A ROOM-TEMPERATURE CONTINUOUS $CaWO_4:Nd^{3+}$ *LASER*

A. A. KAMINSKIĬ, L. S. KORNIENKO, G. V. MAKSIMOVA, V. V. OSIKO, A. M. PROKHOROV, and G. P. SHIPULO

Institute of Nuclear Physics, Moscow State University; P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

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A detailed description and the main characteristics of a water cooled $CaWO_4:Nd^{3+}$ laser operating at 300°K are presented. Problems connected with maintenance of the required working temperature are considered.

INTRODUCTION

THERE are presently a number of lasers which operate continuously and in which the active material is a crystal[1)]. The majority of these operate at liquid-nitrogen or lower temperatures. In the paper by Johnson et al.[1], in addition to a detailed description of the construction and characteristics of a $CaWO_4:Nd^{3+}$ laser operating at 77°, there is brief mention of the achievement of continuous laser action in this material at room temperature. The present article gives a detailed description of the construction and basic properties of a $CaWO_4:Nd^{3+}$ laser operated at room temperature with water cooling.

PROPERTIES OF THE $CaWO_4:Nd^{3+}$ CRYSTAL

The Nd^{3+} doped $CaWO_4$ crystals used were grown by the Czochralski method as described by Nassau and Brover [3]. The $CaWO_4$ charge was prepared by the precipitation method. The starting materials were specially purified ammonium paratungstate and calcium fluoride. The neodymium was introduced in the form of the double salt $NaNd(WO_4)_2$ [4]. In addition, Na_2WO_4 was introduced into the melt in a seven-fold excess with respect to neodymium. Seeds oriented along both the c and the a axes were used [5] and were pulled from the melt at rates of from 7 to 12 mm/hr, with a rotation rate of 50 rpm. The neodymium concentration varied between the limits of 0.1 and 5 at. %. Lowering the growth rate from 12 to 7 mm/hr produced significant improvement in the optical quality of the resulting crystal.

The luminescence and absorption spectra of single crystals of $CaWO_4$ activated with Nd^{3+} have been studied in great detail. The most complete data are given in [6-8]. The infrared luminescence of Nd^{3+} in $CaWO_4$ is due to transitions from the $^4F_{3/2}$ level to the various levels of the ground multiplet ^4I. The strongest Nd^{3+} luminescence occurs at 1.06 μ, corresponding to the transition $^4F_{3/2} \rightarrow {}^4I_{11/2}$ (cf. Fig. 1). It was on this transition that continuous laser action was obtained.

It is of decisive importance in achieving continuous laser action, particularly at 300°K, to provide the necessary cooling of the crystal so as not to allow it to heat up. With this in mind we estimated the contribution of the various neodymium absorption bands to the laser action. In Fig. 2 we

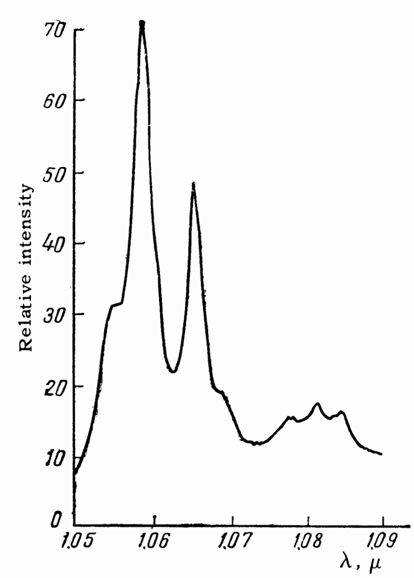

FIG. 1. The luminescence spectrum for the transition $^4F_{3/2} \rightarrow {}^4I_{11/2}$ in Nd^{3+} in $CaWO_4$.

[1)]The paper by Simpson [2] described a neodymium glass laser operated at 300°K with solar excitation.

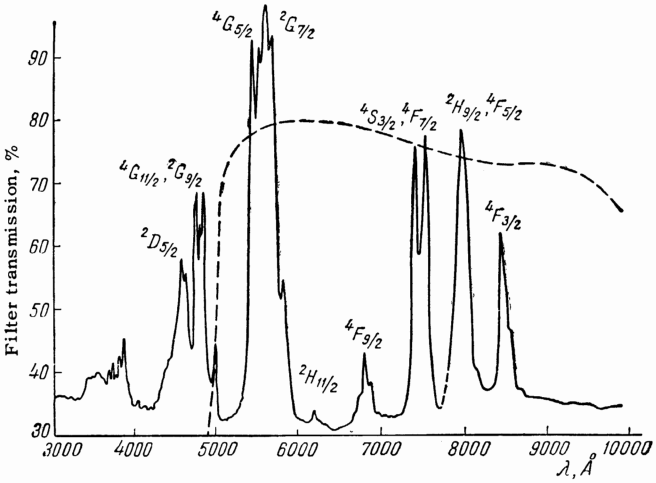

FIG. 2. The absorption spectrum of Nd^{3+} in $CaWO_4$ (intensities in arbitrary units) and the transmission band of the excitation filter in per cent (dotted line).

show the absorption spectrum of Nd^{3+} in $CaWO_4$ at 300°K. It is seen that Nd^{3+} has several absorption bands in the region from 0.3 μ to 0.9 μ, and that the most intense of these is around 5800 Å. The contribution made by each band was estimated from the intensity of the luminescence produced under selective excitation. Excitation in the bands lying between 0.3 and 0.5 μ produces an as yet not clearly understood aging of the Nd^{3+}, which results in decreasing strength of laser action. Analogously, when Nd^{3+} in CaF_2 is excited by the whole spectrum of a xenon lamp, the crystal eventually ceases to lase [9]. For $CaWO_4 : Nd^{3+}$ crystals the aging effect is not so pronounced, but it is no less advisable in this case to filter out the short wavelength emission from the pumping source. This is particularly advisable because the contribution of the absorption bands of Nd^{3+} to laser action in this region is only ~10%.

From the point of view of the desired thermal operation, the most suitable excitation would be selective excitation in the 5800 Å band ($^2G_{7/2}$, $^4G_{5/2}$). However, such selective excitation requires a complicated system of filters. If one simultaneously excites the bands between 0.5 and 0.9 μ, the luminescence intensity increases by 1.5–2 times over the excitation in the 5800 Å band alone. This broad-band excitation requires that the crystal be more strongly cooled. Our studies showed this to be a soluble problem. The apparatus described below isolated the band from .55 to 1 μ from the xenon lamp emission. For operation many times above threshold it is obviously more desirable to use narrow-band excitation at 5800 Å.

The luminescence of the used $CaWO_4$:Nd^{3+} crystals decays exponentially and is practically independent of the temperature [10]. Our laser used a $CaWO_4$ crystal with a Nd^{3+} concentration of about 3.0 at. %. The lifetime of the excited $^4F_{3/2}$ state both at room temperature and at lower temperatures was 172 ± 2 μsec.

PRINCIPAL LASER CHARACTERISTICS

The illuminating system consisted of an elliptical reflector (50 mm long with an eccentricity of about 0.5), in one focus of which was placed a continuously excited straight xenon lamp having a luminous column 45 mm long and 5 mm in diameter. The lamp was surrounded coaxially by a tube made of BS glass. Water was circulated between the lamp and the tube. The $CaWO_4 : Nd^{3+}$ crystal was located at the other focus of the reflector; the crystal was 42 mm long and, 5 mm in diameter, and was also coaxially surrounded by a tube constructed of ZhS-17 glass. The crystal was also cooled by running water. The filter consisting of ZhS-17 glass 1.7 mm thick plus ~10 mm of water had a transmission band which included the fundamental absorption band of Nd^{3+}. In Fig. 2 we show the absorption spectrum and the transmission band of the filter.

The optical resonator consisted of multi-layer dielectric reflectors deposited on the confocal end faces of the crystal. The transmission of these mirrors is shown in Fig. 3. At the operating wavelength the transmission of the mirrors is about 1.6%. The time dependence of the laser action was investigated with a photomultiplier having an oxygen-cesium cathode; the laser spectrum was recorded with a DFS-13 spectrograph. The laser operated at 10584 Å (9448 cm^{-1}) with a linewidth of about 1 Å (0.89 cm^{-1}). Using the pumping system described above, the electrical power delivered

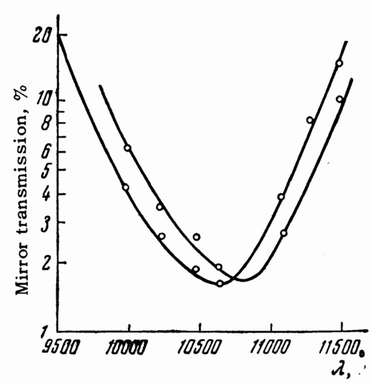

FIG. 3. The transmission band of the multi-layer dielectric mirrors on the crystal.

to the lamp at threshold was 2.6 kW. When the threshold power was increased by about 40% the output power was estimated to be several tens of milliwatts. The illuminating system had a rather low optical efficiency, about 0.1, which is responsible for the high excitation threshold. Under pulsed excitation conditions with the same crystal and the same illuminating system and the same lamp, the threshold was about 2 Joules. In another illuminating system with an optical efficiency of about 0.5 [11], using the same lamp, threshold was about 0.5 J. It is clear from this that only by improving the excitation system can one significantly lower the excitation threshold for the crystal which we used.

In order to estimate the power required at threshold for continuous operation from the value for the threshold energy in the pulsed regime one cannot simply use the relationship P (in watts) = P (in Joules)/τ, where τ is the lifetime of the excited state. There should be a correction coefficient in this formula, depending on the operating conditions of the lamp. In our case, for example, the calculated threshold power would be 11.6 kW whereas the threshold is actually smaller by a factor of about 4.5. This is evidently due to the fact that at low electrical input energies the luminous characteristics of the flash lamp are different from the characteristics during the rated pulsed working conditions. To achieve the rated operating conditions in our lamp the required input was about 3 kW of electrical power.

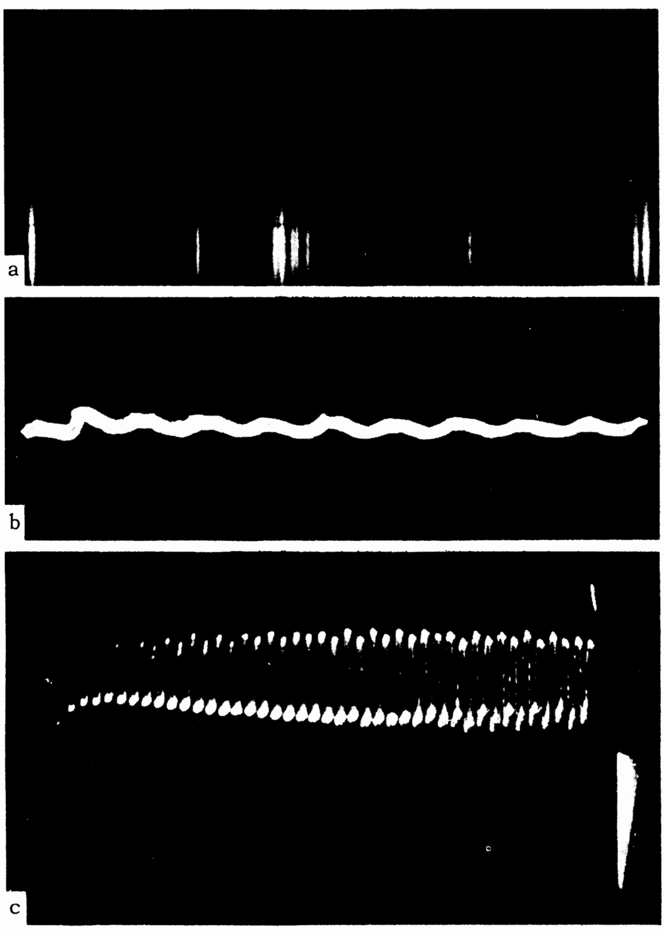

FIG. 4. The cw laser line and the oscillogram of the emission time dependence; a – the upper trace is the laser line at 10584 Å, the lower spectrum is the iron spectrum of second order; b – laser action at threshold, power 2.6 kW (the total duration of the picture is 0.2 sec); c – laser action for an excitation of 3600 kW (the total exposure is 1 sec).

In Fig. 4 we show the emission spectrum of the continuous laser action in $CaWO_4:Nd^{3+}$. The iron spectrum in second order is used as the calibration. The spectrum was photographed on I-1070 film with an entrance slit of 0.1 mm. The exposure lasted about 0.6 sec. Figure 4b shows an oscillogram of the continuous laser action at threshold and in Fig. 4c at 20% above threshold. The latter figure shows the establishment of thermal equilibrium in the crystal. The time constant for this process is somewhat less than 0.1 sec. The low-frequency modulation of the laser output is due to pulsations in the output voltage of the dc generator which fed the lamp. In Fig. 5 we show a photograph of the emission pattern of a cw $CaWO_4:Nd^{3+}$ laser having plane-parallel end faces. The divergence of the laser emission from this crystal was about 1°.

CONCLUSIONS

This investigation has shown that the primary difficulty in obtaining continuous laser action even in the case of very good crystals lies in providing conditions such that the crystal does not heat up.

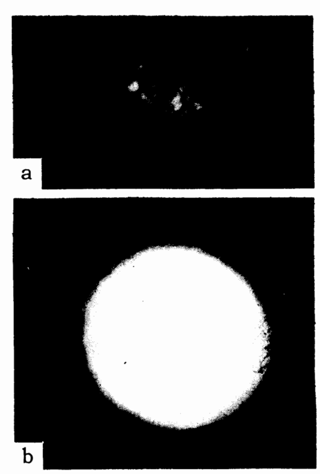

FIG. 5. The emission pattern of the cw $CaWO_4:Nd^{3+}$ laser from a crystal with plane parallel ends: a – at threshold, b – 30% above threshold.

In the case of $CaWO_4$ doped with Nd^{3+} this involves the correct choice of the absorption bands used during the pumping excitation. Also of importance is the choice of crystal diameter for a given concentration of Nd^{3+} and the matching of the crystal geometry to the geometrical parameters of the luminous portion of the excitation lamp.

In conclusion we express our thanks to Yu. A. Kalinin and I. S. Marshak for making the excitation lamp, to S. V. Kolabukhova for growing the neodymium doped $CaWO_4$ crystal, to L. V. Kolpakov for preparation of the illumination system, to A. A. Kolotov for evaporating the dielectric mirrors, and to Yu. K. Voron'ko for help in carrying out the experiments.

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