ISSN 1054-660X, Laser Physics, 2010, Vol. 20, No. 11, pp. 1945–1948.

Diode-End-Pumped CW and Actively Q-switched Tm,Ho:YLF Ring Laser[1]

D. X. Zhang[a], *, Y. L. Ju[b], C. T. Wu[b], and Z. G. Wang[b]

[a] *Xidian University, Xi'an, 710071 China*

[b] *National Key Laboratory of Tunable Laser Technology, Harbin Institute of Technology, Harbin, 150001 China*

*e-mail: zhang_dongxiao2010@126.com

Received May 27, 2010; in final form, June 2, 2010; published online October 3, 2010

Abstract—This paper presents CW and acoustic-optical Q-switched Tm,Ho:YLF laser performance in a laser-diode end-pumping figure-eight ring resonator structure at 77 K. Under CW operation, different transmission of output couplers and different cavity length were used to achieve best characteristics of the laser. The maximum power of 1.85 W is achieved with the threshold of 2.09 W, slope efficiency of 28.14% and optical-to-optical efficiency of 20.3% on the condition of 1 m cavity length and 18% transmission. Under pump power of 4 W, laser characteristics under Q-switched operation with different pulse repeat frequency was investigated. Maximum energy of 5.86 mJ is achieved with pulse width of 171.2 ns, peak power of 34.2 kW and dynamic-static ratio about Q-switch laser of 0.62 at pulse repeat frequency 70 Hz.

DOI: 10.1134/S1054660X10210152

1. INTRODUCTION

2 μm lasers are useful for eye-safe applications, including spatially resolved wind measurements, range finding or water vapor profiling and so on [1–4]. Tm, Ho codoped laser crystals for generation of 2 μm radiation exhibits certain significant properties: two-for-one pumping of the Ho ions via cross relaxation, 0.5–1.8×10^{-20} cm^2 emission cross section, energy storage capability, and especially long fluorescence lifetime of 8~16 ms which are conducive to operation in Q-switched mode [5, 6]. In 2010, Zhang et al. reported single longitudinal mode, continuously tunable frequency and optical bistability Tm,Ho:YLF laser with two solid etalons at room temperature [7–9], However, the quasi-three-level natures of the Ho laser at high temperature results in the necessity of very highly excited density to achieve useful gain. High excited state densities lead up to unconversion processes. In order to achieve the highest gain, we have designed a Tm,Ho:YLF laser operating at 77 K, where the excited state densities for fixed gain are minimized. In 2009, Wang et al. reported the laser characteristics of diode-pumped single longitudinal mode (SLM) of Tm,Ho:YLF microchip laser at 77 K [10]. Yao et al. reported the short-term frequency characteristics of SLM Tm,Ho:YLF microchip laser [11].

In this letter, we demonstrate CW and acousto-optic Q-switched operation of diode-pumped Tm,Ho co-doped YLF laser. Under CW operation, different transmission of output couplers and different cavity length were used to achieve best characteristics of the laser. The maximum power of 1.85 W is achieved with the threshold of 2.09 W, slope efficiency of 28.14% and optical-to-optical efficiency of 20.3% on the condition of 1 m cavity length and 18% transmission. Under Q-switched operation, different pulse repeat frequency was measured to study the characteristics of the pulse laser. Maximum energy of 5.86 mJ is achieved with pulse width of 171.2 ns, peak power of 34.2 kW and dynamic-static ratio about Q-switch laser of 0.62 at pulse repeat frequency 70 Hz on the pump power of 4 W. At the same pump power, the maximum energy of 8.75 mJ is achieved with pulse width of 134.7 ns, peak power of 64.9 kW and dynamic-static ratio about Q-switch laser of 0.21 at pulse repeat frequency 20 Hz.

2. EXPERIMENTAL RESULTS AND DISCUSSION

2.1. Experimental Setup

The experimental setup is shown in Fig. 1. The pump source is a 30 W continue wave (CW) output with fiber-coupled laser-diode (LD), whose central wavelength is 792 nm coincidence with the absorption peak of Tm,Ho:YLF crystal. The fiber core has a diameter of 400 μm and a numerical aperture of 0.22. The mode matching between pump mode and laser mode is optimized by changing the pump beam waist radius and its location. The output of the laser-diode is collected by 25 mm focal length collimating lens, then is focused onto the Tm,Ho:YLF crystal by using a lens with a 75 mm focal length. With this arrangement, the pumping waist is imaged to 1.2 mm beam at the entrance face of the laser crystal. The total transmission efficiency of the beam-reshaping system is about 96% at 792 nm.

[1] The article is published in the original.

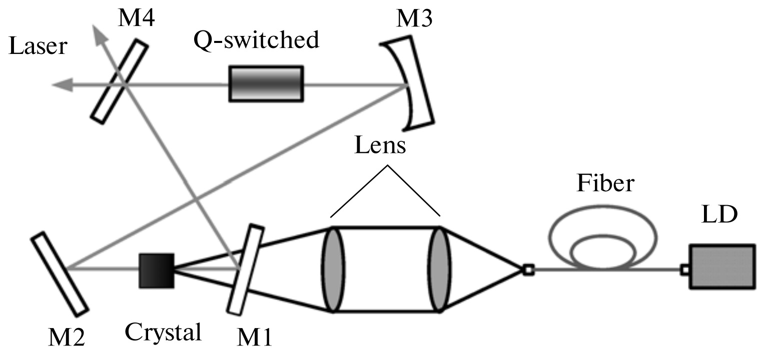

Fig. 1. Schematic diagram of LD-pumped Q-switched Tm,Ho:YLF laser.

The Tm,Ho:YLF laser crystal has dopant concentration of 6% Tm and 0.4% Ho with dimensions of 4 × 4 × 7 mm^3. The faces are polished plane, parallel and coated antireflection near 785 nm (R < 0.5%) and 2.01 μm (R < 0.5%). The crystal is mounted on a copper heat sink and placed in a Dewar flask filled with the liquid nitrogen which is used to cool the crystal. The resonator consists of three plane mirrors and one curved mirror. M1 and M2 are high-reflectivity (R > 99.5% at 2.01 μm) flat mirrors. M3 is high-reflectivity (R > 99.5% at 2.01 μm) curve mirror with a 1000 mm radius of curvature. M4 is the output coupler. Different transmissions of the output couplers and different resonator length were tried to optimize the characteristics of the output laser. A 46 mm long fused silica fused-silica acoustic-optical Q-switch is used to produce Q-switched operation. Both ends of the modulator are antireflection coated at 2050 nm (R < 0.5%). Its maximum RF power is 50 W and its intrinsic diffraction loss is 85%, which is adequate to prevent lasing action. For Q-switched operation, different repetition rates were used to achieve long pulse width output.

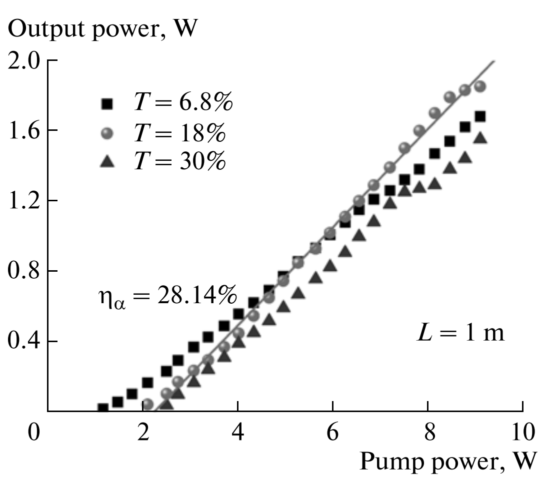

Fig. 2. Output power versus pump power at three different output coupler transmissions.

The output power of Tm,Ho:YLF laser is measured by an power meter. The output pulse width is observed with a 350 MHz digital oscilloscope (wavejet 332, Lecroy) and a room temperature mercury cadmium telluride photoconductive detector with a response time of 1 ns.

2.2. CW Operation

Output couplers with transmissions (T) of 6.8, 18, and 30% were used under the condition that the cavity length is 1 m. The results are shown in Fig. 2. As the transmission of the output coupler become larger, the threshold turned to higher. The threshold for three transmission of 6.8, 18, and 30% is 1.15, 2.09, and 2.89 W, respectively. While the slope efficiency of them is 26.22, 28.22, and 22.04%, correspondingly the optical-to-optical efficiency is 21.87, 28.14, and 23.22%. From the experimental phenomenon mentioned above, we can see, the optimal transmission of output coupler is 6.8%.

Keeping the fixed angle between every two mirrors and increasing the length of M1–M4, M2–M3, M3–M4 to see the laser characteristics of different cavity length of 0.75, 1, and 1.25 m under the condition that the transmission of the output coupler is 18%. The experimental results were shown in Fig. 3. The threshold of the laser is a little higher when the cavity length becomes longer. The threshold of the cavity length 0.75, 1, and 1.25 m is 1.46, 2.09, and 2.49 W respectively. While the slope efficiency of them is 28.22, 28.14, and 25.53%, correspondingly the optical-to-optical efficiency is 21.79, 20.39, and 20.20%. From the experimental phenomenon mentioned above, we can see, the optimal cavity length is 1 m.

To choose the optimum transmission and cavity length obviously, the experimental results under different combination of output coupler and cavity length are shown in table.

As shown in table, the best result is obtained under the cavity length of 1 m and transmission of 18%. Then the characteristics of the Q-switched operation were

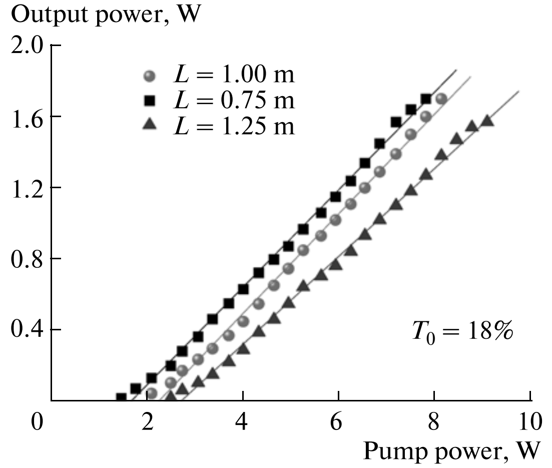

Fig. 3. Output power versus pump power at the output coupler transmission of 18% at three different cavity lengths.

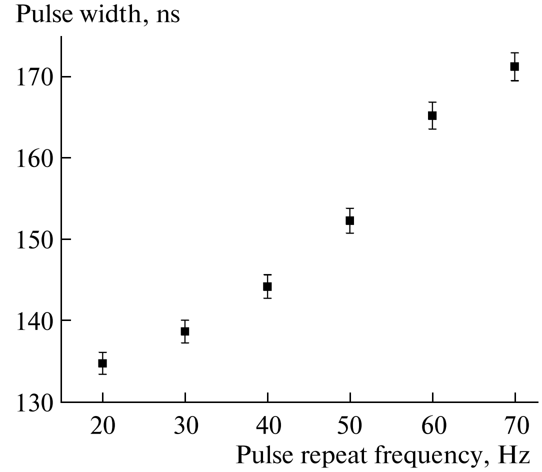

Fig. 4. Pulse width versus pulse repeat frequency.

obtained under transmission and cavity length of 18% and 1 m.

2.3. Q-switched Operation

To comparative study the laser characteristics of Tm,Ho:YLF laser under Q-switched operation with different pulse repeat frequency, the pump power was fixed at 4 W. Figure 4 shows the pulse width versus pulse repeat frequency. While the pulse repeat frequency becomes larger, the pulse width turns broader. The above experimental phenomenon illustrated that at the same pump power, the initial inversion population becomes lower when the pulse repeat frequency become higher. While the initial inversion population becomes lower, the pulse width becomes broader. Therefore, when the pulse repeat frequency becomes higher, the pulse width becomes broader.

Figure 5 illustrated the peak power and the single pulse width versus pulse repeat frequency.

As shown in Fig. 5, the peak power is falling down faster than the output energy versus the pulse repeat frequency. This is because the peak power is equal to the division about the single output energy and the pulse width. While the pulse width becomes broader as the pulse repeat frequency becomes higher. Therefore, the pulse repeat frequency would give more affection to peak power.

Figure 6 shows the ratio of Q-switch laser that the average output power under Q-switched operation takes up the continuous wave output power under the same pump power (the dynamic-static ratio) versus

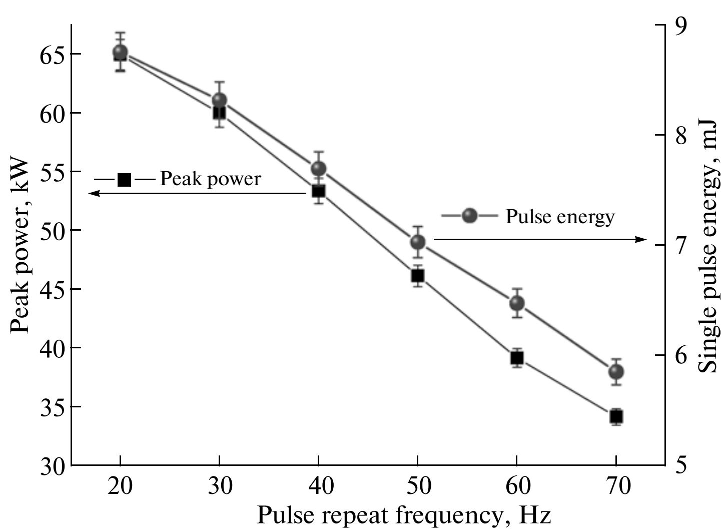

Fig. 5. Peak power versus pulse repeat frequency.

Laser characteristics at different output coupled transmissions and different cavity lengths separately

Transmission of output coupler T, %		6.8	18	30
Cavity length $L = 0.76$ m	Threshold, W	0.84	1.46	2.09
	Slope efficiency, %	26.22	28.22	22.40
	P_{max}, W	1.71	1.70	1.26
	Optical-to-optical, %	21.92	21.79	16.15
Cavity length $L = 1$ m	Threshold, W	1.15	2.09	2.49
	Slope efficiency, %	21.87	28.14	23.22
	P_{max}, W	1.68	1.85	1.55
	Optical-to-optical, %	18.51	20.39	17.08
Cavity length $L = 1.255$ m	Threshold, W	1.46	2.49	2.73
	Slope efficiency, %	24.66	25.53	20.97
	P_{max}, W	1.59	1.64	0.88
	Optical-to-optical, %	19.58	20.20	10.45

pulse repeat frequency. We can see from the Fig. 6, the dynamic-static ratio of Q-switch laser is increasing promptly as the pulse repeat frequency becomes higher. This is because the effective fluorescence lifetime becomes longer when the pulse repeat frequency becomes higher.

3. CONCLUSIONS

In conclusion, we have investigated CW and acoustic-optical Q-switched Tm,Ho:YLF laser pumped by a laser-diode. Under CW operation, the maximum power of 1.85 W is achieved with the threshold of 2.09 W, slope efficiency of 28.14% and optical-to-optical efficiency of 20.3% on the condition of 1 m cavity length and 18% transmission. Under Q-switched operation, the maximum energy of 5.86 mJ is achieved with pulse width of 171.2 ns, peak power of 34.2 kW and dynamic-static ratio about Q-switch laser of 0.62 at pulse repeat frequency 70 Hz on the pump power of 4 W. At the same pump power, the maximum energy of 8.75 mJ is achieved with pulse width of 134.7 ns, peak power of 64.9 kW and dynamic-static ratio about Q-switch laser of 0.21 at pulse repeat frequency 20 Hz.

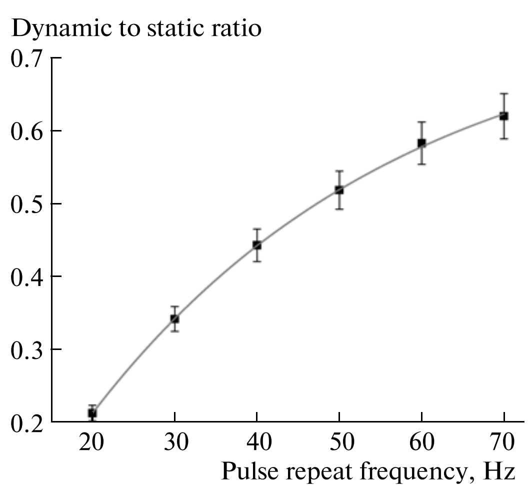

Fig. 6. Dynamic-static ratio of Q-switch laser versus pulse repeat frequency.

ACKNOWLEDGMENTS

This work is supported by the program of Excellent Team in Xidian University and Harbin Institute of Technology.

REFERENCES

1. O. A. Buryy, D. Y. Sugak, S. B. Ubizskii, I. I. Izhnin, M. M. Vakiv, and I. M. Solskii, Appl. Phys. B **88**, 433 (2007).
2. C. T. Wu, Y. L. Ju, Y. F. Li, Z. G. Wang, and Y. Z. Wang, Chin. Opt. Lett. **6**, 594 (2008).
3. V. Kushawaha, Y. Chen, Y. Yan, and L. Major, Appl. Phys. B **62**, 109 (1996).
4. Y. Li, B. Yao, Y. Wang, Y. Ju, G. Zhao, Y. Zong, and J. Xu, Chin. Opt. Lett. **5**, 286 (2007).
5. B. Yao, L. Li, L. Zheng, Y. Wang, G. Zhao, and J. Xu, Opt. Express **16**, 5075 (2008).
6. Xinlu Zhang, Youlun Ju, and Yuezhu Wang, Chin. Opt. Lett. **3**, 463 (2005).
7. X. L. Zhang, L. Li, J. H. Cui, Y. L. Ju, and Y. Z. Wang, Laser Phys. Lett. **7**, 194 (2010).
8. X. L. Zhang, L. Li, B. Jiang, J. H. Cui, Y. L. Ju, and Y. Z. Wang, Laser Phys. Lett. **7**, 108 (2010).
9. X. Zhang, Y. Wang, L. Li, Y. Ju, J. Cui, and Y. Lv, Laser Phys. **19**, 392 (2009).
10. Z. G Wang, Y. L. Ju, C. T. Wu, C. W. Song, Q. Wang, J. Q. Zhao, and Y. Z. Wang, Laser Phys. **20**, 462 (2010).
11. B. Q. Yao, L. Ke, Q. Wang, Z. G. Wang, C. T. Wu, X. M. Duan, Y. L. Ju, and Y. Z. Wang, Laser Phys. **19**, 2077 (2009).