Diode-pumped Tm:LuAG laser at room temperature

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The lasing characteristics of Tm:LuAG at room temperature are reported. The maximum output power at 2.023-μm wavelength is 4.91 W and the slope efficiency is 25.39%. The mode matching between pump mode and laser mode is optimized by changing the pump beam waist radius and its location. Different output couplers are used to realize the optimal laser output. The relationship between operation temperature and output power is also discussed.

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2-μm wavelength laser has many important applications, such as wind measurement, gas sensing, and iatrical applications[1−6]. This letter focuses on the lasing characteristics of Tm:LuAG at room temperature. Thulium-doped $Lu_3Al_5O_{12}$ (Tm:LuAG) crystal is one of the attractive materials for its potential as the sources of coherent radiation at 2-μm wavelength[7]. LuAG is isomorphic to YAG, and the LuAG crystal has the advantages of high heat conductivity similar to the YAG host. As a quasi-three-level laser material, Tm:LuAG is more promising for it has lower population density of the lower laser level. In addition, the emission wavelength of Tm:LuAG is shifted slightly to longer wavelength in comparison with Tm:YAG crystal. The emission wavelength of Tm:LuAG is measured to be 2.023 μm, which is more closer to the optical transmission window than the wavelength of Tm:YAG (2.015 μm). In 1995, a total optical-to-optical efficiency of 7.3% and an optical-to-optical differential efficiency of 23.6% were achieved by a diode-pumped Tm:LuAG laser[8]. In 2000, the maximal output of 0.92 W was obtained from a diode-pumped Tm:LuAG laser when the pump power was 10 W[9]. In 2004, the diode-pumped single-mode Tm:LuAG and Tm,Ho:LuAG lasers were developed as master oscillators for an airborne LIDAR system, 51 mW of output power with a Tm(10%):LuAG laser was reached at room temperature by using a new fourfold pump setup[10].

In this letter, we demonstrate the CW lasing of a 4%-Tm-doped LuAG crystal. The absorption spectrum and the fluorescence spectrum of the active material and CW laser performance are reported and discussed. A maximum output power of 4.91 W at 20 W diode-pumped power is obtained. The slope efficiency is 25.39% and the free running wavelength is 2.023 μm.

The 4%-Tm-doped LuAG crystal is with dimension of 4×4 (mm) in cross section and 7 mm in length. The faces are polished planes, parallel and coated with antireflection at the wavelength near 790 nm and 2.02 μm. Figure 1 shows the absorption cross-section spectrum and the fluorescence cross-section spectrum of Tm:LuAG at room temperature. The absorption spectrum is achieved by using a visible spectrometer and the fluorescence is obtained by making use of an InGaAs detector, a monochromator, and a phase lock amplifier.

The experimental configuration of a one-end-pumped Tm:LuAG laser with fiber-coupled diode is shown in Fig. 2. The output beam of the pump laser is shaped and focused by a series of convex lenses. The mode matching between pump mode and laser mode is optimized by changing the pump beam waist radius and its location. The plane mirror is high reflective at the wavelength near 2.02 μm ($R > 99.5\%$) and high antireflective at the wavelength about 790 nm ($R < 0.5\%$). Different output couplers are used in the experiment. The typical length of the cavity is 30 mm and the operation temperature of the crystal is 290.55 K.

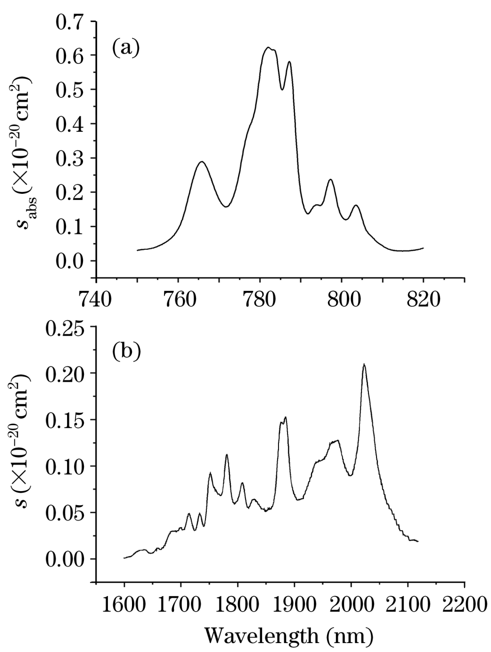

Fig. 1. (a) Absorption and (b) fluorescence spectra of Tm:LuAG.

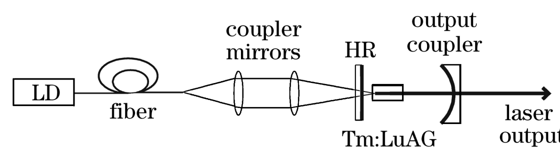

Fig. 2. Cavity configuration of the diode-pumped Tm:LuAG laser.

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Figure 3 illustrates the effect of mode matching. The result shows that the dimension of the pump waist diameter at 480 μm is more efficiency than at 630 μm. It is quite accordant with the theory. The calculated oscillation spot is about 479.4 μm. The maximum output power of 4.91 W and the slope efficiency of 25.39% are achieved under the condition that the pump waist diameter is 480 μm. As the pump waist diameter is up to 600 μm, the maximum output power of 4.51 W and the slope efficiency of 23.28% are obtained.

Figure 4 gives the result of Tm:LuAG laser with different pump powers and couplers. The maximum output powers of 2.91 W ($T = 1.67\%$), 4.91 W ($T = 2.97\%$), and 1.50 W ($T = 6\%$) are obtained under pump power of 20 W at 788-nm wavelength. The thresholds are 1.43, 1.11, and 6.87 W and the slope efficiencies are 15.08%, 25.39%, and 11.82%, respectively. The above results reveal that it would be negative if the output coupler with transmission larger than 5% is used.

At the maximum output power, a beam quality factor of $M^2 = 3.74$ is measured by the traveling knife-edge method. The cavity is too short to restrain multimode oscillation. Increasing the length of the cavity properly is useful to improve the beam quality. When the scale of temperature controller is adjusted, the output power changes correspondingly. The output power change is fitted linearly in the range of room temperature. As Fig. 5 shows, the slope efficiency is about −15 mW/K. It means that increasing the temperature of the laser crystal is unfavorable to release the heat that comes from pump power. Tm:LuAG operating from the $^3F_4$ to $^3H_6$ transition is a quasi-three-level laser. The ground state is thermally populated. As the temperature becomes higher, the number of reversal particles will decrease. And the high temperature will increase the threshold and reduce the output power.

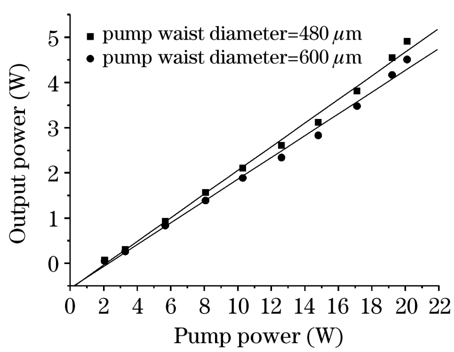

Fig. 3. Output power of Tm:LuAG laser versus input LD power with different pump beam diameters.

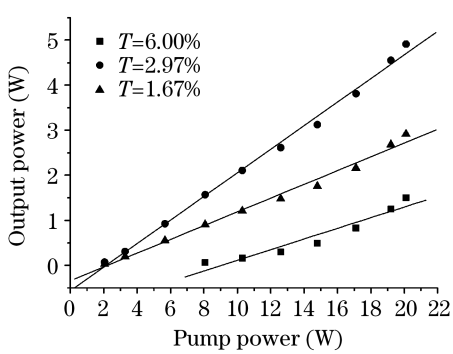

Fig. 4. Output power of Tm:LuAG laser versus input LD power with different output couplers.

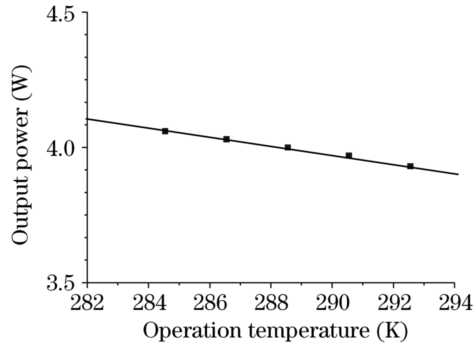

Fig. 5. Output power versus operation temperature.

In conclusion, the lasing characteristics of Tm:LuAG at room temperature are reported. The maximum output power at 2.023 μm is 4.91 W and the slope efficiency is 25.39%. Restricted by the experiment condition, the optimum transmission of output coupler is 2.97%. At room temperature, the higher temperature the laser crystal operates on, the lower power it produces. The relationship is fitted nearly linearly. The instability of the output power is about 1%. The stabilization of the LD and the controlling current of the crystal-refrigeration are still insufficient.

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