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Performance of Q-switched, Nd:YAG triangle slab laser pumped by 100 W quasi-cw diode-bar*

J. K. JABCZYŃSKI, W. ŻENDZIAN

Institute of Optoelectronics, Military University of Technology, ul. Kaliskiego 2, 01–489 Warszawa, Poland.

A Q-switched laser with triangular slab Nd:YAG crystal pumped by 100 W quasi-cw has been designed. Due to beam shaping optics consisting of rod lens and additional anamorphic objective, efficient near diffraction limited output has been achieved. The output energy of about 4.6 mJ was demonstrated for 14 mJ of pump energy in free running mode with optical slope efficiency 42% for multimode output of TEM_{0N} type ($M^2 \sim 1.1 \times 3.2$). In Q-switching experiments, an $LiNbO_3$ Pockels cell was placed between the slab and rear mirror in cavity with length of about 16 cm and flat output coupler with 20% transmission. The energy of 1.8 mJ in 21 ns pulse duration was obtained for output beam of TEM_{00} type. About 0.7 mJ with 50% efficiency was obtained in II harmonic with II type KTP crystal.

1. Introduction

Efficient, high repetition rate, Q-switched TEM_{00} lasers of mJ level of output energy are required in several applications such as: range finding, altimetry, generators for high power systems, technological processes, *etc.* One of the best types of such sources are low energy, solid state lasers pumped by quasi-cw diode laser bars. There were demonstrated several types of such lasers working in end pumped [1]–[4] or side pumped [5]–[8] configurations. The best results in free-running mode, namely more than 5 mJ and over 50% efficiency, were demonstrated in end pumped $Nd:YVO_4$ lasers [3]. The end pumped laser, generating TEM_{00} output beam, requires complicated beam shaping optics; moreover, thermally induced birefringence diminishes efficiency of electrooptical Q-switching in this case. Side pumed lasers with rod active media suffer from bad beam quality, although due to their scalability they are the best choice in the case of high output energy requirements.

The best solution for single diode bar pumps seems to be schemes with slab shape active media. Due to efficient shaping of diode bar beams by means of rod lenses [9] the pump channel in *y* direction (*i.e.*, perpendicular to junction plane) can be very narrow enabling generation of TEM_{0N} type beam in slab lasers. The TEM_{00} beam is achieved in such lasers due to shortening the width of slab to such value that would

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enforce only TEM_{00} beam generation. Reduced thermal lensing and linear polarization forced by Brewster cut facets enable construction of high repetition rate, electrooptically Q-switched slab lasers [7], [8].

We proposed in this paper an alternative method for single transverse mode generation consisting in special shaping of diode bar beams in x direction (*i.e.*, parallel to junction), [10]. The pump beam incident on the base of Brewster cut triangle, single reflection slab has elliptical shape with sizes of 1.7×0.6 mm comparable to the size of TEM_{00} laser mode totally reflected at this plane. There were experimentally demonstrated the TEM_{0N} as well as TEM_{00} output beams in such a laser by means of the proper choice of cavity length, curvature of mirrors and precise alignment. Moreover, linearly polarized output enabled application of simple electrooptical Q-switching scheme without additional polarizer. In the next sections, the scheme of laser, the results of free running mode, Q-switching mode, beam quality and II harmonic generation experiments are presented.

2. Free running mode experiments

As shown in Figure 1, the diode bar beam shaping optics consists of rod lens and anamorphic collimator. The pump channel with height ~ 0.6 mm and divergent horizontal size starting from 1.7 mm at the base of slab is formed inside it. Such asymmetrical pump volume is well matched to laser mode inside slab because its aspect ratio at the base of slab is equal to refractive index $n \sim 1.8$. We found in experimental optimization that the highest performance is achieved in cavity with 2.5 m radius of curvature of rear mirror for resonator length of about 160 mm. For such parameters the laser mode diameter $2w_0$ is about 0.9 mm and mode size on the base of slab is approximately 1×1.8 mm, though pump beam is enclosed inside laser mode ellipse in this plane. Although the laser mode and pump channel inside slab diverge, their overlapping is sufficient to enforce near TEM_{00} output beam in the case of special adjustment of cavity mirrors. Similar thresholds ~ 2.5 mJ and slope

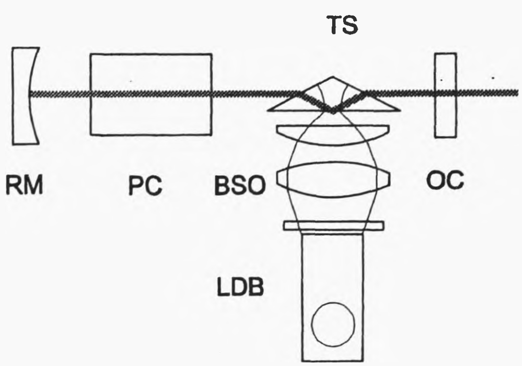

Fig. 1. Scheme of triangle slab laser: TS — Nd:YAG Brewster cut triangle slab, PC — $LiNbO_3$ Pockels cell, OC — flat output coupler, RM — rear mirror with 2.5 m radius of curvature, BSO — beam shaping optics, LDB — quasi-cw laser diode bar SDL 3251-A1

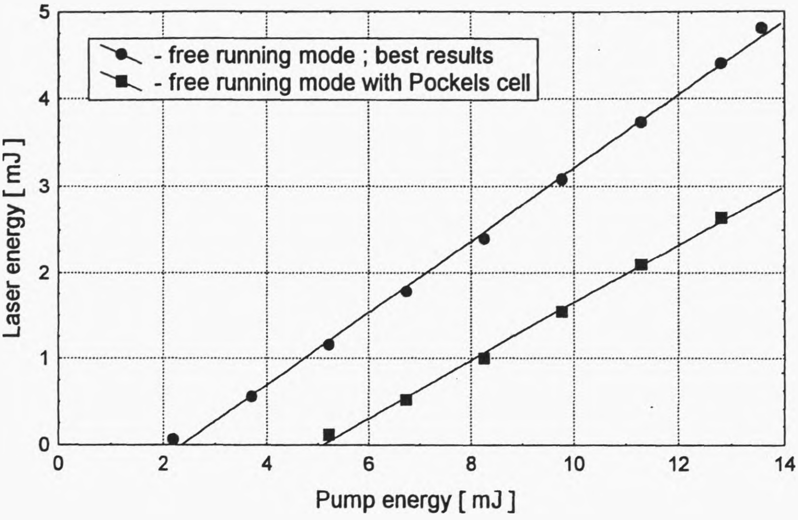

Fig. 2. Energy of free running mode (pump duration 200 μs) vs. energy of pump incident on the slab: • — best results for cavity without Pockels cell, with OC transmission 8%, ■ — results for cavity with Pockels cell and 20% transmission of output coupler

efficiency ~42%, compared to free running mode experiments in the case of end pumped schemes, were obtained (see Fig. 2), although for slightly multimode output of TEM_{0N} type. The quality of such a beam was approximately 1.1×3.2 (see Fig. 3).

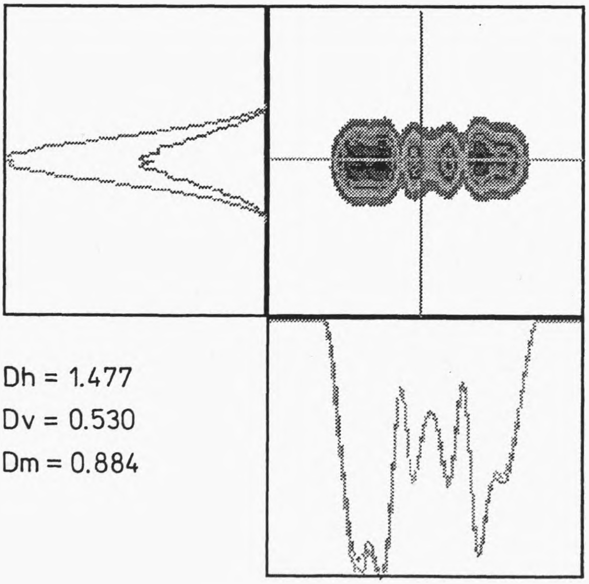

Fig. 3. Intensity distribution of output TEM_{0N} beam in focal plane of a lens of 300 mm focal length; estimated parameters $M^2 \sim 1.2 \times 3.2$

After inserting the $LiNbO_3$ Pockels cell the cavity threshold increased to 4.5 mJ and slope efficiency diminished to about 27%.

3. Q-switched mode experiments

It was found experimentally that the Brewster cut triangle slab enforced linear polarization output which was sufficient to completely break the generation after supplying quarter-wave voltage to $LiNbO_3$ Pockels cell without any additional polarizer. Thus, effective monopulse generation can be realized in this case by switching the quarter-wave voltage. We applied electronic Pockels cell driver enabling 50 ns switching time, so that the observed pulse duration was relatively long

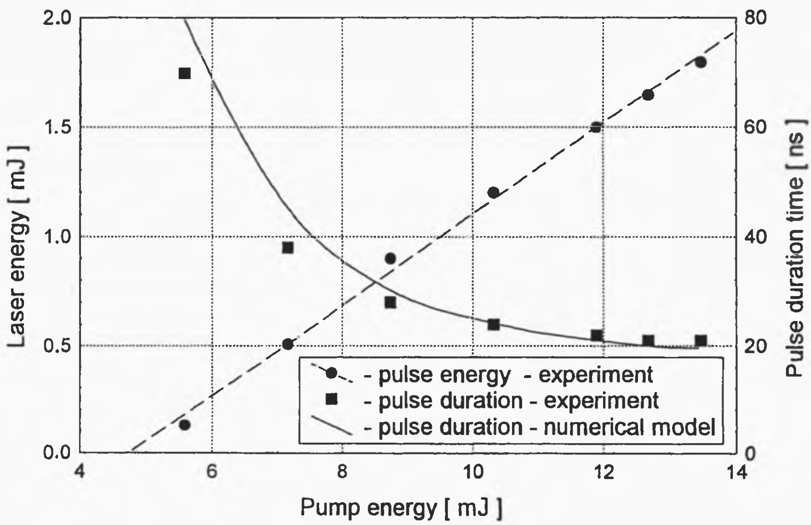

Fig. 4. Energy of Q-switched pulses and pulse durations as a function of pump energy: ● — energy of Q-switched pulses — experiment, ■ — pulse duration — experiment, solid curve — results of numerical simulation of pulse durations

The experimentally defined gain was approximately 0.35 for the highest pump level. (see Fig. 4). Numerical simulations of such Q-switched laser were performed taking into account the switch of time constant of the driver and gain determined in experiments. Figure 4 shows a satisfactory agreement between the pulse duration obtained from numerical simulations and experimental data.

As was mentioned in Section 2, the output beam of TEM_{0N} (see Fig. 3) was preferred in long pulse mode. However, due to application of electrooptical Q-switch, the difference in energy between TEM_{00} and TEM_{0N} output was diminished to about 25%. We obtained about 2.3 mJ of output energy in TEM_{0N} mode (with $M^2 \sim 1 \times 2.5$) and 1.8 mJ in TEM_{00} mode. We suppose that Pockels cell acts in this case as "phase diaphragm" increasing diffraction losses for higher order modes. The TEM_{00} mode of 140 mm length cold cavity has a diameter of about

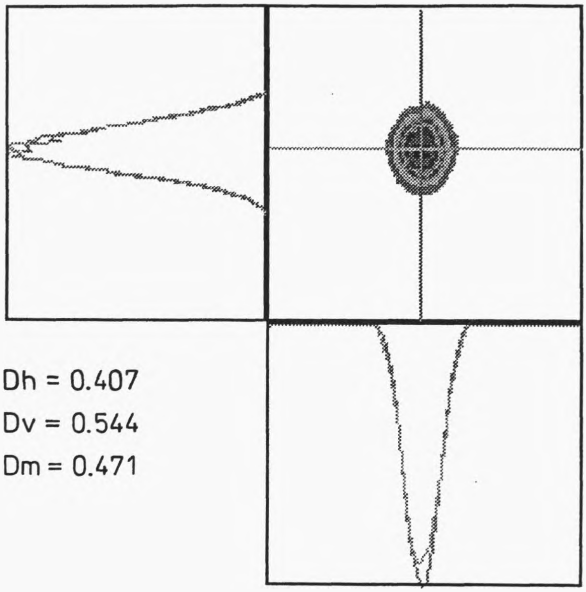

Fig. 5. Intensity distribution of output beam in focal plane of a lens of 300 mm focal length; correlation to Gaussian shape 0.94, averaged diameter 0.47 mm, averaged parameter $M^2 < 1.15$

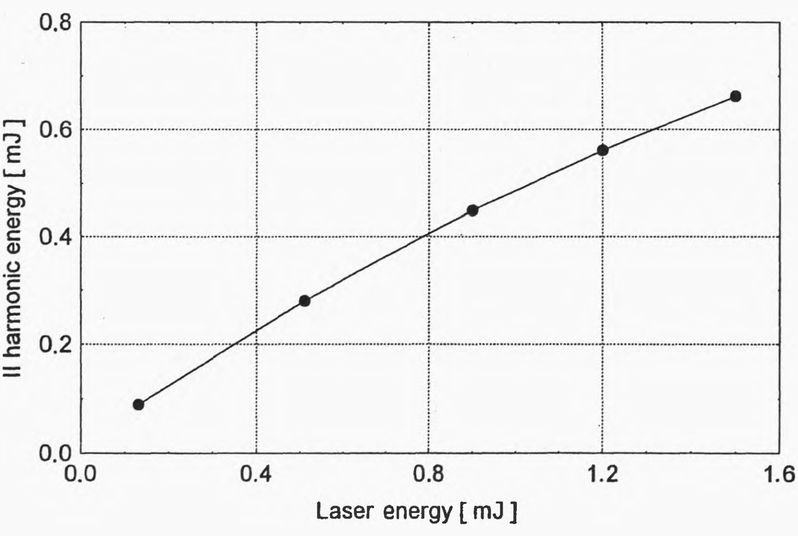

Fig. 6. II harmonic energy vs. laser energy

0.88 mm, Rayleigh range of 570 mm and half-divergence angle of 0.77 mrad. We measured the beam sizes in the focal plane of a lens with 300 mm focal length (Fig. 5). The averaged M^2 parameter defined as a ratio of real averaged divergence angle to diffraction limited divergence was about 1.15. The measured divergence asymmetry (1:1.33) was caused by asymmetry of gain. The narrow pump size was thinner than

TEM_{00} mode diameter in vertical direction, whereas in horizontal one it was comparable to or wider than the horizontal width of fundamental mode inside slab.

Laser source with 90 kW pulse power and single transverse mode output should be efficient in harmonic generation. There were performed investigations of II harmonic generation to prove the quality of our laser. We used uncoated, 11 mm long, II KTP type crystal for II harmonic generation. To match the Rayleigh range of 1.064 μm laser beam to crystal length, a lens with 120 focal length was used. In this case, there was approximately 1.7 GW/cm^2 of power density for 1.6 mJ energy of incident beam with beam diameter of 0.18 mm inside crystal. As Fig. 6 shows, the energy of about 0.66 mJ was obtained on 532 nm wavelength which, accounting for Fresnel losses of uncoated crystal (~16%), gives the efficiency of 51% for the higher pump levels.

4. Conclusions

A simple, efficient, Q-switched Nd:YAG laser of 2 mJ output energy has been presented. The novel scheme of beam shaping optics enabled low threshold and single transverse mode operation ($M^2 < 1.1$). The efficient (>50%) II harmonic generation proved the high quality of output beam. Relatively long pulse duration (~20 ns) can be decreased due to the shortening of cavity length or application of faster Pockels cell driver.

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References

[1] Rae C. F., Terry J. A. C., Sinclair B. D., Dunn M. H., Sibbett W., Opt. Lett. **17** (1992), 1673.
[2] Graf T., Balmer J. E., Opt. Lett. **18** (1993), 1371.
[3] Feugnet G., Bussac C., Larat C., Schwarz M., Pocholle J. P., Opt. Lett. **20** (1995), 157.
[4] Jabczyński J. K., Żendzian W., Opt. Appl. **26** (1996), 35.
[5] Welford D., Rines D. M., Dinerman B. J., Opt. Lett. **16** (1991), 1850.
[6] Jackson S. D., Piper J. A., Appl. Opt. **33** (1994), 2273.
[7] Selker M. D., Afzal R. S., Reichert P., IEEE J. Quantum Electron. **30** (1994), 1616.
[8] Afzal R. S., Selker M. D., Opt. Lett. **20** (1996), 465.
[9] Snyder J. J., Reichert P., Baer T. M., Appl. Opt. **30** (1991), 2743.
[10] Jabczyński J. K., Opt. Appl. **26** (1996), 101.

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