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# *SINGLE FREQUENCY RUBY LASER WITH A VARIABLE RADIATION FREQUENCY UNDER GIANT PULSE OPERATING CONDITIONS*

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We investigate the spectral characteristics of a Q-switched ruby laser under the influence of a narrow-band signal introduced at the instant of Q switching. The external-signal intensity needed for the laser to generate at the external signal frequency is estimated. It is shown experimentally that at a definite value of the external-signal intensity the laser generation spectrum coincides fully with the spectrum of the introduced radiation. Generation at one mode was obtained under pulsed-Q conditions on the $R^1$ and $R^2$ lines of ruby.

THIS paper is devoted to a study of the operating features of a Q-switched ruby laser under the influence of a narrow-band external signal introduced at the instant of resonator Q switching. Certain features of such a regime were investigated in [1,2]. We used as the source of the external signal a single-frequency ruby laser operating in the free-running mode (henceforth called the first laser). Its generation frequency could be varied within a certain range.

## ESTIMATE OF EXTERNAL SIGNAL INTENSITY NEEDED TO SUPPRESS THE NATURAL LASER GENERATION FREQUENCY

We used for the estimate equations of the balance type, averaged over the volume of the crystal.[3] The losses were disregarded. The frequency of the introduced signal was assumed to be the resonant frequency of the investigated (henceforth, second) laser. The equations were written in the form

$$\frac{1}{v}\frac{dI(\nu_c,t)}{dt}=\sigma(\nu_c)\Delta(t)I(\nu_c,t), \tag{1}$$

$$\frac{1}{v}\frac{dI(\nu_i,t)}{dt}=\sigma(\nu_i)\Delta(t)I(\nu_i,t), \tag{2}$$

$$\frac{d\Delta}{dt}=-2\Delta\int\limits_{\delta\nu_c}I(\nu_c,t)\sigma(\nu_c)d\nu_c-2\Delta(t)\int\limits_{\delta\nu_i}I(\nu_i,t)\sigma(\nu_i)d\nu_i. \tag{3}$$

Here $I(\nu_c, t)$ is the spectral density of the photon flux through 1 cm$^2$ per second of the laser's own generation, corresponding to the center of the luminescence line; $I(\nu_i, t)$ is the spectral density of the flux of photons through 1 cm$^2$ per second of the introduced external radiation with frequency $\nu_i$; $\sigma(\nu_c)$ and $\sigma(\nu_i)$ are the cross sections of the stimulated transition at the frequencies $\nu_c$ and $\nu_i$, respectively; $\Delta(t) = n_2 - n_1$ is the inversion; $v = c/\kappa$; c is the velocity of light in vacuum; $\kappa$ is a factor that takes into account the filling of the resonator by the active medium.

If $\delta\nu_c \ll |\nu_c - \nu_i|$ and $\Delta\nu_i \ll |\nu_c - \nu_i|$, then Eq. (3) can be rewritten in the form

$$\frac{d\Delta}{dt}=-2\Delta(t)I(\nu_c,t)\sigma(\nu_c)\delta\nu_c-2\Delta(t)I(\nu_i,t)\sigma(\nu_i)\delta\nu_i. \tag{3'}$$

From the solution of the system (1, 2, 3′) we must

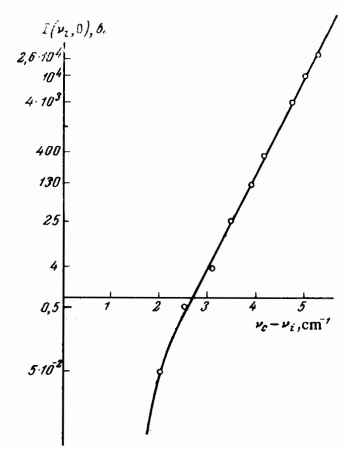


FIG. 1.

find the ratio $I(\nu_c, t)/I(\nu_i, t)$ at the instant of time when $\Delta(t) = 0$. Dividing (1) by (2) and integrating, we get

$$I(\nu_c,t)=I(\nu_c,0)\left[\frac{I(\nu_i,t)}{I(\nu_i,0)}\right]^q, \tag{4}$$

where $I(\nu_c, 0)$ and $I(\nu_i, 0)$ are the values of $I(\nu_c, t)$ and $I(\nu_i, t)$ at the instant of resonator Q switching, and $q = \sigma(\nu_c)/\sigma(\nu_i)$.

Dividing (2) by (3′), taking (1) into account, and integrating with respect to the time, we get

$$\frac{2I(\nu_c,0)\delta\nu_c}{vI^q(\nu_i,0)}\left[(I^q(\nu_i,t)-I^q(\nu_i,0))+\frac{2}{v}(I(\nu_i,t)-I(\nu_i,0))\right]=\Delta(0)-\Delta(t). \tag{5}$$

With the aid of (4) and (5) we can readily calculate the value of the introduced signal intensity $I(\nu_i, 0)$ needed to satisfy the relation

$$I(\nu_c,t)\,/\,I(\nu_i,t)=1 \tag{6}$$

at the instant of time when $\Delta(t) = 0$. The condition (6) determines the threshold (relative to the introduced intensity) for the suppression of the natural generation of the laser. Figure 1 shows a plot of this calculation. The abscissas represent the frequency deviation of the introduced radiation relative to the center of the luminescence line, and the ordinates the function $I(\nu_i, 0)$ in a logarithmic scale. The initial conditions are $\Delta(0) = 8\times10^{19}$ cm$^{-3}$

and $I(\nu_c, 0)$, calculated by the method described in [4], equals $10^{16}$ sec$^{-2}$cm$^{-2}$. The calculation is given for a ruby crystal 120 mm long and 12 mm in diameter, at a resonator length 65 cm.

## EXPERIMENT

The mode selectro of the first laser was made up of four TF-5 glass prisms with a total dispersion 15 seconds of angle per cm$^{-1}$ at $\lambda$ = 6943 Å, and a diaphragm $D_1$ of 2 mm diameter (Fig. 2).

Single-frequency generation of the first laser was ensured at a 5% excess over threshold. The electronic Q-switching circuit for the second laser was triggered by one of the spikes of the first laser. The inertia of the electronic circuitry was not worse than 0.5 $\mu$sec, thus ensuring synchronization of the Q-switching time of the second laser with the instant of entry of the radiation of the chosen spike into its resonator. The second laser then produced a high-power ($10^8$ W/cm$^2$) single-frequency pulse.

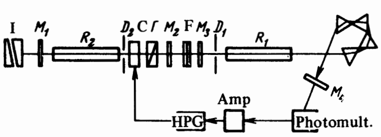


FIG. 2. Diagram of experimental setup: $M_1$, $M_2$, $M_3$, $M_4$ – mirrors with reflection coefficients 30, 96, 96, and 98%, respectively; $R_1$, $R_2$ – ruby crystals 120 mm long and 12 mm in diameter; $D_1$, $D_2$ – diaphragms, 2 mm in diameter; C – cell, F – set of neutral light filters, I – Fabry-Perot etalon, Amp – amplifier, HPG – High-voltage pulse generator.

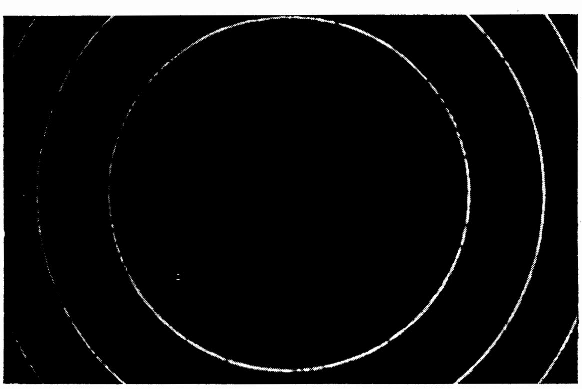

FIG. 3. Spectrogram of emission of second laser.

Figure 3 shows a spectrogram of the emission of the second laser, obtained with the aid of a Fabry-Perot etalon 3 cm thick. The measured emission-line width did not exceed 0.005 cm$^{-1}$. The distance between longitudinal modes of the two resonators was 0.008 cm$^{-1}$. Notice must be taken of the good stability of the emission frequency. In 50 flashes, the largest deviation from the mean frequency did not exceed 0.025 cm$^{-1}$. Such a stability is due to the features of the chosen mode selection method for the first laser to the low pumping level of the ruby $R_2$. The half-width of the second-laser directivity pattern was $1.5 \times 10^{-3}$ rad in the absence of an external signal. Following application of the signal, the width became approximately equal to the half-width of the directivity pattern of the introduced radiation and amounted to $2 \times 10^{-4}$ rad, which is close to the diffraction limit.

The frequency of the first laser could be shifted jumpwise from the center of the ruby $R^1$ line to the center of the ruby $R^2$ line by rotating the mirror $M_4$.[5] The second laser generated in this case a powerful ($10^8$ W/cm$^2$) pulse, likewise at the $R^2$ line. The value of the introduced intensity $I(\nu_i, 0)$ was approximately $10^{-2}$W in the case of generation on the $R^1$ line and several watts for the $R^2$ line. These values are of the same order of magnitude as the calculated ones. To estimate $I(\nu_i, 0)$ for the case of generation on the $R^2$ line, the value of q was chosen to be 7/5,[3] and in the case of generation on the $R^1$ line the frequency detuning was chosen equal to the frequency fluctuation of the second laser in the absence of the external signal. Unfortunately, we were unable to tune the frequency of the first generator within the limits of the ruby $R^1$ line by this method.


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