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A powerful, repetitively pulsed 1444-nm Nd : YAG laser

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Abstract. A powerful, repetitively pulsed 1444-nm Nd :YAG laser is studied. It is shown that the efficiency of this laser is mainly limited by the absorption at 1444 nm in the active element, the UV radiation of the pump lamps, the lasing at the internal mode frequencies of the active elements, and the amplified luminescence at 1444 nm. An optimisation procedure resulted in the creation of a powerful laser producing 1.4-J pulses at a repetition rate of between 1 and 10 Hz at 1444 nm.

It is known that an yttrium aluminium garnet crystal doped with trivalent neodymium ions (Nd^{3+}:YAG) has a complicated energy level diagram [1, 2], which, in principle, allows lasing at a number of spectral lines in the region from 0.941 to 1.839 μm [3, 4].

The possibility to obtain repetitively pulsed emission at 1444 nm from a Nd^{3+}:YAG laser was demonstrated in Refs [5, 6]. Such a laser is of special interest in connection with the problems of ecological safety; therefore, the attempts to increase the efficiency of this laser are topical.

The principal problem one has to deal with when trying to obtain efficient lasing at this wavelength is the competing processes of lasing at 1064, 1318, and 1357 nm (the transition at 1064 nm is particularly strong, its cross section exceeding that of the working transition at 1444 nm by a factor of 9.1 [5].) To prevent lasing at these transitions, one has to use a highly selective cavity. The selective folded multimirror cavities look promising in this respect.

In this work, we study the lasing properties of the laser with a three-mirror cavity. To suppress the spurious lasing, we replaced the totally reflecting mirror by a spectrally selective mirror with the reflection coefficients $R_{1444} \approx 99.9\,\%$, $R_{1064} \approx 7\,\%$, $R_{1318} \approx 8\,\%$, $R_{1338} \approx 24\,\%$, and $R_{1357} \approx 34\,\%$ at 1444, 1064, 1318, 1338, and 1357 nm, respectively. We also used a deflecting (45°) mirror with $R_{1444} \sim 99.9\,\%$ and the minimum possible reflectivity at the other mentioned wavelengths. The output mirror was also spectrally selective with respect to the mentioned wavelengths.

Inside the cavity, one or two active elements (AEs) were installed in single-flashlamp quantrons. In our experiments, we used AEs of the dimensions $\varnothing 10 \times 80$, $\varnothing 10 \times 10$, and $\varnothing 6.3 \times 80$ mm, which had the antireflection coating for the region 1064 – 1444 nm. The mat side surface of AFs had a thread 0.3 – 0.4 mm deep. The AEs were pumped by KINP2-5/90A and KINP4-5/75A flashlamps made of doped quartz that absorbed the UV component of the pump radiation, by an INP3-7/80 lamp with a special coating that served the same purpose, or by an INP5/75A-1 lamp made of ordinary quartz.

The energy of the pump pulses of each lamp was 210 J at a pulse duration of ~ 100 μs and a pulse repetition rate of 1 – 10 Hz. Unless noted otherwise, the laser was cooled by distilled water. The spectrum and temporal characteristics of the output emission were controlled with the aid of its second harmonic, which was produced in a nonlinear crystal.

Under these conditions, we obtained lasing at 1444 nm with no contributions from other spectral lines. The generation had typical peak character and a duration of 60 – 80 μs. Note that in the case of linear cavity arrangement (as opposed to the scheme of Ref. [5]), we failed to suppress the 1357-nm line using the above mentioned totally reflecting and output mirrors.

We found out that the efficiency of lasing at 1444 nm is very sensitive to the losses caused by the inactive absorption in the AE matrix. We studied the transmission and amplification of radiation at 1444 nm for many AEs with various dimensions. The initial transmission of the unexcited elements was found to be between 79 and 94 %. When we used AEs with the initial transmission lower than 86%, no lasing was detected even at the highest pump energies. Measurements of the absorption spectra in the region 1 – 1.5 μm showed that all the crystals exhibit (Fig. 1) a narrow absorption band at 1485 nm with a half-width of 10 – 15 nm. The

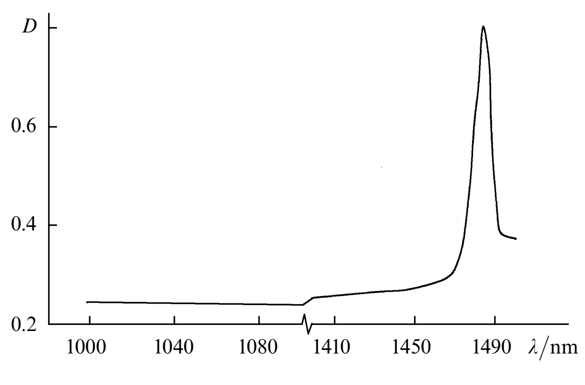

Figure 1. Optical density D of an AE 80 mm long.

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1444-nm line is located at the short-wavelength wing of this absorption band. This absorption band is probably related to uncontrolled impurities that are always present in the mixture used to grow Nd^{3+} : YAG crystals. The maximum single-pass amplifications of 1.27 and 1.16 were obtained in the threaded AEs of dimensions $\varnothing 6.3 \times 80$ mm and $\varnothing 10 \times 100$ mm, respectively.

The experiments have demonstrated that the UV component of the pump spectrum causes a significant decrease in the maximum amplification, which is reversible. This means that the UV radiation produces unstable colour centres in the matrix, which degrade the lasing efficiency at 1444 nm. The lasing power increased by 80% when we used a KN-30 coumarin dye in ethanol solution for cooling the flashlamp and the AE that absorbed the flashlamp radiation at 420 nm and reemitted it in the spectral region 480 – 520 nm. This is probably explained by both an increase in the pumping efficiency and the reduction in the efficiency of the creation of short-lived colour centres.

Our investigation showed that the efficiency of lasing at 1444 nm, as for the single-pulse lasing at 1064 nm [6, 7], is limited by lasing at the AE internal modes and the powerful multipass amplified luminescence at 1064 nm, which is emitted inside the reflector in the transverse direction. This is illustrated in Fig. 2, which shows the dependence of the transmission (gain) on the pump energy for different AEs. One can see that for the same initial transmission, the maximum gain is greater for the AE with a thread on the side surface, which weakens the internal mode generation at 1064 nm.

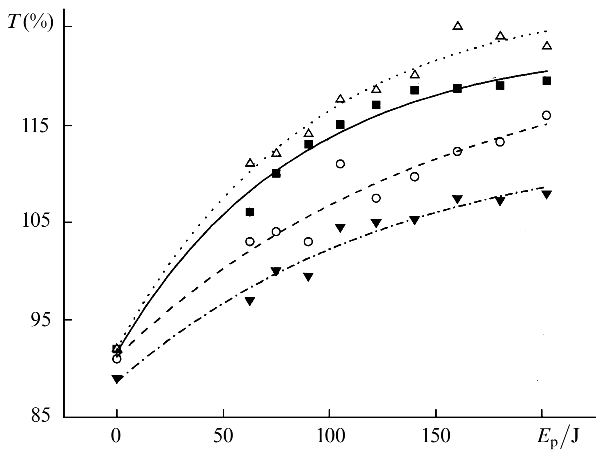

Figure 2. Dependences of the transmission (gain) T on the pump energy E_p for the AE with the dimensions $\varnothing 6.3 \times 80$ mm with (△) and without (■) thread and for the AE with the dimensions $\varnothing 10 \times 100$ mm with (○) and without (▼) thread upon probing by free running lasing emission at 1444 nm.

The reduction in the gain with increasing AE diameter is related to the action of the multipass amplified luminescence at 1064 nm inside the reflector. To reduce these effects, one should use an AE with a deeply embossed side surface, e.g., with a thread, and the reflectors with the minimum reflectivity at 1064 nm, e.g., the ones made of the MS-20 ground glass.

The experiments have shown that the optimal output mirror reflectivity amounts to $\sim 90\%$ in the case when a single AE is used and to $\sim 70\%$ for two AEs. Under optimal conditions, the lasing power reached 0.34 J per pulse in the case of a single $\varnothing 6.3 \times 80$ mm AE and 0.5 – 0.6 J per pulse for a $\varnothing 10 \times 100$ mm AE. The maximum output energy at 1444 nm, obtained with two $\varnothing 10 \times 100$ mm AEs, amounted to 1.4 J.

Note that, in contrast to the data of Ref. [5], the intensity of the 1444 nm line was very low whenever other spectral lines were present in the emission radiation spectrum.

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