Single Frequency Multi Milijoule Sub-nanosecond Nd:YAG Laser at kHz Repetition Rate

Danail Chuchumishev[1], Alexander Gaydardzhiev[1], Anton Trifonov[1], Torsten Fiebig[2], Ivan Buchvarov[1]
[1]*Department of Physics, Sofia University, 5 James Bourchier Blvd., BG-1164, Sofia, Bulgaria*
[2]*Argonne-Northwestern Solar Energy Research (ANSER) Center, Northwestern University, 2145 Sheridan Road, Evanston, IL 60208, USA*
Corresponding author: ivan.buchvarov@phys.uni-sofia.bg

Abstract: We report up to 13 mJ at 0.5 kHz, linearly polarized output with 830 ps pulse duration from a single frequency amplified Nd:YAG microchip laser at 1064 nm.
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1. Introduction

Compact and reliable laser systems providing both high-energy (in the tens of mJ range) and high-peak power (>10MW) pulses at kilohertz repetition rates with diffraction-limited beams find applications in new materials synthesis, remote imaging, chemical sensing and high efficient nonlinear conversion. Passively Q-switched microchip lasers are simple, miniature and robust sources that can provide single-frequency, high-repetition-rate, and sub-nanosecond pulses with diffraction-limited output in the near infrared [1]. 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 [2]. Recently, a Nd:YVO4 bounce geometry was used for amplification of a passively Q-switched laser with energy up to 0.545 mJ and 577-ps pulse duration [3]. 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 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. In order to have efficient amplification (extraction efficiency around 10 %) with amplifiers with 3 mm diameter of the Nd:YAG rod, we need input energy in the mJ range. Thus, we have developed and studied two suitable schemes for efficient pre-amplification – a multipass side-pumped slab amplifier and a single pass longitudinally pumped Nd:YVO_4 amplifier with fibre coupled 808 nm diode pumping. The beam quality of the longitudinally pumped Nd:YVO_4 amplifier is higher than in the case of slab geometry, with less astigmatism, and thus more suitable for multistage amplification. In addition, a considerable advantage of rod geometry is that it can provide gain and withstand the power densities in high-energy pulsed systems. We combine the advantages of the rod geometry with the excellent performance of Nd:YAG as active material with single frequency Q-switched microchip laser oscillator with very high beam quality.

2. Experimental setup

In this work, we present a compact preamplifier and subsequent two-stage rod laser amplifier used in a Master Oscillator Power Amplifier (MOPA) configuration for up-scaling the output pulse energy of the microchip diode pumped Nd:YAG laser more than 80 times, while preserving the intrinsic high beam quality and sub-nanosecond pulse duration.

The optical arrangement of the laser system comprises of a microchip laser, pre-amplifier and two double-pass rod amplifiers. The master oscillator is a diode-pumped Q-switched Cr^{4+}:YAG/Nd:YAG single-frequency homemade microchip laser emitting 240 μJ of linearly polarized, TEM_{00} ($M^2 = 1.3$) radiation with 0.83-ns (FWHM) pulse width at 0.5 kHz. The Nd:YAG/Cr4+:YAG medium was 6-mm thick, which is mandatory for obtaining laser pulses with duration below 1 ns. The composite medium was fixed in a copper holder at temperature of 20ºC. As a pump source we used a fiber-coupled (600-μm diameter, NA= 0.22) diode laser (Jenoptik, Germany), and a 1:1 optical system to image the fiber end into the Nd:YAG. The amplifier stage of the MOPA is a homemade Nd:YAG rod amplifier module with 3-fold geometry comprising of a 60 mm long, 3 mm in diameter, 1 at. % doped Nd:YAG crystal, side-pumped by fifteen 808 nm 40-W laser diode bars. A quarter-wave plate and a beam deflecting thin-film polarizer are used to ensure the double pass through the rod amplifier and linearly polarized output. The diode bars were driven in QCW mode with current pulses up to 40 A with 200 microsecond pulse duration. In the developed construction of the amplifier we used a reflector made from Fluorilon99™ with very high diffusion reflectance (above 99 %) for the pump wavelength.

3. Results and discussion

The oscillator pulse energy reached up to 240 µJ at 0.5 kHz with 830 ps pulse duration and diffraction limited beam. The signal from the oscillator is amplified in a $Nd:YVO_4$ pre-amplifier up to 0.8 mJ preserving the beam quality. The preamplifier is pumped with 100 µs pulses with 6 mJ pulse energy through 600 µm fiber. The fiber end is imaged with 1:1.2 optical system thus achiving 800 µm beam waist dimameter in the crystal. The length of the $Nd:YVO_4$ crystal is 6 mm and the absorption is 80 %.

The signal from the pre-amplifier is then amplified in two stage amplifier in double pass configurations of each stage. Using an input energy of 0.8 mJ (into the first amplifier stage), and 200-µs pump pulses (at a total of 82.8 mJ pump energy into each of the amplifier modules), we were able to produce up to 2.1 mJ pulse energy at 0.5 kHz, with near-diffraction-limited beam quality at a single pass. After the second pass the output energy was 5.1 mJ. With this energy level as an input of the second stage and the same pump conditions for the second laser module we achieved maximum output energy of 13 mJ, corresponding to 6.5 W average power and above 15 MW peak power (fig. 1). The amplified pulse duration is the same as the pulse duration of the microchip oscillator, i.e. 830 ps. The output from the oscillator and the amplified pulse duration were measured by a 1-GHz oscilloscope and an InGaAs photodiode with overall response time of 350 ps.

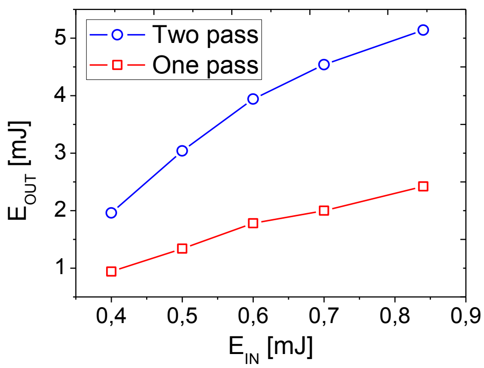

Fig.1a. Output energy after the first amplifier stage

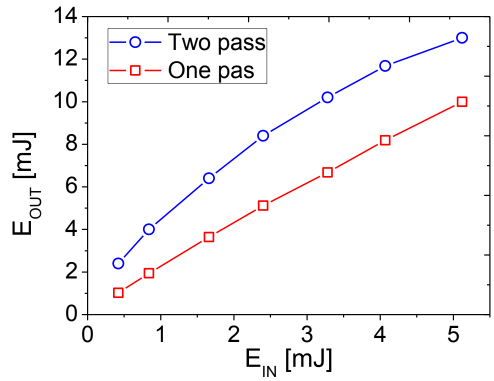

Fig.1b. Output energy after the second amplifier stage

The beam quality and beam profile of this master oscillator power amplifier (MOPA) system was measured with a commercial CCD based beam-analyzer at the output of the oscillator (M_x^2 x M_y^2=1.38 x 1.31) after the first stage (M_x^2 x M_y^2=1.39 x 1.33) and at the output of the second stage of the amplifier (M_x^2 x M_y^2=1.4 x 1.35). The results show lack of considerable beam quality deterioration after the first as well as the second stage of the amplifier (fig.2).

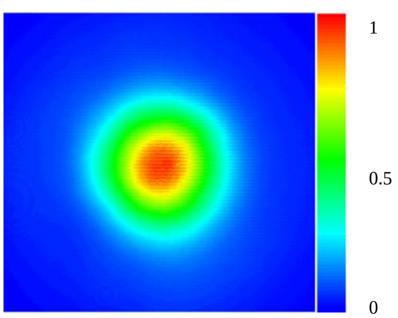

Fig.2a. Beam profile of the microchip oscillator

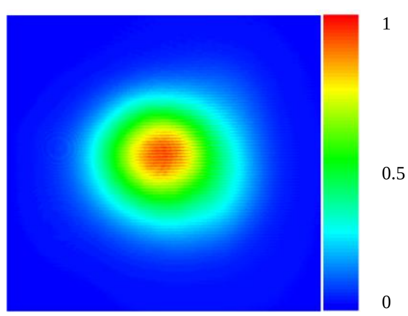

Fig.2b. Beam profile after the first amplification stage

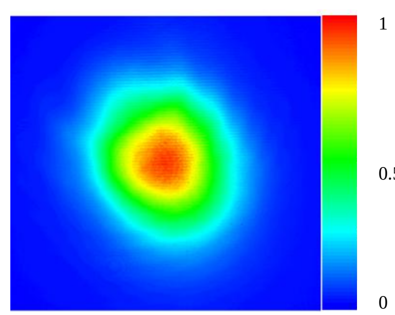

Fig.2c. Beam profile after the second amplification stage

4. Conclusion

In conclusion, we have designed and constructed a compact, two stage Nd:YAG amplifier system with improved pump homogeneity seeded with a pre-amplified single frequency TEM_{00} microchip laser. The obtained output energy was 13 mJ at 0.5 kHz repetition rate with high beam quality and sub-nanosecond pulse duration. Further scaling of the output energy up to 100 mJ is under development by adding boost amplifiers with Nd:YAG rods with larger diameters.

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