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LD double-end pumped dual-rod acousto-optic Q-switched Tm:LuAG laser

Z. Fan[a], Y. Wen[a], X. Shi[a], C.T. Wu[a,*], X.Y. Chen[a], Y. Jiang[a], T.Y. Dai[b]

[a] Jilin Key Laboratory of Solid-State Laser Technology and Application, Changchun University of Science and Technology, Changchun 130022, China
[b] National Key Laboratory of Tunable Laser Technology, Harbin Institute of Technology, Harbin 150001, China

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ABSTRACT

A diode pumped dual-rod acousto-optic Q switched Tm:LuAG laser was reported. Based on the dual-rod Q-switched resonator design, single pulse energy of 5.24 mJ and peak power of 17.6 kW at repetition rate of 100 Hz Tm:LuAG laser was realized at room temperature.

1. Introduction

In the 1980s, LD pumped 2 μm solid-state lasers developed rapidly. Currently, 2 μm band single-doped Tm^{3+} laser had been shown more and more applications and requirements in many fields, such as Coherent Doppler Lidar, 2 μm Differential Absorption Lidar, the pumping source of mid infrared and far infrared laser and so on [1–6,10]. Compared with Tm:YAP, Tm:YLF laser, the central wavelength of Tm:YAG and Tm:LuAG laser were longer than 2 μm, which make them much easier in applications directly. While, compared with the common Tm:YAG laser crystal [7], the emission peak of Tm:LuAG crystal (2.023 μm) deviates more from the absorption peak of water. What's more, its lower energy level is at the sub-level of higher $^3H_6$ level stark splitting with a lower thermal load. The ring cavity type acousto-optic Q-switched Tm:LuAG laser was reported in 2012, obtaining a maximum output energy of 3.3 mJ at a repetition rate of 20 Hz and a pulse width of 199 ns. In addition, a maximum output energy of 1.8 mJ at a repetition rate of 50 Hz and a pulse width of 293 ns with a beam quality factor of $M^2 < 1.4$ was reported [8]. The report in 2014 was a Tm:LuAG laser with an output energy of 2.85 mJ, a pulse width of 204.5 ns, a pulse building time of 3.45 μs when the pumping energy was 142 mJ as well as the operation repetition rate was at 100 Hz [9]. The electro-optic Q-switched Tm:LuAG laser was reported in 2016, with an average power of 1.22 W and a peak power of 4.1 kW at repetition rate of 100 kHz by using a cavity emptying technique. The slope efficiency was 6% and the beam quality factor of M^2 was 1.4 [11].

In this paper, we use dual-rod structure to improve the performance of Tm:LuAG laser at room temperature. The result shows that the laser output is best when the repetition frequency is 100 Hz. Correspondingly, the energy is 5.24 mJ, the peak power is 17.6 kW, the pulse width is 297.15 ns, the central wavelength is 2035 nm and the beam quality is 1.31 in the x direction as well as 1.35 in the y direction.

2. Experimental design

The emission section of Tm:LuAG crystal was 1.4×10^{-21} cm^2, which meant the low gain and not suitable for improving output energy by amplifier. Thus, two Tm:LuAG crystals were used in one resonator cavity, as shown in Fig. 1.

Taking the mirror M1 as a reference, the matrix in the resonant was expressed as follows:

$$T = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & d_1 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ -\frac{1}{f_1} & 1 \end{bmatrix}\begin{bmatrix} 1 & d_2 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ -\frac{1}{f_2} & 1 \end{bmatrix}\begin{bmatrix} 1 & d_3 \\ 0 & 1 \end{bmatrix}$$
$$\begin{bmatrix} 1 & \frac{l}{n} \\ 0 & 1 \end{bmatrix}$$
$$\begin{bmatrix} 1 & d_4 \\ 0 & 1 \end{bmatrix}$$
$$\begin{bmatrix} 1 & 0 \\ -\frac{1}{R} & 1 \end{bmatrix}$$
$$\begin{bmatrix} 1 & d_4 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & \frac{l}{n} \\ 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & d_3 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ -\frac{1}{f_2} & 1 \end{bmatrix}\begin{bmatrix} 1 & d_2 \\ 0 & 1 \end{bmatrix}\begin{bmatrix} 1 & 0 \\ -\frac{1}{f_1} & 1 \end{bmatrix}\begin{bmatrix} 1 & d_1 \\ 0 & 1 \end{bmatrix} \quad (1)$$

The thermal focal length of two Tm:LuAG crystals were estimated to be 130 mm when the pump power was 20 W. The stability of the dual-rod resonator was designed, considering the parameters of d_2, d_3, d_4. Supposed R1 = ∞, R2 = 200 mm, $f_1 = f_2 = 130$ mm and $d_1 = 30$ mm, the variable ranges of d_2, d_3, d_4 were shown in Fig. 2. The results were that d_2 should be between 48 and 50 mm, d_3 should be between 40 and 50 mm and d_4 should be between 20 and 50 mm to keep the stability of

* Corresponding author.
E-mail address: bigsnow1@126.com (C.T. Wu).

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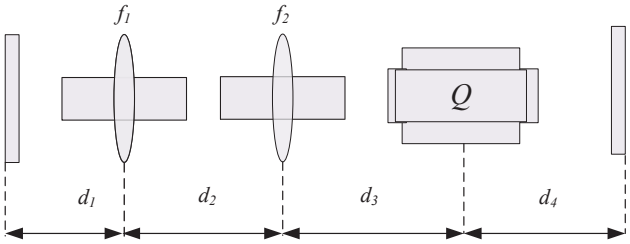

Fig. 1. Resonant of the dual-rod thermal-self-compensation system.

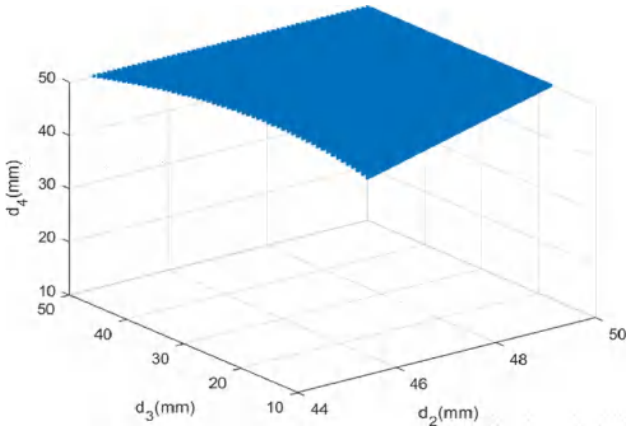

Fig. 2. Influence of the two-rod position and the Q crystal position parameters on resonator stability.

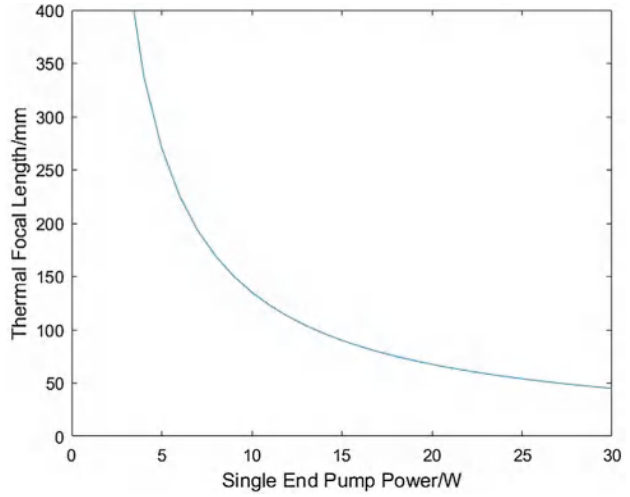

Fig. 3. The variation of thermal focal length with single end pump power.

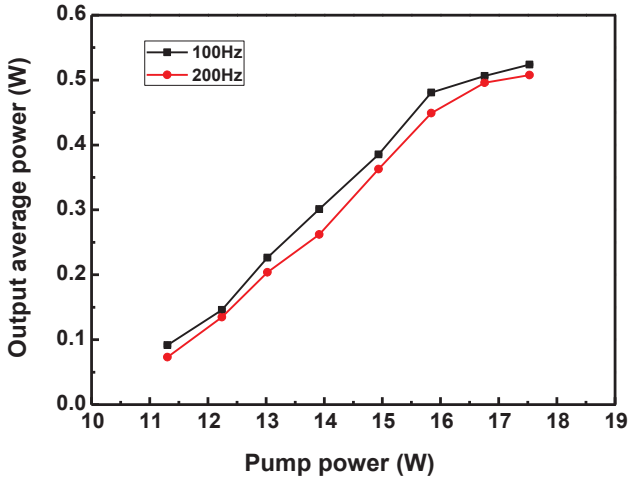

Fig. 5. Output average power versus pump power at different repetition rates.

the dual-rod acousto-optic Q-switched Tm:LuAG resonator cavity.

Fig. 3 shows the variation of thermal focal length with single end pump power.

3. Experiment setup

Fig. 4 showed the experimental setup of LD end pumped dual-rod Q-switched Tm:LuAG laser.

In the experiment, both pumping sources were fiber-coupled lasers with a center wavelength of 788 nm and a maximum output of 60 W. The fiber core diameter was 400 μm and the numerical aperture was 0.22. The focus coupling ratio was 7:15. The flat-concave resonator was used and M1 was coated with high transmission ($R < 0.5\%$) at 788 nm and high reflection ($R > 99.5\%$) at 2 μm. The output mirror M3 was a flat concave mirror with R = 200 mm and coated with part transmission (T = 4%) at 2 μm. The resonant length was 118 mm. Both single-ended bonded Tm:LuAG crystals were the dimension of $3 \times (3YAG + 8Tm:LuAG)$ mm^3 with Tm^{3+} doping concentration of 4 at.%. The crystal was wrapped with 0.1 mm thick indium foil, placed in copper heat sink and cooled by internal circulation water cooling, whose temperature was set as 288 K. A water-cooled Q-switch (manufactured by Gooch, Q-switch model: QS041-10M-HI8, drive model: MQH041-50DM-A05) was used for realizing high peak power laser.

The output average power of LD end pumped dual-rod Q-switched Tm:LuAG laser was measured at repetition of 100 and 200 Hz, as shown in Fig. 4.

As shown in Fig. 5, at pump power of 17.53 W, when the repetition rates were 100 and 200 Hz, the maximum output average power were 0.52 and 0.51 W. With increasing of the pump power, the average power of output laser appeared to be saturated.

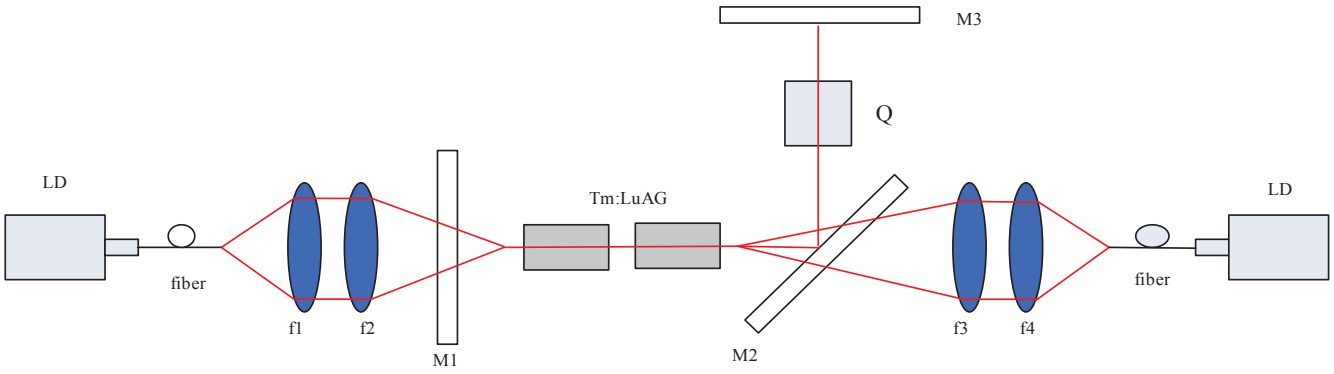

Fig. 4. Experimental setup of LD end pumped dual-rod Q-switched Tm:LuAG laser.

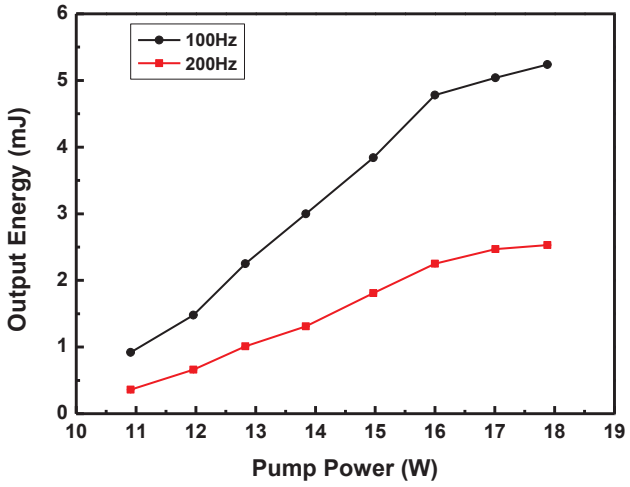

Fig. 6. Pulse energy versus pump power at different repetition rates.

The pulse energy versus pump power was shown in Fig. 6. The maximum output energy was 5.24 mJ and 2.54 mJ at repetition of 100 and 200 Hz, respectively. The comparison showed that when the laser operate repetition rate was at 100 Hz, the output single pulse energy was higher. As the lifetime of the upper level of Tm:LuAG crystal was about 10 ms, the optimum repetition frequency for laser operation was about 100 Hz. In the case of continuous pumping, if the repetition rate of the laser is higher than 100 Hz, insufficient energy storage at the upper level would reduce the single pulse energy of the output laser.

Fig. 7 showed the Q-switched pulse width versus the pump power. When the repetition rates were 100 and 200 Hz, the pulse width were 297.15 and 338.07 ns at pump power of 17.53 W. And the output peak power were 17.6 and 7.5 kW, respectively, as shown in Fig. 7.

The center wavelength of the output laser was measured by a spectrometer (AQ6375Co, manufactured by YOKOGAWA), and the spectrum was shown in Fig. 8. At repetition rates of 100 and 200 Hz, the central wavelength of Tm:LuAG laser was almost 2035.9 nm, which was more deviated from the absorption peak of water, compared with the output wavelength of Tm:YAG laser. This was also an advantage of Tm:LuAG laser in application.

The beam quality of the laser at maximum energy under repetition rate of 100 Hz was measured using a laser beam quality analyzer (SPIRICON model 62JJ-DZZZS1-5DZZ), as shown in Fig. 9. It was 1.31 in the x direction and 1.35 in the y direction in Fig. 10.

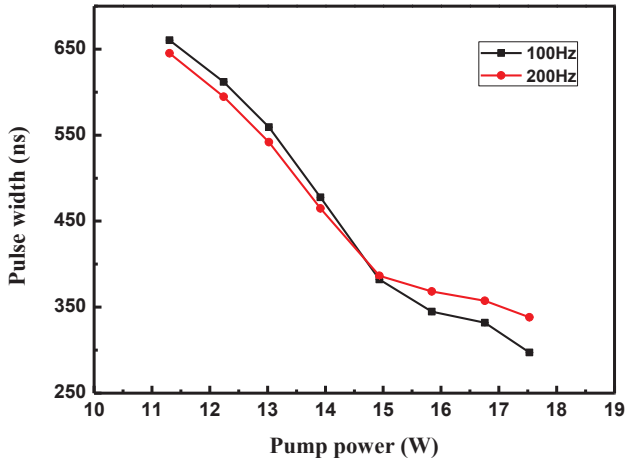

Fig. 7. Pulse width versus the pump power at different repetition rates.

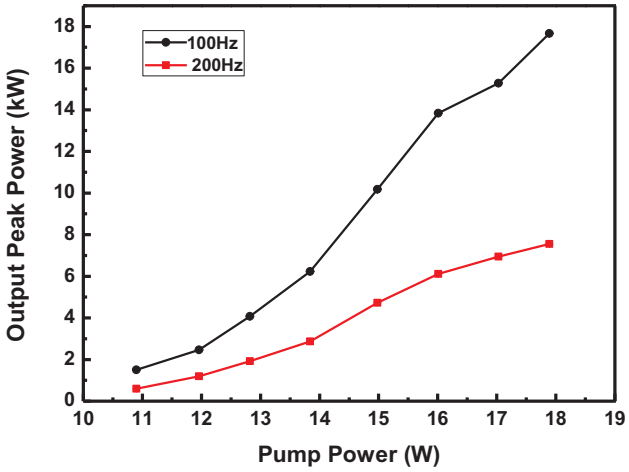

Fig. 8. Output peak power versus the pump power at different repetition rates.

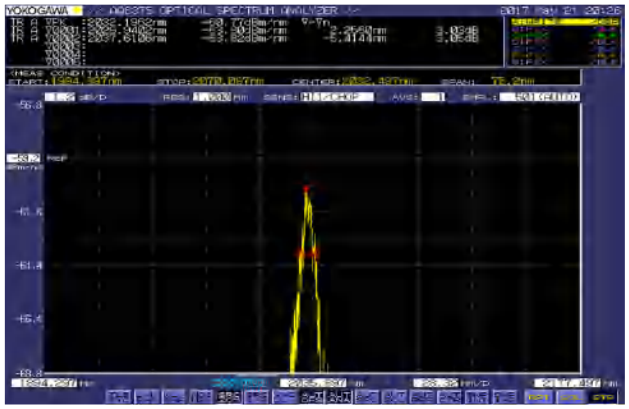

Fig. 9. The output spectrum of the dual-rod Tm:LuAG laser.

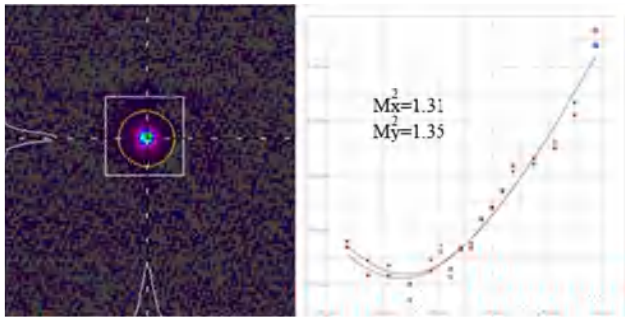

Fig. 10. Laser beam quality of the dual-rod Tm:LuAG laser.

4. Conclusion

In this paper, we demonstrated a dual-rod acousto-optic Q-switched Tm:LuAG laser. At the repetition rate of 100 Hz, the maximum output energy was 5.24 mJ with pulse width of 297.2 ns and peak power of 17.6 kW. At the repetition rate of 200 Hz, the maximum output energy was 2.54 mJ with pulse width of 338.1 ns and peak power of 7.5 kW. The central wavelength of Tm:LuAG laser was 2035.9 nm. The beam quality was Mx = 1.31 and My = 1.35.

Declaration of Competing Interest

I am authorized on behalf of all the authors of this article to confirm that no author has any conflict of interest to disclose, all authors have approved the version submitted for publication, the work in this article

is original and has not been published previously, and the article is not under consideration by any other journal.

Acknowledgement

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