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Picosecond laser amplification system with 93 W high average power

Runwu Peng *, Lin Guo, Xiaofu Zhang, Fangqin Li, Qianjin Cui, Yong Bo, Qinjun Peng, Dafu Cui, Zuyan Xu

Laboratory of Optical Physics, Institute of Physics, Chinese Academy of Sciences, P.O. Box 603, Beijing 100080, China

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Abstract

A high average power picosecond laser amplification system with diode-end-pumped Nd:YVO_4 and diode-side-pumped Nd:YAG is described. Laser with power up to 92.7 W, repetition frequency of 73.3 MHz, pulse duration of 26.5 ps, and beam quality of $M^2 < 3.5$ is generated in the amplification system. Thermal-birefringence-induced depolarization in the Nd:YAG rod laser head amplifier is measured to be 21.9 W though birefringence compensation is performed.

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Keywords: Picosecond laser; Amplification; Diode-pumped; Depolarization

1. Introduction

Lasers with high power, high beam quality, and short pulse duration have been found widely used in many laser applications such as high-precision micro-machining, laser display, efficient harmonic generation in nonlinear media, and laser direct imaging in the printed circuit industry. Thus, passively mode-locked solid-state laser oscillator and solid-state laser amplifier that can generate such characteristic pulsed lasers have been investigated in lots of papers in detailed [1–9]. By employing a commercial mode-locked diode-pumped Nd:YVO_4 seed laser and a Lightwave Electronics direct-coupled pump laser head which consists of a Nd:YAG laser rod directly side pumped with a 40-W 1-cm-long laser diode bar, 9.3 W laser with 20.5 ps in pulse duration has been achieved by Dymott and Weingarten [4]. Eighty one watt laser with pulse duration of 300 ps have been realized by using amplifier consisting of commercial diode-pumped 4-mm-diameter, 116-mm-long and 6-mm-diameter, 146-mm-long Nd:YAG rod laser modules [7]. To generate higher output power to meet many applications, such laser systems are studied further nowadays.

In this paper, we present a high average power picosecond laser amplification system consisting of two single-pass Nd:YVO_4 amplifiers and four single-pass Nd:YAG rod laser heads amplifiers. Nd:YVO_4 is chosen in the oscillator served as seed laser and in the former two amplifiers because it is a laser crystal for reducing the stable CW mode-locking threshold, realizing compact, and high optical efficiency, thanks to its large stimulated-emission cross section. Nd:YAG is used in the following four amplifiers because of its good thermal conductivity and high stress fracture limit. The combination of the advantages of Nd:YVO_4 and Nd:YAG in the system helps us to achieve a high average output power.

2. Experiment setup

Our high average power picosecond laser amplification system consists of two single-pass diode-end-pumped Nd:YVO_4 amplifiers and four diode-side-pumped

* Corresponding author. Tel.: +86 10 82649352.
E-mail address: pengrunwu@163.com (R. Peng).

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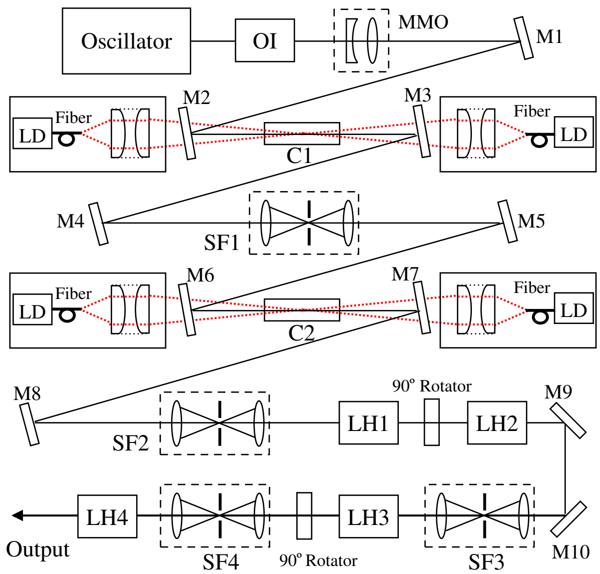

Fig. 1. Schematic of the high average power picosecond laser amplification system. OI, optical isolator; MMO, mode matching optics; LD, laser diode array; C, Nd:YVO_4 crystal; SF, spatial filter; LH, Nd:YAG rod laser head; M, mirror.

Nd:YAG rod laser heads amplifiers. Fig. 1 is the schematic illustration of configuration of the system. A diode-end-pumped passively mode-locked Nd:YVO_4 picosecond oscillator with a semiconductor saturable absorber mirror (SeSAM) is served as seed laser and its configuration is similar in design to that studied in Ref. [8].

Following the seed laser, two mode-matching lenses are used and then two single-pass diode-end-pumped Nd:YVO_4 amplifier is designed, where the Nd:YVO_4 crystals C1 and C2 are 3 mm × 3 mm × 15 mm *a*-cut, 0.2%-doped, double end pumped by 808 nm, 400 μm diameter, 0.22 NA fiber-coupled diode laser systems. Both of the crystals are pumped by 20 W pump powers in each end face. To ensure good beam quality and mode matching, a spatial filter consisting of two lenses and a small hole is inserted between the two Nd:YVO_4 amplifiers.

To obtain high power picosecond laser, highly efficient diode-side-pumped laser heads for the following amplifiers are designed and fabricated by ourselves, which are shown in Fig. 2. In the Fig. 2a, three cw LD arrays, which are formed by combining some 1-cm long bars, symmetrically surround the 3-mm-diameter, 80-mm-length and 0.6%-doped Nd:YAG rod, and each LD array contains three bars arranged along the slow axis of the bar each providing a peak pump power 20 W. In the Fig. 2b, five cw LD arrays, which are formed by the same bars, symmetrically surround the 4-mm-diameter, 120-mm-length and 0.6%-doped Nd:YAG rod, and each LD array contains six bars arranged along the slow axis of the bar. The slow axis of every bar is parallel to the axis of Nd:YAG rod, and the pump light from the bars is directly coupled into laser rod without any transfer optics.

Two ϕ3 mm and two ϕ4 mm Nd:YAG rod laser heads are employed and the basic configuration of the amplifier

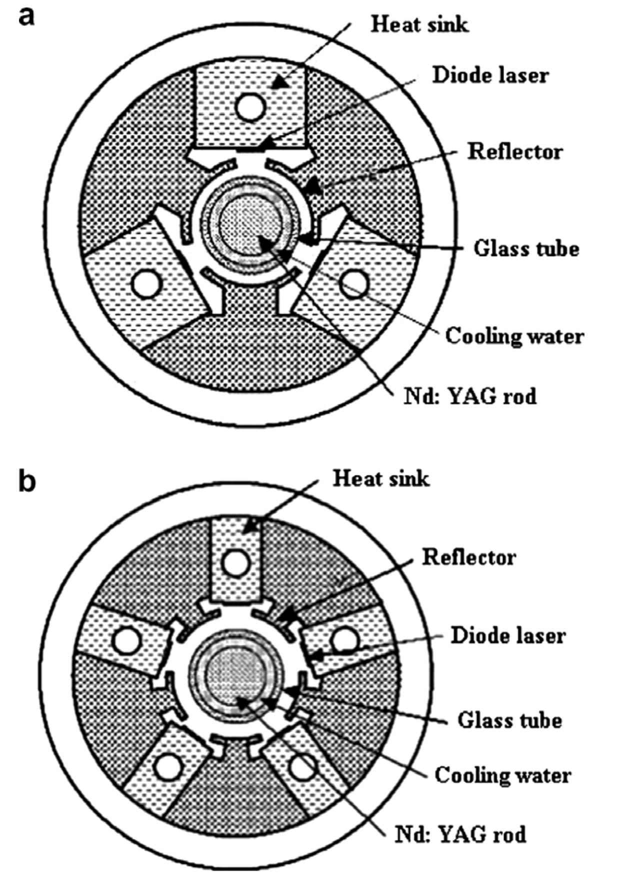

Fig. 2. Schematic of the diode-side-pumped laser head. (a) 3-mm-diameter Nd:YAG rod; (b) 4-mm-diameter Nd:YAG rod.

is also shown in Fig. 1. Firstly, two identical ϕ3 mm Nd:YAG amplifiers are set as closely as possible and a 90° quartz rotator is placed between them to compensate the thermally induced birefringence [10,11]. Following them, a spatial filter is designed for mode matching and improving the beam quality of the beam injected in the following amplifier. Finally, two identical ϕ4 mm Nd:YAG amplifiers are used and a 90° quartz rotator is also set between them to play the same role as in the former ϕ3 Nd:YAG amplifier. In addition, a spatial filter is designed between the two ϕ4 mm amplifiers for mode matching because thermal lens effect is severer than that in ϕ3 mm Nd:YAG amplifier and the effect results in mode mismatching easily between the two ϕ4 mm Nd:YAG amplifiers. Also, the filter helps for improving the beam quality.

3. Experiment results

The oscillator produces laser pulses with output power of 3.1 W, repetition frequency of 73.3 MHz, pulse duration of about 20 ps, and a good beam quality of $M^2 < 1.1$. The 3.1 W laser from the oscillator is injected into the first Nd:YVO_4 amplifier stage. 15.6 W output power is achieved and 12.5 W power is extracted from the first Nd:YVO_4 amplifier stage, where the optical–optical efficiency is about 31.3%. After spatial filter the laser power reduces to 14.4 W and it is injected into the second $Nd:YVO_4$ amplifier stage, which delivers 27.1 W of output power with a good beam quality of $M^2 < 1.1$. The power of 12.7 W is extracted with an optical–optical efficiency of about 31.8% here.

Then, after passing through the spatial filter and reducing to 24.2 W, the laser from the second $Nd:YVO_4$ amplifier is injected into the following two ϕ3 mm Nd:YAG amplifiers stage and laser with a maximal output power of 39.2 W and a beam quality of $M^2 < 1.6$ is achieved. Output power of the amplifier versus drive current of the laser head is shown in Fig. 3. After birefringence compensation by setting a 90° rotator between two amplifiers, only slight birefringence effect is resulted and the polarization is measured as larger than 100:1.

Laser from the ϕ3 mm Nd:YAG amplifier reduces to 37 W after spatial filter and is injected into the two ϕ 4 mm Nd:YAG amplifiers stage. The output power of the last amplifier versus drive current of the laser head is shown in Fig. 4, which indicates polarized laser with up to 92.7 W output power is generated in this amplifier stage and meanwhile the depolarized laser is measured as great as 21.9 W. Though also birefringence compensation is performed by a 90° rotator, severe depolarization is still found in ϕ4 mm Nd:YAG amplifier because of high pump power. Obviously, it is possible that polarized laser of over hundred-watt output power can be achieved in our amplification system with effective compensation techniques. The beam quality factor M^2 of the output laser is measured as given in Fig. 5, which shows the beam quality factor M^2 is 3.5 as the laser reaches the maximal power of 92.7 W. We also measured the pulse duration and optical spectrum and they are shown in Figs. 6 and 7. The pulse duration of the output picosecond laser is approximate to 26.5 ps and the spectral width is about 1.1 nm. It is noted that the pulse width is somewhat longer than that of the oscillator and the spectral width is wider than that of the oscillator. We

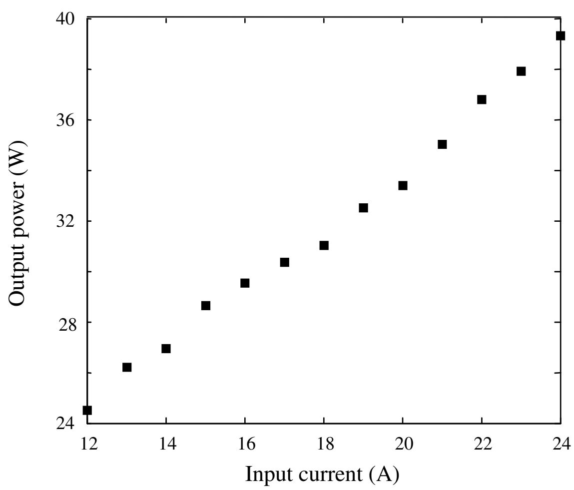

Fig. 3. Output power versus drive current of 3-mm-diameter Nd:YAG rod laser head amplifier.

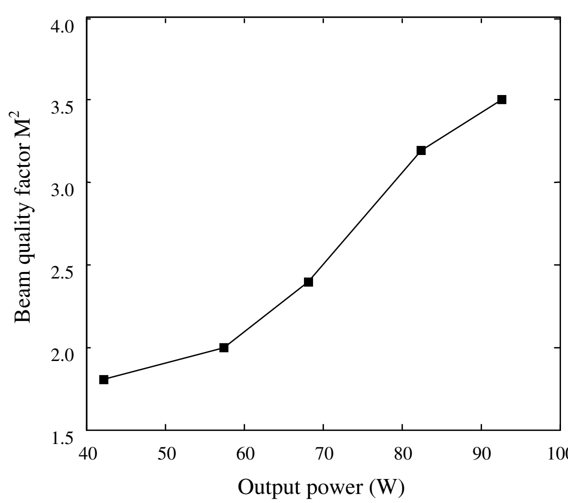

Fig. 5. Beam quality factor M^2 of the output laser.

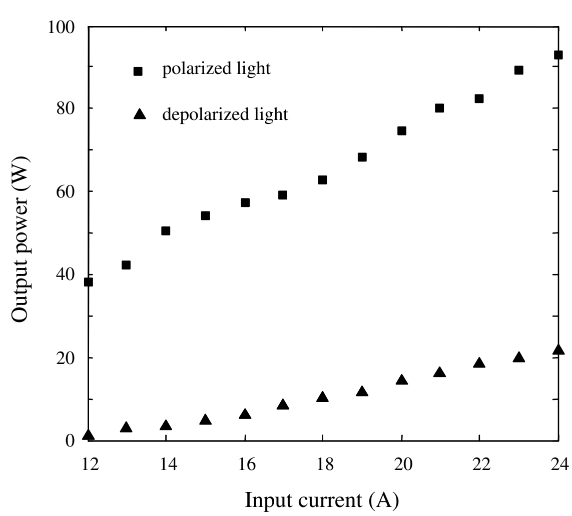

Fig. 4. Output power of polarized and depolarized light versus drive current of 4-mm-diameter Nd:YAG rod laser head amplifier.

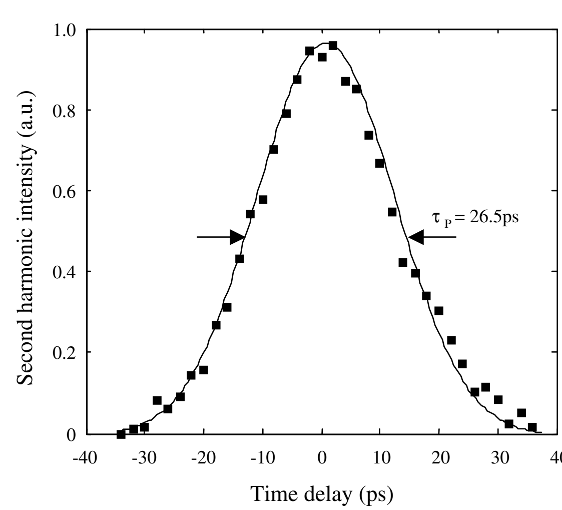

Fig. 6. Autocorrelation trace of the output laser.

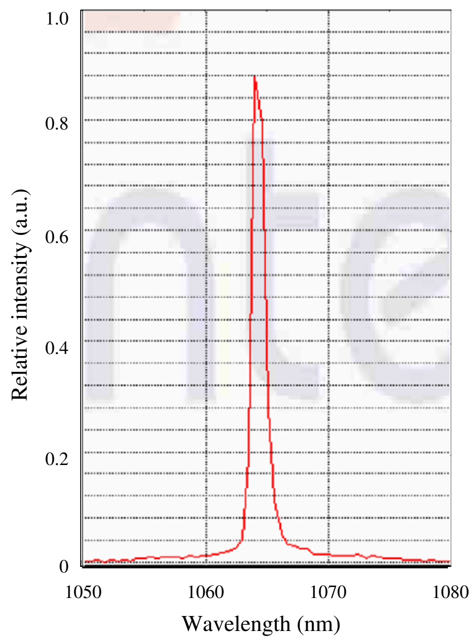

Fig. 7. Optical spectrum of the output laser.

believe these are resulted by the group velocity dispersion and self-phase modulation [4,12].

4. Conclusions

A high average power picosecond laser amplification system with the combination of two single-pass $Nd:YVO_4$ amplifiers and four single-pass Nd:YAG rod laser head amplifiers is discussed in this paper. The advantages of the $Nd:YVO_4$ and Nd:YAG laser crystals are used in the system to achieve a high average output power as great as 92.7 W with a beam quality of $M^2 < 3.5$. The laser is depolarized slightly by birefringence compensation in 3-mm-diameter Nd:YAG amplifier. Though also compensated by a 90° rotator, severe depolarization is still found in 4-mm-diameter Nd:YAG amplifier because of high pump power. Developing effective compensation techniques to reduce thermal depolarization is still a challenging subject.

Acknowledgments

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