High-power diode-end-pumped Tm:YAP and Tm:YLF slab lasers

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Diode-end-pumped continuous-wave (CW) Tm:YAP and Tm:YLF slab lasers are demonstrated. The a-cut Tm:YAP and Tm:YLF slabs with doping concentrations of 4 at.-% and 3.5 at.-%, respectively, are pumped by fast-axis collimated laser diodes at room temperature. The maximum CW output powers of 72 and 50.2 W are obtained from Tm:YAP and Tm:YLF, respectively, while the pump power is 220 W, corresponding to the slope efficiencies of 37.9% and 26.6%, respectively.

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High-power and high-energy 2-μm lasers have great potential applications in medicine, military, and science. Firstly, as eye-safe light sources, 2-μm lasers have been widely used in surgery and dentistry. Secondly, 2-μm lasers have huge application prospects in the fields of remote sensing and optical communications, especially in coherent Doppler light detection and ranging (LIDAR). Thirdly, 2-μm solid-state lasers with high peak powers are effective pump sources of 3–5-μm optical parametric oscillators (OPOs)[1−4].

Because of the long fluorescence lifetime, high quantum efficiency introduced by the cross-relaxation mechanism, and the ability to be pumped directly by commercial laser diodes (LDs), Tm-doped solid-state lasers, such as Tm:YAG, Tm:YLF, Tm:LiLuF$_4$, and Tm:KLu (WO$_4$)$_2$, have been studied and reported recently[5−10]. Except for their similar thermal and mechanical properties as that of Tm:YAG crystal, Tm:YAP and Tm:YLF are natural birefringence crystals that can excite polarized light without external polarizer. Furthermore, high-power Tm:YAP and Tm:YLF lasers are efficient pump sources for Ho-doped materials. Ho-doped materials are more suitable for energy storage than Tm-doped materials because of their larger emission cross. However, Ho-doped materials cannot be efficiently diode-pumped directly commercially[11,12]. Thus, detailed research on how to obtain higher output power with high efficiency is still needed.

In this letter, we present Tm:YLF and Tm:YAP slab-structure lasers that are end-pumped by two diodes from both ends. The maximum output powers of 72 and 50.2 W are obtained from Tm:YAP and Tm:YLF, respectively.

In the experiment, as shown in Table 1, the a-cut Tm:YLF crystal has a dope concentration of 3.5 at.-% with dimension of 12×6×1 (mm). The a-cut Tm:YAP crystal has a dope concentration of 4 at.-% with dimension of 12×8×1.5 (mm). Both end faces of Tm:YLF and Tm:YAP are antireflection (AR) coated for the laser wavelength of 1 950±50 nm and pump wavelength of 790±15 nm. Figure 1 shows the absorption spectra of the a-cut 4 at.-% Tm:YAP and 3.5 at.-% Tm:YLF crystals. The two large surfaces of the slab crystals are wrapped in 50-μm indium foil and cooled by a copper microchannel heat sink. Figure 2 shows the scheme of the Tm:YLF and Tm:YAP lasers. Each fast-axis collimated diode can provide 110-W continuous-wave (CW) output power with central wavelength of 791.5 nm at 24 °C. The pump light is shaped by one plano-convex spherical lens and one cylindrical lens whose focal lengths are both 90 mm. In addition, both surfaces of these lenses are AR-coated at 790±15 nm. The mirror M1 is an output coupler with different reflectivity at 1 950±50 nm and different radii of curvature. The rear mirror M2 is AR-coated at 790±15 nm and HR-coated at 1 950±50 nm. The mirror M3 is AR-coated at 790±15 nm and HR-coated at 1 950±50 nm at 45°.

Only one diode is used to pump the crystal. Figure 3 shows the output power with different transmissions of the output coupler and radii of curvature. For Tm:YAP,

Table 1. Parameters Used in Laser Experiments

Parameter	Tm:YAP	Tm:YLF
Doping Concentration (at.-%)	4	3.5
Dimension (mm)	1.5×8×12	1×6×12
Central Wavelength of Pump LDs	791.5 nm, 24 °C	

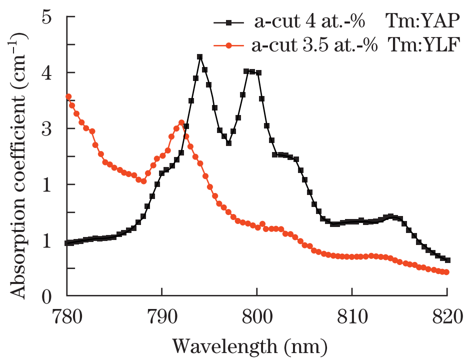

Fig. 1. Unpolarized absorption spectra of the a-cut 4 at.-% Tm:YAP and a-cut at.–3.5% Tm:YLF crystals (780–820 nm).

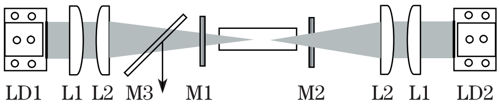

Fig. 2. Scheme of the Tm:YLF and Tm:YAP slab lasers. L1–L2: lenses.

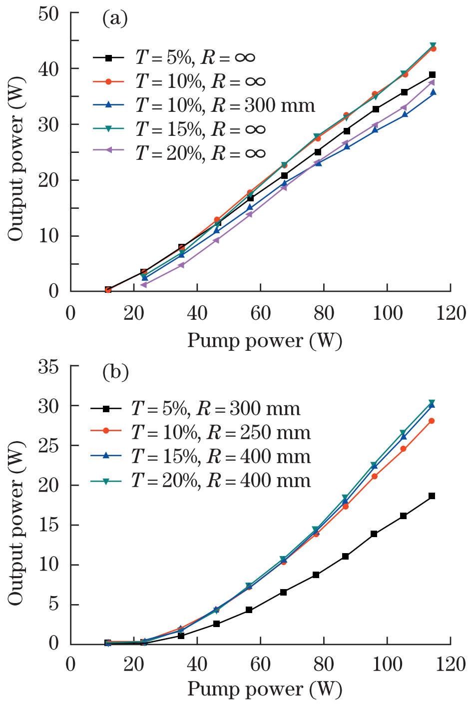

Fig. 3. Output power of single-end-pumped (a) Tm:YAP and (b) Tm:YLF.

the maximum output power is 44.2 W, while the transmission of the output coupler is 15%, corresponding to a slope efficiency of 45.5%. For Tm:YLF, the maximum output power is 30.54 W, while the transmission of the output coupler is 20% and the radius of curvature is 400 mm, corresponding to a slope efficiency of 31.3%. When the two diodes are used to pump the crystal from both ends, the maximum output powers are 72 and 50.5 W, corresponding to slope efficiencies of 37.9% and 26.6%, respectively (as shown in Fig. 4).

The result shows that Tm:YAP with a dope concentration of 4 at.-% has higher slope efficiency than the 3.5 at.-% Tm:YLF with the same pump power. Figure 5 shows the absorption spectra from 1 900 to 2 000 nm. The reabsorption coefficient of the 3.5 at.-% Tm:YLF is about 0.5 cm^{-1} at 1 909 nm, which is higher than the coefficient for 4 at.-% Tm:YAP (about 0.04 cm^{-1} at 1 993 nm). A more serious reabsorption decreases the slope efficiency of Tm:YLF.

Figure 6 shows the output laser spectra of Tm: YAP and Tm:YLF. With the output coupling of 15% and doping concentration of 4 at.-%, the central laser wavelength of the a-cut Tm:YAP is 1 993 nm. For the a-cut 3.5 at.-% Tm:YLF, the central wavelength is 1 909 nm.

In conclusion, we demonstrate high-power CW diode-end pumped Tm:YAP and Tm:YLF slab lasers at room temperature. When the pump power is 220 W, the maximum output powers are 72 and 50.2 W with slope efficiencies of 37.9% and 26.6% for the Tm:YAP and

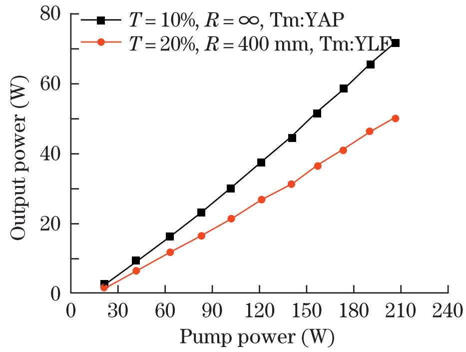

Fig. 4. Output power of double-end-pumped Tm:YAP and Tm:YLF.

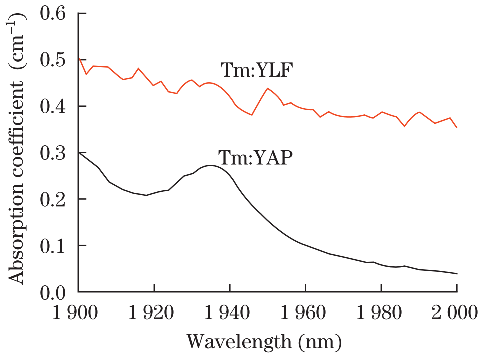

Fig. 5. Absorption spectra of the a-cut 4 at.-% Tm:YAP and a-cut 3.5 at.-% Tm:YLF crystals (1 900–2 000 nm).

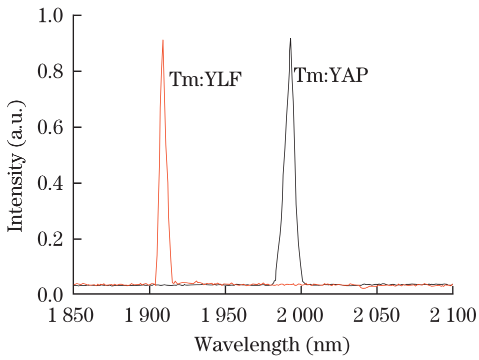

Fig. 6. Laser spectra of a-cut Tm:YAP and Tm:YLF with doping concentrations of 4 at.-% and 3.5 at.-%, respectively.

Tm:YLF slab lasers, respectively. The experimental results show that Tm:YAP and Tm:YLF crystals with slab structure are effective configurations for high-power 2-μm lasers at room temperature.

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