Optics Communications 284 (2011) 1307–1311

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Diode-pumped passively Q-switched Nd:$Lu_xY_{1-x}VO_4$ laser at 1.34 μm with two V:YAG saturable absorbers

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ARTICLE INFO

Article history:
Received 24 August 2010
Received in revised form 24 October 2010
Accepted 24 October 2010

Keywords:
Diode-pumped
Passively Q-switched
Nd:$Lu_{0.15}Y_{0.85}VO_4$
V:YAG

ABSTRACT

Laser performance with the mixed Nd:$Lu_{0.15}Y_{0.85}VO_4$ crystal at 1.34 μm wavelength has been demonstrated. The continuous wave (cw) operation was carried out in a simple plano-concave resonator with an optical conversion efficiency of 23% and a slop efficiency of 25%. At a pump power of 6.78 W, the Q-switched pulses with the largest average output power of 349 mW, the shortest pulse width of 30.6 ns, the largest repetition rate of 42.5 kHz, the highest peak power of 268 W and the largest pulse energy of 8.2 μJ were obtained, corresponding to the V:YAG with initial transmission of 89%.

1. Introduction

Diode-pumped solid-state Q-switched lasers have important applications in many fields owing to their compact structures, good beam qualities and high peak power pulses. As one of the most important components for all-solid-state lasers, the gain medium is the key factor that determines the laser output performance. Neodymium- (Nd-) doped vanadate crystals have been proved to be excellent laser materials due to their large absorption and stimulated emission cross-sections. Some Nd-doped single vanadate crystals, including Nd:YVO_4 [1–3], Nd:$GdVO_4$ [4–9] and Nd:$LuVO_4$ [10,11] have already been investigated and attracted much attention for many years. However, their short upper-level lifetimes weaken the ability of storing energy. To overcome this problem, a new class of Nd-doped mixed vanadate crystals such as Nd:$Gd_xY_{1-x}VO_4$, Nd:$Lu_xGd_{1-x}VO_4$ and Nd:$Lu_xY_{1-x}VO_4$ have been discovered. They are supposed to be good Q-switched laser gain mediums due to their inhomogeneous broadening of fluorescence spectra. There have been some reports on the laser performances of Nd-doped mixed vanadate crystals at 1.06 μm [12–16], but the laser operation at 1.34 μm is relatively less reported.

The 1.34 μm lasers are widely applied in the fields of medical treatment, light-sensing, optical fiber communication and so on. Much attention has been attracted for the laser performances of Nd-doped single vanadate crystals at 1.34 μm in recent years. Cw and Q-switched laser characteristics of Nd:YVO_4 [17,18] and Nd:$LuVO_4$ [19] have been reported. The laser operations at 1.34 μm in which the Nd-doped mixed vanadate crystals – Nd:$Gd_xY_{1-x}VO_4$ and Nd:$Lu_xGd_{1-x}VO_4$ – are employed as the laser crystals have been realized [20,21]. However, there is no report on the laser performance of Nd:$Lu_xY_{1-x}VO_4$ at 1.34 μm.

In this paper, cw and passively Q-switched operations of diode-end-pumped Nd:$Lu_{0.15}Y_{0.85}VO_4$ laser at 1.34 μm have been realized for the first time as we known. The largest output power, the optical conversion efficiency and the slop efficiency of the cw laser were 1.346 W, 23% and 25%, respectively. The Q-switched operation was achieved with V:YAG as the saturable absorber. At a pump power of 6.78 W, an average output power of 349 mW was obtained, with the shortest pulse width of 30.6 ns, the largest single pulse energy of 8.2 μJ, and the highest peak power of 268 W.

2. Experimental setup

The experimental arrangement is schematically shown in Fig. 1, in which a simple plano-concave cavity with a length of 70 mm is employed. The pump source was a commercial fiber coupled laser-diode (FAP system, Coherent Inc., USA) that works at 808 nm. The output pump beam was focused into the laser crystal with a spot size of 440 μm and a numerical aperture (N.A.) of 0.22 by a focusing optical system. The laser resonator was composed of a concave pump mirror M_1 and a flat output mirror M_2. M_1, with a curvature of 200 mm, was AR (anti-reflection)-coated at 808 nm on the pump face, HT (high-transmission)-coated at 808 nm and HR (high-reflection)-coated at 1.34 μm on the other side. M_2 was coated with the partial transmission of 5% at 1.34 μm. In order to suppress the strong oscillation at 1.06 μm, both M_1 and M_2 were HT-coated (T 90%) at this

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doi:10.1016/j.optcom.2010.10.087

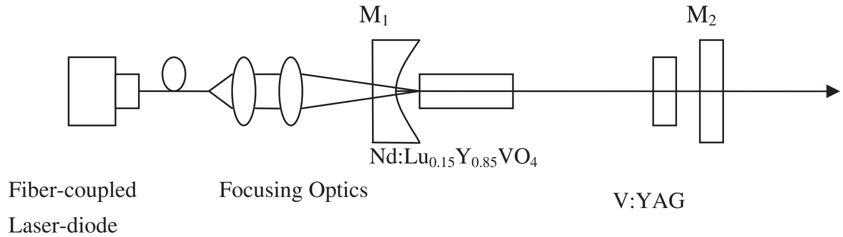

Fig. 1. The schematic arrangement of the experimental setup.

transition. An a-cut $Nd:Lu_{0.15}Y_{0.85}VO_4$ crystal with a Nd^{3+} doped concentration of 0.38 at.% and dimensions of $3\times3\times6\ mm^3$ was employed as the laser gain medium. Its both end sides were HT-coated at 808 nm, AR-coated at 1.34 µm and 1.06 µm. The Q-switched components were V:YAG saturable absorbers with the initial transmissions (T_0) of 89% and 96%. The V:YAG crystals were AR-coated at 1.34 µm on their both surfaces and placed as close as possible to the output coupler. The whole gain medium was tightly wrapped in a copper block cooled at 20 °C using semiconductor cooler and indium foil was used in order to improve the thermal contact between laser crystal and the copper block. The EPM 2000 energy/power meter (Molectron Detector Inc., USA) was used to measure the generated average output power and a TED 6208 digital oscilloscope (500 MHz bandwidth, Tektronix Inc., USA) with a quick photoelectric detector which works at 1.34 µm was used to measure the pulse width and repetition rate of the laser pulses.

3. Results and discussion

Thermal lens effect in the laser crystal, caused by the localized absorption of the pump power, is an important factor that determines the laser output characteristics. The heat, converted from the pump power, mostly accumulates near the pumped face of the laser crystal. The refractive index distribution of the laser crystal depends on the temperature, thus the laser crystal acts as a thermal lens. For Nd-doped mixed vanadate crystals, the thermal lens effects are more remarkable because their thermal conductivity coefficients are relatively smaller. For example, the thermal conductivity coefficient of the $Nd:Lu_{0.15}Y_{0.85}VO_4$ crystal is 4.5 $Wm^{-1}\ K^{-1}$, which is obviously smaller than those of $Nd:LuVO_4$ (9.9 $Wm^{-1}\ K^{-1}$) and $Nd:YVO_4$ (5.1 $Wm^{-1}\ K^{-1}$) [16]. We experimentally measured the thermal focal length of the diode-pumped $Nd:Lu_{0.15}Y_{0.85}VO_4$ 1.34 µm laser using the method mentioned in [22]. Fig. 2 has shown the relationship between experimental measured thermal focal length (f_t) and incident pump power. The expression of the thermal focal length can be written as $f_t = C\omega_p^2/P_{in}$, in which P_{in} is the incident pump power, ω_p is the pump beam radius in the active medium, and C is a constant obtained by fitting the experimental data with the above formula. The constant C was determined to be approximately 1.77×10^5 W/cm from the data shown in Fig. 2. Then we figured out the variation of the thermal focal length versus continuous incident pump power and the variations of the beam radii in the laser gain medium as well as in the saturable absorber versus the incident pump power. Fig. 3 shows the relationship between the beam radius and pump power, in which ω_g and ω_s are the beam radii in the laser crystal and the saturable absorber, respectively. As it can be seen, the spot size in the saturable absorber decreased with the increase of the pump power. In addition, the spot size in the laser crystal was insensitive to the absorbed pump power at first. Then it sharply increased when the pump power was beyond 6.8 W, induced by the serious thermal lens effect.

The variations of the cw output power as well as the Q-switched average output power versus pump power have been shown in Fig. 4. The threshold pump power for cw operation was 0.33 W, and it was much smaller than the threshold in [21] which reported the cw performance of the $Nd:Lu_{0.14}Gd_{0.86}VO_4$ laser (1.61 W). The cw output power linearly increased as the pump power augmented when the pump power was less than 5.6 W and then increased slowly. The optical conversion efficiency at a pump power of 5.6 W was 23%, being larger than 18.8% obtained in [21]. The slop efficiency in the linearly increased region was 25%, and it was slightly larger than that reported in [21] (22%). The largest output power was 1.346 W with an incident pump power of 6.78 W. By inserting the V:YAG saturable absorbers with initial transmissions of 89% and 96% in the cavity, the Q-switched operation was realized. The variational trends of the average output

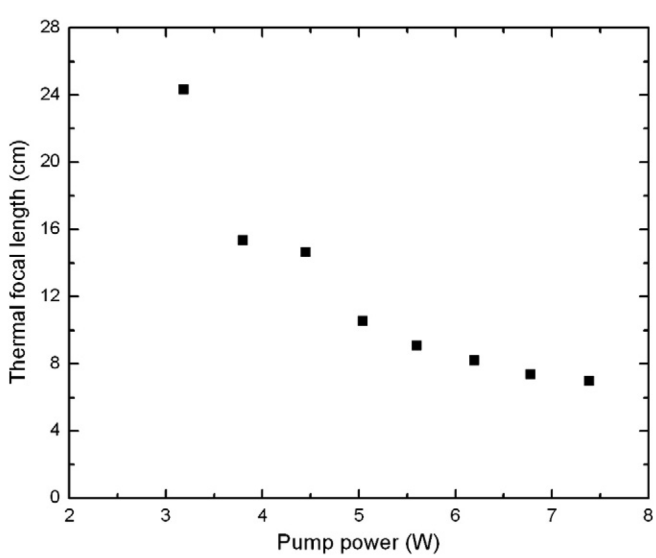

Fig. 2. The relationship between thermal focal length and pump power.

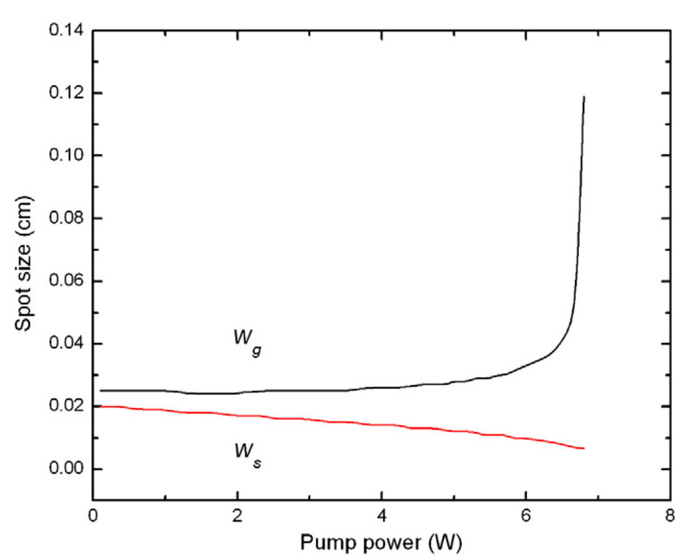

Fig. 3. The beam radii in the laser crystal and the saturable absorber versus pump power.