A diode-pumped continuous-wave Nd:$GdTaO_4$ laser under direct pumping

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In this paper, a continuous wave (CW) 1066 nm Nd:$GdTaO_4$ laser pumped by 879 nm laser diode (LD) was presented. Instead of indirect pumping of 808 nm LD, the using of direct pumping of 879 nm LD reduced the thermal effect of Nd:$GdTaO_4$ crystal obviously. The laser characteristics of output power and slope efficiency were optimized when the parameters of cavity length, transmission of output coupler and waist radius of pumping beam were considered. To the best of our knowledge, the recorded highest output power 6.46 W of and slope efficiency of 53.7% were obtained.

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Keywords: Nd:$GdTaO_4$, Continuous wave, Output power, Slope efficiency, Direct pumping

1. Introduction

Continuous wave (CW) lasers have a widely range of applications in material processing, biomedical science, manufacturing, gas sensing and so on [1-8]. Due to the advantageous of high efficiency, compact structure and low power consumption, diode-pumped solid-state laser (DPSSL) has attracted much attentions [9-11]. With the continuous development of DPSSL, many different laser crystals have been employed as gain media [12-16]. Recently, in the year of 2015, Nd:$GdTaO_4$ single crystal was grown by Czochralski method successfully, and the spectroscopic properties was investigated [17]. The absorption bandwidth of Nd:$GdTaO_4$ was 6 nm at 808 nm, which is much larger than the absorption bandwidth of 1.5 nm of Nd:YAG crystal. Furthermore, the upper-level lifetime of 178 μs of Nd:$GdTaO_4$ was smaller than that of 230 μs of Nd:YAG. This is advantageous to produce a high repetition rates laser. Nd:$GdTaO_4$ is favorable for reducing the demands of pumping source and improving laser efficiency and, therefore, it has attracted much interest in the recent years.

Nd:$GdTaO_4$ crystal has a strong absorption line intensity at 808 nm, therefore, an 808 nm LD is usually used as the pumping source [18,19]. In the pumping process, the ground state population of Nd:$GdTaO_4$ crystal is pumped into the highly absorbing $^4F_{5/2}$ level and then jump to $^4F_{3/2}$ level through nonradiative transition. The transition between $^4F_{3/2}$ energy level and $^4I_{11/2}$ energy level produces the stimulated radiation light output. But the indirect pumping of 808 nm laser diode (LD) generates the serious thermal load due to the quantum defect [20-22]. However, when a direct pumping with 879 nm LD is adopted, the ground state population of Nd:$GdTaO_4$ crystal is pumped into the $^4F_{3/2}$ energy level directly [23-25]. Compared with indirect pumping of 808 nm, it reduces the quantum defect rate from 24% to 17%, and the thermal loading of Nd:$GdNbO_4$ laser crystal is reduced by approximately 28%. Therefore, direct pumping of 879 nm LD is benefit to improve the laser performance of output power, beam quality and slope efficiency. In 2021, a rhenium disulphide (ReS_2) passively Q-switched Nd:$GdTaO_4$ laser is reported [26].

In this paper, a CW 1066 nm Nd:$GdTaO_4$ laser under 879 nm direct pumping was presented. The laser characteristics of output power and slope efficiency were optimized when the parameters of cavity length, transmission of output coupler and waist radius of pumping beam were studied. The highest output power and slope efficiency were obtained for Nd:$GdTaO_4$ laser to the best of our knowledge.

2. Experimental setup

The experimental setup of a CW Nd:$GdTaO_4$ laser under direct pumping of 879 nm LD is shown in Fig. 1.

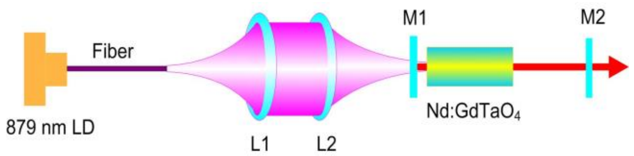

Fig. 1. Schematic of the experimental setup of a CW Nd:$GdTaO_4$ laser under direct pumping of 879 nm LD (color online)

An a-cut Nd:$GdTaO_4$ crystal with size of 2×2×5 mm^3 was used as laser gain media. The Nd^{3+} doped concentration in this Nd:$GdTaO_4$ crystal was 2 at%. A fiber-coupled diode laser with emission wavelength of 879 nm was used as a pumping source. A fiber with numerical aperture of 0.22 and a core diameter of 400 μm was adopted as pigtail for this diode laser. Two plano-convex lenses L1 and L2 were used to focus the output beam of 879 nm LD into the crystal. The focal length for L1 were 26.7 mm and 32.0 mm, respectively. And the focal length for L2 was 42.7 mm. The laser resonant cavity was constituted by two flat mirrors M1 and M2. The input mirror M1 was coated with high transmission film at 879 nm and high reflectivity at 1066 nm. The M2 had different transmissions of 5%, 10% and 15% at 1066 nm to serve as an output coupler. The cavity length was defined by the distance between M_1 and M_2. The Nd:$GdTaO_4$ crystal was put into a copper sink with water circulation for heat diffusion.

3. Results and discussion

When the output coupler M2 with different transmissions of 10%, 15% and 20% was adopted, the output performance was investigated. The cavity length of the distance between M1 and M2 was set to 30 mm. The waist radius (ω_p) of the 879 nm pump beam was adjusted to 240 μm by choosing the focus length of L1 and L2. The absorption efficiency of Nd:$GdTaO_4$ crystal under 879 nm direct pumping was 76%. The experimental result is shown in Fig. 2.

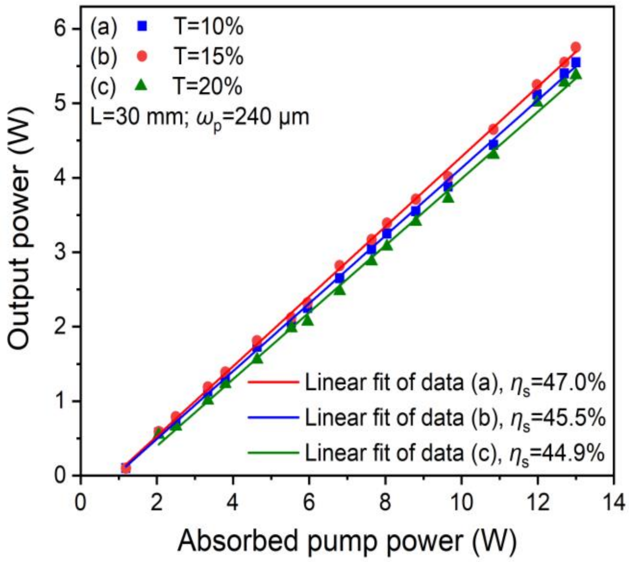

Fig. 2. CW output power of Nd:$GdTaO_4$ laser at the conditions of 30 mm cavity length and 240 μm waist radius of the 879 nm pump beam (color online)

From Fig. 2 it can be found that the CW output power got high at the conditions of absorbed pump power increased. The maximum output power of 5.75 W was achieved when the absorbed pump power was 13 W and the transmission of M2 was 15%. At this situation the slope efficiency (η_s) was 47.0% after the linear fit.

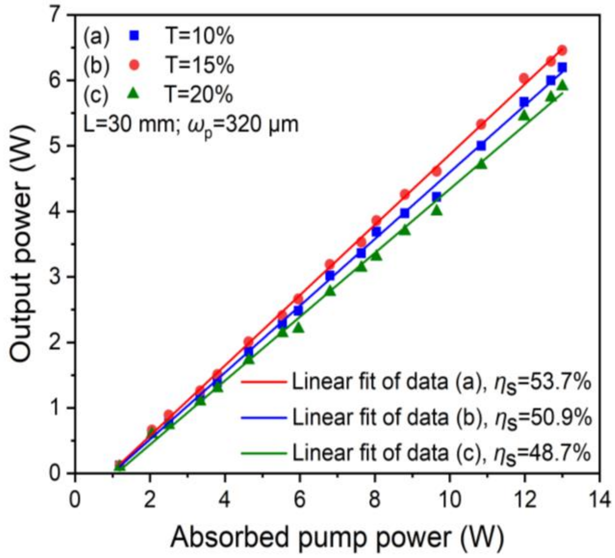

Fig. 3. CW output power of Nd:$GdTaO_4$ laser at the conditions of 30 mm cavity length and 320 μm waist radius of the 879 nm pump beam (color online)

When the waist radius (ω_p) of the 879 nm pump beam was set to 320 μm by changing the focus length of L1 and L2, the output performance was investigated at the conditions of 30 mm cavity length and output couplers with different transmissions. The experimental result is shown in Fig. 3. It can be seen that the CW output power got high when the absorbed pump power increased. The maximum output power of 6.46 W was achieved when the absorbed pump power was 13 W and the transmission of M2 was 15%. At this situation the slope efficiency (η_s) was increased from 47.0 to 53.7%.

When the waist radius (ω_p) of the 879 nm pump beam was set to 320 μm and the transmission of output coupler M2 was 15%, the output performance was researched with different cavity length. The experimental result is shown in Fig. 4. It can be seen, due to the diffraction loss, the CW output power decreased with cavity length increased under a same absorbed pump power. The maximum output power decreased from 6.46 W to 4.86 W when the cavity length changed from 30 mm to 50 mm. The corresponding slope efficiency was decreased from 53.7% to 42.1%.

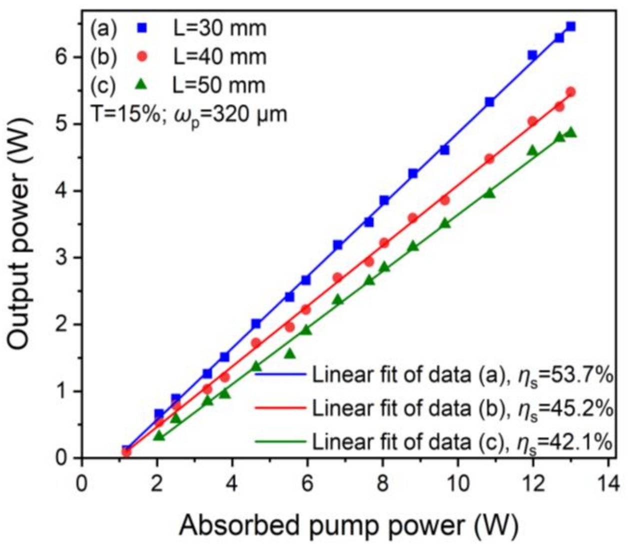

Fig. 4. CW output power of Nd:GdTaO$_4$ laser at the conditions of output coupler with 15% transmission and 879 nm pump beam with 320 μm waist radius (color online)

4. Conclusions

In this paper, a diode-pumped CW Nd:GdTaO$_4$ laser under 879 nm direct pumping was presented. Different from usually used indirect pumping of 808 nm LD, an 879 nm LD was adopted to alleviate the thermal lens effect in Nd:GdTaO$_4$ crystal. The CW output performance of output power and slope efficiency of the Nd:GdTaO$_4$ laser was studied when the transmission of output coupler, waist radius of pump beam, and the length of laser cavity were taken into account. To the best of our knowledge, the highest output power reached 6.46 W and the corresponding slope efficiency was 53.7% under the conditions of cavity length of 30 mm, output coupler's transmission of 15% and waist radius of pump beam of 320 μm.

Acknowledgments

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