Structural investigation of laser luminescent response in a rotating ruby crystal

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Abstract. This paper presents the study of fluorescent trace in a rotating ruby crystal occurring upon irradiation of coherent emission with a wavelength \( \lambda = 532 \) nm. As a sample we used an oriented cylinder-shaped ruby single crystal of 5 mm in length and 10 mm in diameter.

The theoretical framework of moving media optics enables calculations of electromagnetic radiation propagation in moving media away from the absorption medium.

In active media near the resonance absorption frequency one can observe luminescence, and the time of atom relaxation from the excited state to the ground state, may take macroscopic values. Provided radiation passes through a moving medium, during relaxation the medium is able to shift, resulting in a spatial redistribution of luminescent glow intensity.

This shift of the fluorescent trace greatly exceeds the value of the wavefront shift caused by the medium motion as a result of the Fizeau effect.

Indeed, the effects of moving media optics, such as light entrainment, or a rotation of the polarization plane, appear quite weak. The effect size is proportional to the medium velocity, the optical path in the medium, as well as the Fresnel drag coefficient, which depends on the refractive index of the medium \( k = 1 - \frac{1}{n^2} \).

Therefore, having increased the refractive index, one can influence the effect size, and that will open the ways for their practical use.

The purpose of this work is to select the optical material with a long relaxation time that can be regarded as an equivalent increase in the effective refractive index.

This paper presents the study of fluorescent trace in a rotating ruby crystal occurring upon irradiation of coherent emission with a wavelength \( \lambda = 532 \) nm. As a sample we used an oriented cylinder-shaped ruby single crystal of 5 mm in length and 10 mm in diameter. The crystallographic axis c coincided with the rotation z. During the experiment the crystal rotation frequency varied between 2 and 130 Hz. The design of the experiments is depicted in Figures 1, 2. Figure 1 shows the observation results of the laser emission passed through a rotating ruby, and Figure 2 gives observation data on the reflected radiation.
Figure 1. Schematic diagram of the first experiment

To ensure accurate alignment, radiation of the power-stabilized laser L passes through a system of mirrors M1, M2 and falls onto a collecting lens L1. The beam is focused on the side surface of the crystal RD, which is fixed to the engine axis E. The refracted beam exits the ruby, then it is re-focused by the second collecting lens L2, passes through the filter F and falls onto the photodetector PD. From the photodetector the data is transmitted to computer PC for processing the received optical images. When green laser is emitted through the ruby, red radiation propagation is observed, which is due to fluorescent properties of the ruby. To increase the number of produced polaritons, the beam inside the crystal was focused. The red light filter is needed, so that the obtained images record only the emission caused by ruby atoms excitation and not generated by the laser.

Since the fluorescent light propagates in all directions, in an attempt to detect the polaritons entrainment, we made the second experiment (Figure 2): the beam profile detector was placed in a plane perpendicular to the disk rotation. The image of the "ring" within the crystal as it rotated was almost without distortion, the illumination was significantly reduced due to the fact that the photodetector array was not on the path of the laser beam.
Figure 2. Schematic diagram of the second experiment

Experimental results are presented in Figure 3.

Figure 3. Images of the optical response obtained in the first experiment at different speed of crystal rotation: a) f=80 Hz, b) f=100 Hz, c) f=110 Hz
The observed effect of the arc-wise beam path formation on the front surface of the sample is due to the finite lifetime of the impurity electronic state of chromium ions in the ruby excited at green crystals irradiation by ruby laser radiation.

When the rotation frequency changes, the trace area is increased, but the image itself becomes weaker. The integrated intensity remains constant.

![Image](a)  
![Image](b)  
![Image](c)  

**Figure 4.** The images obtained in the second experiment at different speed of crystal rotation: a) f=5 Hz, b) f=8 Hz, c) f=80 Hz, d) f=100 Hz, e) f=110 Hz

In the second experiment, depending on the disc speed, the center-of-intensity shift was observed: in the case of the resting ruby the maximum is at the point of beam incidence on the crystal, but at rotation the maximum begins to shift along the beam path.

At low rotation frequencies, the "trace" expansion at the end of the beam was observed.

In the course of experimental studies of photoluminescence beam traces in a single ruby crystal rotating at speed of 2 to 123 Hz, we registered a type of the laser beam trajectory on the input crystal surface, as well as a form of fluorescent light trace inside the crystal. Depending on the disc rotation speed we observed trajectories as a finite length arc. When the rotational speed increased, the arc length on the crystal surface increased as well. At high rotation speeds the arc degenerated into a circle, and the intensity peak shifted.

In experiments at certain angles we observed the "comet trail", similar in shape to the expected polariton trail.

In the future, it seems appropriate to conduct amplitude measurements along a path of luminescent radiation in a ruby crystal. The research will provide the radiation intensity propagation caused by the conversion of polaritons, drifting to the edge of the rotating ruby disc in fluorescent light. The light response integrated intensity will also be measured at different rotation frequencies.

In prospect the research results can be used in systems determining the space trajectory, spatial orientation, to identify angular speeds and accelerations.
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References
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