{D}'$ and $\boldsymbol{D}''$ we obtain the following rules:

$$\boldsymbol{D}' = \boldsymbol{a}' D_0 \tau' \cos\gamma \cos\varphi \exp(i\omega t), \tag{1}$$

$$\boldsymbol{D}'' = \boldsymbol{a}'' D_0 \tau'' \cos\gamma \sin\varphi \exp[i(\omega t + \delta)]$$

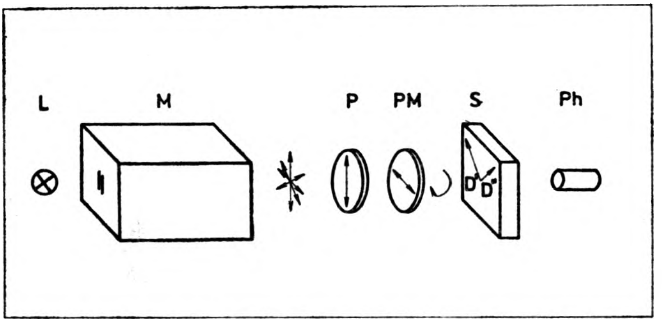

Fig. 1. Scheme of measuring set-up. L – source of light (halogen lamp), M – monochromator (GDM-1000), P – polarizer, PM – rotating polarizer, S – oriented sample ($\boldsymbol{D}'$, $\boldsymbol{D}''$ – main axes of crystal), Ph-detector

where $\boldsymbol{a}'$, $\boldsymbol{a}''$ – unit vectors denote polarization states of both wave componets; τ', τ'' – amplitude coefficients of the total transmission of the crystal (transparency); φ – the angle of the polarization vector of the incident wave after passing through the PM modulator and one of the main axes of the crystal, e.g., the direction $\boldsymbol{D}'$, δ – phase shift in plane parallel sample: $\delta = \omega d c^{-1}(n' \cos\psi' - n'' \cos\psi'')$ (where ψ', ψ'' – the angles of the light refraction, c – light velocity, d – the sample thickness, n', n'' – refractive indices).

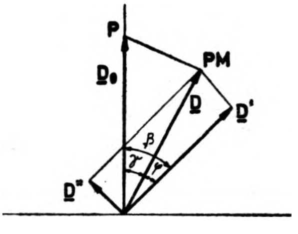

Fig. 2. Decomposition of the electric induction vector $\boldsymbol{D}$ after its passing through the polarizers P and M, φ – the angle between the polarization vector of the light after its passing through the PM and one of the main axes of the crystal (the direction of the $\boldsymbol{D}'$, for example), β – the angle between the polarization vector of the wave after its passing through the P, at the same direction of the crystal

The intensity of light after passing through the sample is proportional to the sum of the main values

$$I \sim \langle \boldsymbol{D}' \boldsymbol{D}'^* \rangle + \langle \boldsymbol{D}'' \boldsymbol{D}''^* \rangle. \tag{2}$$

Since the detector time constant is much greater that the reciprocal of the light wave frequency, the vector qualities can be replaced by scalars of the values equal to the amplitude of these vectors. By applying a series of simple transformations the following equation is obtained for $\beta = 45°$

$$I = \frac{1}{4} I_0 \left[(T' + T'') + (T' + T'')\cos 2\gamma + (T' - T'')\sin 2\gamma + \frac{1}{2}(T' - T'')\sin 4\gamma \right] \tag{3}$$

where $T' = \tau'\tau'^*$, $T'' = \tau''\tau''^*$.

The signal from the detector will be proportional to the above equation.

The phase sensitive detection of this signal with the frequency of 2Ω, with the help of, e.g., lock-in nanovoltmeter, gives for the wavelength λ the following result

$$U(\lambda) \sim \int_0^{\pi/2} I(\lambda)d\varphi - \int_{\pi/2}^{\pi} I(\lambda)d\varphi = \frac{1}{2} I_0(\lambda)[T'(\lambda) - T''(\lambda)]. \tag{4}$$

Hence it is possible to determine precisely the photon energy ranges for which the dichroism in crystal does not occur. In fact, from $T' - T'' = 0$ it results that $\alpha' - \alpha'' = 0$.

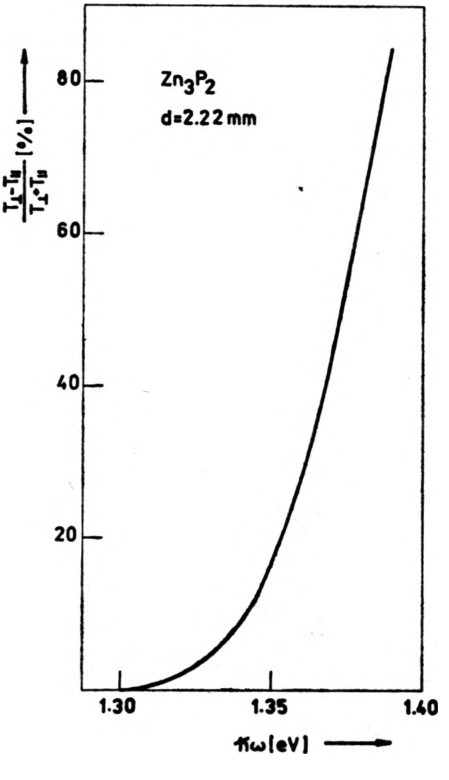

Fig. 3. Polarizability of Zn_3P_2 sample. The dichroism occurs at energy of photons equal to 1.315 eV

From the relation between the coefficients of total transmission and absorption we get the dependence of $T' - T''$ on the $\alpha' - \alpha''$ quantities. Its simplified form, very useful for calculations, can be presented as follows

$$T' - T'' \sim T'\{1 - \exp[(a' - a'')d]\}, \tag{5}$$

(this equation is satisfied for $ad > 1$, d – being the sample thickness, and for $R' - R'' \langle 0.05)$.

As an example, polarizability of Zn_3P_2 sample is plotted in Fig. 3. Zn_3P_2 is a very interesting tetragonal semiconducting compound very useful in solar energy conversion [1]. This plot gives information about the dichroism coefficient. Polarizability of Zn_3P_2 was obtained by independent simultaneous measurements using two lock-in nanovoltmeters according to Eq. (3), and dividing obtained signals. High value of the polarizability indicates that Zn_3P_2 can be used as a detector of the linear polarized light [2].

References

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