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Free-running and electrooptically Q-switched single frequency generation of 1 cm quasi-cw diode-bar-end-pumped Nd:YVO_4 laser

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The 5 mJ output energy of Nd:YVO_4 and 43% slope efficiency were obtained in free-running mode. Single frequency Q-switched generation was obtained applying prelasing technique with $LiNbO_3$ electrooptical Q-switch. A peak power of above 170 W in 5.6 ns pulse duration was achieved in preliminary results.

1. Introduction

Several works on pulsed, medium energy lasers pumped by quasi-cw laser diode bars have been carried over the last years. The end pumping [1], [2], side pumping [3], [4] and slab configurations [5], and several methods of Q-switching were applied. Performance of such type of lasers depends mainly on the quality of beam shaping optics, type of crystals and method of Q-switching. The best results in free-running mode were obtained by FUGNET *et al.* [6] for Nd:YVO_4 crystal. The best results in Q-switching mode were achieved by GRAF and BALMER for Nd:YLF crystal [2].

The aim of this work was to experimentally verify the Nd:YVO_4 crystal as a highly efficient material for Q-switched diode pumped lasers. As a pump source the SDL 3251-A1 quasi-cw diode bar was used. This diode can generate 100 W pulses with repetition up to 100 Hz and energy of 20 mJ for 200 μs pulse duration. It was attached to a thermoelectric cooler to control pump wavelength. There were analyzed several beam shaping optics configurations intended to effectively transform the diode bar beam into the active region [6], [7].

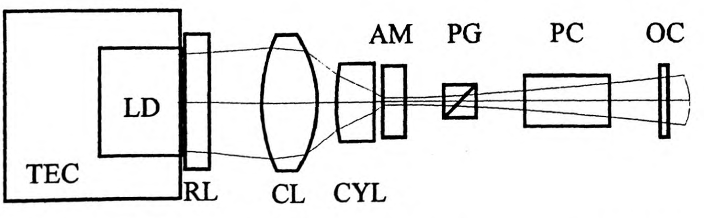

Fig. 1. Scheme of laser: LD — 1 cm quasi-cw laser diode bar SDL 3251-A1, TEC — thermoelectric cooler, RL — rod lens, CL — collecting lens, CYL — cylinder lens, AM — active medium, OC — output coupler, PG — Glan polarizer, PC — Pockels cell ($LiNbO_3$ crystal)

The beam shaping system consisting of rod lens attached to diode bar, the collecting lens CL and the cylinder lens CYL (Fig. 1) was constructed for end-pumping scheme experiments. The sizes of the pump volume were verified both theoretically and experimentally [7]. The minimum pump volume size was 1.8×0.7 mm with caustics length <1 mm for Nd:YVO_4 laser version of beam shaping optics.

2. Free-running mode experiments

There was applied a flat-flat cavity scheme in all experiments to achieve almost circular output with good beam quality. The quasi-cw laser diode driver SDL 928-10 and the energy meter RJ7100 were used for pump supply and energy measurements. Beam quality measurements were performed by means of LBA100A system equipped with Pulnix TM6CN CCD camera. The threshold energy, slope efficiency and beam quality depend on cavity length, but to apply electrooptic Q-switch the cavity length could not be less than 120 mm. In all experiments in free-running mode the cavity length was 120 mm, and the best output coupler transmission was about 15%.

In experiments we used crystals of Nd:YVO_4 with the sizes of $5 \times 5 \times 1$ mm^3 and 1% Nd doping. In preliminary experiments we found that absorption efficiency for such a crystal was about 60%, so we used two crystals with different coatings. In both crystals the AR coatings for 0.8 μm and HR for 1.06 μm were deposited on the rear facet. On the other facet the only AR coatings for 1.06 μm were applied for the first crystal, whereas the additional HR coatings for pump wavelength for the second crystal were ordered. The estimated internal resonator losses were about 1%. For both crystals a linearly polarized beam was observed. The higher output energy and slope efficiency were achieved for the second one (Fig. 2).

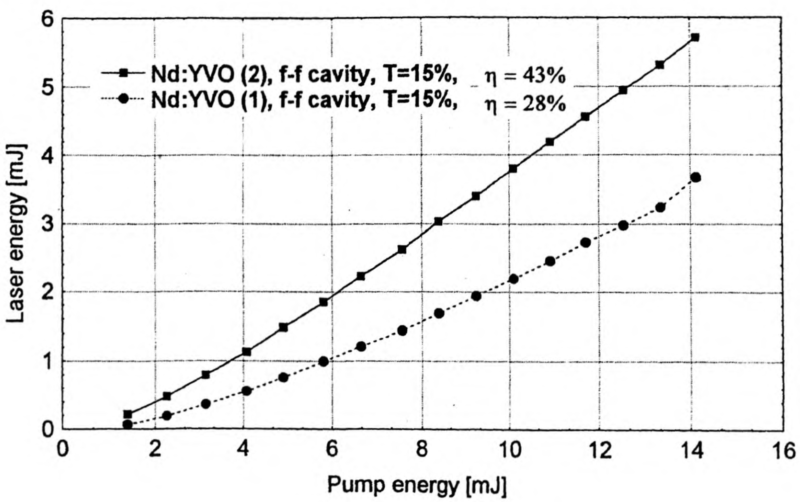

Fig. 2. Output energy of free-running mode of Nd:YVO_4 laser versus pump energy

Table. Beam parameters of Q-switched Nd:YVO_4 laser: Z_R – Rayleigh range, D_0 – width of beam in the waist plane, Θ_0 – beam divergence, M^2 – beam quality factor

	Z_R [mm]	D_0 [mm]	Θ_0 [mrad]	M^2
X plane	71	0.33	4.7	1.1
Y plane	41	0.29	7.1	1.54

In spite of asymmetry of pump beam neraly circular output was obtained. For cavity longer than 200 mm the quasi-TEM_{00} mode was observed. For 120 mm long cavity near diffraction limited beam was observed for free-running as well as Q-switching experiments (see the Table).

3. Q-switching mode experiments

The experiments with an electrooptic Q-switching were performed on the set-up shown in Fig. 1. The diffraction limited output was observed for cavity lengths of more than 200 mm. However, to increase the output energy and to minimize the pulse duration the cavity length should be as short as possible. In our experiments the cavity length of about 120 mm was limited by the sizes of a typical Glan polarizer and a Pockels cell. As a Q-switch there was applied a typical Pockels cell (C1043) made from $LiNbO_3$ crystal ($6\times6\times30$ mm) by Solaris Optics. We used in Q-switching experiments only the first crystal. The Q-switching mode in the second one was unobtainable because of the weak free-running generation as a result of coupling between the crystal facets. That was probably caused by bad quality of AR coatings. Thus the results of the Q-switching experiments should be considered as preliminary, not optimized ones.

After applying a typical Pockels cell driver, high depolarization losses and relatively long pulses were observed due to slow piezo-optic relaxation phenomena in $LiNbO_3$ crystal. To eliminate this effect, there was applied a method of Pockels cell supply similar to that presented in [1]. It was found experimentally that the best results in respect of output energy and pulse power were obtained after applying the dc bias voltage of 2500 V to one electrode and 900 V to another to maintain $U_{\lambda/4} = 2500\ \mathrm{V} - 900\ \mathrm{V} = 1600\ \mathrm{V}$. Fast removing of high voltage 2500 V caused the generation of short (~ 5 ns pulse duration) high power pulse. The measurements of pulse duration were performed by means of SCD1000 oscilloscope equipped with vacuum avalanche photodiode TF1850. After applying prelasing technique [1], [8] the smooth pulse profile (Fig. 3) was observed. The interferogram registered for Fabry–Perot interferometer with base of 25 mm gives evidence of the single frequency generation (Fig. 4). When the generation started from chaotic oscillations the modulated pulses were observed giving evidence of the axial multimode output.

The best results were obtained for output coupler with transmission 36%. For 5.8 mJ of pump energy and 100 μs duration the output energy was 0.7 mJ with pulse duration 6.8. ns, which corresponds to 105 kW of pulse power. For pump duration 250 μs the output energy was 1 mJ with pulse duration 5.6 ns which

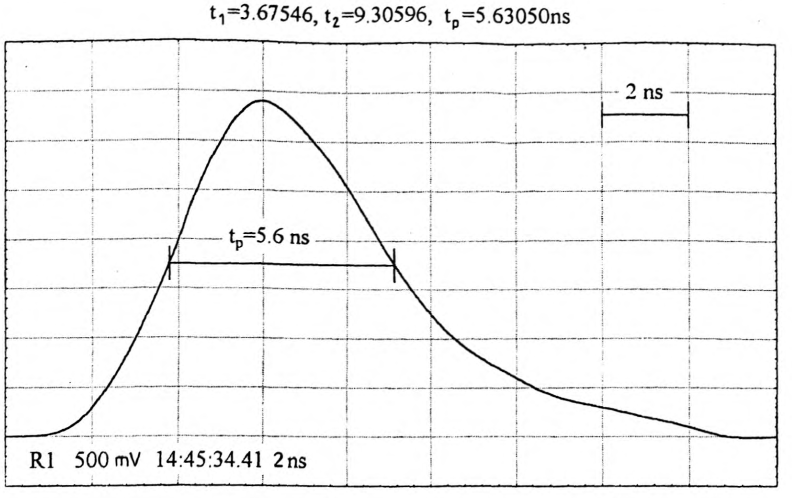

Fig. 3. Oscilloscope trace of single frequency pulse of an electrooptically Q-switched Nd:YVO_4 laser

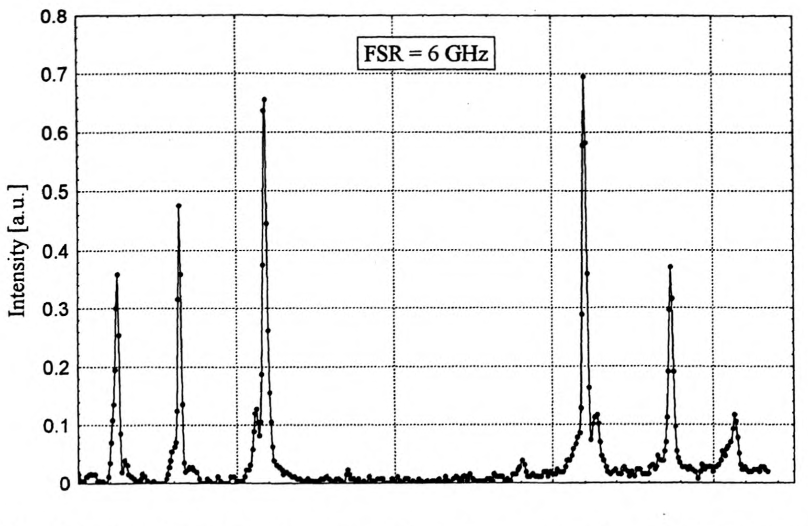

Fig. 4. Fabry–Perot interferogram of single frequency pulse of Nd:YVO_4 laser

corresponds to 178 kW of pulse power. The maximum repetition rate, limited by heat removing from the diode bar, was about 100 Hz.

4. Conclusions

The results of free-running experiments of Nd:YVO_4 lasers, *i.e.*, over 5 mJ for 15 mJ pump with slope efficiency above 43% and up to 100 Hz repetition showed the high quality of Nd:YVO_4 crystal as a material for highly efficient pulsed low energy lasers. Preliminary results of electrooptic Q-switching experiments (178 kW in 5.6 ns pulse duration in single axial, diffraction limited output) show that it is possible to produce an efficient, high performance, Q-switched laser.

The energetic parameters of Q-switched Nd:YVO_4 laser can be significantly improved by applying crystal with higher absorption and better elements of electrooptic Q-switch. Moreover, applications of new construction of beam shaping optics (see [6], [7]) can increase the optical efficiency significantly. We expect that in next experiments the output pulse power from Nd:YVO_4 laser should increase to 0.5 MW level. Applying a diode bar with microchannel cooling [9] the repetition rate can increase over 1 kHz with the same pulse parameters.

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