Physics

1964

SovietRxiv

Figure 1

Figure 1: Figure 1

Abstract

Full Text

Physics

N. K. Bel' skii, D. A. Mukhamedova

On the Shape of the Absorption and Dispersion Curves of the R-Lines of Ruby

(Presented by Academician N. V. Obreimov, 17 IV 1964)

In studying the R-lines of ruby, the question often arises of the shape of the contour of the absorption lines. Some authors assume a Lorentzian line shape ([1]), while others in their calculations proceed from a Gaussian shape ([2]). It therefore proved necessary to measure experimentally the shapes of the R-lines.

The contour shape of the R_1- and R_2-lines of ruby was obtained by the photographic method. The absorption spectra were taken at room temperature on a DFS-3 spectrograph with a linear dispersion of 4 Å/mm. The slit of the spectrograph was uniformly illuminated by a three-lens system. The source was an incandescent lamp, the light from which, after passing through a water filter, a KS-14 filter, and a Nicol prism, fell on the ruby crystal. The crystal was chosen so as to

Fig. 1. Contour of the R-absorption lines in ruby for the ordinary $E \perp C_3$ *(1)* and extraordinary $E \parallel C_3$ *(2)* rays

obtain the dispersion and absorption curves on the same specimen. This is essential when working with ruby, since, because of the nonuniform distribution of Cr^{3+} in Al_2O_3, the absorption coefficient at the same concentration can vary from crystal to crystal and even, within a single crystal, from point to point. The specimen was a cylinder 24.1 mm long and 4.3 mm in diameter. The concentration of Cr^{3+} was 0.1%. The optical axis of the crystal was perpendicular to the axis of the cylinder.

Figure 1 shows the absorption of the R_1- and R_2-lines for the ordinary ($E \perp C_3$) and extraordinary ($E \parallel C_3$) rays. Along the ordinate is plotted the absorption coefficient: on the left,

$$\chi = \frac{\lambda}{4\pi d} \ln \frac{I_0}{I},$$

Fig. 2. Photograph of the course of interference fringes near the R_1- and R_2-lines in ruby

Figure 2: Fig. 2. Photograph of the course of interference fringes near the R_1- and R_2-lines in ruby

Fig. 3. Absorption (1) and dispersion of the birefringence (2) at the R-lines of ruby

Figure 3: Fig. 3. Absorption (1) and dispersion of the birefringence (2) at the R-lines of ruby

where λ is the wavelength of light in vacuum, d is the thickness of the crystal, and I_0 and I are the intensities of the incident light and of the light transmitted through the crystal; on the right, α is plotted in cm^{-1}, and along the horizontal axis, the frequency ν in cm^{-1}. The mean relative error in determining χ is 8%. For the ordinary ray, $\chi_{\max} = 50 \cdot 10^{-7}$ at $\nu = 14\,397.6$ cm^{-1} for R_1, and $\chi_{\max} = 35 \cdot 10^{-7}$ at $\nu = 14\,427.3$ cm^{-1} for R_2; the half-width is 14 cm^{-1} (R_1) and 12 cm^{-1} (R_2). Extraordi-

the extraordinary ray is absorbed much more weakly; therefore, for the given ruby crystal it is possible only to estimate qualitatively the ratio of the values $\chi_{\max}$ for the R-lines in the ordinary and extraordinary rays. For R_1 this ratio is 0.03, and for R_2, 0.16.

Fig. 2. Photograph of the course of interference fringes near the R_1- and R_2-lines in ruby

On the same ruby specimen, a curve of anomalous dispersion for the R_2-lines was obtained by the method proposed in the preceding paper ([3]), which may be called the method of a uniaxial polarization interferometer. This method, intended for measuring the dispersion of strongly polarized lines, consists in the fact that the anomalous-dispersion curve of a strongly polarized absorption line in a crystal can be obtained by measuring the course of the birefringence as a function of frequency. A photograph of the interference pattern is given in Fig. 2. By determining the displacement of the interference fringes according to the formula

$$\Delta\mu = \mu_o - \mu_e = \frac{\Delta h}{h}\frac{\lambda}{d} + \mu$$

the dispersion curve of the birefringence was constructed. Here $\Delta h, h$ are the displacement of an interference fringe and its width. The quantity μ depends only weakly on frequency.

Fig. 3. Absorption (1) and dispersion of the birefringence (2) at the R-lines of ruby

Fig. 4

Figure 4: Fig. 4

The course of the birefringence in the region of the R-lines is shown in Fig. 3, 2. Along the vertical axis on the right is plotted the difference of the refractive indices $\Delta\mu$ of the ordinary μ_o and extraordinary μ_e rays. The origin of coordinates was chosen in such a way that $(\Delta\mu_{\max} - \Delta\mu_{\min}) - \mu = 0$ at the frequency of the absorption maximum R_1. The relative error of the dispersion curve is 8%. The measured value $\Delta\mu_{\max} - \Delta\mu_{\min} = 63 \cdot 10^{-7}$ for R_1 and $30 \cdot 10^{-7}$

for R_2. The difference on the frequency scale between the points $\mu_{\max}$ and $\mu_{\min}$ is 11 cm^{-1} for R_1 and 8 cm^{-1} for R_2.

The course of the birefringence near the strongly polarized R_1-line reproduces the anomalous dispersion of the R_1 absorption line in the ordinary ray. The error introduced by the weak absorption in the extraordinary ray,

Fig. 4. Approximation of the contour of the curves: a—absorption, b—dispersion, c—luminescence. Solid lines—Lorentz curves, dashed lines—Gaussian curves, points—experimental values.

is about 3%. For R_2, the absorption in the extraordinary ray amounts to 16% of that in the ordinary ray in intensity, and it cannot be neglected. The course of the birefringence describes the difference of two anomalous-dispersion curves: $\Delta\mu = \mu_o - \mu_e$. For comparison, Fig. 3 shows, on the same scale, the course of the birefringence and the absorption in the ordinary ray.

An attempt to approximate the experimental absorption and dispersion curves by Lorentz and Gaussian curves is presented in Figs. 4a and 4b. The solid

solid line is the sum of two Lorentzian curves; the dashed line is the sum of two Gaussian ones. It is of interest to approximate the luminescence curve of the R_1- and R_2-lines. In Fig. 4b an approximation is given of the contour taken from (4). As is seen from Fig. 4, the sum of two Gaussian curves falls off very rapidly upon moving away from $\chi_{\max}$ of the R-lines and, on the wings of the curves, deviates sharply from the experimental values. The sum of two Lorentzian curves, on the contrary, falls off slowly on the wings—more slowly than the experimental values—but passes close to them. Thus, the contour of the ruby R-lines can be approximated by the sum of two Lorentzian curves.

In calculating the oscillator strengths of the R_1- and R_2-lines, the question arises of how to separate two overlapping lines. Since the area of the experimental curve $\int \chi(\nu)\, d\nu$ is $1.4 \cdot 10^{-4}$ cm^{-1}, while the area of the sum of two approximating Lorentzians is $1.5 \cdot 10^{-4}$ cm^{-1}, the oscillator strengths of the R_1- and R_2-lines can be obtained by taking separately the areas of the approximating Lorentzian curves for R_1 and R_2. Their parameters are: $\Delta\nu$ 13.6 cm^{-1} (R_1), 10.4 cm^{-1} (R_2); $\chi_{\max}$ $48.0 \cdot 10^{-7}$ (R_1), $33.6 \cdot 10^{-7}$ (R_2). The oscillator strengths for the ordinary ray, calculated from the formula

$$f = \frac{4mc^2\nu_0}{Ne^2}\,\mu \int \chi(\nu)\,d\nu,$$

where μ is the refractive index for the ordinary ray, are equal to $f_1 = 1.5 \cdot 10^{-6}$ for R_1, and $f_2 = 0.8 \cdot 10^{-6}$ for R_2.

The authors express their deep gratitude to Acad. I. V. Obreimov for his constant attention to this work, and also to M. A. Mazing and A. M. Leontovich, who kindly provided the apparatus and ruby samples.

Institute of Organoelement Compounds
Academy of Sciences of the USSR

Received
17 VI 1964

CITED LITERATURE

1. D. E. McCumber, M. D. Sturge, J. Appl. Phys. **34**, No. 6, 1682 (1963).

2. G. V. Gvaladze, V. K. Konyukhov et al., Optics and Spectroscopy, **16**, 58 (1964).

3. N. K. Belskii, DAN, **143**, No. 6, 1313 (1962).

4. A. L. Schawlow, Advances in Quantum Electronics, N. Y.–London, 1961, p. 50.

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