52-mJ, kHz-Nd:YAG Laser with Diffraction Limited Output

B. Oreshkov [1*], D. Chuchumishev [1], H. Iliev [2], A. Trifonov [1], Torsten Fiebig [3], Claus-Peter Richter [3], I. Buchvarov [1,3]

1. Department of Physics, Sofia University, 5 James Bourchier Blvd., BG-1164 Sofia, Bulgaria
2. Binovation Ltd., 20A Inzh. Georgi Belov str., Sofia, 1712, Bulgaria
3. Deptartment of Otolaryngology, Northwestern University, 303 E. Chicago Ave, Searle 12-561, Chicago, IL 60611, USA
**corresponding author: b.oreshkov@phys.uni-sofia.bg*

Abstract: We present Nd:YAG, diode pumped amplifier system emitting up to 52-mJ pulse energy with 1.6-ns pulse duration and near diffraction limited beam, operating at 0.75-kHz repetition rate.

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Reliable high-energy (>10 mJ) laser systems with high-peak power (>10MW) pulses at kHz repetition rates, having diffraction-limited beams are highly desirable for a number of industrial, military and scientific applications, e.g. chemical sensing, various LIDARs, materials synthesis and processing [1], highly efficient nonlinear frequency conversion, etc. However, in the vast majority of kHz ns-laser systems the output pulse energy is below few tens of microjoules, whilst the repetition rate of the presently existing high pulse-energy systems does not exceed 50-100 Hz and are far from single TEM_{00} mode. For generating a ~1 ns pulses with diffraction limited laser pulses, at a kilohertz repetition rate, a passively q-switched laser oscillator is preferred. These lasers usually are simple and reliable devices. However they have significant drawbacks – the output energies are typically in the range of several hundred microjoules, which is not enough to reach saturation of the amplification in a Nd:YAG power amplifiers, for example. Therefore a pre-amplifier must be employed in order to boost the oscillator pulse energy to the few milijoules, required for efficient extraction of the stored in power amplifiers energy [2]. Moreover, the method of passive q-switching results in a significant time jitter between the successive pulses and more complex electronics are required in order to synchronize the oscillator output with other devices.

Active q-switching, on the other hand, can offer significantly higher average power, because of the absence of unsaturable losses, inherent for passive modulators, and a very small time jitter. Moreover, the synchronization with other devices is easily achievable, through simple control of the triggering signal, which allows flexible control on the system output (the exact time of the pulse appearance, number of pulses, frequency etc.).

In this work, we report an amplification of laser pulses generated by a near diffraction limited, compact actively Q-switched Nd:YAG oscillator with 1.6 ns, 1.2 mJ output pulses at 0.75 kHz. Using a master oscillator power amplifier (MOPA) architecture, we were able to boost the energy up to 52-mJ in a two stage amplifier, using a diode pumped boost Nd:YAG-rod amplifiers, whilst preserving the pulse duration, beam quality and linear polarization.

The master oscillator we used is an actively q-switched diode pumped Nd:YAG micro-laser, emitting at 1064 nm. The gain medium is a 7 mm long, 1 at. % concentration of Nd^{3+} ions with an aperture of 3×4 mm^2. It is

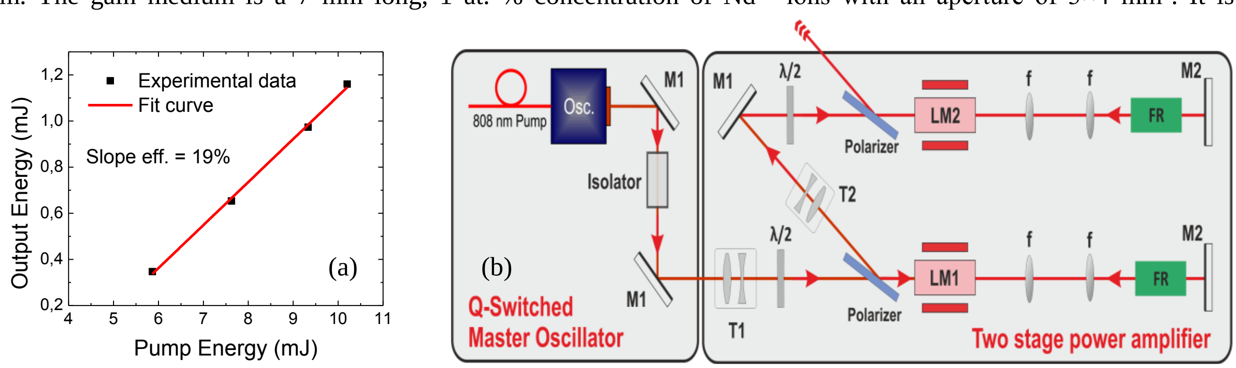

Fig. 1. (a) Oscillator slope efficiency, (b) Schematic diagram of the MOPA laser system, where **M1** is mirror, HR@ 1064 nm, 0-45^{O}; **M2** – mirror, HR@1064, 0^{O}; **T1** – beam forming optics 1; **T2** – beam forming optics 2; **Osc.** – oscillator; **LM1** – amplification module 1; **LM2** – amplification module 2; **f** – focusing lens; **FR** – faraday rotator.

longitudinally pumped by a 70W Quasi-CW diode laser, emitting at 808 nm. Q-switching operation is achieved by use of an electro-optical modulator, which employs a dual-crystal RTP Pockells cell (Lasertec Inc). The laser generates up to 1.2 mJ laser pulses, with a pulse duration of 1.6 ns (at maximum output power) at a repetition rate of 0.75 kHz – fig. 1 (a).

The signal from the oscillator is subsequently amplified in a two-stage, two-pass boost amplifiers employing a depolarization-compensating scheme [3] resulting in a polarized pulse output with energy up to 12 mJ, from the first stage, and up to 52 mJ from the second stage. A schematic of the laser system is shown on fig. 1 (b). Both stages employ a 0.6 at. % doped Nd:YAG crystals, transversely-diode pumped by linear stacks composed of 60 W QCW laser diode bars in three-fold and five-fold geometry, respectively. First stage is equipped with a 3 mm in diameter, 55 mm long crystal, and the total pump peak power was 1,3 kW, whereas the second is with 5 mm in diameter and 65 mm long rod and 2,6 kW total pump power.

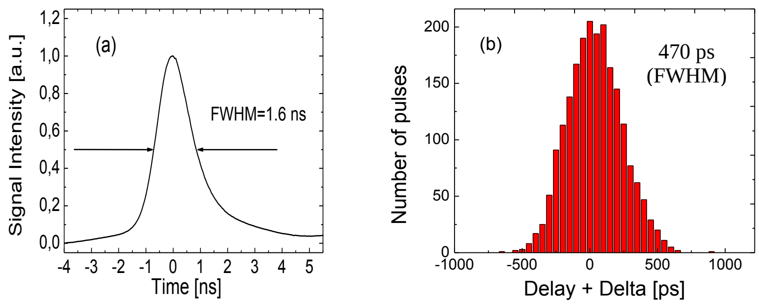

Fig. 2. (a) Pulse shape and (b) time jitter of the laser system.

After amplification a change in the pulse duration was not observed – fig.2 (a). The time jitter of the entire system was measured to be 470 ps (FWHM) – fig.2 (b). The beam quality is near diffraction limited (fig.3) with quality factor from the oscillator M_x^2 x M_y^2=1.05 x 1.04. Little beam deterioration is observed after the second amplification stage – M_x^2 x M_y^2=2.5 x 1.5.

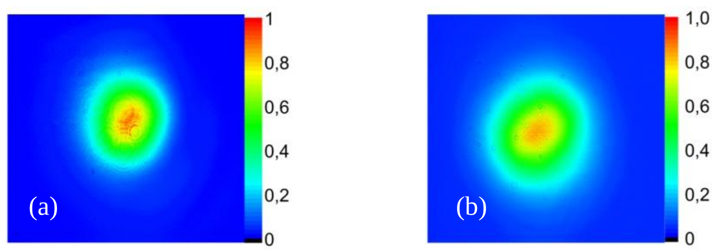

Fig. 3. Laser beam profile after (a) the master oscillator and (b) the second amplification stage.

In conclusion, we have demonstrated a MOPA laser system generating single frequency, 1.6 ns pulses with energy of up to 52 mJ, at 0.75 kHz repetition rate and near diffraction limited beam quality. The proposed approach preserves pulse duration and beam quality and is easily scalable towards higher pulse energies (>100 mJ). Currently achieved intensity levels and beam characteristics make the reported system, an attractive pump source for nonlinear frequency down-conversion devices in the MID-IR, as well as a highly efficient material ablation and precise micromachining source.

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