

Tunable CW Tm,Ho:YLF laser at 2 μm

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A tunable continuous wave (CW) low temperature operating Tm (6 at.-%),Ho (0.6 at.-%):YLF laser pumped by fiber-coupled diode laser is reported. The maximum output power is 4.16 W at 2073 nm by use of 30% output coupling, the slope efficiency is 33%. A tuning range from 2049 to 2081 nm is achieved with a birefringent filter (BF). The factors that contribute to the output power and tuning range are discussed.

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Eye-safe diode pumped holmium lasers operating at 2 μm are regarded as promising sources for Doppler radar wind sensing, differential absorption lidar, water vapor profiling, low altitude wind detection, pump sources for optical parametric oscillators, medical instruments, and eye-safe remote systems^[1-3].

At elevated temperature, the quasi-three-level properties of the Ho laser transition results in very highly excited density to achieve useful gain. High-excited state density leads to up-conversion processes, which is manifested by the decrease of upper level lifetime and the nonlinear relationship between gain and pump energy. So, in order to achieve the highest gain, we have selected operating temperature at 77 K^[4] where the excited state density for the fixed gain is minimized.

The experimental setup is shown in Fig. 1. The gain medium is an a-cut Tm (6 at.-%),Ho (0.6 at.-%):YLF^[5,6] crystal with the dimension of $10 \times 5 \times 5$ (mm). It was put on the heat sink and cooled by liquid-nitrogen. The diode-laser emits a maximum coupling output power of 15 W around 792 nm with the couple-fiber core diameter of 400 μm and a fiber numerical aperture of 0.22. The focuses of the lenses L1, L2 are respectively 35 and 50 mm. The laser cavity was formed by a high-reflectance mirror near 2 μm and a 70% reflectance output-coupler with curvature radius of 300 mm. The cavity was typically 150 mm long. A 5-mm-thick^[7] birefringent filter (BF) is inserted into the cavity. The filter is mounted on a rotator to allow for the control of the angle between the optical axis and the laser field and is placed at the Brewster angle to minimize the reflection losses.

In our experiment, different transmissivity output couplings of 10% and 30% were tested for high power and efficiency output laser. Figure 2 shows the output

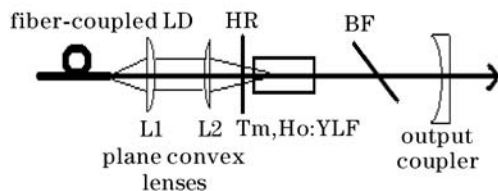


Fig. 1. Experimental setup for tunable CW Tm,Ho:YLF laser pumped by a diode in 2- μm region.

powers versus the input power in different output couplings. The slope efficiency and maximum output power are 34% and 4.16 W for 30% output coupling, and for 10% coupling, the slope efficiency and maximum output power reduce to 26.7% and 3.6 W, respectively. Without any wavelength selector in the cavity the wavelength of the free running laser cavity is different with the change of the reflectivity of output coupling. Figure 3 shows the change of wavelength in different couplings. In this case, the wavelength jumps when changing three output couplings. The reason is that the reabsorption in higher reflectivity cavity forces the laser to operate

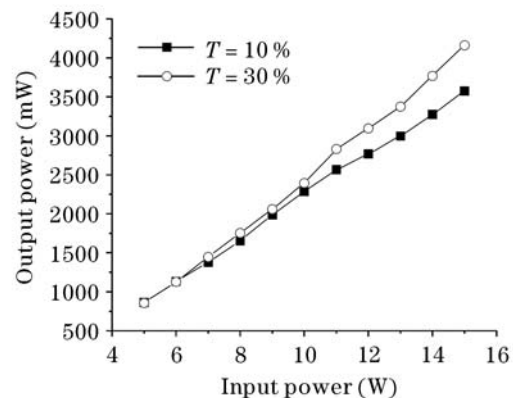


Fig. 2. Tm,Ho:YLF output power versus input power without BF in the cavity.

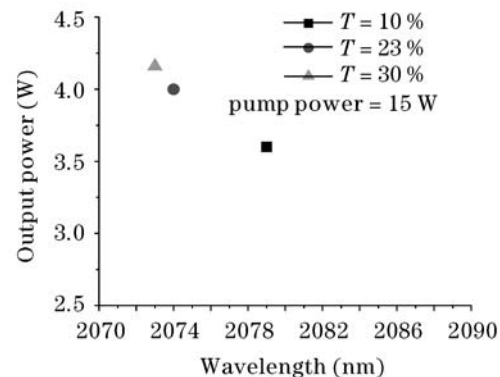


Fig. 3. Output power versus laser wavelength without BF in the cavity at different transmissivities.

further in the wing of emission spectrum. The wavelength dependence of the gain makes it possible to use the wavelength selective element to continuously change the wavelength.

Wavelength tuning is obtained by inserting a 5-mm-thick quartz plate acting as a BF with 7 THz free spectral range (corresponding to more than 100 nm at the laser wavelength), the optical axis is parallel to the plate faces.

The resonance wavelength of the cavity with BF in it can be calculated as

$$\lambda = \frac{d(n_o - n_e) \sin^2 \gamma}{K \sin \theta} \quad (K = 0, \pm 1, \pm 2, \dots), \quad (1)$$

where d is the thickness of BF, $n_o - n_e$ is the difference in indices of refraction between o and e lights, θ is incident angle of laser, γ is the angle of o-light with optical axis of BF. When tuning around the BF, γ is changed and then the resonance wavelength can be selected.

Figure 4 shows the tunable curve and linewidth measured at 15-W input power. A tuning range of 32 nm from 2049 to 2081 nm is achieved with 30% output coupling. Maximum output power of 3.5 W near 2073 nm is lower than free running laser without BF in the cavity. The reason is that the reflection losses brought by BF cannot be avoided without precise tuning system.

Green fluorescence can be seen in the Tm,Ho:YLF crystal when the pumping light focused onto it and the

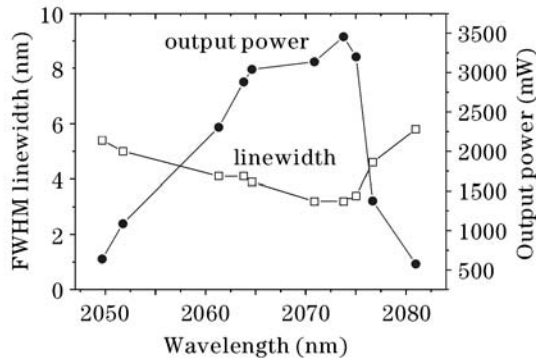


Fig. 4. Tunable curves of the Tm,Ho:YLF laser at 15-W incident pump power.

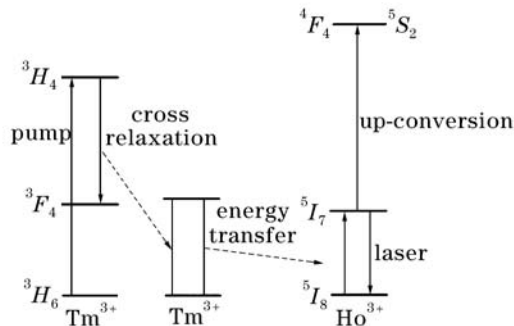


Fig. 5. Diagram of up-conversion in Tm,Ho system.

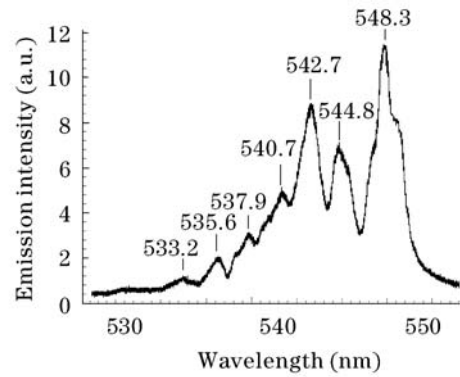


Fig. 6. Up-conversion green fluorescence spectrum of Ho^{3+} in CW diode pumped Tm,Ho:YLF crystal.

brightness became darker when the tunable laser operates near 2073 nm. According to Fig. 5, this green light mainly comes from the transition of $\text{Ho}^{3+} : {}^5S_2 \rightarrow {}^5I_8$ (539–550 nm), ${}^5F_4 \rightarrow {}^5I_8$ (534–546 nm)^[8,9]. Figure 6 shows the Ho^{3+} up-conversion fluorescence measured by electron-multiplier phototube. When more and more pump power turn to heat, this up-conversion loss increases with the increase of crystal temperature. This up-conversion is not helpful to extending the tuning range and makes the wing of tuning line near 2073 nm decrease fast. So the good cooling system is very important to help decreasing heat aggregation, realizing high power, and widely tunable laser operating.

In conclusion, a tunable Tm,Ho:YLF laser in 2- μm region has been demonstrated. For higher power and wider tuning range, it is necessary to optimize resonator parameter and the design of BF plate. This work is still in progress.

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