# High-beam-quality, 5.4 J, 5 Hz diode-pumped Nd:YAG active mirror laser amplifier

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Received July 19, 2018; accepted October 24, 2018; posted online November 27, 2018

A high-beam-quality diode-pumped neodymium-doped yttrium aluminum garnet (Nd:YAG) active mirror laser amplifier was demonstrated. The size of the Nd:YAG crystal was 48 mm × 42 mm × 11 mm with 0.6 at.% Nd doped. When the pump energy was 26.8 J and the input energy was 0.3 J, the output pulse energy reached 5.4 J, and the pulse width of 11.3 ns at a 5 Hz repetition rate was obtained for the two gain modules in three-pass amplification, with corresponding optical-to-optical efficiency of 21.2%. The beam quality was measured as $M_x^2 = 2.48$ and $M_y^2 = 2.43$ in horizontal and vertical directions, respectively.

*OCIS codes: 140.3280, 140.3460, 140.3538.*
*doi: 10.3788/COL201816.121402.*

Over the last decade, the active mirror configuration has been widely used in the laser diode pump laser system[1–4]. The active mirror configuration with front or back surface pumping has two advantages[5]: on one hand, the pump area was larger, which can increase the pump energy at the same pump energy density; on the other hand, the surface of the gain medium can be directly cooled by liquid. The output energy of 2.43 J/1 Hz was achieved with an active mirror ytterbium-doped yttrium aluminum garnet (Yb:YAG) laser in 2009[6].The output energy of 6.05 J/1 Hz pulse was achieved based on a cryogenic Yb:YAG active mirror amplifier in 2014[7]. The output energy of 14 J/2 Hz was realized from a room temperature operation Yb:YAG active mirror amplifier by LUCIA in 2013[8]. Tsinghua University reported that the output energy of 12 J/10 Hz, 2 J/20 Hz diode-pumped active mirror neodymium-doped yttrium aluminum garnet (Nd:YAG) slab amplifier was realized in 2015 and in 2017, respectively[9,10]. In Ref. [10], the laser amplifier system used four gain media with the light traveling at the incidence angle of 45°. The distribution of the near-field profile was not even because the gain media were directly pumped by the laser diode without the coupling system.

In this Letter, we demonstrate a diode-array-pumped Nd:YAG active mirror laser amplifier system with a small input angle. We have achieved a stable operation of 5.4 J per pulse with two Nd:YAG laser gain media. Two image relaying systems and the pump coupling system were used to ensure the quality of the near-field profile in the laser amplifier. The single longitude pulse was achieved at 5 Hz. We adopt a zigzag slab amplifier as the booster amplifier and active mirror amplifiers as the main amplifier.

Figure 1 shows a schematic diagram of the laser amplifier system. A laser diode dual-end-pumped single frequency Nd:YAG laser was used as the front end, generating up to 10 mJ at 1064 nm. The pulse width was 12 ns. The pulse energy was amplified up to 500 mJ by the zigzag slab amplifier. After passing through the Faraday isolators, the light beam was expanded to 3.2 cm × 3.2 cm by the image relaying system. The light beam was directed to the Nd:YAG third-pass active mirror amplifier system. The other image relaying system was used between the first passage and the second passage.

The main amplifier consisted of two 0.6 at. % doped Nd:YAG slabs, having a thickness of 11 mm and a transverse aperture size of 48 mm × 42 mm for light traveling at the incidence angle of 15°. The front surface of the crystal was antireflection (AR) coated for 1064 nm and high-reflection (HR) coated for 808 nm, while the back surface was HR coated for 1064 nm and AR coated for 808 nm. Each Nd:YAG crystal was pumped from the back surface. The pump source was an 808 nm laser diode array. After passing through a coupling system, the emitted pump light was directed to the amplifier head. The size of the pump light was 3.2 cm × 3.4 cm. Each gain module was cooled by water that directly flowed over back surface of the slab. The pumping coupling system consisted of a gold-plated smoothing device and a coupling lens. The passive loss of the pumping coupling system was measured as 10%. The passive loss of the amplifier system was 13%.

Figure 2 shows the small signal gain coefficient and energy storage with different pump energy on a single pass. The input energy was 3.6 mJ. The small signal gain coefficient and energy storage increase greatly as the pump energy increases when the pump energy was less than 27 J. However, the gain saturation occurred when the pump energy was greater than 27 J. We analyze the limit of storage energy, which comes from amplified spontaneous emission (ASE) and parasitic oscillation. The maximum small signal gain coefficient and energy storage were 0.47 $\text{cm}^{-1}$ and 6.3 J when the laser diode array

 

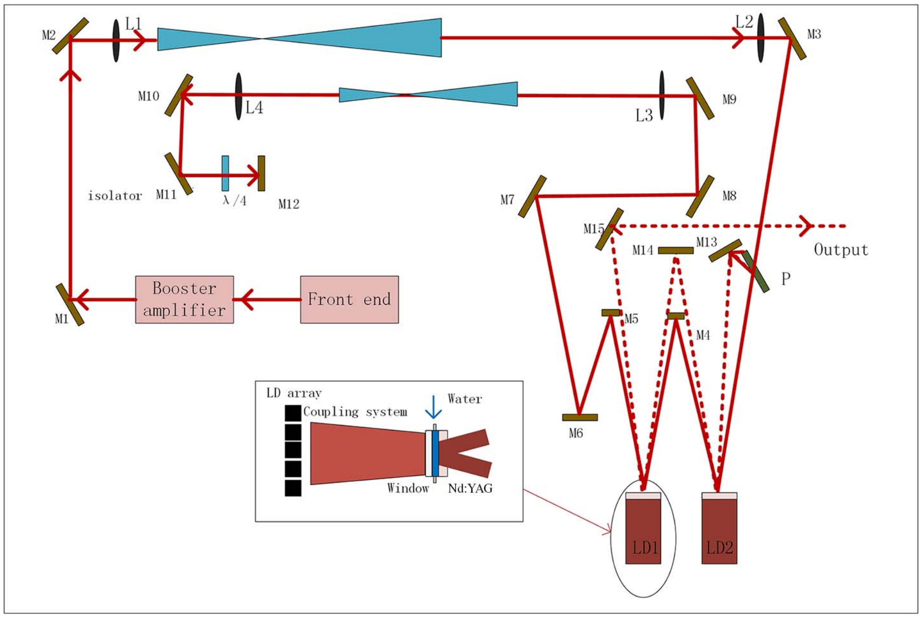


Fig. 1. Light path schematic of the laser amplifier system: M1–M15, high reflection (HR) at 1064 nm.

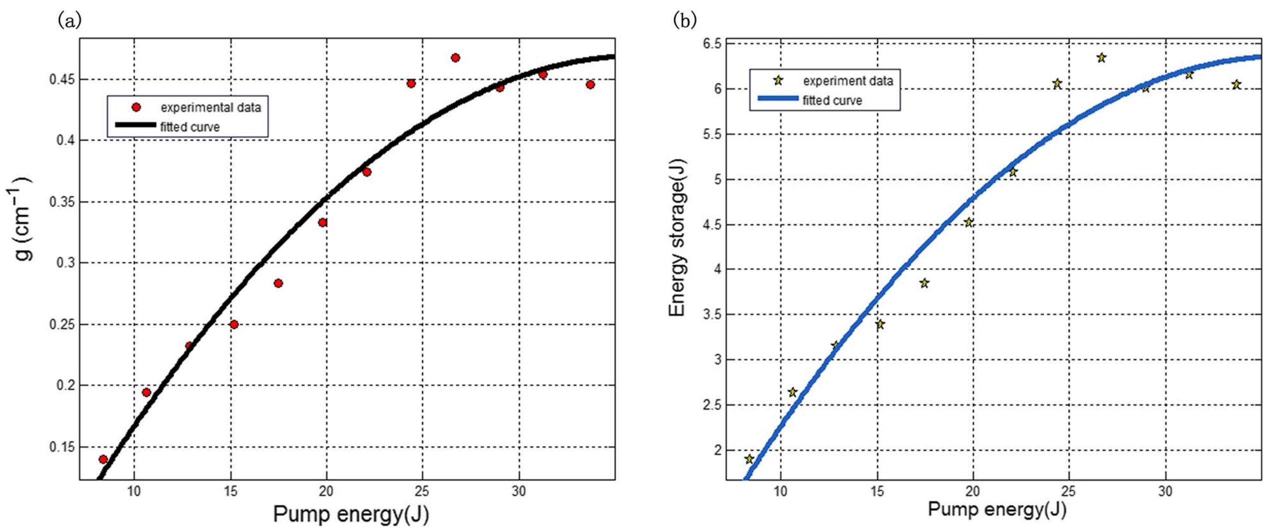


Fig. 2. (a) Small signal gain coefficient with different pump energy on single pass; (b) energy storage with different pump energy on single pass.

produced 67 kW peak power with a pulse length of 200 μs, corresponding to the pump energy of 26.8 J.

Figure 3 describes the measured dependence of the output energy on the input energy, when the total pump energy was 26.8 J. For the main amplifier with the double gain modules, there was a linear amplification of output energy for the first pass. When the input energy was 0.3 J, the output energy of the single pass was 2.1 J. After the second pass of amplification, output energy of 3.6 J was achieved with the extraction energy of 1.5 J. The output energy was up to 5.4 J for the third pass with the total extraction energy of 5.1 J and optical-to-optical efficiency of 21.2%. The gain saturation occurred as the input energy increased in the third pass. The temporal trace of the output laser pulse was shown in Fig. 4. The pulse width was 11.3 ns when the output pulse energy was 5.4 J at 5 Hz repetition rate. The pulse waveform was smooth, so the output pulse was the single longitude.

The near-field beam profile was distributed evenly, as shown in Fig. 5. In order to enhance the near-field beam quality, the double image relaying system was used, and the pump light was shaped by the coupling system. The beam radius of different positions was measured, as shown in Fig. 6, and the beam quality factor for the amplified output was calculated as $M_x^2 = 2.48$ and $M_y^2 = 2.43$ in the horizontal and vertical directions, respectively. There was divergence between the horizontal and vertical directions, mainly owing to the active mirror configuration

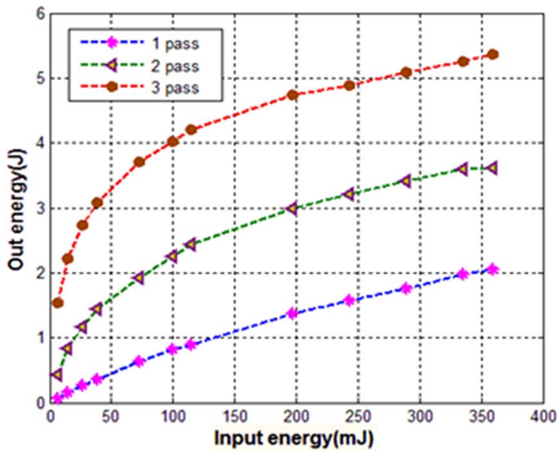


Fig. 3. Output pulse energy as a function of seed energy.

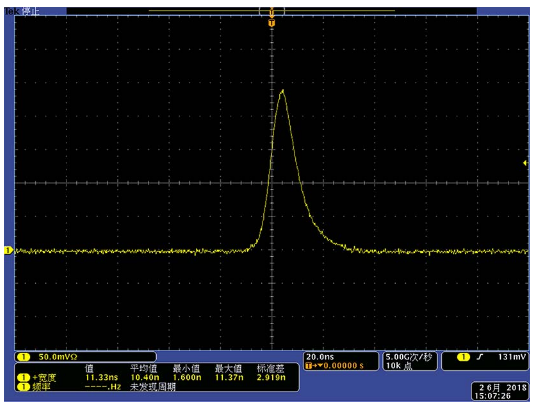


Fig. 4. Temporal trace of output laser pulse.

Fig. 5. Near-field beam profile.

being more sensitive to the thermal effect. The beam quality can be further enhanced by improving the clamping structure of crystal or adding the compensating systems to the light path.

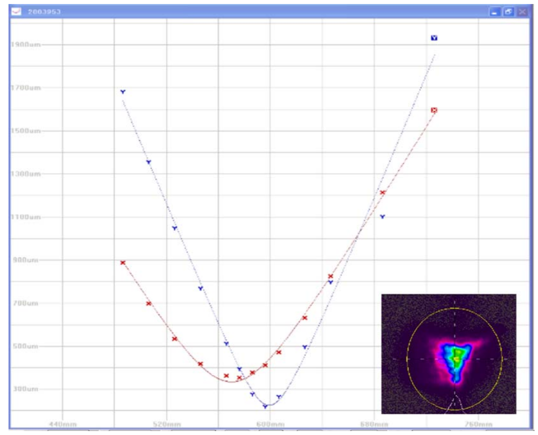

Fig. 6. Beam radius variation of the output laser.

In conclusion, we have demonstrated an active mirror Nd:YAG slab laser amplifier. When the pump energy was 26.8 J, the 5.4 J energy, 11.3 ns pulse at 5 Hz repetition rate was obtained for the both gain modules in three-pass amplification, corresponding to optical-to-optical efficiency of 21.2%. The high beam quality was measured as $M_x^2 = 2.48$, and $M_y^2 = 2.43$ in the horizontal and vertical directions, respectively. The experiment results demonstrate that it is possible to realize larger output energy by increasing the number of the crystals, but we should pay more attention to the beam quality because the active mirror configuration introduces wavefront distortion more easily than the transmission configuration after increasing the number of the crystals. We can improve the clamping structure of the crystal or add the compensating systems to the light path to enhance the beam quality.

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