Efficient dual-wavelength operation of Nd:LYSO laser by diode pumping aimed toward the absorption peak

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By aiming the pump wavelength of the laser diode to the absorption peak at 811 nm of the $(Nd_{0.005}Lu_{0.4975}Y_{0.4975})_2SiO_5$ (Nd:LYSO) crystal, an efficient dual-wavelength operation at 1,075 and 1,079 nm is obtained. The maximum output power is 702 mW when the incident pump power is 2.53 W, corresponding to an optical conversion efficiency of 27.7% and a slope efficiency of 37.0%

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Diode pumped solid-state lasers have attracted much attention in recent years as efficient and cost-effective light sources[1−8]. Among all of the designing sections, the choice of laser gain medium is a key factor that determines output performance. Since the first report published in 1997, the use of mixed oxyorthosilicate crystal LYSO on scintillator applications[9−11] and Yb-doped lasers[12−15] has been studied in numerous work. LYSO crystallizes in monoclinic with excellent mechanical property. Owing to the inhomogeneous broadening of its spectrum, mixed crystal has some particular advantages over single crystal, such as enhancement of pulse energy in Q switching[16] and much shorter pulse width in mode locking[17]. Efficient tunable continuous-wave (CW)[12,18], passively Q-switched[13], and self-mode-locked[15] laser actions have been obtained with Yb:LYSO crystal, suggesting the excellent performance of LYSO. In addition, there have also been some reports on Nd-doped LYSO crystal and its laser action.

In 2010, Li *et al.* have reported the growth of Nd:LYSO crystal using the traditional Czochralski technique[19]. The absorption and fluorescence spectra as well as the fluorescence decay lifetime of 226 μs have been presented. The strongest absorption is located at 811 nm, corresponding to an absorption cross section of 6.14×10^{-20} cm^2 with a full-width at half-maximum (FWHM) of 5 nm. The peak emission cross sections are 7.17×10^{-20} cm^2 at 1,074 nm and 7.84×10^{-20} cm^2 at 1,078 nm, with FWHM of 2.7 and 6.1 nm, respectively. Using an 808-nm laser diode (LD) as the pump source, Li *et al.* obtained the highest output power of 814 mW under an absorbed pump power of 3.4 W[19]. Given that the absorption efficiency of Nd:LYSO crystal to 808-nm light has been measured to be 38%, the optical conversion efficiency only reached 9.1% when the incident pump power is considered[19]. Due to the much larger absorption cross section at 811 nm (6.14×10^{-20} cm^2) than that at 808 nm (1.94×10^{-20} cm^2), this result is expected to improve if a LD with a central wavelength at 811 nm is used as the pump source.

In this letter, we report an efficient 811-nm LD pumped dual-wavelength laser of Nd:LYSO crystal. The maximum output power of 702 mW is obtained under an incident pump power of 2.53 W, corresponding to an optical conversion efficiency of 27.7% and a slope efficiency of 37.0%.

The laser setup is shown in Fig. 1. The pump source was a fiber-coupled laser diode with central wavelength at 811 nm. Through a focusing system, the pump light was delivered into the laser medium with a spot radius of 0.1 mm. The input mirror M1 was a plane one with antireflective (AR) coating at 811 nm on the pump face, high-reflection (HR) coating at 1,075 nm, and high-transmission (HT) coating at 811 nm on the other face. The output coupler (OC) M2 was a flat partial reflection (PR) mirror with different transmissions of 1.6%, 5%, 10%, and 16% at 1,075 nm. A Nd:LYSO crystal (3×3×7 (mm), cut along the b-axis) with Nd^{3+} concentration of 0.5 at.-% was used as the laser medium. Its end faces were polished and AR coated at 811 and 1,075 nm. The cavity length was about 2.7 cm. To remove the residual heat, the crystal was wrapped with indium foil and mounted on a water-cooled copper block. The temperature of the cooling water was controlled at 15 °C. The CW output power was measured by a power meter (EPM 2000, Molectron Inc.). The laser spectrum was recorded using an optical spectrum analyzer (HR4000CG-UV-NIR, Ocean Optics Inc.).

The CW laser performance of Nd:LYSO was measured using 4 mirrors with different transmittance values of

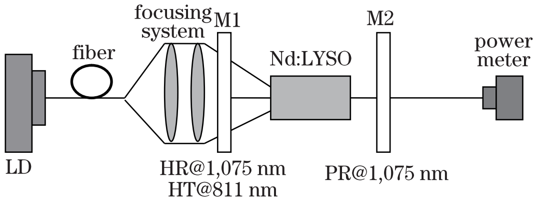

Fig. 1. Schematic diagram of the laser setup.

1.6%, 5%, 10%, and 16% as the OC. The dependence of the output power on the incident pump power is shown in Fig. 2. The best result comes from the 10% output mirror. The maximum output power of 702 mW is obtained at the incident pump power of 2.53 W, corresponding to an optical conversion efficiency of 27.7% and a slope efficiency 37.0%. These results are obviously better than those reported in Ref. [19]. Such improvement could be attributed to the two changes of pump source. Firstly, the pump wavelength changed from 808 to 811 nm, which aimed to the strongest absorption peak of Nd:LYSO crystal accurately, and the absorption efficiency is elevated from 38% to more than 80%; secondly, the radius of pumping specula reduced from 0.256 to 0.1 mm, so the pump intensity shown in this letter is much higher (∼6 times) than that in Ref. [19]. The above efficiencies are also better (∼30%) than those of the single crystal Nd:LSO reported in Ref. [20], when the incident pump power is considered. Figure 2 shows that the output power is not saturated even at the highest incident pump power of 2.53 W. The maximum incident pump power that our laser diode can provide is 2.53 W, which prevents the output power scaling to a higher level. High transmittance of the output mirror increases the optical loss of the cavity, thereby increasing the laser threshold, so the lowest threshold of 0.235 W is obtained from the 1.6% output mirror. Figure 3 shows the respective laser spectra under different incident pump power levels of 0.348, 0.727, and 2.53 W. The 1,079-nm component appears first at the threshold due to the larger emission cross section at 1,078 nm than that at 1,074 nm[19]. When the incident pump power reached 0.633 W, the 1,075-nm component appeared and rose with the increase of pump power, although it is weaker than the 1,079-nm component during all the conditions. Figure 3(c) shows that the output power ratio between 1,075 and 1,079 nm is about 7:8 at the highest pump power of 2.53 W.

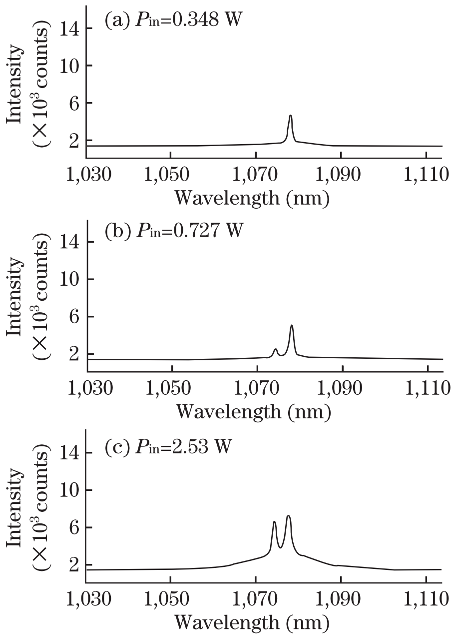

Fig. 3. Spectra of the Nd:LYSO laser.

The stability for 20 min at the output power of 630 mW is shown in Fig. 4, which demonstrates that the output power is comparatively stable (the instability of output power is less than ±2%). The dependence of the output power on the temperature of LD is shown in Fig. 5. The maximum output power is obtained at a temperature of 26.5 °C, which corresponds to the pump wavelength of 811 nm. When the temperature of the laser diode deviates from 26.5 °C, the output power decreased rapidly. The dependence of pump wavelength and pump absorptivity of the laser crystal on the temperature of laser diode was also measured. Figure 6 shows that the maximum pump absorptivity of 81.7% is obtained at a temperature of 26.5 °C, corresponding to a pump wavelength of 810.74 nm. By comparing Figs. 5 and 6, output power and pump absorptivity are seen to have similar varying disciplines, thereby illustrating that the pump absorptivity is a key factor affecting the laser output.

In conclusion, we demonstrate an 811-nm LD end-pumped Nd:LYSO laser at 1,075 and 1,079 nm. The maximum output power is 702 mW at an incident pump power of 2.53 W, with an optical conversion efficiency of 27.7% and a slope efficiency of 37.0%. Our research shows that aiming the pump wavelength to the absorption peak of Nd:LYSO crystal, as well as increasing the pump brightness, is an effective means to lessen thermal

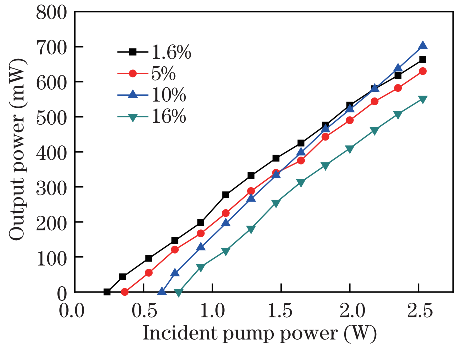

Fig. 2. Output power versus incident pump power.

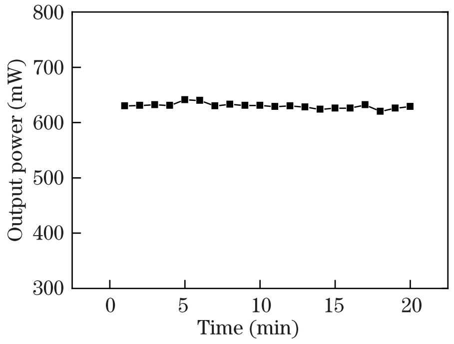

Fig. 4. Stability at the output power of 630 mW.

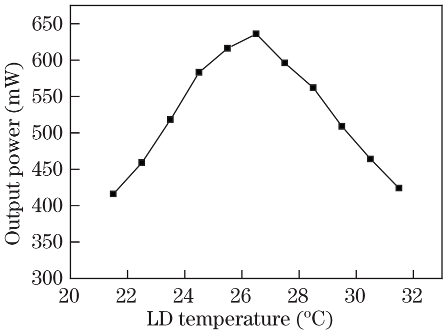

Fig. 5. Dependence of the output power on the temperature of LD.

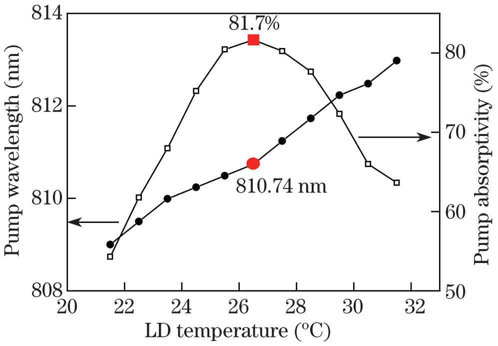

Fig. 6. Dependence of pump wavelength and pump absorptivity on the temperature of LD.

loading and enhance the conversion efficiency of Nd:LYSO laser. Given that the Rayleigh length of our present pump source is calculated to be 39 mm, which is much longer than the 7-mm crystal length that we have used, the crystal can be lengthened in future experiments to fit better with the Rayleigh length of the focus spot. This can also increase pump absorptivity. The output power is still expected to be increased substantially if an 811-nm LD with higher pump power is available and the doping concentration of Nd:LYSO crystal is increased moderately. The improvement brought by these methods can promote the potential uses of dual-wavelength Nd:LYSO laser in many scopes undoubtedly, including new green laser generation by doubling frequency or sum frequency, 1 THz radiation generation by difference frequency, as well as Q-switched and ultrafast laser systems.

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