CONTINUOUS STIMULATED EMISSION OF AN LaF_3–Nd^{3+} LASER AT ROOM TEMPERATURE

Yu. K. VORON'KO, M. V. DMITRUK, A. A. KAMINSKIĬ, V. V. OSIKO, and V. N. SHPAKOV

P. N. Lebedev Physical Institute, Academy of Sciences, USSR; Crystallography Institute, Academy of Sciences, USSR

Submitted September 15, 1967

Zh. Eksp. Teor. Fiz. 54, 751–753 (March, 1968)

Continuous stimulated emission of a water-cooled LaF_3–Nd^{3+} laser is studied at 300 K.

AT the present time, only oxygen-containing crystals ($CaWO_4$, $Y_3Al_5O_{12}$, $CaMoO_4$) activated with Nd^{3+} and ruby[1] are used as active media in continuous lasers operating at room temperature. This is principally because of their quantum-mechanical parameters and spectroscopic characteristics.

In the past year at the P. N. Lebedev Physical Institute and the Crystallography Institute of the USSR Academy of Sciences, we have been carrying out an exploratory investigation of new crystals for different types of lasers and improving already known ones. Fluoride crystals have occupied a prominent place in these investigations. One of the results of this research has been the realization of a continuous laser operating at 300°K based on a fluoride crystal-tysonite (LaF_3–Nd^{3+}). We present below some of the results of the investigation of this laser.

Crystals of LaF_3–Nd^{3+} have recently been studied by many groups of authors. The principal results of the study of the spectroscopic generation characteristics and of the physico-chemical properties have been published in[2-7].

The crystals of tysonite used in our experiments were synthesized by the method described in[4,5]. The concentration of Nd^{3+} in them varied from 0.5 to n 6 wt.%. For experiments on induced emission, cylindrical rods of circular cross section (diameter about 5 mm), 25 to 40 mm long, were prepared. The end faces were parallel to within about 10″. The optical quality of the crystals was satisfactory. Figure 1 shows an interferogram and the "passive" divergence of a crystal of LaF_3, 38 mm long, and containing 2 wt. % Nd^{3+}, which was used in a continuous laser. These characteristics were obtained by the method described in[8]. In Fig. 1 the optical quality of the crystal is demonstrated in the field of the ordinary and extraordinary waves (in the investigated sample the c axis lies in a plane which is perpendicular to the geometric axis).

Since the principal spectral characteristics of our crystals of LaF_3–Nd^{3+} were similar to those described in[2-7], we did not consider them. We measured the lifetime of the excited state $^4F_{3/2}(\tau_e)$ and the integrated intensity of the luminescence (I_{lum}) of the working transition $^4F_{3/2} \rightarrow {}^4I_{11/2}$, which characterizes the relative quantum yield. The concentration dependence was investigated at room temperature and at 77°K. Figure 2a shows the experimental dependence $\tau_e(C)$ for 77 and 300°K, and Fig. 2b shows $I_{lum}(C)$

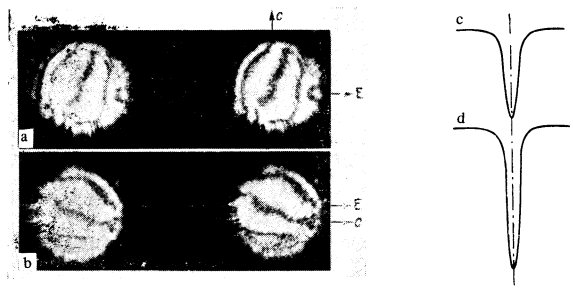

FIG. 1. Interferogram of a crystal of LaF_3 – Nd^{3+} (2 %) in the field of the ordinary (a) and extraordinary (b) waves; c – "passive" divergence in the field of the ordinary and extraordinary waves; d – divergence of an LG-35 gas laser.

of the transition $^4F_{3/2} \rightarrow {}^4I_{11/2}$. It is seen that τ_e at 77°K is markedly shorter than at 300°K. Such an unusual quenching of the luminescence is connected with the emergence of a channel for resonant cross-relaxation of the excitation energy via the intermediate levels of the $^4I_{15/2}$ term.[4] As can be seen, the probability for cross-relaxation also increases with increasing activator concentration. The results of the luminescence investigation (see Fig. 2b) correlate well with the behavior of $\tau_e(C)$. These experiments show that the best Nd^{3+} concentration for a room temperature laser is about 1 wt.%. The measurements of $\tau_e(C)$ and $I_{lum}(C)$ were carried out by the method described in[9,10].

In the pulsed laser we used an illuminator of elliptical cross section with a light efficiency of about 0.5[11] with a type IFP-400 xenon lamp. For the continuous mode we used an excitation chamber similar to that described in[12,13]. The working crystal and the pumping lamp were cooled by flowing water. In both cases the laser was made with external confocal spherical mirrors with a multilayer dielectric coating. The transmission of the mirrors at 1.06 μm was about 0.5%. With the pumping system used, a crystal of LaF_3 containing 2 wt.% Nd^{3+} of length 38 mm and diameter about 5 mm began to radiate stimulated emission in the A line (10 407 Å)[7] with 4 kW of electrical power dissipated in the lamp. This same sample in the high-efficiency illuminator in the pulsed regime had a threshold of 2.8 J. Analysis of the radiation with Nicol prisms showed that the crystal generates the extraordinary ray in the A line, i.e., The **E** vector of the emitted electromagnetic wave is almost parallel to the optic axis of the crystal c.

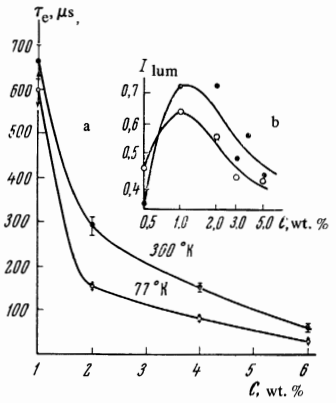

FIG. 2. Dependence on Nd concentration: a – τ_e and b – I_{lum} of crystals of LaF_3 – Nd^{3+} at 77 and 300°K.

We should also mention here the remarkable property of this crystal to generate the B line (10 633 Å) at T = 400–500°K with a low threshold, close to that of the A line at 300°K. This becomes possible because of the effect of resonant high-temperature sensitization[7] arising at these temperatures, which is of great value from the point of view of providing the requisite temperature regime.

Thus, crystals of LaF_3–Nd^{3+} are the first active substance of the fluoride class in which a continuous generation regime has been realized at 300°K. We also note here that the relatively high threshold of excitation of our crystals is due to insufficiently high optical quality and an activator concentration that was not optimal.

In conclusion the authors thank V. T. Udovenchik for participating in synthesis of the crystals and V. Ya. Khaimov-Mal'kov for consultations.

[1] A. A. Kaminskiĭ and V. V. Osiko, Izv. Akad. Nauk SSSR, ser. neorgan. materialy, **1**, 2049 (1965); **3**, 417 (1967).

[2] M. B. Schulz and C. D. Jeffries, Phys. Rev. **149**, 270 (1966).

[3] H. H. Caspers, H. E. Rast, and R. A. Buchanan, J. Chem. Phys. **42**, 3214 (1965).

[4] C. K. Asawa and M. Robinson, Phys. Rev. **141**, 251 (1966); M. Robinson and D. M. Cripe, J. Appl. Phys. **37**, 2072 (1966).

[5] M. V. Dmitruk and A. A. Kaminskiĭ, Zh. Eksp. Teor. Phys. **53**, 874 (1967) [Sov. Phys.-JETP **26**, 531 (1968)].

[6] P. H. Klein and J. Croft. J. Appl. Phys. **38**, 1603 (1967).

[7] A. A. Kaminskiĭ, ZhETF Pis. Red. **6**, 615 (1967) [JETP Lett. **6**, 115 (1967)]; Zh. Eksp. Teor. Fiz. **54**, 727 (1968) [Sov. Phys. JETP **27**, 388 (1968)].

[8] Yu. K. Voron'ko, A. A. Kaminskiĭ, V. V. Osiko, and V. Ya. Khaimov-Mal'kov, Izv. Akad. Nauk SSSR, ser. neorgan. materialy, **1**, 1521 (1965).

[9] A. A. Kaminskiĭ, L. S. Kornienko, and A. M. Prokhorov, Zh. Eksp. Teor. Fiz. **48**, 1262 (1965) [Sov. Phys.-JETP **21**, 844 (1965)].

[10] Yu. K. Vorn'ko, A. A. Kaminskiĭ, and V. V. Osiko, Zh. Eksp. Teor. Fiz. **49**, 420 (1965) [Sov. Phys.-JETP **22**, 295 (1966)].

[11] A. A. Kaminskiĭ and L. S. Kornienko, Zh. Priklad. Spektr. **2**, 87 (1965).

[12] A. A. Kaminskiĭ, L. S. Kornienko, G. V. Maksimova, V. V. Osiko, A. M. Prokhorov, and G. P. Shipulo, Zh. Eksp. Teor. Fiz. **49**, 31 (1965) [Sov. Phys.-JETP **22**, 22 (1966)].

Translated by L. M. Matarrese
88