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Abstract

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Quantum Optical Generator Based on CaF_2:Dy^{2+}

Fluorite crystals doped with the trivalent dysprosium ion Dy^{3+} were obtained in the single-crystal laboratory of the P. N. Lebedev Physical Institute of the Academy of Sciences of the USSR. The rare-earth ion Dy^{3+} impurity was contained in the initial substances in the melt. Crystals were prepared with different concentrations of the trivalent Dy^{3+} ion impurity (0.05; 0.1; 0.2; 0.3; 0.5%). Upon irradiation of the crystals with γ rays, the trivalent Dy^{3+} ion is converted into the divalent Dy^{2+} ion, and the crystals acquire coloration. The irradiation dose was varied from 10^6 to 10^8 r. As experiments showed, saturation occurs at a dose of 10^8 r. These crystals were used to create an optical quantum generator. Lasing in fluorite crystals with the divalent Dy^{2+} ion was first obtained by Kiss and Duncan in 1962 ([1]).

Before proceeding to the study of CaF_2:Dy^{2+} crystals in pulsed lasing mode and in continuous mode, the luminescence and absorption spectra of CaF_2:Dy^{2+} crystals were observed.

The absorption spectrum of CaF_2:Dy^{2+} consists of a strong absorption band extending from 2300 to 4900 Å, and three less intense but narrow bands whose maxima lie, respectively, at wavelengths of 5800, 7150, and 9100 Å. Pumping in any of these three bands leads to strong luminescence in the region 2.3–2.6 μ. The most suitable pump lamps in the pulsed mode and in continuous-generation mode are xenon lamps, since their energy maximum falls in this wavelength region.

The luminescence spectrum of CaF_2:Dy^{2+} crystals was recorded with an IKS-12 spectrometer. The most intense line, on which lasing occurs, corresponds to a wavelength of 2.36 μ. The intensity of the lines changes little from sample to sample at the same concentration and depends only weakly on the Dy^{3+} impurity concentration.

In the pulsed-generation mode, the lasing threshold was measured for crystals with different concentrations. The lasing threshold was determined by changing the pump energy until the lasing effect disappeared. The lowest lasing threshold for crystals with silvered ends was 25 J. The lasing threshold practically does not change when the transmission of the silver coatings is varied from 5 to 10%. When dielectric coatings are applied to the ends of the crystals, the threshold

Fig. 1. Block diagram of the setup with a Fabry—Perot interferometer for measuring the generation linewidth. 1 —continuous-action laser; 2 —modulator; 3 —Fabry—Perot interferometer; 4 —objective; 5 —photoresistor; 6 —narrow-band amplifier; 7 —synchronous detector; 8 —EPP-09 recorder; 9 —pump; 10 —manometer

Figure 1: Fig. 1. Block diagram of the setup with a Fabry—Perot interferometer for measuring the generation linewidth. 1 —continuous-action laser; 2 —modulator; 3 —Fabry—Perot interferometer; 4 —objective; 5 —photoresistor; 6 —narrow-band amplifier; 7 —synchronous detector; 8 —EPP-09 recorder; 9 —pump; 10 —manometer

decreases sharply. All data are given for crystals with dimensions: length 70-80 mm, diameter 7-10 mm.

In Yariv' s work (^{2}), data are given on lasing thresholds for crystals with silvered ends. The lasing threshold is 20-22 J (concentration 0.05%). For operation of crystals in continuous lasing mode, crystals with thresholds no higher than 30 J were selected.

To estimate the pump power of the lamps in continuous mode, it is necessary to measure the luminescence lifetime. For all inv-

of the samples we studied, the luminescence lifetime was 18-26 msec. According to Ref. (2), the luminescence lifetime varies from 1 msec and upward.

For operation of the crystal in the continuous-generation regime we used supercooled liquid nitrogen. To protect the crystal from ultraviolet irradiation, which converts the Dy^{2+} ion into the Dy^{3+} ion, a liquid filter was used, which at the same time served to cool the continuous-action lamps (a $K_2Cr_2O_7$ solution).

In the continuous-generation regime we measured the generation linewidth of CaF_2:Dy^{2+} crystals. The luminescence linewidth is approximately 0.1 cm^{-1} (3). It was therefore natural to expect that the generation linewidth would be much smaller than this value. Instruments with high resolving power are needed to determine the width of narrow lines. Instruments with diffraction gratings do not have such resolution in the region of 2.36 μ. We therefore chose a Fabry —Perot interferometer. Another advantage of the interferometer is that, by changing the spacing between the plates, one can change the etalon constant, i.e., the dispersion range. The Fabry—Perot interferometer is convenient for studying the linewidth in the continuous-generation regime, since the setup is simple and the interpretation of the spectrum is elementary.

Fig. 1. Block diagram of the setup with a Fabry—Perot interferometer for measuring the generation linewidth. 1 —continuous-action laser; 2 —modulator; 3 —Fabry—Perot interferometer; 4 —objective; 5 —photoresistor; 6 —narrow-band amplifier; 7 —synchronous detector; 8 —EPP-09 recorder; 9 —pump; 10 —manometer.

Fig. 2 and Fig. 3

Figure 2: Fig. 2 and Fig. 3

For a given resolving power of the instrument, which depends on the reflection coefficient r and on the spacing between the plates t, the greatest light-gathering power of the setup is obtained by selecting the central interference ring while scanning the optical path length by some method. By scanning the optical path, one can record the spectral range of the instrument, equal in magnitude to the etalon constant $\Delta\nu = 1/2\mu t$ (the spacing between maxima of adjacent orders), where μ is the refractive index of the medium, and t is the spacing between the etalon plates.

In the present work, scanning is accomplished by changing the pressure inside the etalon plates. For this purpose the etalon is placed inside a casing from which the air is pumped out, and then, at the required rate, the pressure inside the chamber is raised to atmospheric pressure. In this way one can record several orders of the central interference ring. The method of scanning the optical path length by changing the pressure has been used in a number of works (4-6).

The block diagram of the setup assembled for measuring the linewidth is shown in Fig. 1. Radiation at a wavelength of 2.36 μ from continuous-action laser 1 falls on the plates of the interferometer, which are placed in chamber 3. The rings of equal inclination obtained as a result of interference are focused by objective 4 onto photoresistor 5, which serves as the radiation receiver at this wavelength. Modulator 2 interrupts the radiation at a frequency of 375 Hz so that the signal can be amplified by narrow-band amplifier 6 at the modulation frequency. After amplification the signal is synchronously detected 7 and recorded on the tape of EPP-09 recorder 8. Initially we recorded the spectrum at an etalon thickness $t = 3.0$ cm; the dispersion range of the instrument in this case was $\Delta\nu = 0.166$ cm^{-1}.

When the pressure is varied from 0 to 1 atm, three orders of the central interference ring are recorded (Fig. 2). It is evident from the figure that the ratio of the line width to the distance between maxima is equal to 1/18. If the line width is determined by the instrumental function, then, using the tables (7), one can determine the reflection coefficient of the plates, which in the present case is $r = 84\%$. The instrumental function of the etalon is then ~ 0.01 cm^{-1}. Figure 2 shows spectrograms of the generation line with different diameters of diaphragms placed on the photoresistor. It turns out that, in operation without a diaphragm (Fig. 2a), the line broadens. This can be explained by the fact that other rings, besides the central ring, can fall on the area of the photoresistor, 6×6 mm in size, which leads to line broadening. Figures 2b and 2c show spectrograms with diaphragms of 3 and 2 mm diameter. A further reduction in the diaphragm diameter does not lead to narrowing of the line.

Fig. 2. Spectrograms of the generation lines (etalon thickness $t = 3$ cm): *a*—

without diaphragm; *b*—with a diaphragm of 3 mm diameter; *c*—with a diaphragm of 2 mm diameter

Fig. 3. Spectrograms of the generation line (etalon thickness $t = 15$ cm): *a*—with a diaphragm of 3 mm diameter; *b*—with a diaphragm of 2 mm diameter

To determine the width of the generation line, an etalon with a plate spacing $t = 15$ cm was used. Figure 3 shows a recording of the spectrum on this etalon, for which the dispersion region is $\Delta\nu = 0.033$ cm^{-1} and the instrumental function is ~ 0.002 cm^{-1}. It is evident from the figure that complete resolution between the orders was not obtained (the ratio of the line width to the distance between orders is 1/3). Reducing the diaphragm diameter from 3 to 2 mm does not lead to narrowing of the line.

Thus, one may say that the width of the generation line, as the experiment shows, does not exceed 0.01 cm^{-1}. From the literature only one work (8) is known in which there are data on the measurement of the width of the luminescence and generation lines on these same crystals. The generation and luminescence spectra were recorded on a diffraction instrument, and the obtained width value 0.08 cm^{-1} was determined by the resolving power of the apparatus.

In the future we intend to investigate the width of the generation line at the temperature of liquid neon and helium, where a narrower generation line is expected.

It should be noted that the lasing linewidth, equal to 0.01 cm^{-1}, is record-narrow for solid-state lasers.

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