Diode-pumped Nd:$Y_xGd_{1-x}VO_4$ crystal continuous-wave laser

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The diode-pumped Nd:$Y_xGd_{1-x}VO_4$ crystal continuous wave (CW) laser operating at 1.06 μm with a simple plane-concave cavity and a "V-shaped" folded cavity for intracavity frequency-doubling have been studied. With the incident pump power of 8 W, an output power (1.06 μm) of 3.4 W was achieved, giving an optical conversion efficiency of 42.5%. 884 mW of stable green radiation was generated with the incident pump power of 5.9 W, giving an optical conversion efficiency of 15%.

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There are many applications for diode-pumped solid-state lasers in the visible spectral range. Some are for under water communication, projection displays, measurement technique, chemical processing and so on. Laser crystal is one of the most important components of a diode-pumped solid-state laser. Nd:YVO_4 and Nd:$GdVO_4$ are very efficient laser materials, and have been widely used in commercial laser products for their good thermo-physical, chemical and laser properties at present. The Nd:YVO_4 crystal has larger absorption coefficient and stimulated emission cross section. The Nd:$GdVO_4$ crystal has a large thermal conductivity along the direction of ⟨110⟩. Nd:YVO_4 and Nd:$GdVO_4$ have been extensively studied in diode-pumped solid-state lasers[1−10]. Recently, the studies on Nd:$YGdVO_4$ crystals were reported[11,12]. Nd:$Y_xGd_{1-x}VO_4$ crystal has more excellent mechanical properties than Nd:$GdVO_4$ and high thermal conductivity than Nd:YVO_4. The absorption spectra show that the co-doped crystals have large absorption cross section and a wide absorption band efficiently pumped by laser diodes, and have been proved to be excellent laser materials at 1.06 and 1.34 μm[11]. However, efficient intracavity frequency-doubled Nd:$Y_xGd_{1-x}VO_4$ lasers were not reported until now.

In this paper, we present a compact continuous wave (CW) diode-pumped Nd:$Y_xGd_{1-x}VO_4$ laser at 1.06 μm, and an efficient diode-pumped intracavity frequency-doubled Nd:$Y_xGd_{1-x}VO_4$/KTP green laser with a "V-shaped" folded cavity.

A Schematic diagram of the CW Nd:$Y_{0.88}Gd_{0.12}VO_4$ laser is shown in Fig. 1. The length of the plano-concave cavity was about 70 mm. The Nd:$Y_{0.88}Gd_{0.12}VO_4$ crystal was pumped by a fiber coupled semiconductor laser at 808 nm with the maximum output power of 10 W and a numerical aperture of 0.12. The a-cut

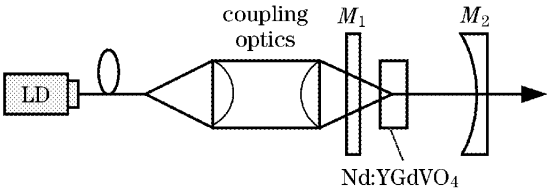

Fig. 1. Schematic of CW Nd:$Y_xGd_{1-x}VO_4$ laser at 1.06 μm.

Nd:$Y_{0.88}Gd_{0.12}VO_4$ crystal has a Nd^{3+} concentration of 0.5 at.-% with dimensions of 3.5×3.5×6 mm^3 ($b \times c \times a$) with anti-reflection (AR) coating at 808 nm and 1.06 μm on both faces. A flat mirror (M_1) as the input mirror was AR coated at 808 nm and high-reflection (HR) coated at 1.06 μm. The output from the semiconductor laser was focused into the crystal with a coupling optical system. The output coupler (M_2) was a concave mirror (radius of 100 mm) and its transmission was 10% for 1.06 μm.

Figure 2 shows the measured output power at 1.06 μm of the Nd:$Y_{0.88}Gd_{0.12}VO_4$ laser versus the incident pump power. The highest output power of 3.4 W was achieved with an 8-W incident pump power. The pump threshold was about 0.55 W. The optical conversion efficiency was 42.5%, and the slop efficiency of 46% was calculated from the curve. The output power was linear with the incident pump power and was not getting to saturate, mainly because the internal loss of the laser was small.

Nonlinear frequency conversion of the laser is a convenient method to extend the wavelength to green range. Diode-pumped Nd:YVO_4 and Nd:$GdVO_4$ green lasers have been successfully demonstrated[1−5]. As a promising laser crystal, diode-pumped Nd:$Y_xGd_{1-x}VO_4$ green laser is also efficient. The schematic for CW Nd:$Y_{0.88}Gd_{0.12}VO_4$ /KTP green laser is shown in Fig. 3. It was a three mirror folded resonator. The total cavity length was about 170 mm. The physical length between M_2 and M_3 was about 42 mm. M_2 was a flat mirror with high reflection at the fundamental wavelength (1.06 μm)

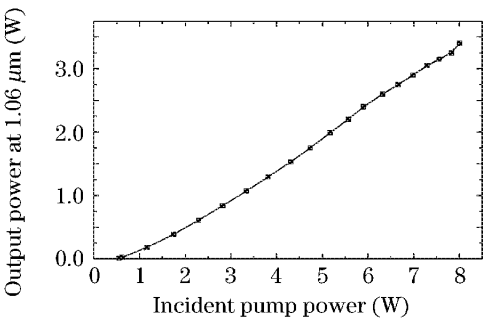

Fig. 2. CW output power at 1.06 μm as a function of the incident pump power.

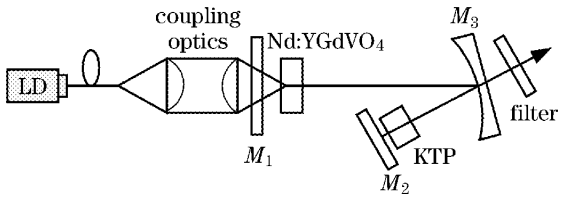

Fig. 3. Schematic of the Nd:$Y_xGd_{1-x}VO_4$/KTP green laser.

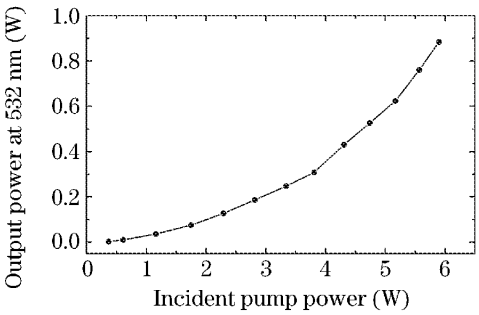

Fig. 4. CW green output power of the Nd:$Y_xGd_{1-x}VO_4$/KTP green laser as a function of the incident pump power.

and the second harmonic wavelength (532 nm). M_3 was a concave mirror (radius of 80 mm) with high reflection at 1.06 μm and high transmission at 532 nm.

A KTP crystal was used for frequency doubling, setting close to M_2, and was cut for II-type phase matching ($\theta = 90°$, $\phi = 23.4°$) at 1.06 μm and with dimensions of $3\times3\times5$ mm^3. Both the faces were AR coated for 1.06 μm and 532 nm. The KTP crystal was mounted on a copper stand without active cooling or temperature control.

Figure 4 shows the output characteristics of the green laser. As seen, 884 mW of CW green power was obtained at 5.9 W of incident pump power. The conversion efficiency of the pump power into green output power was about 15%. The pump threshold was only 0.37 W, as no thermal lensing was required to make the resonator stable, so the threshold was determined only by the total internal losses. The green output power increased rapidly and smoothly as the enhancement of the intracavity fundamental light. When the pump power was raised further, the green output power began to decrease, caused by the increasing thermal lensing in the resonator. To examine the output stability, we measured the fluctuation of the average green output power, which is only 3% for 30 minutes. The green light output has good round beam spot.

In summary, a compact CW laser at 1.06 μm and an efficient intracavity frequency-doubled green laser have been demonstrated with a co-doped crystal Nd:$Y_xGd_{1-x}VO_4$. With the incident pump power of 8 W, an output power (1.06 μm) of 3.4 W was achieved with a 10% coupler, giving an optical conversion efficiency of 42.5%. 884 mW of stable CW green radiation was generated with the pump power of 5.9 W, giving an optical conversion efficiency of 15%. The laser output was a TEM_{00} mode. Our results have proved that Nd:$Y_xGd_{1-x}VO_4$ crystal is a new potential laser material.

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