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Dispersion of Optical Characteristics of Anisotropic CdP_2 Single Crystals

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The refined results of the specified dispersion of refractive indexes, birefringence, optical activity of anisotropic β-CdP_2 single crystals and the components of both the gyration tensor G_{33} and the optical activity tensor γ_{123} in a wide spectral band of polarized light under normal conditions are presented. The influence of temperature and radiation intensity of neodymium and ruby lasers on these characteristics of CdP_2 single crystals is studied and analyzed.

Key words: CdP_2 crystals, dispersion, refractive index, optical activity, plane of polarization, gyration tensor.

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I. Introduction

Widespread application of cadmium diphosphide crystals as the functional components of quantum electronic devices has heightened interest in these semiconductors for a long time [1-4]. However, the precise and detailed information on some their optical properties has been absented. We therefore carried out comprehensive investigation of the dispersion of the optical characteristics of anisotropic β-CdP_2 single crystals in the light fields of low and sufficiently high intensity. The paper reports the refined results of the dispersion of the optical characteristics in the visible and in the near infrared regions of spectrum. The influence of temperature and laser radiation of high intensity on these characteristics is also studied.

II. Experiment

The investigated β-CdP_2 single crystals are optically uniaxil and they belong to the tetragonal crystal system (class of symmetry 422). The crystals possess a considerable anisotropy of the crystal lattice parameters (a = b = 0.5283 nm, c = 1.98 nm) that leads to apparently expressed anisotropy in their physical properties.

To measure the refractive indexes the prisms were cut from the oriented β-CdP_2 single crystals. Prisms had the refraction angles of about 5° in order to make the direction of the optical axis of a crystal in parallel to its refraction side. To exclude birefringence the optical activity was measured on flat parallel wafers of 1-3 mm thickness which were cut from oriented β-CdP_2 crystal in such a way that its optical axis was rigorously perpendicular to the surface of wafers. Orientating of wafers as perpendicular to a parallel laser beam was monitored by using an autocollimator.

The measurements were carried out according to the standard procedure [1] in the spectral region from the fundamental absorption edge to $\lambda = 2.325$ μm. The mercury tube DRS-250 in combination with a monochromator DMR-4 and Glan prism served as the source of linearly polarized monochromatic radiation. In the visible spectral region the measurements were carried out visually and in the near infrared region by means of an infrared radiation photodetector. A signal from this detector was fed to the input of a resonance amplifier joined with a self-recorder.

The influence of radiation intensity on the refractive indexes was investigated according to the prism method [1] by using a GS-5 goniometer with a much longer basis. The dependences of the specific optical activity on radiation intensity were studied according to the methods described in the Ref. [2]. All temperature measurements were carried out using an ingenious thermostat.

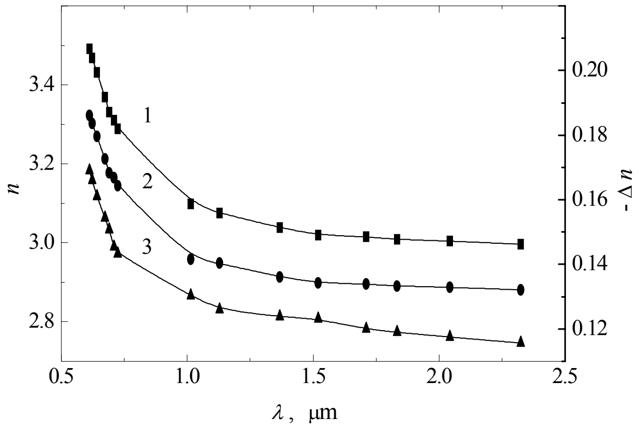

Fig. 1. Dispersion of the refractive indexes for ordinary n_o (1) and extraordinary n_e (2) electromagnetic waves and the value of birefringence Δn (3) (where $\Delta n = n_e - n_o$) of β-CdP_2 single crystal.

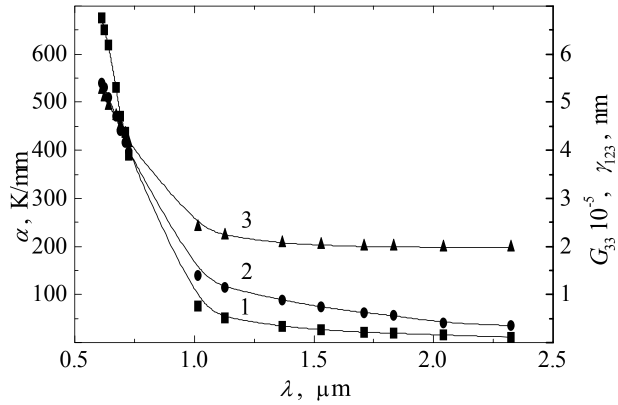

Fig. 2. Dispersion of the specific optical activity α (1) and the components of the gyration tensor G_{33} (2) and the optical activity tensor γ_{123} (3) of β-CdP_2 single crystal.

III. Experimental results and discussion

Figure 1 shows the results of measurements of the refractive indexes for ordinary n_o (curve 1) and extraordinary n_e (curve 2) electromagnetic waves and the magnitude Δn (curve 3), where $\Delta n = n_e$ – performed at linearly polarized radiation. There is a table for the practical use of the experimental results of n_o, n_e and Δn.

The dispersion of the refractive indexes in the investigated spectral region is trivial for normal dispersion that indicates the absence of local absorption bands. The Δn sign ($n_o > n_e$) shows that β-CdP_2 single crystal is optically negative. The corresponding evolution of the experimental results has shown that in the region of β-CdP_2 crystal transparency the dispersion of the refractive indexes is well expressed in the context of a one-oscillator model [3]. A slight difference in the values n_e and hence Δn from those given in the Ref. [4] can be explained by imperfection of obtained previously crystals.

Experimental results of the dispersion of optical activity of β-CdP_2 single crystals (specific optical activity α (curve 1) and the components of the gyration tensor G_{33} (curve 2) and the optical activity tensor γ_{123} (curve 3)) are shown in Fig. 2 and in the table. A manifestation of both left- and right-handed rotations of the plane of polarization was observed. This was due to the existence of two enantiomorphous CdP_2 structures in the limits of the 422 class symmetry with the space groups $P4_12_12$ and $P4_32_12$. In the region of CdP_2 crystal transparency the value of the specific optical activity α

Table

Dispersion of the refractive indexes n_o, n_e, values of birefringence Δn and parameters (the specific optical activity α and the components of the gyration tensor G_{33} and the optical activity tensor γ_{123}) characterizing the optical activity of β-CdP_2 single crystal

λ, μm	n_o	n_e	-Δn	α, K/mm	$G_{33}\times10^{-5}$	γ_{123}, nm
0.6123	3.491	3.322	0.169	676.0	5.40	5.26
0.6220	3.468	3.302	0.166	650.0	5.30	5.10
0.6410	3.431	3.270	0.161	619.1	5.10	4.92
0.6716	3.369	3.212	0.157	531.0	4.70	4.70
0.6907	3.331	3.177	0.154	470.0	4.40	4.50
0.7100	3.310	3.165	0.145	438.0	4.16	4.33
0.7240	3.289	3.145	0.144	390.0	3.96	4.15
1.0140	3.099	2.958	0.141	76.0	1.40	2.40
1.1287	3.075	2.949	0.126	52.0	1.14	2.22
1.3673	3.038	2.913	0.125	34.0	0.88	2.06
1.5295	3.019	2.898	0.121	27.3	0.74	2.02
1.7110	3.016	2.896	0.120	21.0	0.62	2.00
1.8330	3.008	2.890	0.118	18.6	0.56	1.99
2.0420	3.004	2.887	0.117	15.0	0.41	1.98
2.3250	2.996	2.881	0.115	11.3	0.36	1.97

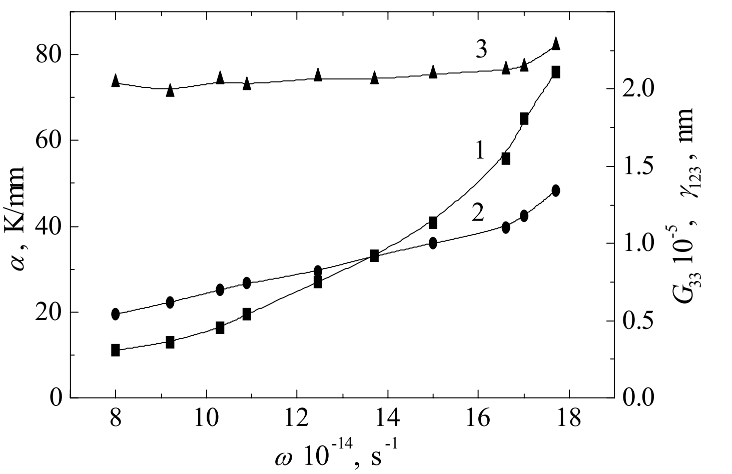

Fig. 3. Dependences of the specific optical activity α (1) and of the components of the gyration tensor G_{33} (2) and the optical activity tensor γ_{123} (3) on radiation frequency ω for β-CdP_2 single crystal.

changes rather weakly, however as λ approaches to the fundamental absorption edge, α is sharply risen. This fact conforms with the well-known theories [5-7]. According to the theory of the spatial dispersion [6,7] the electrical polarization at the point is determined not only by the vector of the electrical field in this point but by its value and direction in the neighborhood, too. The rotation power of a substance is determined by the pseudotensor of gyration G_{ek} and in case of the propagation of light along the optical axis of CdP_2 crystal one is described with the expression:

$$\Psi = \frac{\pi\ n_0^3\ d}{\lambda_0} G_{33}, \tag{1}$$

where Ψ is the angle of optical rotation, n_0 is the refractive index for light propagating along the optical axis of the crystal, λ_0 is the light wavelength in vacuum, d is the thickness of the crystal. The gyration tensor is dual to the antisymmetrical tensor of the optical activity γ_{ijk}. These quantities are related by the expression:

$$\gamma_{ijk} = \frac{\lambda_0}{2\pi} \delta_{ijk} G_{lk}, \tag{2}$$

where δ_{ijk} is the unit simple antisymmetrical tensor. For the crystals of the 422 class symmetry (β-CdP_2 belongs to it) the equation (2) takes the form:

$$\gamma_{123} = \frac{\lambda_0}{2\pi} G_{33}, \tag{3}$$

Using the results of the dependence of the specific optical activity α and ordinary refractive index n_o on the wavelengths λ (curves 1 in Fig. 2 and Fig. 1, respectively) as well as using the expressions (1) and (3), the values of G_{33} and γ_{123} can be calculated. The dispersion of these parameters is shown in Fig. 2 (curves 2 and 3) and in the Table.

According to the theory [7] the value of the specific rotation $\alpha = \Psi/d$ in the region of crystal transparency is approximately proportional to the quarter of radiation frequency ω^2, gyration tensor G_{lk} is proportional to frequency ω and the optical activity tensor γ_{123} depends rather weakly on frequency ω. As seen from Fig. 3, the experimental frequency dependences of α, G_{33} and γ_{123} characterizing the natural optical activity of CdP_2 crystals are in good agreement with the theory.

It is significant that an increase in the intensity of radiation of the wavelengths corresponding to ruby and neodymium lasers does not influence on the value of refractive indexes. The optical activity depends heavily on the radiation intensity [2]. The temperature dependences of the investigated parameters are also discovered.

IV. Conclusions

The dispersion of the refractive indexes and birefringence in anisotropic β-CdP_2 single crystals are refined. It is found that values of the refractive indexes depend on temperature and do not depend on the radiation intensity. The values of the refractive indexes and the parameters of the optical activity of β-CdP_2 single crystals and dependences of these parameters on temperature, wavelengths and intensity of radiation are very important in using crystals as working elements of optical and quantum electronic devices.

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Дисперсія анізотропних властивостей анізотропних кристалів CdP_2

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Результати дисперсії коефіцієнта заломлення, оптичної активності анізотропних кристалів β-CdP_2 та компоненти тензора циркуляції G_{33} і оптичної активності γ_{123} в широкій спектральній зоні поляризації представлено при нормальних умовах. Вивчається і аналізується вплив температури і радіаційної інтенсивності неодимових і рубінових лазери на ці особливості CdP_2.