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KINETICS OF FREE GENERATION SPECTRA OF A SOLID-STATE LASER IN THE TRAVELING-WAVE REGIME WITH MODE DISCRIMINATION EXCLUDED

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Besides relaxation processes in the active medium, factors influencing the kinetics of the free generation spectrum of a solid-state laser to a considerable degree are the spatial inhomogeneity of the field in the cavity [1] and also parasitic mode selection by the cavity elements [2, 3]. Exclusion of these "masking" factors has enabled us to observe in the present investigation the kinetics of the spectra of ruby and neodymium-glass lasers in pure form. A rapid transition from multimode to single-mode generation was observed, for the first time, in a ruby laser at all pump levels and in a neodymium-glass laser at low pump level during the generation process. At high energies in a neodymium laser, on the other hand, a sharp increase of the spectrum width is observed rather than a transition to the single-mode regime; this is apparently connected with the inhomogeneous character of the neodymium luminescence line broadening. It should be noted that in an investigation [4] of the emission spectrum of a neodymium-glass traveling-wave laser, the spectrum width remained constant during the lasing in the entire range of working pump levels, and amounted to 0.1 - 0.2 cm^{-1} (equal to about 15 - 30 modes), i.e., the lasing was multimode. Our results are of great interest for the study of relaxation processes in the active medium, which determine the kinetics of the generation spectrum.

The influence of the spatial inhomogeneity of the radiation field was eliminated by using the traveling-wave regime. A diagram of the resonator is shown in Fig. 1. To exclude possible mode selection, the resonator mirrors with $R_1 \approx 1.0$, $R_2 \approx 0.5$, $R_3 \approx 0.8$, and $R_4 \approx 1.0$ were coated on wedge-shaped substrates, and the active rods AR (ruby rod of 15 mm dia and 120 mm long and KGSS-7 glass rod of 10 mm dia and 130 mm long) had plane-parallel end surfaces cut at the Brewster angle to the resonator axis. The optical length of the resonator was L ≈ 180 cm. To eliminate effects connected with the change of the transverse indices of the exciting modes during the lasing time, a diaphragm D with approximate diameter 2 mm was placed in the resonator. The laser emission was projected through a suitable spectral instrument SI on the entrance slit of an SFR high-speed camera operating in the slit-scanning mode. The SI for the ruby laser was a set of Fabry-Perot interferometers with plate separation t_{FP} = 1 - 50 mm. For the neodymium laser we used a diffraction spectrograph with dispersion $d\lambda/d\ell \approx 2.5$ Å/mm and resolution ~0.2 cm^{-1}, and also a set of interferometers with t_{FP} = 1 - 50 mm.

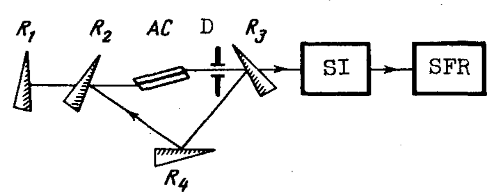

Fig. 1. Experimental setup

The time sweeps of the free-generation spectrum of ruby and neodymium-glass lasers in the traveling-wave regime are shown in Fig. 2. The width of the spectrum of the first spike is $\Delta\nu_1 \approx 0.2$ cm^{-1} and 6 cm^{-1} for the ruby and neodymium lasers, respectively, and these values are practically independent of the pump energy W. In the ruby laser, in the entire pump range (up to $W \lesssim 2.5W_{thr}$, where W_{thr} is the threshold pump energy), the spectrum narrows down to one mode ($\Delta\nu \lesssim 3\times10^{-3}$ cm^{-1}) rapidly, after 3 - 4 spikes, so that a single-mode regime is obtained for the majority of the spikes. On going from spike to spike, however, the lasing frequency shifts monotonically by an amount that agrees with the temperature shift of the maximum of the ruby luminescence line (Fig. 2a), in contrast with the more complicated behavior of the laser spectrum in the standing-wave regime, where the effect of inhomogeneous spatial burnup of the inverted population appears, as demonstrated by us in [3]. The observed kinetics of the ruby-laser spectrum in the traveling-wave regime is in good agreement with the theoretical model [5], which predicts a single-mode generation regime for a laser with a homogeneously-broadened luminescence line at a sufficiently large distance from the first spike.

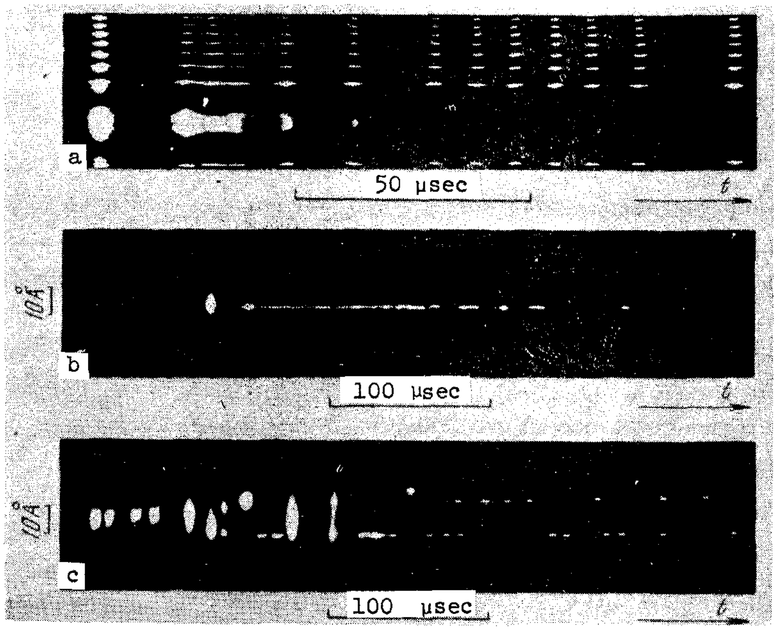

Fig. 2. Time sweep of traveling-wave laser free-generation spectrum: a - ruby laser, $W = 2W_{thr}$, $t_{FP} = 6$ mm; b - neodymium-glass laser, $W = 1.3W_{thr}$; c - neodymium laser, $W = 2.5W_{thr}$. The intensity ratio of the forward and backward waves is not less than 50.

The behavior of the neodymium-glass laser at small pumps ($W_{thr} \lesssim W \lesssim 1.5W_{thr}$) is very close to that observed for the ruby laser (Fig. 2b). Here, too, the width of the spectrum decreases to one mode, with $\Delta\nu \lesssim 3\times10^{-3}$ cm^{-1}, within 5 - 7 spikes, and the generation frequency decreases monotonically as a result of the temperature shift of the luminescence line. When a certain definite pump energy W_{def} is exceeded (in our case $W_{def} \approx 1.7W_{thr}$), the character of the neodymium-laser spectrum kinetics changes radically, and several spikes following the start of lasing the spectrum broadens to $\Delta\nu \approx 20$ cm^{-1} (Fig. 2b), after which a dip appears in the center.

Such a radical difference in the kinetics of the neodymium laser at different pump rates is apparently connected with the cirumstance that the behavior of the spectrum of a laser with an inhomogeneously-broadened luminescence line is determined by the relation between three parameters: the rate of exchange of excitation energy between the different ions (migration), the pumping rate, and the radiation-field intensity [6]. At low pumping rates the energy migration causes the amplification-line contour to stay undeformed, the line behaves like a homogeneously-broadened one, and narrowing of the spectrum is observed, in accord with [5]. At a definite value of the migration rate, however, there exist such values of the pumping rate and of the radiation-field density, that the amplification-line contour becomes deformed and broadening of the spectrum is possible. On the other hand, when the migration rate in a neodymium laser decreases, this critical value of the pumping rate can approach the threshold, and then the spectrum should broaden during the course of lasing in almost the entire pumping range. It is this circumstance which explains, apparently, the broadening of a neodymium-laser spectrum at 4.2°K, observed in [7], since the rate of energy migration in neodymium glass is greatly reduced at these temperatures. From this point of view, the use of materials with high migration rate promises to yield single-mode generation in a wide range of pump energies.

[1] T. I. Kuznetsova and S. G. Rautian, Fiz. Tverd. Tela 5, 2105 (1963) [Sov. Phys.-Solid State 5, 1535 (1964)].
[2] V. I. Malyshev, A. S. Markin, and A. A. Sychev, ZhPS (J. of Appl. Spectr.) 7, 662 (1967).
[3] V. I. Malyshev, A. S. Markin, and A. A. Sychev, Zh. Tekh. Fiz. 39, 334 (1969) [Sov. Phys. Tech. Phys. 14 (1969)].
[4] A. M. Bonch-Bruevich, V. Yu. Petrun'kin, N. A. Esepkina et al. ibid. 37, 2031 (1967) [12, 1495 (1968)].
[5] C. L. Tang, H. Statz, et al. Phys. Rev. 136, 1A (1964).
[6] V. D. Katsubanov, Yu. V. Naboikin, A. M. Ratner, and I. A. Rom-Krichevskaya, Zh. Eksp. Teor. Fiz. 53, 807 (1967) [Sov. Phys.-JETP 26, 534 (1968)].
[7] M. N. Tolstoi and V. N. Shapovalov, Opt. i spektr. 23, 648 (1967).

RADIATIVE PERTURBATION OF POTASSIUM TERMS IN A RUBY-LASER RADIATION FIELD

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In [1 - 4] they observed intense directional glow of potassium vapor following irradiation with a giant ruby-laser pulse (ν = 14 399 cm^{-1}) and with the Stokes SRS of this pulse in nitrobenzene (ν = 13 054 cm^{-1}). The frequencies of the potassium transitions $4S_{1/2} - 4P_{3/2}$ (ν_{no} = 13 042 cm^{-1}) and $4P_{3/2} - 6S_{1/2}$ (ν_{mn} = 14 407.8 cm^{-1}) are very close to the SRS and laser frequencies, respectively, thus explaining the population of the excited levels, the feasibility of negative absorption, and the powerful stimulated emission observed in [1 - 4] for many transitions. In Fig. 1 these transitions are marked by arrows.

We investigated the radiation in the visible part of the spectrum connected with the transitions $4S_{1/2} - 4P_{3/2,\,1/2}$ (λ = 7665/99 Å) and $4S_{1/2} - 5P_{3/2,1/2}$ (λ = 4044/47 Å). We were interested in the fine structure of these lines (which was not investigated in [1 - 4]), since the potassium terms should be strongly disturbed in the laser-emission field.

The potassium vapor was contained in a glass cell

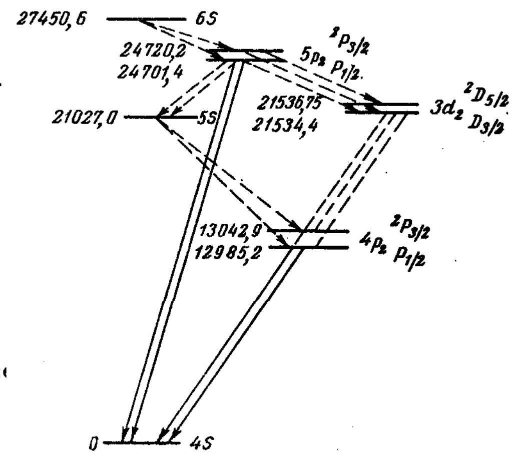

Fig. 1. Potassium terms