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High-power picosecond regenerative amplifier based on CW diode side-pumped Nd:YAG with high beam quality

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A compact high-power picosecond regenerative amplifier based on continuous wave (CW) diode side-pumped Nd:YAG is demonstrated. Average power of 8.8 W is achieved at a repetition rate of 5 kHz at a wavelength of 1 064 nm with a pulse duration of 28 ps, corresponding to a pulse energy of 1.76 mJ and a peak power of 62.9 MW. The beam quality is close to the diffraction limit with $M^2_x = 1.24$, $M^2_y = 1.03$. To the best of our knowledge, this is the highest pulse energy obtained from a CW diode-pumped Nd:YAG picosecond regenerative amplifier.

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where $g_0$ is the small signal gain coefficient, $l$ is the length of the gain medium, $E_0$ is the saturation fluence defined by $E_0 = \frac{hv}{\sigma}$, $h$ is Planck's constant, $v$ is the lasing frequency, $\sigma$ is the stimulated emission cross-section of the laser medium, and $g_0E_s$ is the stored energy in the upper laser level.[17] $E_{in}$ is the input fluence, and $N$ is the total number of pulses experiencing a round trip though the gain medium during one pump stage. As the pump stage is much longer than the amplification stage, $N$ is defined by $N = \frac{E_{in}}{F_d}$, where $F_o$ is the frequency of the pulses from the oscillator, and $F_d$ is the dumping frequency of the RA. In our RA laser system, the gain medium is a side-pumped Nd:YAG crystal. $g_0$ is measured 0.11 in our system, with $l = 6.4$ cm. Other parameters are given as follows: $h = 6.63 \times 10^{-34}$ J·s, $v = 2.8 \times 10^{14}$ Hz, $\sigma = 2.8 \times 10^{-19}$ cm$^2$, $E_s = 0.66$ J/cm$^2$, $F_o = 100 \times 10^6$ Hz, and $F_d = 5 \times 10^3$ Hz.[17] Figure 1 gives the extraction efficiency $\eta_E$ versus the input fluence $E_{in}$ during the pump stage. According to our computation, $\eta_E$ is less than 5% when $E_{in}$ is below 380 nJ/cm$^2$. Therefore, in a relatively low single-pass gain medium-based RA, the absence of a pulse picker has little effect on the whole system.

A schematic view of the experimental setup is depicted in Fig. 2. The master oscillator is a home-made diode-pumped Nd:YVO$_4$ passively mode-locked laser. It generates a pulse train with a pulse duration of 9.3 ps at a repetition rate of 100 MHz; its maximum output power is 500 mW. The seeding pulse train is directly injected into the RA cavity using the thin film polarizer (TFP2). A 6.4-cm-long, 3-mm-diameter Nd:YAG operates as the gain medium. Combined with a $\lambda/4$ wave plate, one barium boron oxide (BBO) PC with a clear aperture of 4 mm is used to switch the pulses. The 1.1-m-long RA cavity is shorter than the oscillator cavity length, effectively preventing a second pulse trapped during the amplification stage. The input pulse energy at the Nd:YAG is 2.8 nJ, with $E_{in} = 53$ nJ/cm$^2$. A fast photodiode is used to monitor the intracavity signal through the leakage light after $M_2$.

Figure 3 shows the intracavity signal of the RA. The recorded pulses are temporally spaced by the cavity round-trip time of 7.3 ns. The pulse energy grows until the gain becomes equal to the resonator losses. The saturated pulse is then dumped out of the RA cavity. The buildup time required to reach the peak pulse energy in our system is 285 ns, corresponding to 39 round trips. However, only 8 of them can be observed in Fig. 3, which also proves that the energy extraction is very Fig. 1. Extraction efficiency in a time period $\eta_E$ versus input fluence $E_{in}$.

Fig. 2. Sketch of the experimental setup. FR: Faraday rotator.

Fig. 3. Intracavity signal of the RA. The inset shows the trace of the amplified output pulse.

Fig. 4. Autocorrelation of the seeding pulses and output pulses.

Fig. 5. Camera-based measurement of the beam quality. The inset is the transverse beam profile.
small at the beginning of the amplification stage. The output pulse is shown in the inset in Fig. 3. The system generates a clean output pulse without noticeable pre- or post-pulses. A clean output pulse is also ensured by locating TP2 between the Nd:YAG and the PC, effectively avoiding the unwanted coupling of substantial power to the output due to the thermally induced birefringence. Pulse duration is also measured with a second harmonic auto-correlator, as shown in Fig. 4. Due to the limited bandwidth of the Nd:YAG, the output pulse width is broadened to 28 ps, unlike the oscillator that has a pulse width of 9.3 ps.

Diode-side pumping is adopted in our laser system to achieve a more compact scale and higher power output because the pumping zone is much larger than that in end-pumping. However, diode-side-pumped laser systems always suffer from poor beam quality due to thermally induced deviation from the uniform pump distribution. To overcome this shortcoming, a thermal compensating plane-convex RA cavity design is used in our system, ensuring a uniform gain zone in the laser rod. The transverse beam profile measured with a charge-coupled device (CCD) camera is shown in the insert in Fig. 5, indicating a perfect TEM$_{00}$ mode (TEM is the transverse electric and magnetic field). The result is close to the diffraction limit, giving a beam quality of $M_2^x = 1.24$, $M_2^y = 1.03$ in both directions perpendicular to the axis of propagation.

In conclusion, a compact and high-energy picosecond regenerative amplifier based on CW diode side-pumped Nd:YAG with high beam quality is demonstrated. An average power of 8.8 W is demonstrated at a repetition rate of 5 kHz and wavelength of 1064 nm with a pulse duration of 28 ps, corresponding to a pulse energy of 1.76 mJ and peak power of 62.9 MW. With a thermal compensating plane-convex resonator design, the beam quality is close to the diffraction limit. We believe that this compact and cost-effective picosecond laser system is applicable in micro-machining applications.

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References