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Design of a Compact Diode-Pumped Intracavity-Doubled Nd:GdVO$_4$ Laser with 820-mW Red Light *

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We report a design of diode-pumped high power Nd:GdVO$_4$/LBO red laser with a compact linear cavity, which can output 820-mW red light at 670 nm with an optical conversion efficiency of 9.6%. The maximum output power of the fundamental light at 1.34 μm was 4 W with a slope efficiency of 45%.

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Diode-pumped solid-state red-light lasers have attracted much attention for their wide applications in colour display, medical treatment, and the pumping of Cr:LiSAF lasers. Intracavity second-harmonic generation of the 1.3 μm transition of Nd^{3+}-doped laser materials is a popular approach for obtaining red laser radiation. Nd:GdVO$_4$ is a relatively new laser material first developed by Zagumennyi *et al.* in 1992.[1] Nd:GdVO$_4$ is a novel and excellent laser crystal due to its excellent physical, optical and mechanical properties. Besides the large absorption coefficient and stimulated emission cross section, Nd:GdVO$_4$ crystals also have a large thermal conductivity along the ⟨110⟩ direction (about 11.7 W/m·K), which is even higher than that of Nd:YAG crystals[2,3] Many researchers have reported the studies on this crystal in red laser by using a multi-mirror folded cavity.[4−6] In comparison, the linear cavity is simple, compact, small in size and suitable to realize industrialization. Zheng *et al.* reported a compact 97-mW diode-pumped 671 nm red laser.[7] In this Letter, we describe a continuous-wave (cw) diode-pumped Nd:GdVO$_4$ intracavity frequency-doubled red laser using a compact three-element linear cavity in length of 49 mm. The maximum red output of 820 mW was generated with respect to an absorbed pump power of 8.6 W with an optical conversion efficiency of 9.6%. To our knowledge, this is the highest power achieved in red lasers using such a simple and compact cavity.

The experimental setup is shown in Fig. 1. The pump source used in our experiment is a high-brightness 30-W fibre-coupled diode laser. The pump power from the fibre with a core diameter of 400 μm and a numerical aperture of 0.22 was coupled into the gain medium Nd:GdVO$_4$ by the coupling system. The Nd:GdVO$_4$ crystal with Nd^{3+} concentration of 0.5 at.% and dimensions of $3 \times 3 \times 8\,mm^3$ was cooled directly with flowing water ($T = 17.0°C$). For simplicity and less loss of the cavity, the pump facet of Nd:GdVO$_4$ was coated for high reflection (HR) at 1.34 μm and antireflection (AR) at 808 nm. High transmission (HT) at 1064 nm was also specified to suppress parasitic oscillation at this wavelength. The other end of Nd:GdVO$_4$ was AR coated at 1.34 μm and 1064 nm. The output coupler employed different transmission at 1.34 μm in the fundamental- and red-light experiments (the transmission 6.3% in the fundamental light experiment), whereas it was coated for HR at 1.34 μm in the red light experiment.

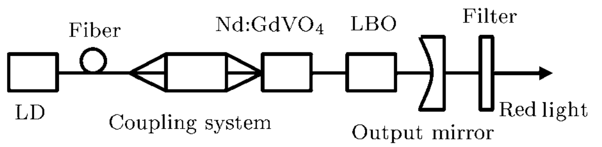

Fig. 1. Schematic of the diode-pumped intracavity-doubled Nd:GdVO$_4$ laser.

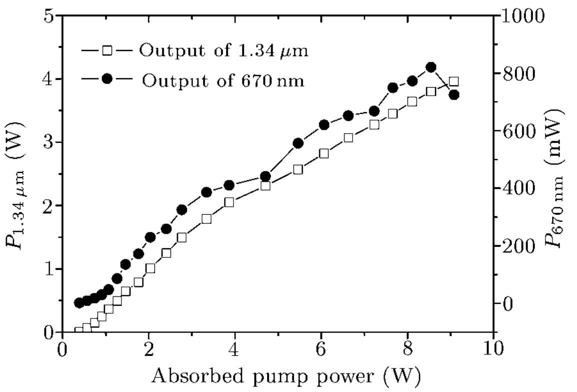

Fig. 2. Output power of 1.34 μm and 670 nm laser versus absorbed pump power.

The 1.34-μm laser experiment was carried out in the absence of the LBO crystal and the filter. The output coupler was a concave mirror with transmission 6.3% at 1.34 μm and a curvature radius of 80 mm. We

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tested the laser behaviour at 1.34 μm with the cavity length of 53 mm. Figure 2 shows the output power at 1.34 μm as a function of the absorbed pump power. The maximum output power is 4 W at an absorbed pump power of 9 W with a slope efficiency of 45%. The output power is very stable and no degradation can be observed in the operation of 1 h.

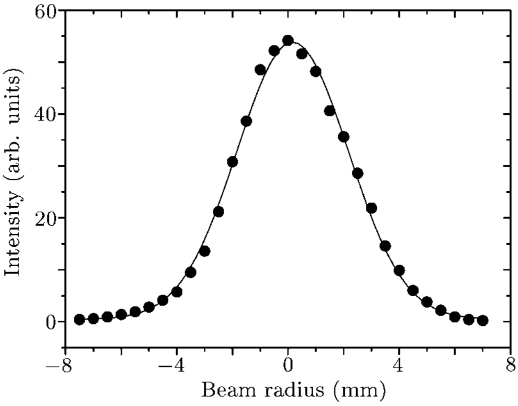

Fig. 3. The red beam spatial profile at 80 cm behind the output mirror.

In the red laser experiment, the output coupler was replaced by a mirror with 80-mm radius of curvature coated for HR at 1.34 μm and HT at 670 nm. A filter was placed after the output coupler in order to reflect the fundamental light that leaked out of the cavity. The frequency doubler of the LBO crystal ($3 \times 3 \times 18\,\mathrm{mm}^3$) was inserted into the laser cavity. Both the sides of the LBO crystal were polished and AR coated for 1.34 μm and 670 nm. The crystal was wrapped with indium foil and fixed inside a copper block that was mounted upon a thermoelectric cooler for active temperature control. The LBO crystal was cut for type-II noncritical phase matching at about 40°C derived from the dispersion equation and the phase-matched conditions. The optimum LBO temperature was measured to be 40.2°C in our experiment. Figure 2 shows the output power of the red laser at 670 nm as a function of the absorbed pump power. The maximum red laser output power of 820 mW with an optical conversion efficiency of 9.6% was generated at an absorbed pump power of 8.6 W. The output power began to drop because of the thermal-lensing effect when the absorbed pump power exceeds 8.6 W. The leakage for 1.34 μm from the output coupler decreases the intracavity intensity. We could expect higher red output if the coatings would be improved. The beam spatial profile of the red laser at output power of 500 mW was measured at 80 cm behind the output mirror by using a small pinhole scanning across the laser beam. The result was shown in Fig. 3. A nearly Gaussian beam intensity profile with a divergence of 5 mrad (half-angle) was obtained. We observed the stability of the laser by monitoring the red output power with a power meter. As shown in Fig. 4, the output noise was 2% (rms) in 30 min at the output power level of 500 mW. Mode hopping was observed at higher output power. Possible reasons about this phenomenon could be attributed to transverse mode competition, heat effect and the so-called " red problem".[8]

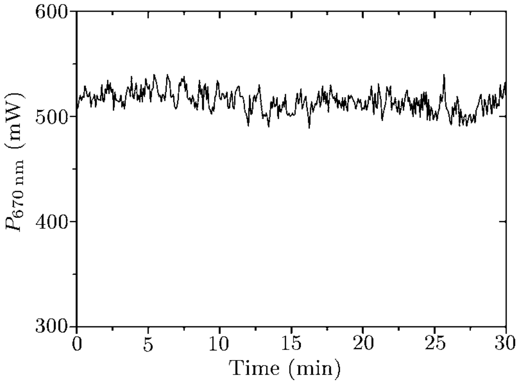

Fig. 4. The stability testing at the red power level of 500 mW.

In conclusion, we have experimentally demonstrated a cw operation of a diode-pumped Nd:$GdVO_4$ 1.34 μm and 670 nm laser with a simple and compact linear cavity in power of 4 W at 1.34 μm with a slope efficiency of 45% with respect to the absorbed pump power. We obtained 820 mW red light at 670 nm with an optical conversion efficiency of 9.6% by intracavity doubling with an LBO crystal for type-II noncritical phase matching. If the coatings were improved and the cavity was further optimized, higher output power and stability should be achieved.

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