Single frequency MOPA system with near diffraction limited beam quality

D. Chuchumishev, A. Gaydardzhiev, A. Trifonov, I. Buchvarov

Abstract

Near diffraction limited pulses of a single-frequency and passively Q-switched Nd:YAG laser (240-µJ, 830-ps at 0.5-kHz) are amplified up to 13-mJ in a master oscillator power amplifier system, that consists of a preamplifier and two stage diode-pumped amplifier, whilst preserving pulse duration, beam quality and linear polarization.

Keywords: • Laser systems and new laser materials, laser amplifiers, diode pumped solid state lasers

1. Introduction

Ultra-compact and reliable laser systems providing both high-energy (in the tens of mJ range) and high-peak power (>10MW) pulses at kHz repetition rates with diffraction-limited beams are desirable for a number of applications, e.g. new materials synthesis, remote imaging, chemical sensing, LIDAR [1-2], materials processing [3-4], high efficient nonlinear optical conversion [5] and optical parametric processes [6]. Passively Q-switched microchip lasers are simple, miniature and robust sources that can provide single-frequency and sub-nanosecond pulses at high-repetition-rate with diffraction-limited output in the near infrared spectral range [7]. However, the small gain volume limits the amount of energy that can be stored in the active medium, thus microchip lasers can reach only very modest output energy, typically up to hundreds of micro joules. In order to overcome this deficiency, complicated amplification geometries have been developed and up to 5.7-W (0.2-mJ) and 0.4-MW at 500-ps were achieved [8]. Recently, a Nd:YVO_4 bounce geometry was used for amplification of a passively Q-switched laser with energy up to 0.54-mJ and 577-ps pulse duration [9]. Even though these approaches have some advantages in terms of extraction efficiency they have limitations in energy scaling either due to the active medium or the amplification scheme. For a 1.064-nm Nd:YAG Q-switched microchip laser both Nd:YAG and Nd:YVO_4 [10] can be used as active media for the amplifier. The choice of the active material and its geometry is dictated by the targeted and the initial pulse energy. For example, Nd:YVO_4 exhibits a larger emission cross section and a lower saturation fluence. Hence it is a better choice for up-scaling the output from oscillators with pulse energies ranging from a few to several tens of micro joules. On the other hand, Nd:YAG has a lower amplification gain than Nd:YVO_4 but shows favorable mechanical and thermal properties, in addition to a longer excited state lifetime. Consequently, Nd:YAG is the preferred gain medium for high-energy (1 to10-mJ at ~1kHz repetition rates) sub-nanosecond laser systems. However, in the vast variety of the existing kHz laser systems the output pulse energy is substantially smaller than 10-mJ while, on the other hand, the repetition rate of the 10-100 mJ systems does not exceed 100-Hz.

In this work we report on the amplification of pulses from a near diffraction limited, single frequency, passively Q-switched Nd:YAG laser (240-µJ, 830-ps at 0.5-kHz) up to 13-mJ in a two stage diode pumped amplifier, whilst preserving pulse duration, beam quality and linear polarization.

2. Experimental setup

A schematic diagram of the experiment is shown on fig. 1. As a master oscillator, we use a passively Q-switched chip laser with mirror coatings deposited directly on the Cr^{4+}:YAG/Nd:YAG active element. It is longitudinally pumped by a fiber-coupled 70-W quasi-cw diode laser array (Jenoptik Laser GmbH, JOLD70-QPXF-1L) driven with 80-µs 70-A current pulses at 0.5-kHz repetition rate. The pump beam is delivered through a 400-µm core optical fiber and imaged in the active element through an aspheric-lens objective with 1:1 magnification ratio. The single frequency operation of the oscillator is achieved through the short resonator length (7-mm) and the maximum energy of the polarized output is 240-µJ at 0.5-kHz repetition rate. The duration of pulses from the oscillator and from the output of the MOPA system are measured by a 1.5-GHz oscilloscope and an InGaAs photodiode and the overall response time of the detection system is 350 ps. Beam quality at each amplification stage is measured with a commercial CCD-based beam-analyzer. The signal from the oscillator is pre-amplified with only one passing through an end-pumped, 9 mm long Nd:YVO_4 crystal, with 0,5 at.% doping. Further amplification is done by utilizing two double-pass stages with transversely pumped modules (fig. 1). Each module employs a 0,6 at% doped Nd:YAG rod crystal, that is 3 mm in diameter and 90 mm long, of which 50 mm are pumped by three linear stacks of laser diode bars in a three-fold geometry; each stack composed by five 40-W laser diode bars. Optimal beam sizes in each amplification stage are achieved by using two lens objectives that ensure diameters of 0.7-mm, 1.3-mm and 2-mm (at $1/e^2$ level) in the preamplifier, first and second amplification stages, respectively. Double-pass amplification in the final two stages is realized by a polarizer and a quarter-wave plate. In this setup the linear P-polarized radiation makes one pass through the polarizer, the amplification module and the quarter-wave plate. After the reflection at the rear mirror the pulse makes a second pass through the quarter-wave plate, thus changing its polarization to S-state and after traversing the active crystal is then reflected by the polarizer (sees fig. 1).

3. Results and discussion

In general, to achieve efficient energy extraction from a pulse amplifier, the energy density of the input signal must be close to the saturation density of the used laser material. Taken into account, that the Nd:YAG media has a saturation density of 0.67 J/cm^2 and diameter of the used rods is 3-mm, there is a need to reach an energy of a few mJ for the 0.8-ns input pulses in order to extract efficiently the stored energy in the active media. In our setup, this condition is met by implementing a pre-amplifier with 9-mm long Nd:YVO$_4$ crystal, longitudinally pumped by 808-nm laser pulses with 120-μs duration and 6,2-mJ total energy, delivered from a second fiber-coupled laser diode array (Jenoptik Laser GmbH, JOLD70-QPXF-1L). The type of amplification medium for the preamplifier is chosen to be Nd:YVO$_4$ due to its low saturation density – more than five times lower (0.12-J/cm^2) compared to Nd:YAG, allowing high amplification for a single pass. With such preamplifier, we were able to produce up to 0,84-mJ pulse energy at 0.5-kHz, with

10% extraction efficiency and near-diffraction-limited beam quality (fig.2 a and b). To further boost the pulse energy over ~10 mJ, we applied 120 mJ optical pump energy in 200 µs pulses in each of the amplifier modules. We were able to achieve average output power of the entire system of 6.5 W, corresponding to 13 mJ energy in a single pulse (Fig.3,4). The measured pulse duration on the output of the MOPA is the same as the one of the microchip oscillator, i.e. 830 ps. Hence, the obtained pulse peak power is 15.7 MW. The observed beam profiles after: the master oscillator (M_x^2 x M_y^2=1.38 x 1.31), the first stage (M_x^2 x M_y^2=1.39 x 1.33) and at the output of the second stage (M_x^2 x M_y^2=1.4 x 1.35) are shown on fig. 5. The results show lack of considerable beam quality deterioration after the first as well as the second stage of the amplifier.

4. Conclusions

In conclusion, we have demonstrated a sub-nanosecond single frequency MOPA laser system generating an intense (15.7-MW) 830-ps pulses with energy up to 13-mJ at 0.5-kHz with near diffraction limited beam quality at 1.064 µm. The proposed approach is easily scalable towards higher pulse energy. The currently achieved intensity level and beam characteristics make the MOPA system an attractive source for pumping optical parametric devices as well as for LIDAR applications and material ablation.

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Figure Captions

FIGURE 1 Schematic layout of the MOPA system, consisting of a preamplifier and two stage diode-pumped amplifiers. Abbreviations are: LM1, LM2 – transversely pumped amplification modules; POL - polarizer

FIGURE 2 (a) - Output energy vs. pump energy for the single pass amplification in the Nd:YVO^4 pre-amplifier; (b) - Laser beam profile after the pre-amplifier

FIGURE 3 Output energy vs. input energy for single and double pass amplification in the first amplification stage

FIGURE 4 Output energy vs. input energy for single and double pass amplification in the first amplification stage

FIGURE 5 Laser beam profile from the oscillator (a), after the first amplification stage (b) and after the second amplification stage (c)

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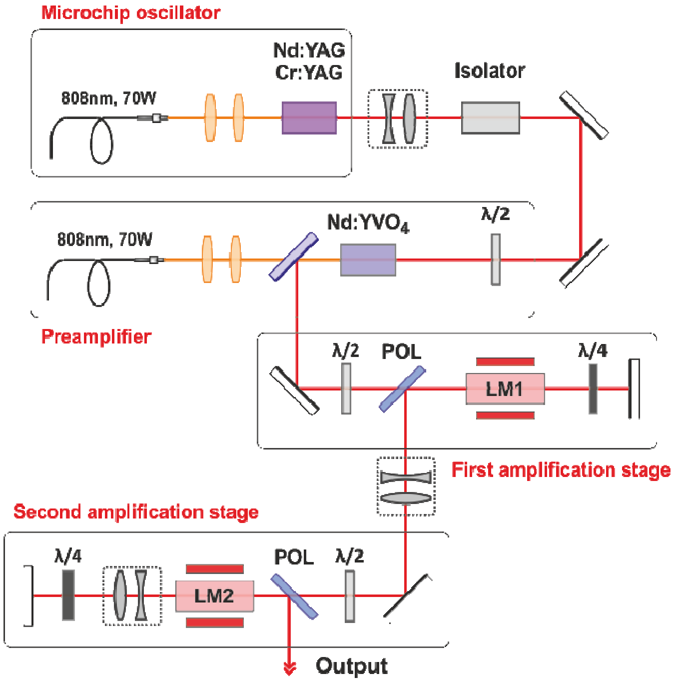

FIGURE 1
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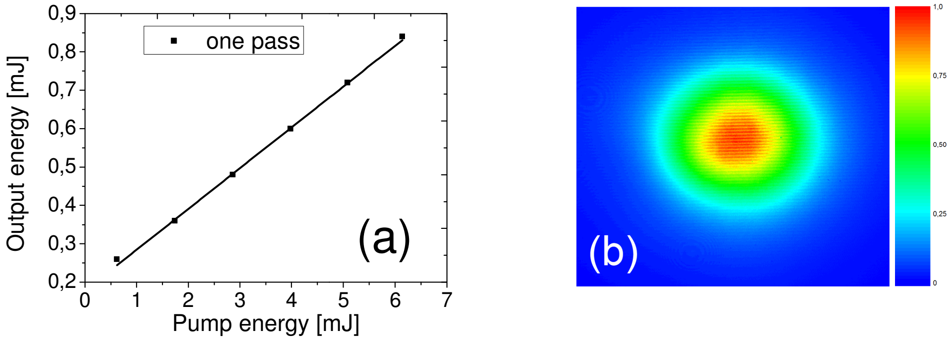

FIGURE 2
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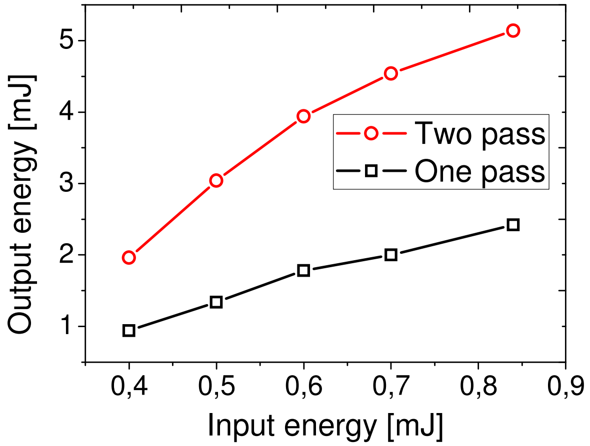

FIGURE 3
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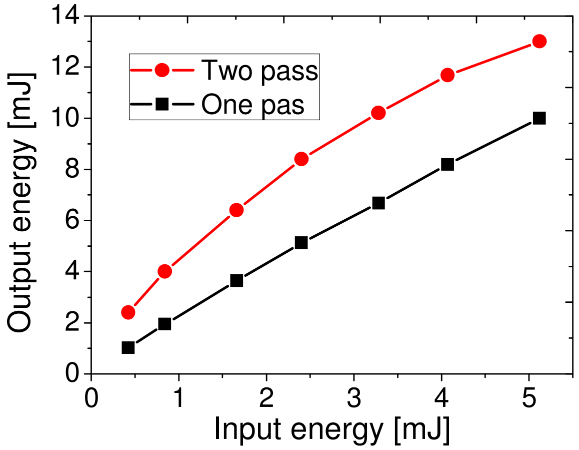

FIGURE 4
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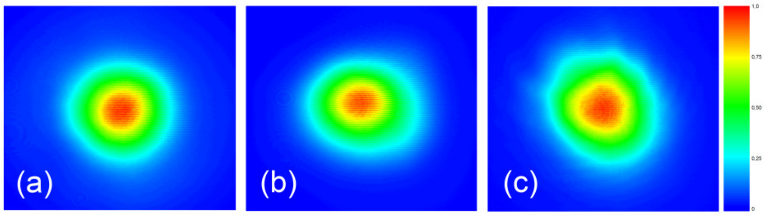

FIGURE 5
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