a double pass through one crystal after reflection of the waves from the mirror) makes it possible in principle to suppress the generation of waves with two-dimensional interaction (inasmuch as synchronism in both passes occurs only for one-dimensional interactions). Thus, the results presented above demonstrate the possibility of producing a PLG with a large conversion coefficient and large power at a small width of the radiation spectrum.

[1] L. B. Kreuzer, Appl. Phys. Lett. 13, 57 (1968).
[2] J. E. Bjorkholm, ibid. 13, 53 (1968).
[3] G. I. Freidman, Nelineinaya optika (Nonlinear Optics), Proc. 2nd All-union Symposium on Nonlinear Optics, Nauka, Novosibirsk, 1968.
[4] V. M. Fortus and G. I. Freidman, Izv. Vuzov, Radiofizika (in press). Proc. 3rd All-union Symposium on Nonlinear Optics, Erevan, 1967, in press.

INVESTIGATION OF THE TEMPORAL STRUCTURE OF NEODYMIUM-LASER EMISSION IN THE MODE SELF-LOCKING REGIME

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The development of lasers with mode locking and self-locking [1,2] has confronted experimenters in quantum electronics with the task of measuring time intervals of duration $\sim 10^{-12}$ sec. The time resolution of oscillographic procedures is presently limited to $\sim 3 \times 10^{-10}$ sec, i.e., at least two orders of magnitude lower than the required value. An original procedure proposed in [3,4] has demonstrated that short durations can be measured by nonlinear-optics methods. Nonetheless, methods of measuring the durations of light pulses, based on the observation of nonlinear optical effects, do not make it possible, in their present form, to determine uniquely the temporal structure of the radiation [5]. Naturally, a direct answer to this question can be obtained only by a direct measurement method, and such a method, in our opinion, is electron-optical high-speed photography. While the experimental temporal resolution of this procedure, $\sim 10^{-11}$ sec [6], does not make it possible to measure the duration of ultrashort pulses (we can estimate only the upper limit of their duration), it does make it possible to solve many problems.

In this paper we dwell essentially on the question of the temporal structure of the generation of a neodymium laser operating in the mode self-locking regime with Q switching by means of a saturable filter. We also compare the results obtained by investigating the same laser with the aid of an electron-optical camera and by the method of two-photon luminescence.

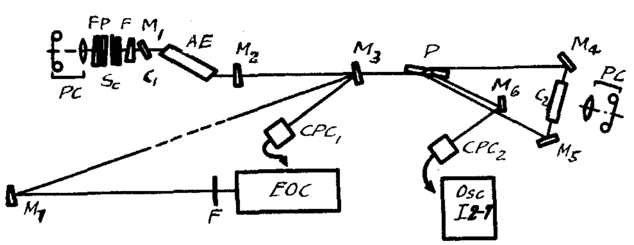

Fig. 1. Diagram of experimental setup.

The experimental setup, which makes it possible to register simultaneously the temporal and spectral characteristics of the neodymium-laser emission, is shown in Fig. 1. Here M_1 and M_2 are the resonator mirrors, which are coated on wedge-like substrates (~5°), with reflectances 99 and 50% respectively. C_1 is a cell installed in the resonator at the Brewster angle, with a solution of a saturable dye in nitrobenzene (initial transmission 40 - 50%), AE is a neodymium active element, cut at the Brewster angle (l = 240 mm and 15 mm diameter). M_3 and P are wedge-like and plane-parallel beam-splitting plates; M_4, M_5, and M_6 are mirrors with 99% reflectance. C_2 is a cell with a solution of rhodamine-6G in ethyl alcohol. EOC is an electron-optical camera based on an UMI converter, operating in the slit-scanning mode. CPC_1 and CPC_2 are coaxial photocells, the first to trigger the EOC, and the second to register the radiation with an I-2-7 oscilloscope. FP is a Fabry-Perot interferometer (t = 0.3 mm) to register the integral emission spectrum. PC is a photocamera, F filters, and S_c the scatterer. The experiment was performed at a laser-resonator optical length ~750 mm, a distance from the saturable filter to the dense mirror corresponding to ~1/15 of the optical length of the resonator.

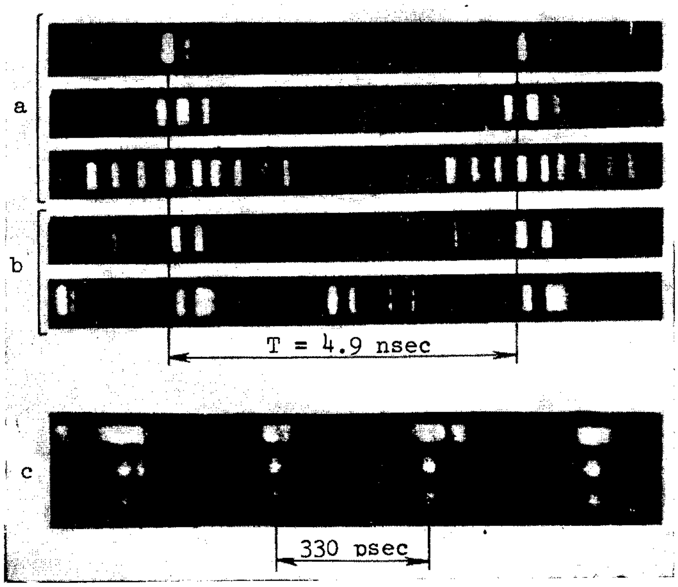

Fig. 2. a and b - axial period of neodymium laser generation for different flashes, c - fine temporal structure of generation within the axial period.

The time structure of the generation as a function of the position of the saturable filter inside the resonator was already investigated earlier in [7,8]. However, at small distances from the totally-reflecting mirror to the filter, the oscilloscope registers usually single pulses in the axial interval. An investigation of the generation pulse with the aid of the EOC has shown that in this case the generation consists of groups of pulses whose separation is determined by double the distance from the filter to the dense mirror (in our case ~330 psec). Figure 2a shows one axial generation interval (4.9 psec) for different flashes under constant experimental conditions. In some cases the structure of the pulses, located at a distance ~330 psec, reveals a "break," which reaches ~100 psec. A structure is also observed inside the axial period, again with the same characteristic time, but whose position, as well as the number of components, changes from flash to flash (Fig. 2b).

Further increase of the sweep rate has made it possible to observe an even finer temporal structure of the generation pulse. Figure 2c shows a group of pulses spaced 330 psec apart, each pulse consisting in turn of individual spikes, the distance between which is on the order of several dozen picoseconds. The use of a photographic wedge placed in front of the EOC slit makes it possible to estimate the ratio of the intensities of the spikes in the fine structure (the neighboring steps in the attenuator differ by a factor 1.6). The experiment has shown that the distance between the spikes, their number, and the relative intensity in the fine structure can vary in a wide range. These facts have not yet been satisfactorily

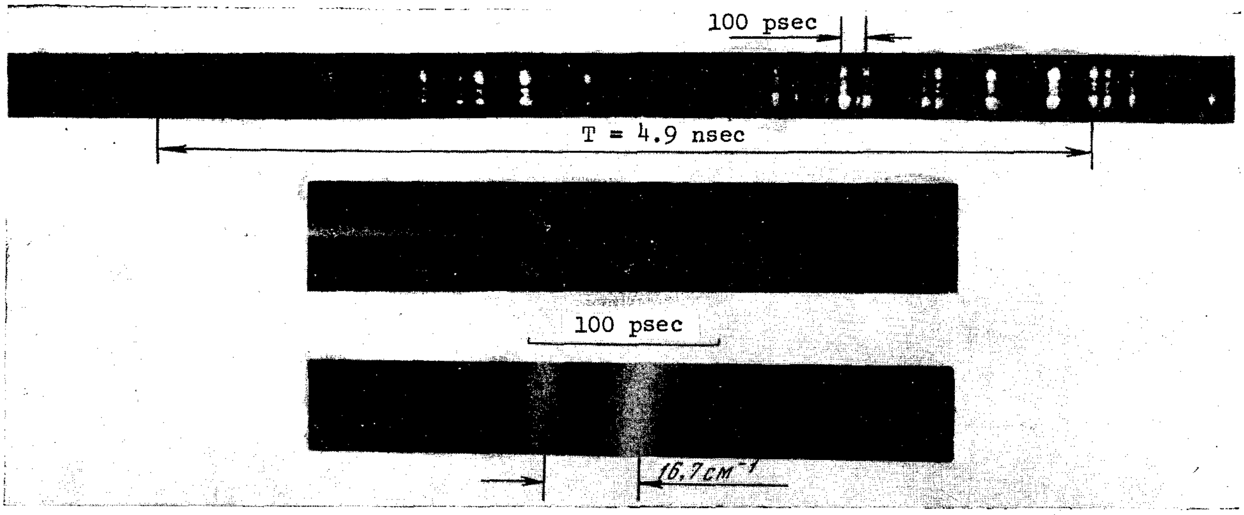

Fig. 3. a - axial generation period, b - luminescence picture, c - spectrum for one generation pulse.

explained.

As already indicated, simultaneously with electron-optical registration we photographed the luminescence of rhodamine-6G and the generation spectrum (Figs. 3a, b, c). While the type of the generation varied greatly, the pictures of the two-photon luminescence and the generation spectrum changed insignificantly. The pulse duration determined by the two-photon procedure ranged from 1.5 to 2 psec, and the spectrum ranged from 5 to 7 cm^{-1}. In some cases, the short pulse in rhodamine was observed against a background of a broader one (~15 - 20 psec). The results of the comparison of the picture of the generation on the EOC screen and in the rhodamine serve apparently as one more confirmation of the fact that the two-photon procedure is insufficiently reliable for determining the temporal structure of the generation. Even measurements of the duration of the ultrashort pulses by this method is not satisfactory, since the number of phased modes, and consequently the phase duration, can vary within the generation time [9], while the registered rhodamine luminescence picture is usually integrated over the pulses. Even if the necessary contrast-measurement accuracy required for the reconstruction of the temporal picture of the generation (~0.1%) is attained, these considerations remain in force.

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[1] L. E. Hargrove, R. L. Fork, and M. A. Pollack, Appl. Phys. Lett. 5, 4 (1964).
[2] A. J. De Maria, D. A. Stetser, and H. Heynau, ibid. 8, 174 (1966).
[3] J. A. Armstrong, ibid. 10, 221 (1967).
[4] J. A. Gordmaine, P. M. Rentzerpis, S. L. Shapiro, and K. W. Wecht, ibid. 11, 216 (1967).
[5] T. I. Kuznetsova, Zh. Eksp. Teor. Fiz. 55, 2453 (1968) [Sov. Phys.-JETP 28, No.6 (1969)].
[6] V. V. Korobkin and M. Ya. Schelev, High-speed Photography, ed. by N. R. Nilsson and L. Hogberg, Stockholm, 1968, p. 36.
[7] T. I. Kuznetsova, V. I. Malyshev, and A. S. Markin, Zh. Eksp. Teor. Fiz. 52, 438 (1967) [Sov. Phys.-JETP 25, 286 (1967)].
[8] R. Harrach and G. Kachen, J. Appl. Phys. 39, 2482 (1968).
[9] W. H. Glen and M. I. Brienza, Appl. Phys. Lett. 10, 221 (1967).