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Experimental study of a VBG-based Tm:YLF slab laser at different output coupler parameters

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Abstract. **The performance of a Tm:YLF slab laser is studied at different output coupler parameters. Use is made of a 20-mm-long *a*-cut slab crystal doped with 2.5 at.% thulium ions. With a volume Bragg grating and a Fabry–Perot etalon, the selected output wavelength of this Tm:YLF slab laser is 1908 nm. For the optimised output coupler with a transmission of 20% and a radius of curvature of 300 mm, the output power exceeds 74.1 W and the slope efficiency with respect to the absorbed pump power reaches 48.4%. In addition, the beam quality of the Tm:YLF slab laser is improved.**

Keywords: *solid-state laser, diode pumping, Tm:YLF, volume Bragg grating.*

1. Introduction

Solid-state lasers operating around 2 μm can be successfully used in a variety of applications such as remote-sensing and medicine [1–3]. Thulium-doped materials have several attractive features which allow generation of light in this wavelength band, including a broad emission bandwidth, a long lifetime of the upper laser level and a potential for the high quantum efficiency due to a two-for-one cross-relaxation process [4]. Therefore, high-power Tm lasers have been widely investigated [5–7].

Tm:YLF crystals exhibit excellent spectroscopic properties which allow relatively low brightness diode pump sources to be used. In addition, they have an emission spectrum that overlaps the main absorption lines of interest in Ho-doped crystals [8–10]. Slab geometries of Tm:YLF crystals allow the pump and, therefore, output power to be significantly scaled, by spreading out the heat load in the horizontal direction. Cheng et al. [11] demonstrated a single-end-pumped Tm:YLF slab laser producing a 30.5-W cw output at 1909 nm with a slope efficiency of 31.3%. Schellhorn et al. [12] fabricated a Tm:YLF slab laser producing a 148-W cw output at 1912 nm with a slope efficiency of 41% with respect to the absorbed pump power. High average powers (~200 W) from the Tm:YLF slab laser around 1.9 μm have been obtained by Li et al. [13]. However, the laser performance was only briefly discussed in this paper. Thus, the performance of the Tm:YLF slab laser still needs to be further investigated in detail.

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A more stable wavelength and a narrower linewidth of Tm:YLF lasers make it possible to improve their efficiency, as compared to Ho lasers. A volume Bragg grating (VBG), used in solid-state lasers, exhibits stability and wavelength selectivity, which allow one to realise a narrow linewidth of the laser output. In this paper, we study a 1908-nm VBG-based Tm:YLF slab laser at different output coupler parameters. For the output coupler with the transmission of 20% and the radius of curvature of 300 mm, the output power is 74.1 W at an incident pump power of 270.3 W, which corresponds to the 48.4% slope efficiency with respect to the absorbed pump power.

2. Experimental setup

The schematic diagram of the setup is shown in Fig. 1. The pump unit consists of a 6-bar laser-diode (LD) stack, collimated along the fast axis. The stack has an output power of 300 W at a cooling water temperature of 25 °C. The centre wavelength of the pump was measured to be 788 nm at the lasing threshold and increased nearly linear to 792 nm at the maximum operation current. The spectral width of the pump was 1.5 nm. Cylindrical lenses L1 and L2 with a focal length of 100 mm and 50 mm were used to focus the beam of the diode bars along the x axis to a spot of 4 mm in diameter. A cylindrical lens L3 with a focal length of 80 mm collimated the beams of the diode bars along the y axis to a spot of 0.8 mm in diameter.

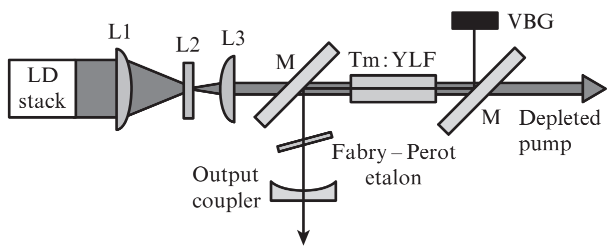

Figure 1. Scheme of the experimental setup.

The Tm:YLF slab crystal has a doping concentration of 2.5 at.% and measured 1.5 mm in thickness, 12 mm in width and 20 mm in length. Both ends of the slab crystal are antireflection coated for 790 nm and the lasing wavelength around 1.9 μm. The slab was sandwiched between two water-cooled copper heat sinks using a 0.1-mm-thick indium foil. The temperature of the cooling water for the laser crystal was controlled at 18 °C. The folded resonator consisted of a VBG, two flat 45° dichroic mirrors (M) with a high reflectivity ($R >$

99.7%) in the wavelength range 1.9–1.95 μm and a high transmission at the pump wavelength ($T > 95\%$), and a concave output coupler. A fraction of the pump radiation absorbed at the pump wavelength of 792 nm was 80%. The physical resonator length was approximately 80 mm. The diffraction efficiency of the VBG was greater than 99% at 1907.4 nm and the incidence angle of 0.5°. This angle with respect to the surface allows one to avoid unwanted parasitic reflections. The VBG and the Fabry–Perot etalon made of a 0.3-mm-thick YAG crystal made it possible to select the laser wavelength.

3. Experimental results

In our experiment, we studied the influence of the output coupler parameters on the Tm:YLF slab laser output (Fig. 2). We used couplers with a radius of curvature $R = 200$ mm and $R = 300$ mm and different transmissions. Considering the slope efficiency, the optimised transmissions amounted to 30% and 20% for the radius of curvature of 200 mm and 300 mm, respectively. In this case, the lasing thresholds were 50.8 W and 41.7 W and the slope efficiencies with respect to the absorbed pump power were 48.4% and 46.3%, respectively. For the output coupler with the transmission of 30% and radius of curvature of 200 mm, the maximum cw output power reached 74.1 W at a pump power of 270.3 W. For the output coupler with the transmission of 20% and radius curvature of 300 mm, the maximum cw output power was 71.8 W at a pump power of 256.4 W.

For the output coupler with the transmission of 30% and radius of curvature of 200 mm, the laser wavelength was measured with an EXFO WA-650 spectrum analyser combined with an EXFO WA-1500 wavemeter. At the output power of 1.5 W and the linewidth of 0.1 nm, the wavelength peak was at 1907.8 (Fig. 3). At the maximum output level, the wavelength peak was at 1908.1 nm. When the output power was varied from 1.5 to 74.1 W, we observed a laser wavelength shift of only 0.3 nm.

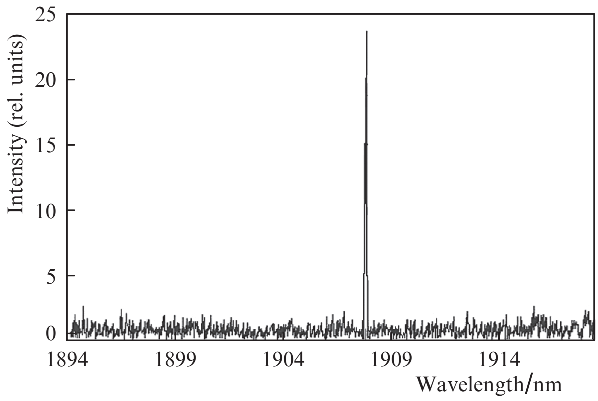

Figure 3. Emission spectra of a Tm:YLF slab laser at a power of 1.5 W.

The beam quality of the output laser was measured with the help of the travelling 90/10 knife-edge method. The M^2 factors at the output power of 20 W and 40 W were calculated to be 55.6 and 98.1 in the x axis direction and 1.4 and 1.7 in the y axis direction, respectively (Fig. 4). Under the same output level, the centre wavelength of the Tm:YLF slab laser with a VBG and an etalon was better matched with the absorption peak of the Ho:YAG crystal, as compared with Ref. [11]. Furthemore, the use of a VBG and an etalon inserted in the cavity of the Tm:YLF slab laser at a higher

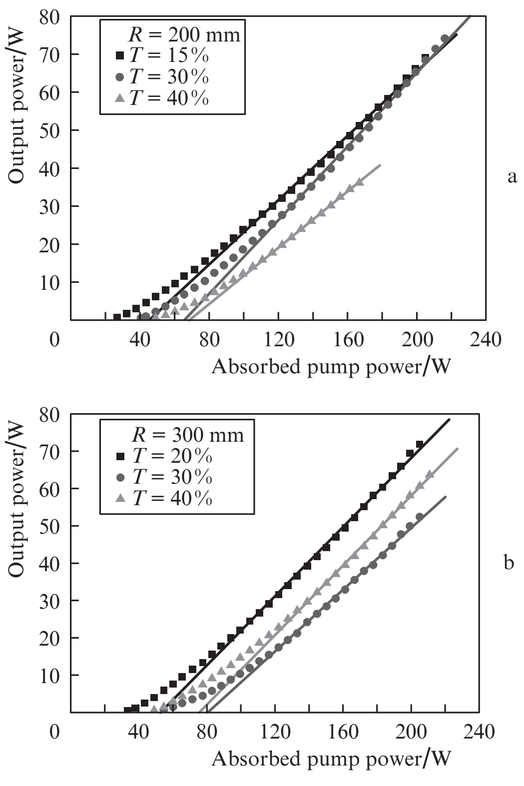

Figure 2. Dependence of the output power on the absorbed pump power at R = (a) 200 and (b) 300 mm.

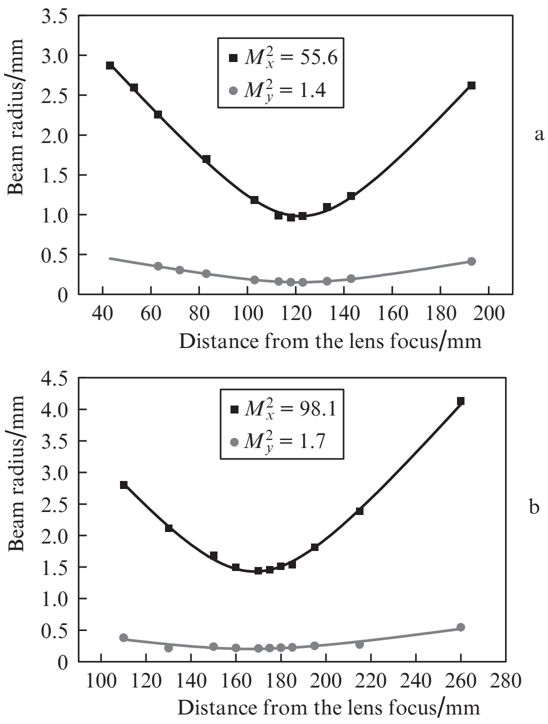

Figure 4. Beam quality factor M^2 at an output power of (a) 20 and (b) 40 W.

output power level is expedient not only to limit the wavelength, but also to improve the laser beam quality.

4. Conclusion

We have investigated the performance of the Tm:YLF slab laser at different output coupler parameters. The output wavelength of the Tm:YLF slab laser was selected at 1908 nm by a volume Bragg grating and a Fabry–Perot etalon. For the optimised output coupler with the transmission of 20% and the radius of curvature of 300 mm, the output power exceeded 74.1 W and the slope efficiency with respect to the absorbed pump power reached 48.4%. The M^2 factors at the output power of 20 W and 40 W were calculated to be 55.6 and 98.1 in the x axis direction and 1.4 and 1.7 in the y axis direction, respectively. The subject of future work is the scaling of the structure to higher output powers, which can be done by adding another slab crystal and a diode stack.

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