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Abstract

Full Text

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M. I. Dzhibladze, T. M. Murina, Academician A. M. Prokhorov

TIME CHARACTERISTICS OF A LASER ON CaF_2:Dy^{2+} CRYSTALS IN CONTINUOUS GENERATION REGIME

The present work is devoted to investigating the possibility of obtaining a spikeless generation regime in a laser on CaF_2:Dy^{2+} crystals in a continuous single-mode regime.

As follows from the solution of the kinetic equations, in a single-mode generator we should observe a spikeless generation regime. The radiation pattern of the generator should consist of transient processes leading to a steady-state generation regime. However, experimentally such a pattern was not observed by us, even in the case of generation on one mode. The radiation of the generator, both in multimode and in single-mode regimes, has a spiky character.

Fig. 1. Schematic of the setup. 1 –crystal, 2 –Dewar, 3 –illuminator, 4 –pump lamp, 5 –diaphragm, 6 –mirror with reflection coefficient 100%, 7 –mirror with reflection coefficient 90%, 8 –output tube, 9 –photoresistor, 10 –oscilloscope

In this work we investigated the characteristics of the generator, namely the time intervals between spikes and packets of spikes, as well as the duration of spikes as a function of various generator parameters under selection of oscillation types.

The laser design (Fig. 1) provided for operation both with external mirrors and with mirrors deposited on the end faces of the crystal. The resonator length was varied from 40 to 300 mm. Since in CaF_2:Dy^{2+} the luminescence-line width is 0.28 cm^{-1} ($T = 78°K$), at such resonator lengths the selection by axial mode indices can be carried out by the resonator itself. In our experiments this is confirmed by the fact that the laser generation-line width was less than 0.01 cm^{-1}, whereas the spacing between neighboring axial modes was 0.021-0.08 cm^{-1}. Selection by angular mode indices for a resonator with external mirrors

Fig. 2. Oscillogram of the radiation of a continuous laser at different pump powers P/P_0 and oscilloscope sweeps, respectively: a—1; 500 msec, b—1.1; 200, c—1.8; 200. Resonator with external mirrors

Figure 2: Fig. 2. Oscillogram of the radiation of a continuous laser at different pump powers P/P_0 and oscilloscope sweeps, respectively: a—1; 500 msec, b—1.1; 200, c—1.8; 200. Resonator with external mirrors

was carried out by us with the aid of diaphragms $d = (0.7 \div 1.5)$ mm placed in the resonator, and without external mirrors—by depositing reflecting coatings of diameter $0.3 \div 1$ mm on the end faces of the crystal. The laser radiation was recorded with a PbS photoresistor and an InSb photodiode.

The laser radiation without selection of oscillation types consists of chaotic spikes. Under selection, individual regular pulses are observed, each pulse containing a packet of irregular spikes.

The "silence" time of the laser—the time between two packets of spikes—is determined by the pump power. The same radiation pattern is observed in a continuous ruby laser with selection of oscillation types (1).

Figure 2 shows the laser generation pulses for $CaF_2 : Dy^{2+}$ under continuous pumping. For a resonator with external mirrors and a diaphragm $d = 0.7$ mm, at the generation threshold the distance between packets of spikes (Fig. 2a) is of the order of 200-500 msec. As the pump power is increased, $P/P_0 \approx 2 \div 5$, where P_0 is the threshold pump power, the distance between pulses decreases to 10-20 msec (Figs. 2b, c), while the number of spikes in a packet increases. When the diaphragm diameter is decreased, the number of spikes in a packet decreases. The spikes in a packet are irregular and have a duration of $2 \div 4$ μsec. The distance between spikes varies with the pump power and, at $P/P_0 \approx 2 \div 5$, is $5 \div 20$ μsec. At high pumping levels and when the diaphragm diameter is increased to > 1.5 mm, overlap of the spike packets occurs.

If the mirrors are deposited on the end faces of the crystal, then, in addition to regular packets of spikes, a spiking background of generation of smaller amplitude is observed; this can be explained by generation of off-axis modes formed upon reflection from the lateral surfaces of the crystal.

Thus, the observed radiation pattern of the laser with selection of oscillation types, as already mentioned, is not characteristic of the operating regime of a single-mode laser; i.e., a stationary generation regime is not observed experimentally.

Fig. 2. Oscillogram of the radiation of a continuous laser at different pump powers P/P_0 and oscilloscope sweeps, respectively: a—1; 500 msec, b—1.1; 200, c—1.8; 200. Resonator with external mirrors.

What reasons can explain the observed regular pulses?

First, one may suppose that the regular spikes are associated with the transient process of generation. If this is so, then the transient process must be rapidly damped. Indeed, for a $CaF_2 : Dy^{2+}$ laser the damping time of oscillations is tens of microseconds, with the oscillation period being $\sim 6\ \mu$sec. The experimentally observed pulses are not damped, and the time interval between them is 3-4 orders of magnitude greater than the calculated one. Thus, the radiation pattern shown in Fig. 2 does not represent a transient process.

The second assumption is connected with multimode operation. Let us assume that the laser radiation we observe consists of regular pulses of duration 1 μsec, with intervals between them of $\sim 30\ \mu$sec, and that such a pattern is associated with the excitation of many modes. Since the fundamental frequency is determined by the time interval between the pulses, then, in order to obtain a spike duration of 1 μsec, $\sim 3 \cdot 10^3$ oscillation types are required. This

could occur only at the expense of nonaxial types of oscillations, but in our case their number is small because of the presence of the diaphragm. Consequently, this assumption also falls away.

It should be noted that the time interval between trains of spikes does not depend on the diaphragm diameter, i.e., on the number of excited modes. This fact indicates that generator radiation in the form of individual pulses is characteristic not only of the single-mode regime, but also of the multimode regime; however, when the number of modes is limited, this character manifests itself more distinctly.

It follows from the above that there is some other process, leading to the spiking regime, which is not determined by multimode operation. Possibly this process has the character of a kind of Q-modulation, which can lead to the generation of individual spikes separated by times of tens of milliseconds.

Indeed, the large experimentally obtained values of the times between trains of spikes give grounds to suppose that, during the generation of a train of spikes, the population inversion decreases to values Δn_{np}, which are below the threshold value Δn_{p}. Consequently, for generation of the next train of spikes, a time is required during which the population at the metastable level again reaches the threshold value.

The time interval between trains can be obtained from the kinetic equations if one takes into account that in this interval of time there is no induced emission. The formula obtained for the time interval Δt has the following form:

$$\Delta t = \frac{\tau}{k(P/P_0)+1} \times \ln \frac{1 - \dfrac{\Delta n_{\mathrm{np}}}{n}\,\dfrac{k(P/P_0)+1}{k(P/P_0)-1}}{1 - \dfrac{\Delta n_{\mathrm{p}}}{n}\,\dfrac{k(P/P_0)+1}{k(P/P_0)-1}}, \tag{1}$$

where τ is the lifetime at the metastable level, P_0 is the threshold pump power,

Fig. 3. Dependence of the time interval between pumpings on pump power. 1 —calculated curve, 2 —experimental curve.

Figure 3: Fig. 3. Dependence of the time interval between pumpings on pump power. 1 —calculated curve, 2 —experimental curve.

n is the total number of atoms in 1 cm^3,

$$k = \left(1 + \frac{\Delta n_{\mathrm{p}}}{n}\right) \Big/ \left(1 - \frac{\Delta n_{\mathrm{p}}}{n}\right).$$

Fig. 3. Dependence of the time interval between pumpings on pump power. 1 —calculated curve, 2 —experimental curve

The threshold value Δn_{p} can be determined from formula (2):

$$\Delta n_{\mathrm{p}}/n = \alpha/Bn, \tag{2}$$

where α is the loss in the resonator, B is the probability of induced emission. As is evident from the formula, the threshold value of the population inversion does not depend on the pump power, but depends only on the losses in the resonator; therefore, for a given type of resonator Δn_{p} may be considered constant. The losses in the resonator for reflection coefficients $R_1 = 100\%$ and $R_2 = 90\%$ are of the order of $2 \cdot 10^8$ s^{-1}, and $B = 4 \cdot 10^{-9}$ s^{-1} for the luminescence linewidth $\Delta\nu = 0.15$ cm^{-1} and the radiative time $\tau = 0.4$ s [3]. Taking the total number of particles $n = 5 \cdot 10^{17}$, we obtain from (2) the value $\Delta n_{\mathrm{p}}/n \simeq 0.1$. If it is assumed that the maximum decrease in the value of the population inversion during the time of spike generation occurs down to zero, then the curve of the dependence of Δt on P/P_0, constructed for the values $\Delta n_{\mathrm{p}}/n = 0.1$ (Fig. 3, 1), does not coincide with the experimental curve (Fig. 3, 2), i.e., calc-

the calculated times are significantly shorter than the experimental ones. Nor is it possible to obtain agreement between the calculated and experimental data by increasing $\Delta n_{\mathrm{th}}/n$ up to 0.9.

An even greater discrepancy between the calculated Δt and the experimental Δt is observed for resonators in which the mirrors are deposited on the ends of the crystal. Nevertheless, formula (1) correctly describes the nature of the dependence of the time interval between spikes and, in order of magnitude, the interval itself. The quantitative discrepancy can apparently be explained by the dependence of the lifetime on the pump power. Thus, during generation in the continuous regime with selection of oscillation types, a strong change in the population of the levels occurs (approximately by 10%), whereas in the single-mode generation regime solutions of the kinetic equations give a change in the population of the levels during generation of only a few hundredths of a percent.

In conclusion, it is necessary to emphasize once again that the spiking regime of generation cannot be explained either by transient processes or by excitation of many oscillation types. It is also clear that the observed spiking regime is not connected with thermal effects.

P. N. Lebedev Physical Institute
Academy of Sciences of the USSR

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