SPECTRAL KINETICS OF THE RADIATION FROM A NEODYMIUM GLASS "TRAVELING MEDIUM" LASER

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The spectral kinetics of the radiation from a neodymium glass "traveling medium" laser is subject to great variations. This is a natural result of small perturbations that are introduced into the oscillatory system of the laser during the motion of the active body. This signifies that the emission spectrum is unstable with respect to small changes in the parameters of the generating system.

1. EXPERIMENTAL SETUP

As is known from our preceding investigations,[1,2] a "traveling-medium" laser is realized when the volume of the resonator is partly filled with an active medium that executes translational motion in the direction of the laser axis. This can be attained specifically by moving the illuminating system with the active rod relative to the resonator mirror during the generation time.

Figure 1 shows a diagram of the setup. The active rod (AR) in a laser with a flat resonator of length ~70 cm is set to vibrate. The generation is effected in the time interval when the velocity of the rod reaches its maximum value, ~80 cm/sec. Since the time of pumping by the flash lamps IFP-2000 is $\sim 10^{-3}$ sec, the velocity can be regarded in this case as constant, since the period of the vibrational motion of the rod is usually to ~0.5–1 sec. Thus, the rod actually moves in translation during the generation time with a velocity v ≈ 80 cm/sec.

An active rod 13 cm long, made of neodymium glass of type LGS-5 with flat end faces parallel to the mirrors, is secured in a glass tube which is rigidly coupled to the moving system. It is possible to introduce a diaphragm (D) inside the resonator. The substrates of mirrors M_1 and M_2 are wedge-shaped to eliminate mode selection.[3] The emission spectra, formed in the plane of the cassette of the DFS-13 spectrograph with linear dispersion 4 Å/mm, were registered with the aid of a superhigh speed camera SFR-2m in the continuous-scanning regime. The resolving time of the SFR was $\sim 10^{-6}$–10^{-7} sec.

EXPERIMENTAL RESULTS

The photographs in Fig. 2 (a–g) show the kinetics of the generation spectra. Figure 2a shows the emission spectrum of an ordinary laser with an immobile rod.

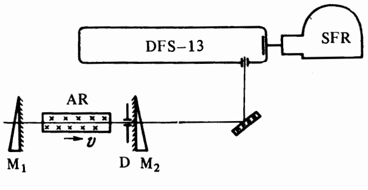

FIG. 1

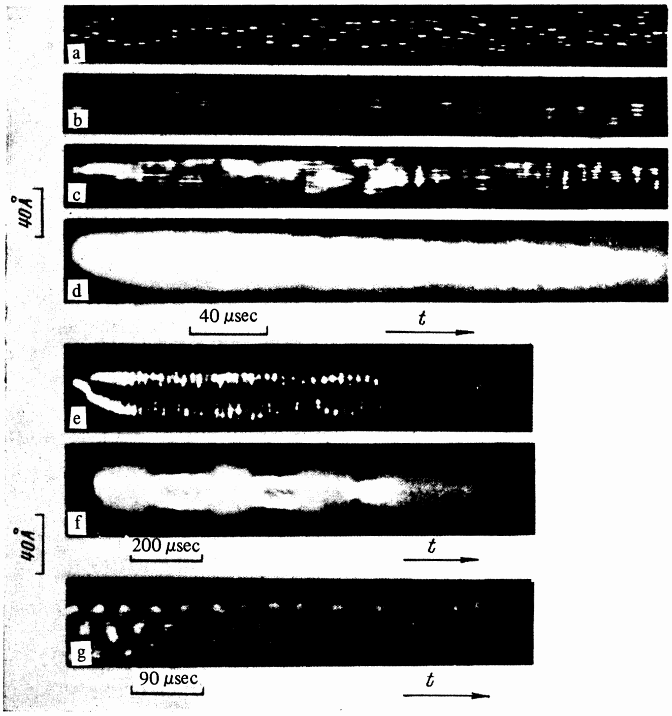

FIG. 2

Motion of the rod with velocity v ~ 80 cm/sec causes a change in the spectrum, as can be seen in Fig. 2b. The relatively rare and time-elongated generation spikes with spectra that are different (but are broad compared with Fig. 2a) are the results of the influence of the motion on the generation spectrum.

Limitation of the active zone by means of a round diaphragm of 2 mm diameter lengthens the individual generation pulses even more, until they overlap (Fig. 2c). The latter photograph shows clearly the general frequency periodicity in the spectrum, which amounts to $\sim 3\ \mathrm{cm}^{-1}$.

A decrease of the diaphragm diameter to 1.5 mm and less leads to the occurrence of the generation spectra shown in Figs. 2d–g. The appearance of any particular spectrum depends on the additional conditions concerning the state of the active rod as part of the resonator. The spectrum of Fig. 2d corresponds (at the best setting of the rod in the sense of parallelism of its end surfaces to the resonator mirrors) to the minimum of the generation threshold. In addition, shocks in the moving system have been eliminated as much as possible. As can be seen, the generation has a continuous character in this case, accurate to 10^7 sec. The generation spectrum is continuous (within the limits of the resolving power of the spectrograph ~ 0.1 cm^{-1}), with a width that changes continuously in accordance with the pump. The distribution of the intensity over the spectrum is of the bell-shape type. In this case (and only in this case, see Fig. 2d), the already mentioned periodicity ~ 3 cm^{-1} is missing from the spectrum.

Misalignment of the rod relative to the position of the minimum threshold, by $1'$–$2'$, leads to transformation of the kinetics of the spectrum, which takes the form of a "fork" (Fig. 2e). The distances between the "prongs" of the fork is ~ 20–30 cm^{-1}.

If a rod misaligned by $1'$–$2'$ experiences a slight jolt at the beginning of the motion, then a spectrum combined in time is produced, consisting of time intervals of the continuous spectrum alternating with intervals of the "fork" spectrum (Fig. 2f).

Finally, if the rod is not misaligned at the start of the motion and is subjected to a relatively strong jolt prior to the generation, then periodic oscillation of the radiation intensity over the spectrum sets in, with a characteristic periodic alternation in time of the generation bands (Fig. 2g). A still stronger jolt can stop the generation, owing to the large misalignment of the rod.

In all cases shown in Fig. 2, the pump was ~ 1.5 the threshold value.

3. ANALYSIS OF THE EXPERIMENTAL DATA

The evolution of the spectrally-kinetic pictures of generation, shown in Fig. 2, depict in succession the transition from the irregular generation regime of Fig. 2a to different regular regimes in Figs. 2d–g.

Figures 2a–d taken together contain an explanation of the nature of the spike generation.[4] Indeed, the motion of the active medium eliminates the nonequivalent distribution of the active centers relative to the electromagnetic field of the different modes in the longitudinal direction of the resonator.[3] The sharp broadening of the spectrum of the individual generation spikes and the increase of their duration with simultaneous decrease of the average frequency of their appearance, observed during the course of motion of the active medium (Fig. 2b), denotes that the rapid fluctuations of the generation spectrum are connected with the statistical nature of those laser parameters which depend on the longitudinal coordinate. Such parameters are the pumping and the loss of the resonator mode in the active medium.

The "traveling medium" laser has an essential inhomogeneity only in the transverse direction. It is precisely this inhomogeneity which causes those relatively slow fluctuations of the generation spectrum, which appear in the case represented in Fig. 2b. The decrease of the fluctuation frequency is apparently due to the appreciably larger value of the spatial period of the mode in a transverse direction than in the longitudinal one.

The simplest way of eliminating the transverse inhomogeneity is to limit the transverse dimensions of the active medium. As can be seen from Figs. 2c and d, the insertion of a diaphragm into the resonator leads to a gradual changeover (with decreasing diaphragm) of the spike generation into continuous generation.

In Fig. 2c, the spectrum was obtained with a diaphragm of 2 mm diameter, and in Fig. 2d, where there is a spectrum that is continuous in time and in space, was obtained with a diaphragm of 1.5 mm diameter. Thus, the neodymium-laser emission spectrum is characterized, as the influence of the space-time fluctuations on its kinetics becomes gradually removed, by a gradual changeover from a random time sequence (with an average appearance frequency of 10^5–10^6 Hz) of generation spikes with an irregularly varying spectrum into generation in the form of relatively narrow discrete bands (stationary rod, Fig. 2a), and continuous generation (accurate to 10^{-7} sec) with a continuous emission spectrum, the width of which changes in accordance with the time variation of the pump (Fig. 2d).

However, the continuous spectrum, as shown by experiment, is very unstable (Figs. 2e, f). Namely, if the active rod deviates by only $1'$–$2'$ from the position corresponding to the minimum of the generation threshold, then a so-called "forked" time evolution of the spectrum sets in.[5, 6] This indicates that a speed of ~ 80 cm/sec turns out to be sufficient not only for smoothing the time fluctuations of the pump and of the losses along the resonator axis, but also to eliminate the spatial inhomogeneity of the inverted population in this direction, occurring in an immobile active medium[7] as a result of the spatial inhomogeneity of the modes. At the same time, it shows that a small perturbation introduced into the resonator (the deviation of the plane of the end face from parallelism to the plane of the mirror) is sufficient to "destroy" the continuous spectrum. The latter circumstance should be the starting point in the solution of the problem of the origin of the continuous spectrum in "traveling medium" lasers.

As is known from the theoretical paper of Mashkevich,[8] in spectrally inhomogeneous media, when the spectral distance between the longitudinal modes is $\delta\nu \ll \Delta\nu$, where $\Delta\nu$ is half the homogeneous width of the working transition of the laser, in the absence of spatial inhomogeneity of the inverted population, the dependence of the laser emission spectrum on the pump (and consequently on the time during one flash of the pump lamp) should have a "forked" character, as is the case in Fig. 2e. Therefore the appearance of the continuous spectrum (Fig. 2d) must be regarded either as proof of non-uniqueness of the solution of the problem of the spectrum of stimulated emission of spectrally-inhomogeneous media, or else as a result of the action of additional (more readily resonator-connected) conditions on the formation of the generation spectrum of the laser.

We note here that the alternation of the continuous and "forked" spectra, observed in Fig. 2f, is apparently connected with flexural vibrations of the active rod,[9] which change periodically its orientation relative to the resonator axis. The fact that these vibrations of the rod can strongly influence the generation is confirmed by the following experiment.

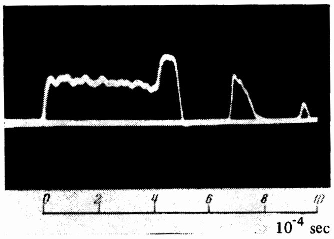

FIG. 3

If the rod is secured in the tube only on one end, and the other end is left free, then even negligible jolts in the "traveling medium" laser system lead to a characteristic generation with "dead" bands (Fig. 3). A calculation shows that the time between the maxima of the emission spikes is equal to the period of the fundamental flexural vibration of the rod. Periodic cessation of the generation, obviously, means a periodic increase of the losses in the resonator during the process of the flexural vibrations of the rod, and this leads to interruption of the generation.

As to the known cases when continuous neodymium-laser emission spectra have been observed at low temperatures ($\lesssim$ 20 K),[10, 11] these are close to the situation that is customary for gas lasers, when $\delta\nu \approx \Delta\nu$, for $\Delta\nu \lesssim 0.1\ \text{cm}^{-1}$ at such low temperatures, whereas $\delta\nu$ amounts to $\sim 0.1\ \text{cm}^{-1}$ in the indicated experiments, at resonator lengths $L = 5$ cm.

Thus, the problem of the continuous spectrum is unique to neodymium-glass "traveling medium" lasers, and at present we see a way of solving it by increasing the time resolution of the registered continuous spectrum.

Proceeding, finally, to the typically-nonstationary spectral-kinetic picture (Fig. 2g), we recall that it is produced under the influence of mechanical jolts that are experienced by the moving system. It is easy to see that the spectrum in Fig. 2g develops on the basis of a "forked" structure of the type shown in Fig. 2e. The time picture of the spectrum is in this case characterized by two periods, $\tau_1 \approx 30-35\ \mu\text{sec}$ and $\tau_2 \approx 8-10\ \mu\text{sec}$ (Fig. 2g). The period τ_1, as shown by an earlier paper by the authors,[9] is connected with the longitudinal vibrations of the active rod, excited in it by mechanical jolts, whereas the period τ_2 corresponds to the natural resonant oscillations of the laser-emission intensity.[12] The resonant oscillations are most noticeable at the start of the generation and in regions where rapid realignment of the spectrum takes place.

The emission-intensity oscillations at neighboring "prongs" of the fork of the spectrum are shifted in phase by an angle π. This is a general law in the kinetics of the "forked" spectrum of the emission of "traveling medium" neodymium-glass lasers under conditions when the resonator is periodically perturbed.

In the aforementioned regions of strong resonant intensity oscillations one can see filling of the emission spectrum between the "prongs" of the fork. In other words, each peak of the resonant oscillation has an almost continuous spectrum, bounded by the "prongs" of the fork characteristic of the stationary generation. At the present time there is no theory of spectra for nonstationary generation of lasers using spectrally-inhomogeneous active media. We therefore confine ourselves to the foregoing description of the regularities observed in the nonstationary generation spectra of "traveling medium" lasers.

In conclusion we must emphasize two circumstances. First, all the emission spectra given above, with the exception of the continuous one, have a periodic structure with a period of 3 cm^{-1}; second, all the changes of the generation spectrum, occurring within times shorter than 10^{-7} sec, could not be registered in the present work.

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