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Diode-Pumped Continuous-Wave Nd:YLF Laser at 1313 nm[1]

C. L. Li, X. H. Zhang*, W. Liang, and Z. M. Zhao

School of Science, Changchun University of Science and Technology, Changchun, 130022 China

*e-mail: laser.optics@yahoo.com

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Abstract—We present an efficiency Nd:$LiYF_4$ (Nd:YLF) laser operating at 1313 nm pumped directly into the emitting level $^4F_{3/2}$. At the incident pump power of 10.3 W, as high as 3.1 W of continuous-wave output power at 1313 nm is achieved. The slope efficiency with respect to the incident pump power was 36.1%. To the best of our knowledge, this is the first demonstration of such a laser system. Comparative results obtained for the pump with diode laser at 806 nm, into the highly absorbing $^4F_{5/2}$ level, are given in order to prove the advantages of the 880 nm wavelength pumping.

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1. INTRODUCTION

Traditionally, the Nd^{3+} ions are pumped into the highly absorbing $^4F_{5/2}$ level by diode laser around 0.81 μm. Successful attempts to lase the Nd^{3+} doped laser have been reported [1–11]. However, the output power and slope efficiency of Nd^{3+} doped laser operating at 1.3 μm were also limited by the small stimulated-emission cross-section and the low quantum efficiency under 0.81 μm pumping. A more efficient pumping method was presented recently, which was to pump the Nd^{3+} ions directly into the $^4F_{3/2}$ upper lasing level. As a result, the slope efficiency can be increased and threshold decreased with lower heat generation, while a ~15% decrease in quantum defect than traditional pumping for 1.3 μm laser emission was obtained. Direct pumping, at 869 nm, was used in the first demonstration of diode laser pumped Nd:YAG laser [12]. Direct pumping of 1.06 μm continuous-wave laser emission was recently investigated for Nd:YAG [13, 14], Nd:YVO_4 [15, 16], and Nd:$GdVO_4$ [17, 18] crystals. However, only several works about 1.3 μm emission by direct pumping were reported. In 2005, N. Pavel et al. first reported a 885 nm diode laser pumped Nd:YAG laser operating at 1.3 μm [19]. In the same year, a 1.3 μm continuous-wave Nd:$GdVO_4$ laser pumped by a 879 nm Ti:Sapphire laser was reported, [20]. In 2008, a 1.3 μm continuous-wave Nd:YVO_4 laser pumped by an all-solid-state Q-switched Ti:Sapphire laser at 879 nm was reported [21]. Recently, a 1.3 μm continuous-wave Nd^{3+} lasers pumped by 0.88 μm diode laser were reported [22–25].

In this paper, we first report a 1313 nm Nd:YLF laser directly pumped by a diode laser at 880 nm. A high slope efficiency in incident power of 36.1% was obtained in a 16-mm-long, 1.0 at % Nd:YLF crystal, with a maximum output power of 3.1 W at the incident pump power of 10.3 W.

2. EXPERIMENTAL SETUP

The schematic of the system is shown in Fig. 1. The pump diode laser at 880 nm was fiber-coupled (400 μm diameter, NA = 0.22) with 20 W maximum output power. The fiber length was 8.5 cm and it was used without bending. In traditional fiber coupled pumping schemes, the polarization of the pump light is mixed up in the fiber depending on fiber length, coiling and stress in the fiber. This leads to an uncontrolled output polarization ranging from unpolarized to a strong preferential direction of polarization. A 1:1 achromatic optical system was employed in order to image the fiber end into the Nd:LYF crystal. The optical pumping into $^4F_{5/2}$ level at 806 nm was performed with a diode laser that had the same fiber characteristics.

In the experiment, a plano-concave cavity was carefully designed. The laser crystal is a c-cut 1.0 at %-doped Nd^{3+}, 16 mm long Nd:YLF. The pumping side (S1) of the Nd:YLF crystal was acted as one mirror of the cavity coated with antireflection (AR) at 806 and 880 nm, and with highly reflective (HR) at 1313 nm and high transmission ($T > 95\%$) at 1047 nm to suppress the strong parasitical oscillation at this transition. The opposite side (S2) was AR coated for 1313 nm, and in order to increase the pump beam absorption efficiency, HR coated for the pumping wavelengths. The crystal is wrapped with indium foil, mounted in a copper holder and cooled through the resonator base plate, which is kept at a constant temperature of 15°C by a thermo-electric cooler favorable to yield a small thermal population of the terminal laser level and the stability of the output power. The output mirror with a curvature-radius of 500 mm was

[1] The article is published in the original.

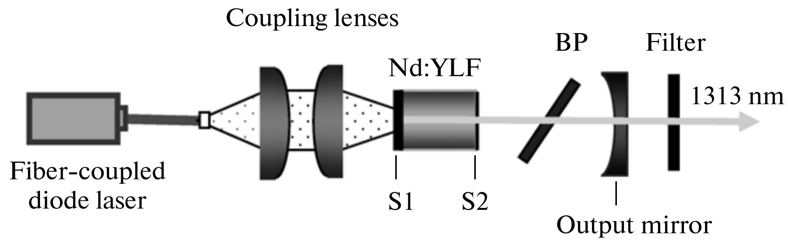

Fig. 1. Schematic diagram of the 1313 nm Nd:YLF laser. BP: Brewster plate.

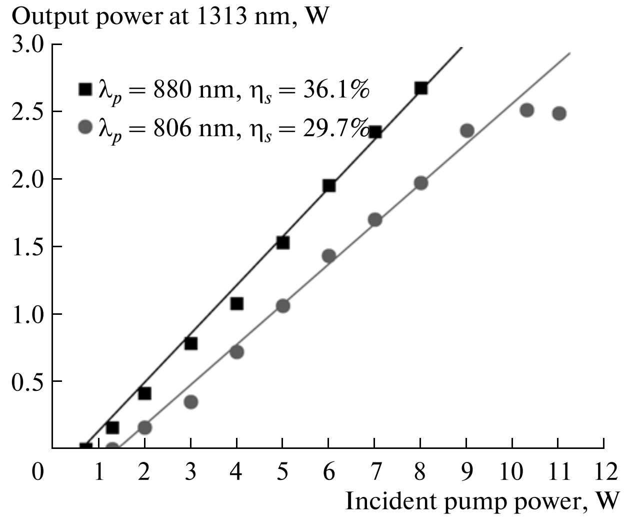

Fig. 2. Output power at 1313 nm vs. incident pump power.

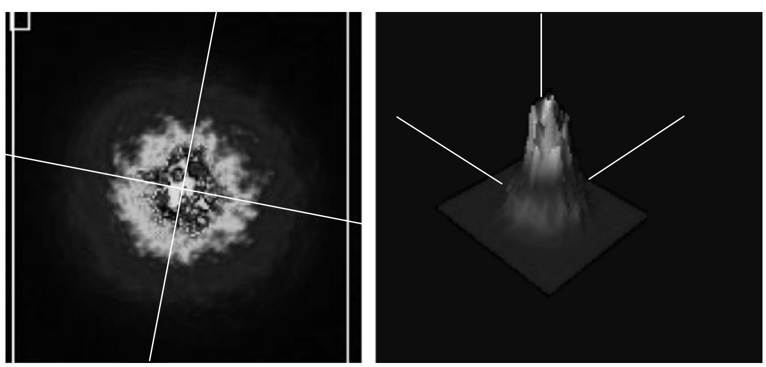

Fig. 3. Energy distribution of the 1313 nm laser emission.

employed, with a transmission of 4% at 1313 nm. The geometric cavity length was about 60 mm. Due to the birefringent nature of Nd:YLF in the crystal is different for those two lines. Therefore a Brewster plate was used to have stable single-line operation at 1313 nm by adding additional losses for the π-polarization.

3. RESULTS AND DISCUSSION

The Nd:YLF laser continuous-wave output power at 1313 nm versus the incident pump power measured is shown in Fig. 2.

Under 806 nm pumping, the output power increases almost linearity with the pump power until

2.4 W with the slope efficiency with respect to the incident pump power of 29.7%. The optical-to-optical efficiency and the threshold were 26.3% and 1.24 W, respectively. Behind this point the output power saturates. The strong thermal lens induced in Nd:YLF may be responsible for this behavior. When the pumping was made at 880 nm, the maximum output power increased to 3.1 W. The threshold was 0.75 W, and the slope efficiency was 36.1%. The M^2 factor is 1.27 measured by knife-edge technique which shows that the laser output at 1313 nm is operating at TEM_{00} mode. The stability testing is carried out by monitoring with a Field-Master-GS powermeter at 10 Hz. The fluctuation of the output power is about 3.5% in 4 h. The energy distribution diagrams of the 1313 nm emission measured by a Laser Beam Profiler (made by Photon Inc.) is shown in Fig. 3. The beam profile was measured to be TEM_{00} and the ellipticity of spot is 0.97.

4. CONCLUSIONS

A Nd:YLF laser with 1.0 at % doping concentrations under direct pumping at 880 nm was experimentally demonstrated. By contrasting with the output performances of traditional 806 nm pumping in the experiment, the slope efficiency and the threshold with respect to the incident pump power increased by 21.5% and decreased by 39.8%, respectively. By optimizing the cavity, a high slope efficiency of 36.1% and a maximum output power of 3.1 W were achieved, leading to an optical-to-optical conversion efficiency of 30.0%. These results show that Nd:YLF is a potential laser crystal for high power laser systems.

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