Compact 50 W All-Solid-State Picosecond Laser System at 1 kHz

Shuaishuai Yang 1,2, Zijian Cui 1, Ziming Sun 1,2, Pan Zhang 1,2 and Dean Liu 1,*

1 Key Laboratory of High Power Laser and Physics, Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800, China; ssyang@siom.ac.cn (S.Y.); cuizijian@siom.ac.cn (Z.C.); sunziming@siom.ac.cn (Z.S.); zhangpan@siom.ac.cn (P.Z.)
2 Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, Beijing 100049, China
* Correspondence: liudean@siom.ac.cn

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Abstract: Compact, stable, high-power and high repetition rate picosecond laser systems are excellent sources for optical parametric chirped pulse amplification systems and laser satellite ranging systems. Compared with the traditional complex high-power amplifier, this article reports a compact high-power picosecond laser system at a repetition rate of 1 kHz based on Nd:YAG bulk crystal. The thermal lens effect limits the regenerative amplifier to directly output higher energy. For this reason, multi-stage traveling-wave amplifiers are usually used to gradually increase the laser pulse energy. So as to achieve a compact structure, a regenerative amplifier that can output higher power at 1 kHz is designed in the laser system. The regenerative amplifier can output the power of 6.5 W at the pump power of 41.5 W; the beam quality of M² factor was about 1.3. A more flexible thermal depolarization compensation structure is applied in the side-pumped amplifier, which can effectively compensate for thermal lens effect and thermal depolarization at different pump powers. Finally, the laser pulse can achieve an output power higher than 50 W at 1 kHz after passing through an end-pumped traveling-wave amplifier and a side-pumped traveling wave amplifier.

Keywords: picosecond; high repetition; Nd:YAG laser system; depolarization compensation

1. Introduction

The development of short-pulse laser technology in recent years has tremendous impetus in the developing of industrial micro-machining, scientific research and medical equipment [1]. High repetition rate and high-power picosecond laser is an excellent light source for material cold working, pumping high repetition rate optical parametric chirped pulse amplification (OPCPA) system, laser satellite ranging, UV light generation, terahertz generation, and imaging [2–4]. Passive Q-switching technology can be used to directly output picosecond pulses, however the pulse duration is usually more than 500 ps. Shorter pulse width can usually be obtained by mode-locking techniques. The oscillator of Nd:YVO₄ usually can get a pulse width of 10–100 ps at the wavelength of 1064 nm. Due to the large gain factor of the regenerative amplifier, it is very suitable for amplifying low-energy seed pulses. The structure of the regenerative amplifier is an optical resonator, so it has good beam directivity and beam quality. Based on the characteristics of the regenerative amplifier, the regenerative amplifier is very suitable as a pre-amplifier. Usually seed pulses can be amplified to several millijoules by regenerative amplifier. The traveling-wave amplifier can be used as a post-amplifier. Traveling-wave amplifiers have two pumping methods: side pumping and end pumping. The beam quality and polarization characteristics of the end-pumped amplifier is better however, and the output power is relatively low due to the limitation of the end-pumped power.
Although the beam quality of the side-pumped amplifier is not good, the side-pumped amplifier can achieve higher output power. Usually end-pumped and side-pumped hybrid amplifiers are used to obtain laser pulses with high power and high beam quality.

For the purpose of obtaining higher output power, the higher population inversion density of gain medium is required. The high population inversion density usually derives from higher pumping power. Thus, reducing the thermal effect and thermal management are the key issues in a high-power diode-pumped solid-state laser. In recent years, various types of high-power picosecond laser systems via different cooling technologies have been constructed. The high-power laser systems via rod gain medium pulses with 75 mJ and 64 pS at 300 Hz [5], 80 mJ and 50 pS at 1 kHz [6], 130 mJ and 95 pS at 1 kHz [7], 64.8 mJ and 15 ps at 1 kHz [8], 363 mJ and 63 ps at 100 Hz [9], 50 mJ and 100 ps at burst mode 1 kHz [10], and with 131.83 µJ and 16.9 ps at 496.85 kHz were demonstrated with the gain mediums of Nd:YAG or Nd:YVO₄ [11]. In the above-mentioned systems, the output power of the regenerative amplifier stage is usually about 2 W at 1 kHz. In order to achieve higher output power, three or more traveling-wave amplifiers are usually required. The Yb-doped crystal laser is usually a three-level system, which requires higher energy to generate population inversion compared to the four-level system. At the same time, the Yb-doped crystal usually has a wider gain bandwidth, so it can be used in chirped pulse amplification (CPA) system to output high-energy and ultra-short laser pulses. In order to solve the heat dissipation problem of the Yb-doped crystal, take the Yb:YAG crystal as an example, which can usually be made into a thin disk to reduce the influence of the thermal effect. Based on thin-disk technology and chirped pulse amplification technology, pulses with 300 mJ and 1.8 ps at 100 Hz [12], 90 mJ and 1.2 ps at 1 kHz [13], and with 200 mJ and 1.1 ps at 5 kHz were reported [14]. The thin-disk laser systems generally can output higher energy at high repetition rate, however the CPA system is more complex and the price of a thin-disk module is extremely high. Bulk material laser systems usually have higher efficiencies and simpler structures, thus making them more attractive to many application fields. In some outdoor applications of high-power picosecond lasers, the laser system requires a smaller volume, which is also more conducive to the stability of the laser system. So as to further simplify the structure, it is necessary to increase the output power of each stage amplifier. Nd:YAG, because of its large emission cross-section, long upper level lifetime, and good thermal and mechanical properties, is suitable for amplification at 1 kHz. In the paper, a compact structure 50 W and 50 ps at 1 kHz laser system based on Nd:YAG bulk crystal is reported. The thermal lens effect is very significant in the amplifier at 1 kHz, especially in the regenerative amplifier, and the thermal lens effect will cause the beam waist in the resonant cavity to become smaller and limit the output power of the regenerative amplifier. For this, a homemade high-power regenerative amplifier is used in this system; the regenerative cavity can achieve maximum output power of 6.5 W at pump power of 41.5 W. Compared with the amplification systems of the above-mentioned literature, this regenerative amplifier can achieve higher output power, thereby reducing the number of subsequent traveling-wave amplifications. The laser pulse output by the regenerative amplifier can be amplified to 50 W at 1 kHz after passing through an end-pumped traveling-wave amplifier and a side-pumped traveling-wave amplifier. Compared with the above-mentioned high-power laser systems, this laser system has a more compact structure.

2. Experiment and Results

The experimental setup, as shown in Figure 1, consisted of 4 main parts: Nd:YVO₄ oscillator, regenerative amplifier, end-pumped single-pass amplifier, and side-pumped double-pass amplifier.
2.1. Picosecond Oscillator

The seed pulses were generated by a Nd:YVO₄ oscillator pumped with a 2 W, 808 nm continuous wave (CW) laser diode. The laser crystal was an a-cut, 0.5 at. % Nd-doped YVO₄ crystal with a size of 3 × 3 × 5 mm³. The mirror of M1 was plane-concave mirror with 200 mm radius of curvature. M2 and M3 had 75 mm radius of curvature. The mirror of OC was an output coupler mirror with transmission rate of 10%. Semiconductor saturable absorption mirror (SESAM) can help the oscillator run in a mode-locking state and provided ~300 mW average power at 80 MHz repetition rate. The oscillator used an etalon with the length of 0.5 mm to directly get ~52 ps laser pulses at 1064 nm, as shown in Figure 2.

2.2. Regenerative Amplifier

The seed pulses were input to a Nd:YAG regenerative amplifier. The crystal in the cavity was a 0.3 at % Nd-doped YAG crystal with a size of 3 × 3 × 40 mm³, which was wrapped with indium foil and mounted tightly on a thermoelectric cooler (TEC) copper heat sink. The crystal surface was
2.2. Regenerative Amplifier

The seed pulses were input to a Nd:YAG regenerative amplifier. The crystal in the cavity was a 0.3 at % Nd-doped YAG crystal with a size of $3 \times 3 \times 40 \text{ mm}^3$, which was wrapped with indium foil and mounted tightly on a thermoelectric cooler (TEC) copper heat sink at 20 °C. The crystal was coated with 1064 nm and 808 nm antireflection films. The M7 to M12 were high reflectors. M7 curved mirrors had 780 mm radius of curvature, while M8 had −1400 mm radius of curvature, and the other mirrors were plane mirrors. Due to thermal effects, the crystal acted as a thermal lens in the cavity. It was found that as the focal length of the crystal thermal lens becomes shorter, the beam waist radius at the crystal also becomes larger in this cavity. Therefore, under different pump powers, the cooling power of the TEC for the crystal should also change accordingly. The pump laser was a 300 W fiber-coupled quasi-CW (QCW) laser diode with a 600 μm core diameter centered at 808 nm (DILAS, Mainz, Germany), which was controlled by a trigger signal with gate width of 180 μs at 1 kHz. By optimizing the focal length of the thermal lens crystal, the regenerative cavity can achieve maximum output power of 6.5 W at pump power of 41.5 W. Figure 3 shows the beam quality ($M^2$ factor) of the output pulses measured by a commercial $M^2$ factor instrument (M2-200S-FW, Ophir-Spiricon Inc., North Logan, UT, USA). The $M^2$ value in x and y direction were 1.327 and 1.445 respectively with the output power of 6.5 W.

![Figure 3. Beam quality of output pulses from regenerative amplifier with the output power of 6.5 W.](image)

2.3. End-Pumped Amplifier

According to the regenerative amplifier presented above, we had obtained high-quality beam quality laser pulses. Higher pulse power required more traveling-wave amplifiers. In comparison with end-pumped traveling-wave amplifier, side-pumped traveling-wave can achieve higher single-pass gain. However, due to that the population inversion is more evenly distributed in end-pumped medium, end-pumped traveling-wave amplifier can obtain higher beam quality. The picosecond laser system used a hybrid power amplifier consisting of an end-pumped single-pass amplifier and a side-pumped double-pass amplifier. A $3 \times 3 \times 40 \text{ mm}^3$, 0.3 at % Nd-doped YAG crystal, which was wrapped with indium foil and mounted tightly on a TEC copper heat sink at 20 °C, was used as a gain medium in the end-pumped single-pass amplifier. A 300 W fiber-coupled quasi-CW laser diode with a 600 μm core diameter centered at 808 nm (DILAS, Germany) was used as a pump source for end-pumped amplifier. The QCW laser diode produced 200 μs pulses at the repetition of 1 kHz and focused on the Nd:YAG crystal via a lens system. When the laser pulses output by regenerative amplifier traversed the medium with an inverted population, the pulse power was amplified higher.
In order to improve the amplification efficiency, the diameter of seed pulses should match with pump pulses in Nd:YAG crystal. L3 was a plane-convex lens used to adjust the beam size of the laser pulses. The measured power curve and beam image are shown in Figure 4. The picosecond pulses were amplified to 10.8 W after the end-pumped single-pass amplifier, corresponding to an optical efficiency of 17.7%.

![Figure 4. Power curve and beam image of end-pumped single-pass amplifier.](image)

2.4. Side-Pumped Amplifier

Since the power of the side-pumped module is extremely high, the thermal effect of the gain medium is relatively obvious. The non-uniform temperature distribution could cause thermally induced birefringence inside the crystal. For a Nd:YAG rod in which the z axis is in the [1 1 1] direction, the principle of axes of thermally induced birefringence are radial and tangential within the rod cross-section. Therefore, when the linear polarized beam traverses the gain medium, the tangential and radial components could experience different phase retardation, resulting in significant depolarization [15]. The compensation of birefringence is a significant issue for the Nd:YAG rod side-pumped amplifier [16–19].

The Nd:YAG crystal is an isotropic medium. The refractive index ellipsoid is a regular sphere without thermally induced birefringence. The refractive index ellipsoid is

\[
B_1 x_1^2 + B_2 x_2^2 + B_3 x_3^2 = 1, \quad (1)
\]

where the \( B_i = 1/n_i^2 = 1/n_0^2 \), \( i = 1, 2, 3 \) are principal refractive indexes. The refractive index ellipsoid with thermally induced birefringence is

\[
B_{11} x_1^2 + B_{22} x_2^2 + B_{33} x_3^2 + 2B_{12} x_1 x_2 + 2B_{31} x_1 x_3 + 2B_{13} x_2 x_3 = 1, \quad (2)
\]

\[
B_{ij} = \Delta B_{ij} + B_{0ij}, \quad i, j = 1, 2, 3. \quad (3)
\]

In the Equation (3), \( \Delta B_{ij} \) implies the change of index with thermally induced birefringence, and \( B_{011} = B_{022} = B_{033} = 1/n_0^2, B_{012} = B_{013} = B_{023} = 0 \). According to previous studies,

\[
\Delta B_{ij} = \pi_{ijkl} \sigma_{kl}, \quad (4)
\]

where the elastomer coefficient \( \pi_{ijkl} \) is a fourth-order tensor and the \( \sigma_{kl} \) is deformation tensor. In order to simplify the calculation, the form converted into a matrix is

\[
\Delta B_m = \pi_{mn} \sigma_n, \quad m, n = 1, 2, 3, 4, 5, 6. \quad (5)
\]
The beam propagates along the z-axis direction, so there is no polarization component in the z-direction. Equation (2) can become

\[
\begin{pmatrix}
  x_1 \\
  x_2
\end{pmatrix} \begin{pmatrix}
  1/n_0^2 + \Delta B_1 \\
  \Delta B_6
\end{pmatrix} \begin{pmatrix}
  x_1 \\
  x_2
\end{pmatrix} = 1.
\]

(6)

The new principle refractive indexes can be given by the following formula:

\[
n_\alpha = \frac{1}{\sqrt{\frac{1}{n_0^2} + \frac{1}{2} (\Delta B_1 + \Delta B_2) \pm \frac{1}{2} \sqrt{(\Delta B_1 - \Delta B_2)^2 + 4 \Delta B_6^2}}}
\]

(7)

The angle \( \alpha \) between the axis with thermal birefringence and the original axis can be given by the formula:

\[
\tan(2\alpha) = \frac{2\Delta B_6}{\Delta B_1 - \Delta B_2}.
\]

(8)

The difference of phase retardation between tangential and radial components is

\[
\delta = \frac{2\pi l}{\lambda} (n_+ - n_-).
\]

(9)

By swapping the phases of the tangential and radial components of polarization and traversing the thermally-induced birefringent crystal again, an equal phase retardation can be achieved at each point within the crystal cross section. When the beam passes through the depolarized crystal for the second time, if the beam distribution at each point in the z direction is the same as the first, the depolarization can be perfectly compensated. Figure 5 shows the simulation patterns of thermal depolarization and perfect compensation for the side-pumped amplifier.

\[\text{Figure 5. Simulation patterns of thermal depolarization and compensation (a) without compensation; (b) perfect compensation.}\]

The gain medium is equivalent to a thick lens in the side-pumped amplifier, and the collimated beam will become a convergent beam after passing through the crystal. A convergent beam can usually be collimated by a concave lens, however, the convergence angle is different at different pump powers in the side-pumped amplifier. To solve this problem, the side-pumped amplifier can apply the structure shown in Figure 6. The matrix after the beam passes through the gain crystal can be defined as

\[
\begin{pmatrix}
  r \\
  \theta
\end{pmatrix}.
\]
$r$ and $\theta$ are the waist radius and divergent angle respectively. The ABCD matrix of the beams passing through the optics in the Figure 6 can be expressed as:

$$
\begin{pmatrix}
A & B \\
C & D
\end{pmatrix}
= \begin{pmatrix}
1 & L \\
0 & 1
\end{pmatrix}
\begin{pmatrix}
1 & 0 \\
-\frac{1}{f} & 1
\end{pmatrix}
\begin{pmatrix}
1 & 1 \\
0 & -1
\end{pmatrix}
\begin{pmatrix}
1 & 0 \\
-\frac{1}{f} & 1
\end{pmatrix}
\begin{pmatrix}
1 & L \\
0 & 1
\end{pmatrix}. 
$$

(10)

The length of $l$ can be obtained according to Figure 6:

$$
l = \frac{f(\theta L + r)}{r + \theta L - f \theta}.
$$

(11)

$l$ is a dependent variable, affected by variables $\theta$ and $r$. Therefore, the $l$ can vary with different pump powers of the side-pumped amplifier. The matrix where the beam returns to the crystal surface again can be expressed as:

$$
\begin{pmatrix}
\theta' \\
\theta'
\end{pmatrix}
= \begin{pmatrix}
A & B \\
C & D
\end{pmatrix}
\begin{pmatrix}
r \\
\theta
\end{pmatrix}
= \begin{pmatrix}
r \\
-\theta
\end{pmatrix}.
$$

(12)

FR was a 45° Faraday Rotator, and a roundtrip in a 45° FR was equivalent to a single pass in a 90° rotator. With this structure, the tangential and radial components of polarization can exchange phase retardation, and the divergent angle changed from $\theta$ to $-\theta$, while the diameter of the beam was invariant. This is an ideal structure for birefringence compensation in a single-rod amplifier.

Finally, the 10.8 W picosecond pulses from amplifiers presented above were input to the side-pumped double-pass amplifier. The side-pumped module consisted of a $6 \times 160$ mm$^3$, 0.5 at % Nd-doped YAG crystal side-pumped by QCW laser diode. The maximum output power (at 110 A) of the side-pumped module was 1008 W with the pulse duration of 180 $\mu$s at the repetition of 1 kHz. In this experiment, by using the depolarization compensation technique described above, the side-pumped module working at a current of 70 A and output power of 50 W can be obtained. Figure 7 shows the power curve and beam image of the laser system.
1.3. The homemade regenerative amplifier worked in the state that output power was 5 W, as a pre-amplifier for a subsequent amplifier. The pulses were amplified to 10.8 W via an end-pumped single-pass amplifier, which can overcome the limitation of the beam waist radius due to the thermal lens effect under high power pumping. Maximum output power of the regenerative amplifier was 6.5 W at 1 kHz, and the beam quality of $M^2$ factor was about 1.3. The homemade regenerative amplifier worked in the state that output power was 5 W, as a pre-amplifier for a subsequent amplifier. The pulses were amplified to 10.8 W via an end-pumped single-pass amplifier. In order to compensate for the thermal depolarization of the side-pumped amplifier, we made a theoretical analysis of the depolarization compensation and applied a more flexible depolarization compensation structure. After the picosecond laser pulses traversed the side-pumped amplifier, the pulses’ power was amplified to more than 50 W at 1 kHz. This is a simple and compact structure in which the output power can achieve more than 50 W at 1 kHz. The compact high-power picosecond laser will be a perfect source for high power OPCPA systems in the future.

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References
1. Hilinski, E.F.; Rentzepis, P.M. Biological applications of picosecond spectroscopy. Nature 1983, 302, 481–487. [CrossRef] [PubMed]
2. Wilkinson, M.; Schreiber, U.; Procházka, I.; Moore, C.; Degnan, J.; Kirchner, G.; Zhongping, Z.; Dunn, P.; Shargorodskiy, V.; Sadovnikov, M.; et al. The next generation of satellite laser ranging systems. J. Geol. 2019, 93, 2227–2247. [CrossRef]
3. Ochi, Y.; Nagashima, K.; Maruyama, M.; Tsubouchi, M.; Yoshida, F.; Kohno, N.; Mori, M.; Sugiyama, A. Yb:YAG thin-disk chirped pulse amplification laser system for intense terahertz pulse generation. Opt. Express 2015, 23, 15057–15064. [CrossRef]
4. Elu, U.; Baudisch, M.; Pires, H.; Tani, F.; Frosz, M.H.; Köttig, F.; Ermolov, A.; Russell, P.S.J.; Biegert, J. High average power and single-cycle pulses from a mid-IR optical parametric chirped pulse amplifier. *Optica* 2017, 4, 1024–1029. [CrossRef]

5. Noom, D.W.E.; Witte, S.; Morgenweg, J.; Altmann, R.K.; Eikema, K.S.E. High-energy, high-repetition-rate picosecond pulses from a quasi-CW diode-pumped Nd:YAG system. *Opt. Lett.* 2013, 38, 3021–3023. [CrossRef]

6. Michailovas, K.; Smilgevičius, V.; Michailovas, A. High average power effective pump source at 1 kHz repetition rate for OPCPA system. *Lith. J. Phys.* 2014, 54, 150–154. [CrossRef]

7. Budriūnas, R.; Stanislauškas, T.; Adamonis, J.; Aleknavičius, A.; Veitas, G.; Gadonas, D.; Balickas, S.; Michailovas, A.; Varanavičius, A. 53 W average power CEP-stabilized OPCPA system delivering 5.5 TW few cycle pulses at 1 kHz repetition rate. *Opt. Express* 2017, 25, 5797–5806. [CrossRef]

8. Jiaxing, L.; Wei, W.; Zhaohua, W.; Zhiguo, L.; Zhiyuan, Z.; Zhiyi, W. Diode-pumped high energy and high average power all-solid-state picosecond amplifier systems. *Appl. Sci.* 2015, 5, 1590–1602. [CrossRef]

9. Yutao, H.; Hongbo, Z.; Xiaochao, Y.; Guangyan, G.; Zhenao, B.; Weiran, L.; Zhijun, K.; Jisi, Q.; Tianzhuo, Z.; Zhongwei, F. High-Brightness 100 Hz/363 mJ Picosecond Nd:YAG Laser System for Ultra-Remote Laser Ranging. *IEEE J. Quantum Electron.* 2020, 56, 1–10. [CrossRef]

10. Ning, M.; Meng, C.; Ce, Y.; Shang, L.; Xie, Z.; Xibiao, D. High-efficiency 50W burst-mode hundred picosecond green laser. *High Power Laser Sci. Eng.* 2020, 8, e1. [CrossRef]

11. Xuesheng, L.; Wenzeng, J.; Yiheng, S.; Song, Y.; Shu, L.; Youqiang, L.; Anru, Y.; Zhiyong, W. High energy, high brightness picosecond master oscillator power amplifier with output power 65.5 W. *Opt. Express* 2020, 28, 8016–8026. [CrossRef]

12. Robert, J.; Johannes, T.; Ingo, W. Regenerative thin-disk amplifier for 300 mJ pulse energy. *Opt. Express* 2016, 24, 883–887. [CrossRef]

13. Jakub, N.; Jonathan, T.G.; Thomas, M.; Tomáš, M.; Bedrich, H.; Martin, H.; Zbyněk, H.; Robert, B.; Roman, A.; František, B.; et al. Thin disk amplifier-based 40 mJ, 1 kHz, picosecond laser at 515 nm. *Opt. Express* 2016, 24, 5728–5733. [CrossRef]

14. Thomas, N.; Martin, K.; Moritz, U.; Martin, G.; Ayman, A.; Hanieh, F.; Jonathan, B.; Oleg, P.; Helena, G.B.; Zsuzsanna, M.; et al. 1 kW, 200 mJ picosecond thin-disk laser system. *Opt. Lett.* 2017, 42, 1381–1384. [CrossRef]

15. Oliver, P.; Henrik, T.; James, J.M.; Peter, W.; Maik, F.; Jörg, N.; Dietmar, K. Intrinsic reduction of the depolarization in Nd:YAG crystals. *Opt. Express* 2010, 18, 20461–20474. [CrossRef]

16. Clarkson, W.A.; Felgate, N.S.; Hanna, D.C. Simple method for reducing the depolarization loss resulting from thermally induced birefringence in solid-state lasers. *Opt. Lett.* 1990, 24, 820–822. [CrossRef] [PubMed]

17. Martin, O.; Damien, M.; Peter, J.V.; Jesper, M. Thermally induced birefringence in Nd:YAG slab lasers. *Appl. Opt.* 2006, 45, 5368–5376. [CrossRef]

18. Fluck, R.; Hermann, M.R.; Hackel, L.A. Birefringence compensation in single solid-state rods. *Appl. Phys. Lett.* 2000, 76, 1513–1515. [CrossRef]

19. Lü, Q.; Kugler, N.; Weber, H.; Dong, S.; Müller, N.; Wittrock, U. A novel approach for compensation of birefringence in cylindrical Nd:YAG rods. *Opt. Quant. Electron.* 1995, 28, 57–69. [CrossRef]