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Abstract

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NEGATIVE DISPERSION OF LIGHT IN A $CaWO_4 : Nd^{3+}$ CRYSTAL

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In the optical laboratory of the Institute of General and Inorganic Chemistry of the Academy of Sciences of the USSR, a method was developed that made it possible to investigate the dispersion of light both in the ground and in the excited state ([2]). In the preceding brief communication ([3]), the phenomenon of negative dispersion of light was described for the first time in the investigation of the R line in a ruby crystal. In the present article we report the results of optical experiments with a crystal

Fig. 1. Optical scheme for measuring negative dispersion

$CaWO_4$ activated with neodymium. The aim of this work was to obtain negative dispersion in a spectral region in which the usual anomalous dispersion and absorption are not observed. The $CaWO_4 : Nd^{3+}$ crystal is tetragonal and dichroic. Absorption and luminescence bands polarized along the c axis of the crystal belong to the π spectrum; bands polarized perpendicular to the optical axis belong to the σ spectrum.

In the spectrum of the triply charged neodymium ion ([4]), there is a transition between the terms ${}^4I_{11/2}$ and ${}^4F_{3/2}$, lying in the infrared region at $1.06\,\mu$. The lower state ${}^4I_{11/2}$ is located 2000 cm^{-1} above the ground state and is practically unpopulated; therefore, in absorption the transition ${}^4I_{11/2} \to {}^4F_{3/2}$ is not observed. The upper state ${}^4F_{3/2}$ can readily be populated by illuminating the crystal in the region of the strong Nd^{3+} absorption bands in the yellow and green parts of the spectrum. In this way, a considerable magnitude of inverted population is achieved in $CaWO_4 : Nd^{3+}$.

The optical scheme of the experiment is shown in Fig. 1. As the light source it proved convenient to use an optical quantum generator (OQG) with glass activated by neodymium. The luminescence in the $CaWO_4 : Nd^{3+}$ crystal and the generation in the glass with neodymium belong to the same transition in Nd^{3+}, ${}^4F_{3/2} \to {}^4I_{11/2}$, and their positions in the spectrum coincide; the width of the OQG generation spectrum is sufficient for observing dispersion on an individual line in the crystal.

The polarization interferometer shown in Fig. 1 consists of a crystalline quartz wedge KK, the investigated crystal O, and a compensating quartz crystal K, which are placed between crossed polarizer N_1 and analyzer N_2. The optical axes of these three crystals are directed vertically or horizontally, and the principal planes of the polarizer and analyzer make an angle of 45° with the vertical. The image-

of horizontal interference fringes is projected by the rotating mirror 3 and a lens onto the slit of the DFS-13 spectrograph. The zero interference fringe in the focal plane of the spectrograph directly represents, on a certain scale, the course of the birefringence-dispersion curve of the light, and, in the case of a sharply polarized isolated absorption line in the crystal, the anomalous dispersion of light at this line. This method of measuring the dispersion of light has a substantial advantage over the commonly used methods of measurement with interferometers of the Jamin, Michelson, and Rozhdestvenskii types. The temperature coefficient of birefringence is an order of magnitude smaller than the temperature coefficient

[Fig. 3 and Fig. 4 graphs]

Fig. 3

Fig. 4

Fig. 3. 1 —π-spectrum of the luminescence of a $CaWO_4$ crystal activated with neodymium; 2 —σ-spectrum of luminescence. The bending of the interference fringes in Fig. 2 occurs in the large rise of the π-band, although the σ-band also affects the shape of the interference fringes.

Fig. 4. Solid line —curve of the negative dispersion of birefringence, calculated by Rashba' s method from the luminescence curves shown in Fig. 3; circles — experimentally observed points.

of each of the refractive indices separately. This makes it possible to photograph the interference pattern under optical pumping conditions, although the crystal under study is heated.

The $CaWO_4 : Nd^{3+}$ single crystal is a cylindrical rod with polished plane-parallel end faces, cut perpendicular to the fourth-order axis, 46 mm long and 6 mm in diameter. The neodymium concentration was 2 wt.%, and the excess charge was compensated by sodium.

The sample under study was pumped by an IFP-2000 pulsed lamp in an elliptical illuminator. The pump energy exceeded by several times the energy at which generation begins in the same illuminator. The pumped crystal, with an inverted level population, was illuminated by a light pulse from an optical quantum

Fig. 2

Figure 2: Fig. 2

generator (OQG in Fig. 1). To synchronize the crystal pumping and the OQG generation, the pulsed lamp L_2 and the OQG illuminator lamp L_1 (IFP-2000) were connected in series and operated from a single power supply.

The interference pattern obtained when the crystal under study is pumped is shown in Fig. 2a. A bending of the interference fringes due to negative dispersion is visible. In Fig. 2b, for comparison, a photograph of the unpumped crystal is given. In this case the interference fringes are horizontal. No anomalous dispersion is observed.

In the luminescence spectrum of the $CaWO_4 : Nd^{3+}$ crystal, the transition $^4F_{3/2} \to {}^4I_{11/2}$ corresponds to a group of polarized lines, closely spaced and partially overlapping. The dispersion curves of each of these lines are superposed on one another, and in the experiment a resultant dispersion pattern is obtained. From the measured luminescence spectrum of $CaWO_4 : Nd^{3+}$ (see Fig. 3), using the method for obtaining the light-dispersion curve from a known absorption curve proposed by E. I. Rashba ([5]), we calculated the course of the curve of negative dispersion of light in the region of 1.06 μ.

Fig. 2. Pattern of interference fringes obtained against the background of the spectrum of induced emission of neodymium glass (OKG in Fig. 1), which has a line structure ([6]). The spectrograph slit width is 0.4 mm = 1.6 Å. The centers of the interference fringes are indicated by arrows: **a** –the crystal is pumped; the interference fringes bend as a result of negative dispersion; **b** –the crystal is not pumped; the interference fringes are horizontal. The comparison spectrum is the spectrum of an iron arc in the third order; the wavelengths of two lines of this spectrum are given at the top of the figure.

in relative units. The calculated pattern and the measurement of the negative dispersion from the interferogram agree well (Fig. 4). The wavelength range of the interferogram measurements is determined by the width of the OQT spectrum. It is proposed subsequently, by changing the OQT generation region, to measure the course of the negative dispersion over the entire region near $1.06\,\mu$.

The largest shift of the interference fringes caused by the negative dispersion is 0.14 ± 0.02 of the distance between neighboring interference fringes. This corresponds to a change in the refractive index of $3 \cdot 10^{-6}$.

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Note: Figure translations are in progress. See original paper for figures.