SOME RESULTS OF AN EXPERIMENTAL INVESTIGATION OF THE EFFECT OF A MAGNETIC FIELD ON THE RADIATION SPECTRUM OF A RUBY LASER

A. M. KUBAREV and V. I. PISKAREV

Radiophysics Institute, Gor'kiĭ State University

Submitted to JETP editor August 9, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) **46**, 508-510 (February, 1964)

The lines generated by ruby at T = 120°K are split experimentally under the action of a pulsed magnetic field. It is noted that the frequency readjustment does not occur gradually but by discrete amounts from one axial mode of the resonator to another. At room temperature a regular decrease of the generated frequency was observed.

RECENTLY there have been published several papers devoted to the effect of a magnetic field on the operation of a laser. For example, experiments [1] have been described on the pulsed modulation of a ruby laser by means of the superposition on the crystal of a pulsed, spatially inhomogeneous magnetic field. The magnetic readjustment of the frequency and magnetic amplitude modulation of the $CaF_2:Dy$ laser has been reported.[2]

We have examined the time behavior of the spectral composition of the radiation from ruby when a pulsed magnetic field, homogeneous over the region of the crystal, is applied to it. An oscillogram of the field is shown in Fig. 1. The ruby was placed in a double-walled quartz tube with an evacuated space between the walls. Nitrogen vapor was blown through the tube, and by regulating the quantity of vapor, the temperature of the crystal could be varied from 300 to 120°K. (The temperature was measured by a copper-constantan thermocouple affixed to a side surface of the ruby.) The magnetic field, the force lines of which were directed along the geometrical axis of the crystal, was created as the result of a discharge of a capacitor bank through a nickel coil wound directly on the quartz tube. By varying the delay time between the initiations of the magnetic field and lamp pulses, it was possible to switch on the field pulse at any moment of time relative to the initiation of the induced emission. The ruby emission was directed into the system used to record the spectrum of the radiation as a function of time.

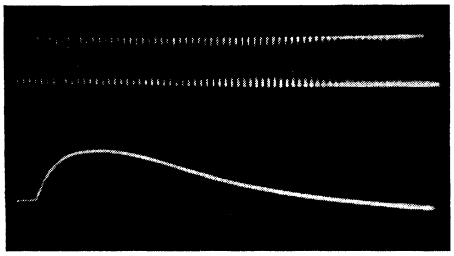

FIG. 1. Oscillogram of the pulsed magnetic field. The calibrating sine wave has a period of 5 μsec.

The principal optical scheme of the whole apparatus, consisting of the laser, an objective O_1 with focal length $F_1 = 21$ cm, a Fabry-Perot interferometer with a mirror separation of 8 mm, and a high speed camera (SFR), is similar to that shown in the paper by Korobkin and Leontovich.[3] The laser beam, passing through the Fabry-Perot interferometer and the entrance lens of the SFR, gives in the focal plane of the latter ($F_2 = 21$ cm) a system of interference rings. In this plane was positioned a slit, which cuts out from the ring pattern along its diameter a narrow band (width about 0.05 mm), which is passed to the plate by means of a second lens in the SFR ($F_3 = 7.5$ cm) and a rotating mirror, with a magnification of 3.3 times. The rate of motion of the image of the slit along the plate equalled 1500 m/sec. The objective O_1 in our apparatus was placed in such a way as to eliminate the effect of the asymmetry of the light source [4] at a distance from the crystal not equal to the focal length. With such an arrangement of the objective O_1 there is obtained on the photographic plate a time scan of the spectrum of the irradiation of the whole crystal without a frequency background, as explained in [3].

Figure 2 shows one of the photographs obtained at a crystal temperature of 120°K. The magnetic field pulse, of intensity $H_{max} = 3.6$ kOe was switched on a time $t_3 = 20$ μsec after the initiation of generation. The corresponding photograph in the absence of magnetic field is shown in

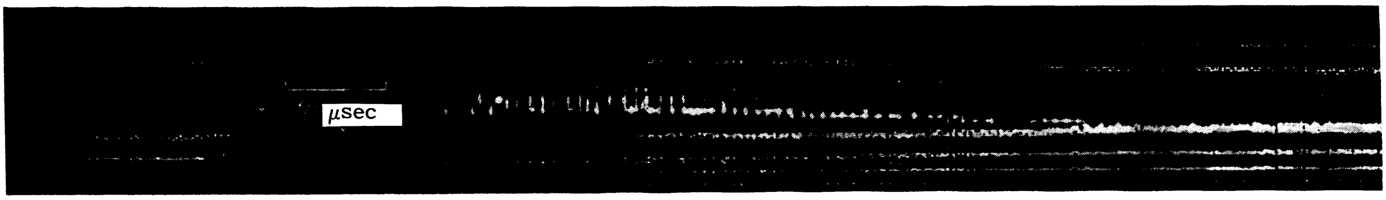

FIG. 2. Scan of the spectrum of the radiation from ruby at the initiation of generation. T = 120° K. Diameter of the crystal 3.75 mm, length 50 mm, transparency of the silver coatings 7 and 0%, angle between c axis and cylinder axis ~60°. Lamp energy 1.7 times threshold. H_{max} = 3.6 kOe. Magnetic field switched on 20 μsec after initiation.

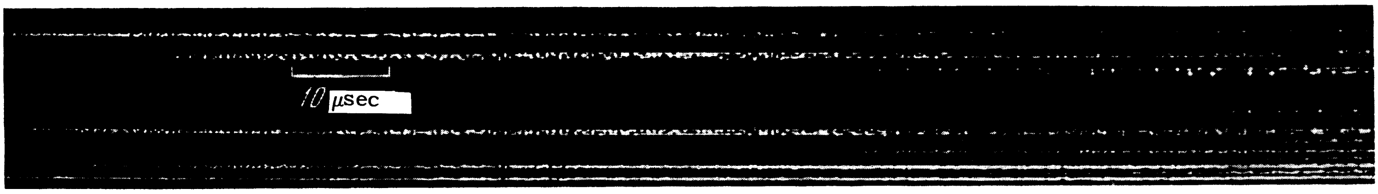

FIG. 3. Scan of the spectrum of the radiation from ruby 50 μsec after initiation of generation. T = 120° K. Crystal and pump power same as in Fig. 2. H = 0.

Fig. 3. Without magnetic field two lines are observed, corresponding to the splitting of the ground energy state in ruby. At first, the induced emission occurs at a frequency $\overline{E}(^2E) \rightarrow \pm 1/2(^4A_2)$,[1)] then after a certain time (in our case 120 μsec), radiation appears also at the frequency $\overline{E}(^2E) \rightarrow \pm(3/2)(^4A_2)$. The time between the initiation of generation at one transition and initiation at the other varies from several microseconds to several hundreds of microseconds depending on the shape of the lamp pulse, its intensity, and the properties of the crystal.

In each transition up to four frequencies are generated, corresponding to different axial modes of the Fabry-Perot resonator formed by the mirrors on the ends of the crystal (for a ruby rod of length 50 mm, the spectral interval between the modes equals 0.057 cm^{-1}). No change of the mean frequency of the radiation with time was observed within the limits of 150 μsec from the initiation of generation. It is interesting to note that close to the threshold, where the radiation goes only in one or two modes, peaks in the generation arise periodically in each. The periods of the different modes can differ, and it is possible for the peaks of the generation in one of them not to coincide with the peaks of another. All of this can be noticed also in Fig. 2, at the start of generation, up to the moment the magnetic field is switched on.

Let us trace in Fig. 2 how the generated spectrum changes under the influence of the magnetic field pulse. At the moment the magnetic field is turned on there has been generation only at the transition $\overline{E}(^2E) \rightarrow \pm 1/2(^4A_2)$. Within 2 to 3 μsec a disruption of the generation is observed. The radiation in the case considered is renewed only in 20 μsec after the collapse, and then near the maximum value of the field H there are two new lines in it. The average value of the frequency in one of them (strong generation in three or four axial modes) decreases with diminishing H; in the other (weak generation in one mode), it increases. The dependence of the frequency on magnetic field for the strong line agrees satisfactorily with $\nu(H)$ calculated according to [5,6] for the transition $-1/2\overline{E}(^2E) \rightarrow -(3/2)(^4A_2)$.[2)] An adequately definite identification of the weak line with any transition has not yet been made.

Note that the readjustment of the frequency by the magnetic field takes place not gradually, but in steps—from one mode of the resonator to another (this is particularly clearly seen from the change in diameter of the central interference ring).

Figures 4 and 5 are photographs[3)] obtained at a temperature of the ruby T = 120°K and with

[1)]The conclusion that the first transition is $\overline{E}(^2E) \rightarrow \pm 1/2(^4A_2)$ and not $\overline{E}(^2E) \rightarrow \pm(3/2)(^4A_2)$ is arrived at on the basis of measurements of the diameters of the interference rings corresponding to both frequencies and the magnitude of the splitting of the ground state, which is equal to 0.38 cm^{-1}.

[2)]The designation of the sublevels of the group $^4A_2$ is taken, in accordance with [5], in the order of increasing energy.

[3)]These photographs were obtained without the objective O_1.

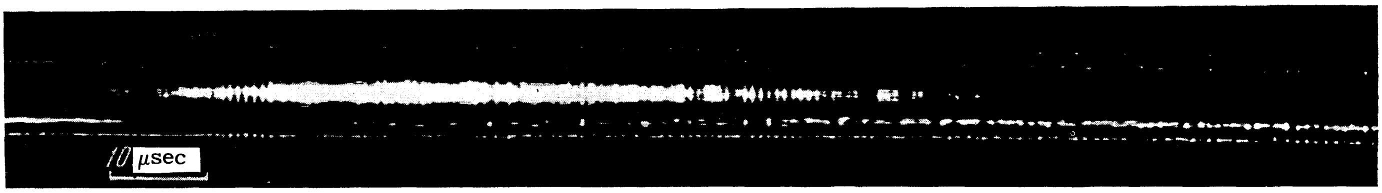

FIG. 4. Scan of the spectrum of the radiation from ruby 600 μsec after initiation of generation. T = 120° K. Crystal and pump power same as in Fig. 2. H_{max} = 1.7 kOe. Field turned on 12 μsec after start of scan.

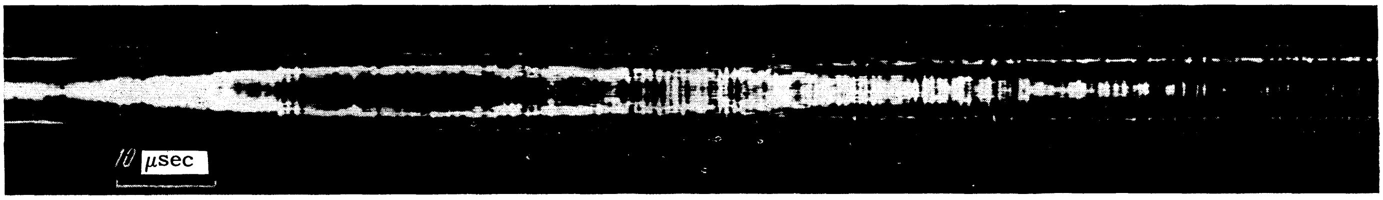

FIG. 5. Scan of the spectrum of the radiation from ruby 500 μsec after initiation of generation. T = 120° C. Crystal and pump power same as in Fig. 2. H_{max} = 3.5 kOe. Field turned on 8 μsec after beginning of scan.

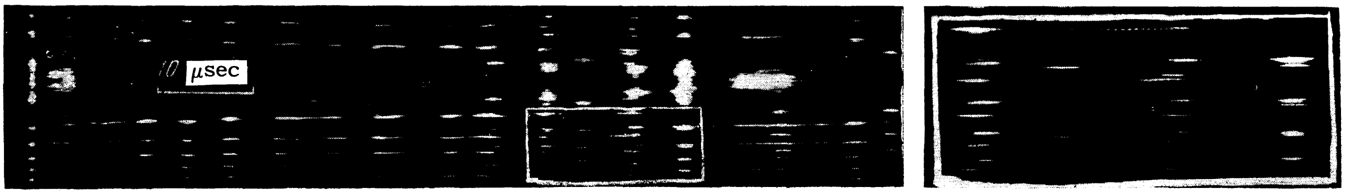

FIG. 6. Scan of the spectrum of the radiation from ruby at the initiation of generation. T = 290° K. Diameter of the crystal 14.25 mm, length 58 mm, transparency of silver coatings 8 and 0%, angle between c axis and cylinder axis ~60°. Pump power 1.05 times threshold. H = 0.

H_{max} = 1.7 kOe, t_3 = 600 μsec and H_{max} = 3.5 kOe and t_3 = 500 μsec, respectively. In both cases the generation at the transition $\overline{E}(^2E) \to \pm 1/2(^4A_2)$ collapsed when the field was turned on and was renewed only after some interval of time. A stable generation is observed at the transition $-1/2\overline{E}(^2E) \to -(3/2)(^4A_2)$. It is difficult to identify the remaining lines with corresponding transitions in the photographs obtained.

At room temperature no marked effect of a pulsed magnetic field with intensity $H_{max} \approx 3.5$ kOe was observed on the spectrum of radiation from ruby. In photographs (Fig. 6) obtained at the start of generation at room temperature without magnetic field, a regular increase in the wavelength with time is observed. In this, the change proceeds in stepwise transitions from one mode to another ($\Delta\lambda_M \approx 0.024$ Å). In Fig. 6 this increase in λ within the first 40 μsec from initiation attains the value $\Delta\lambda \approx 0.11$ Å. Approximately 30 μsec after the start of the radiation two new lines are observed, just as at low temperatures, and the peaks of one may not coincide with the peaks of the other. Judging from the diameters of the interference rings, the first generation is at the transition $\overline{E}(^2E) \to \pm 1/2(^4A_2)$.

It should be noted that along with the usual peak modulation of the laser emission in our photographs there is sometimes observed a high-frequency modulation with a period of from 1 to 0.1 μsec.[4)] For example, in Fig. 6 (in the rectangle), 50 μsec after initiation such a modulation with a period of ~ 0.28 μsec is visible in the transition $\overline{E}(^2E) \to \pm 1/2(^4A_2)$. When there is generation in several modes, the high-frequency modulation can be observed both in one mode and in two or three modes simultaneously. The simultaneous modulation of different modes is completely correlated in some cases, independent in others.

The authors are deeply grateful to V. I. Bespalov and A. V. Gaponov for their attention to the work and discussion of the results.

[1] Nedderman, Kiang, and Unterleitner, Proc. Inst. Radio Engrs. 50, 1687 (1962).

[4)]The presence of such a modulation with a frequency of 40 Mcs (period 0.025 μsec) was reported in [7].

[2] Electronics Weekly, May 22, 1963.
[3] V V. Korobkin and A M. Leontovich, JETP 44, 1847 (1963), Soviet Phys. JETP 17, 1242 (1963).
[4] S. Tolansky, High Resolution Spectroscopy, Pitman, NY, 1947; Russ. Transl. IIL, 1955.
[5] E. O. Schulz-Du Bois, Bell System Tech J. 38, 271 (1959); Russ. Transl. in Kvantovye paramagnitnye usiliteli (Quantum Paramagnetic Amplifiers), IIL, 1961, p. 86.
[6] Geschwind, Collins, and Schawlow, Phys. Rev. Letters 3, 545 (1959).
[7] Clark, Wuerker, and York, J. Opt. Soc. Am. 52, 878 (1962).

Translated by L. M. Matarrese
75