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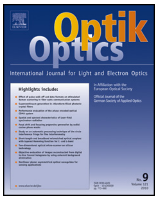

High power Tm:YLF bulk laser wavelength-stabilized by two F-P etalons

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In this work, we report a 1908 nm Tm:YLF bulk laser pumped by the fiber coupled diode laser, the maximum output power of which was 70.8 W at the incident pump power of 184.6 W, corresponding to the optical-to-optical efficiency of 38.4% and slope efficiency of 43.7%. The laser wavelength was selected and restricted at 1908.1 nm by two etalons inserted in the cavity. The laser beam quality factors M^2 were measured to be 1.79, 1.85 and 1.90 at the output power of 20.1 W, 41.2 W and 65 W, respectively. A laser wavelength shift of only 0.1 nm with the incident pump power varying from 20.1 W to 184.6 W was observed.

1. Introduction

2 μm thulium laser source is of interest for many applications in the scientific [1], defensive and medical fields. At room temperature, an excellent way to obtain 2 μm source is to use a high-power laser emitting around 1.9 μm to pump a holmium-doped material. The low quantum defect of holmium-doped lasers make the heat load small, and give the potential for scaling to high output powers. A diode-pumped Tm:YLF laser is an attractive 1.9 μm source. It has a lot of advantages compared with other mediums [2–6], such as, no thermally induced birefringence, low up-conversion loss, higher optical damage threshold, better thermal stability and the polarizing emission laser output. Diode dual-end-pumped Tm:YLF laser is a excellent 1.9 μm source, because the thulium-doped crystals have high absorption peaks at 790 nm which is just the emission wavelength of the fiber coupled output diode laser [7,8]. The 1.9 μm Tm:YLF laser can efficiently pump the holmium laser [12–14]. Especially, its emission lines have a good overlap with the main absorption lines of Ho:YAG [15].

These years, high power Tm lasers around 1.9 μm have been widely investigated [9–11]. The mainly used bulk crystals for 1.9 μm radiation are Tm:YLF. In the year of 2000, Budni et al. used four fiber coupled diode lasers to pump two crystals Tm:YLF laser and 36 W CW laser at 1.91 μm had been obtained [8]. Dergachev et al. reported a broadly tunable diode-pump Tm:YLF laser producing CW output power of 18 W [3]. Using a volume Bragg grating, 111.7 W pump power laser of 792 nm, a 41.1 W CW output power at 1908 nm was obtained [16]. Li et al. obtained 200 W of output power with respect to 486 W of incident pump power [17]. To our knowledge, this is the highest published data for Tm:YLF innoslab laser. However, the beam quality factor of M_x^2 was very big, meanwhile, the laser was operated in very high order mode.

In this work, we demonstrated a high efficient CW diode dual-end-pumped Tm:YLF laser around 1908 nm with two etalons tuning in the cavity. The crystal temperature was controlled at 19 °C. When the incident power of 792 nm pump laser reached up to 184.6 W, we obtained 70.8 W output power of the emission wavelength at 1908.1 nm. The corresponding optical-to-optical conversion efficiency was 38.4% and the slope efficiency was 43.7%. The laser beam quality factors M^2 were measured to be 1.79, 1.85 and 1.90 at the output power of 20.1 W, 41.2 W and 65 W, respectively. A laser wavelength shift of only 0.1 nm with the incident pump power varying from 20.5 W to 184.6 W was observed.

2. Experimental setup

The experimental setup of the dual crystal Tm:YLF laser is shown in Fig. 1. The length of the physical resonator was 120 mm. The output coupler was a plano-concave mirror with a 200 mm radius of curvature, and it was coated for 30% transmittance at 1.91 μm. The flat 0° (M1) and 45° dichroic mirrors (M2&M3) had high reflectivity ($R > 99.97\%$) around 1.9 μm and high transmission at the pump wavelength ($T \sim 98.6\%$). The 0.3 mm-thickness and 0.05 mm-thickness YAG etalons were inserted into the cavity to restrict the laser wavelength at 1908.1 nm, avoiding spiking in the Tm:YLF laser output caused by the water absorption lines near 1.91 μm.

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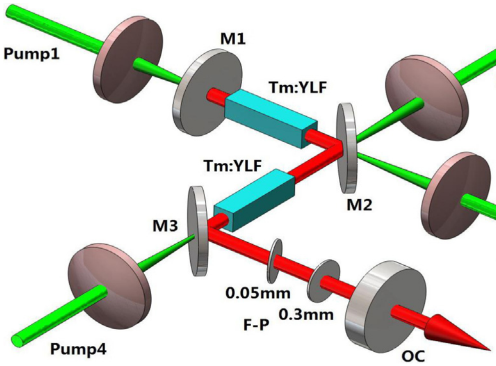

Fig. 1. Experimental setup of Tm:YLF laser.

A dual-end-pump configuration was utilized here. We used a dual-bulk resonator in a folded geometry in order to accommodate four laser diodes as pump sources. Two laser crystals were used to facilitate the use of four laser diodes as pump and to distribute the thermal load. The pump sources were four fiber-coupled (core diameter of 400 μm and numerical aperture of 0.17) 50 W laser diodes centered at 792 nm at a temperature of 45 °C, and it can be tuned by changing the temperature of the heat sink to match the best absorption of the Tm:YLF crystal. Each pump light was collimated and then focused into the crystals, forming a waist radius of 550 μm in order to further increase the maximum incident pump power.

By tuning two YAG etalons (0.3 and 0.05 mm in thickness) with no coating in the cavity, the Tm:YLF laser had a single line emission, which was well centered within the Ho:YAG absorption peak.

The transmittivity function of double etalons is given by Ref. [18]:

$$\begin{aligned} T(\lambda) &= T_1(\lambda)T_2(\lambda) \\ &= \left(1-\frac{A_1}{1-R_1}\right)^2 \frac{1}{1+F_1\sin^2(2\pi n_1 d_1\cdot\cos\ \alpha_1/\lambda)} \\ &\quad \times\left(1-\frac{A_2}{1-R_2}\right)^2 \frac{1}{1+F_2\sin^2(2\pi n_2 d_2\cdot\cos\alpha_2/\lambda)} \end{aligned} \quad (1)$$

where T_1, T_2 were the power transfer function of two etalons respectively; A_1, A_2 were the loss of two etalons (the loss was ignored, assuming $A=0$); F_1, F_2 were the finesse of the etalon, $F=\pi\sqrt{R}/(1-R)$, R was the reflection of the etalon; n_1, n_2 were the refractive index of the etalon; d_1, d_2 were the thickness of two etalons respectively; α_1, α_2 were the angle of refraction through two etalons respectively; λ was the wavelength. We used the following parameters:

	First F-P	*Second F-P*
F	2	2
n	1.82	1.82
α	24.8°	12.2°
d	0.05 mm	0.3 mm

The calculated result is shown in Fig. 2.

For bulk crystals, a power-scaling method is lowering the doping concentration of Tm^{3+}, which leads to less heat deposited per unit length due to the weaker pump absorption and reduced energy-transfer up-conversion [19]. Meanwhile, the length of the crystal should be increased to maintain the total gain of the media at the same level. So a longer crystal with lower concentration will endure higher pump power. In this work, we used two Tm:YLF crystals with doping concentration of 2.5 at.% for the experiment were *a*-cut and had a cross section of 3 mm × 3 mm (*c*- and *a*-axes) and a length of 20 mm (*a*-axis). The crystals were wrapped with Indium foil and clamped in a cooper heat sink which was cooled at 19 °C by a thermoelectric controller (TEC).

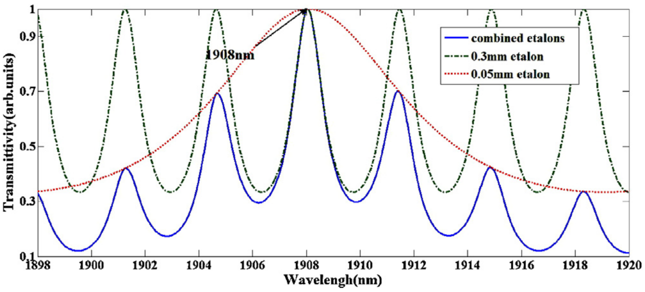

Fig. 2. The transmittivity curve of etalons.

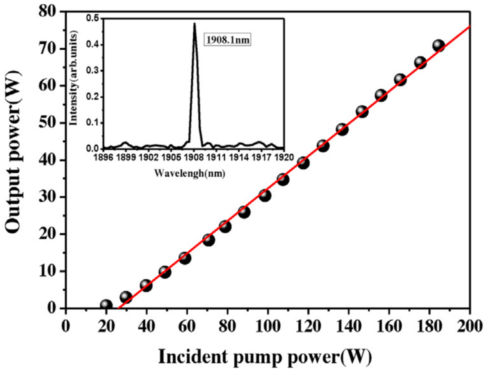

Fig. 3. The output power of Tm:YLF laser.

3. Results and discussion

Fig. 3 shows the output power with respect to the incident pump power. The power meter used in the experiment was a Coherent PM150. The lasing threshold was 20.1 W. Output power of 70.8 W was obtained under an incident pump power of 184.6 W, corresponding to a slope efficiency of 43.7% and an optical-to-optical conversion efficiency of 38.4%.

The laser wavelength was measured by an EXFO WA-650 spectrum analyzer combined with an EXFO WA-1500 wave-meter. A laser wavelength shift of 0.1 nm with the incident pump power varying from 20.1 W to 184.6 W was observed. The wavelength peak was at 1908.1 nm (insert Fig. 3). Fig. 4 depicts the stability of the laser spectra in different pump power.

The beam quality of the output laser was measured in the 90/10 knife-edge method. The laser beam quality factors M^2 were measured to be 1.79, 1.85 and 1.90 at the output power of 20.1 W, 41.2 W

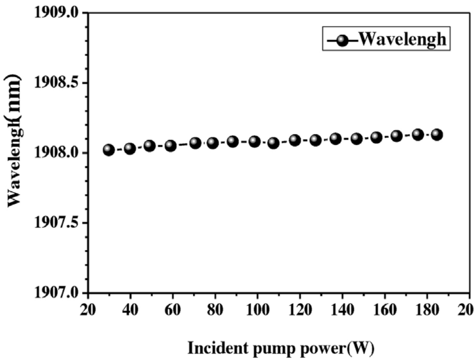

Fig. 4. Stability of the laser wavelength.

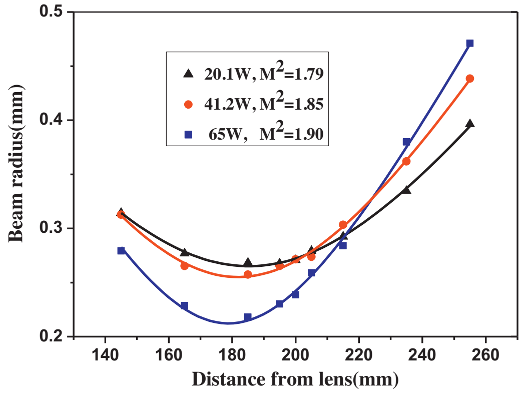

Fig. 5. The beam quality factor M^2 measurement of Tm:YLF laser.

and 65 W, respectively (shown in Fig. 5). The beam radius increased with respect to the output power, as we expected, the location of the beam waist was shifted backwards, which both indicated that the negative thermal lens effect had obvious impacts.

4. Conclusions

In this paper, we demonstrated a diode dual-end-pumped Tm:YLF laser working at 1908 nm. The maximum output power was 70.8 W at the pump power of 184.6 W, corresponding to the slope efficiency of 43.7%. The wavelength was selected and restricted by two etalons. The laser beam quality factors M^2 were measured to be 1.79, 1.85 and 1.90 at the output power of 20.1 W, 41.2 W and 65 W, respectively. Only a 0.1 nm laser central wavelength shift was observed when the incident pump power increased from 20.1 W to 184.6 W. The laser wavelength was very stable.

Acknowledgements

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