Appl Phys B (2012) 107:67–70
DOI 10.1007/s00340-011-4838-z

Applied Physics B
Lasers and Optics

2 μm single-frequency Tm:YAG laser generated from a diode-pumped L-shaped twisted mode cavity

C. Gao · R. Wang · Z. Lin · M. Gao · L. Zhu · Y. Zheng · Y. Zhang

Received: 30 August 2011 / Published online: 14 January 2012
© Springer-Verlag 2011

Abstract A 2 μm single-frequency Tm:YAG laser was developed by using a diode pumped L-shaped twisted-mode-cavity. By suppressing the spatial hole-burning, the 2 μm single-frequency laser was obtained, with the output power of 1.46 W and the slope efficiency of 19.2%.

1 Introduction

The diode pumped solid state lasers with wavelength around 2 μm have important applications in laser medicine and laser remote sensing [1–3]. Among them 2 μm single-frequency lasers are important laser sources of Coherent Doppler Wind Lidars and Differential Absorption Lidars which are very important for the weather forecast and greenhouse gases measurement [4, 5]. Various techniques have been investigated to obtain 2 μm single-frequency laser operation, such as the microchip laser, the ring laser, the laser with intracavity etalons, the laser with a volume Bragg grating and the twisted-mode-cavity. Single-longitudinal-mode (SLM) operation can be achieved in a microchip laser in the 2 μm region, but it is not capable of high-power output because of the thinness of the active medium [6, 7]. Laser operation in a ring laser cavity is another technique to obtain 2 μm single-frequency laser output. Coluccelli et al. reported a diode-pumped single-frequency Tm:$LiLuF_4$ ring laser with the output power of 120 mW and the slope efficiency of 12% [8]. Building a laser with intracavity etalons is also a method to obtain 2 μm single-frequency operation [9, 10]. In 2010, J. Li et al. reported a 2 μm single-frequency Tm:YAP laser with two etalons inside the cavity. The maximum output power of the 2 μm single-frequency Tm:YAP laser was 514 mW. The 2 μm single frequency laser can be also generated by using a volume Bragg grating as an output coupler. C.T. Wu et al. reported a diode pumped single frequency Tm:YAG laser with a volume Bragg grating. The 2 μm single frequency laser output was 457.3 mW, with a slope efficiency of 16.7% [11]. High power 2 μm single-frequency laser can be realized by using the non-planar ring oscillator (NPRO) [12–14]. C. Gao et al. reported a 2 μm single-frequency laser from a diode-pumped Tm:YAG non-planar ring oscillator with a sandwich structure [14]. Up to 867 mW 2 μm single-frequency lasers were obtained with the diffraction limited beam quality. Compared with the microchip laser, the ring laser, and the NPRO, the twisted-mode-cavity (TMC) is also a useful technique to obtain the 2 μm single-frequency laser operation [15]. The spatial hole-burning in the active medium is eliminated in the twisted-mode-cavity. In 2009, Y.S. Zhang et al. reported a 2 μm single-frequency Tm:YAG laser from the twisted-mode-cavity with a linear resonator. Up to 514 mW 2 μm single-frequency laser was generated from a diode-pumped Tm:YAG twisted-mode-cavity, and the slope efficiency was 9.7%. Because it was not easy to realize polarization control in higher pumping power, the 2 μm single-frequency output power could not be further increased in [15]. In this paper, we report a 2 μm single-frequency laser from an L-shaped twisted-mode-cavity Tm:YAG oscillator. To realize polarization control, a polarizer was used. Up to 1.46 W single-frequency laser was obtained, with a slope efficiency of 19.2%. To our knowledge, this is the highest 2 μm single-frequency laser from diode pumped Tm:YAG lasers with different resonators. The experimental setup and results of

C. Gao (✉) · R. Wang · Z. Lin · M. Gao · L. Zhu · Y. Zheng · Y. Zhang
School of Opto-Electronics, Beijing Institute of Technology, Beijing 100081, China
e-mail: gao@bit.edu.cn
Fax: +86-10-68912574

the 2 μm single-frequency twisted-mode-cavity Tm:YAG laser are reported below.

2 Experimental setup

The schematic of the experimental setup of a diode pumped single-frequency L-shaped twisted-mode-cavity Tm:YAG laser is shown in Fig. 1. The pump source was a fiber-coupled laser diode with the center wavelength of 785 nm and the core diameter of 100 μm. A coupling optics with a magnification factor of 1:2 was used behind the pumping fiber. The laser medium was a Tm:YAG crystal with a diameter of 3 mm and a length of 10 mm. The Tm doped concentration in the Tm:YAG crystal was 3.5 at%. The two surfaces of the Tm:YAG crystal were coated with high transmission coating at 2.02 μm ($T > 99.9\%$) and high transmission coating at 785 nm ($T > 95\%$). The Tm:YAG laser had a concave–concave resonator. The input concave mirror ($R = 200$ mm) was coated with an antireflection coating at 785 nm and a high reflection coating at 2.02 μm. The output coupler ($R = 200$ mm) had a transmissivity of 3.6% at 2.02 μm. For controlling the polarization state of the Tm:YAG laser, a polarizer was inserted inside the resonator. The polarizer was coated with high reflection coating for the s-polarized beam and high transmission coating for the p-polarized beam. Two 2 μm quarter-wave plates were placed beside the Tm:YAG crystal to build the twisted mode cavity. The principal axes of the quarter-wave plates were oriented with their fast axes perpendicular or parallel to each other, and at 45° to the direction of the polarizer. By optimizing the laser mode, an L-shaped resonator was designed. The mode size of the Tm:YAG laser inside the resonator was simulated by using the software LASCAD. In the middle of the Tm:YAG crystal, the radius of the oscillating mode was about 150 μm. The Tm:YAG crystal was mounted in a copper heatsink, and the temperature of the heatsink was controlled at 20°C by using a semiconductor TEC cooler. An infrared filter was used behind the output coupler for blocking the non-absorbed pumping beam.

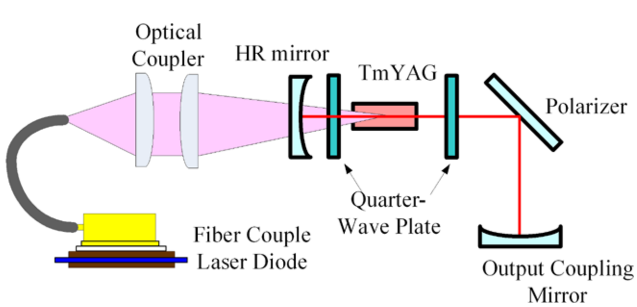

Fig. 1 Experimental setup of diode pumped 2 μm Tm:YAG laser with an L-shape twisted mode cavity

3 Experimental results

The L-shaped twisted-mode-cavity Tm:YAG laser was experimentally investigated. When two quarter-wave plates were not inserted inside the resonator (the free-running mode), the Tm:YAG laser operated in the multi-longitudinal-mode. Figure 2 (blue square) shows the experimental result. The threshold of the free-running mode Tm:YAG laser was 0.9 W. When the laser diode output power was 10 W, the output power of the Tm:YAG laser was 2.06 W, with a slope efficiency of 23.9%.

When two quarter-wave plates were inserted inside the Tm:YAG cavity, single-frequency laser operation was obtained. For the twisted-mode-cavity Tm:YAG laser, the single-frequency operation was influenced by the orientations of the two quarter-wave plates and the orientation of the principal axes of the quarter-wave plate and the polarizer. Furthermore, the Tm:YAG crystal had heat-induced birefringence when the pump power was very high, and the birefringence of the crystal affected the polarization state of the oscillating mode. The orientation of the quarter-wave plate was adjusted when the laser diode output power was above 8 W, in order to balance the influence of the heat-induced birefringence of the Tm:YAG crystal. The experimental results of the single-frequency L-shaped twisted-mode-cavity Tm:YAG laser are shown in Fig. 2 (black dots). The threshold of the single-frequency Tm:YAG laser was 1.6 W. The maximum single-frequency output power was 1.46 W, with a slope efficiency of 19.2%. When the laser diode output power was above 9.25 W, the multi-longitudinal-mode operation began.

Figure 3 shows the spectrum of the L-shaped twisted-mode-cavity Tm:YAG laser. The spectrum was measured by a scanning Fabry–Perot (F–P) interferometer with a free spectral range of 3.75 GHz. Figure 3 (left) shows the spectrum of the Tm:YAG laser in the multi-mode operation when two quarter-wave plates were not inserted in the cavity. The upper trace was the F–P ramp voltage, and the lower trace

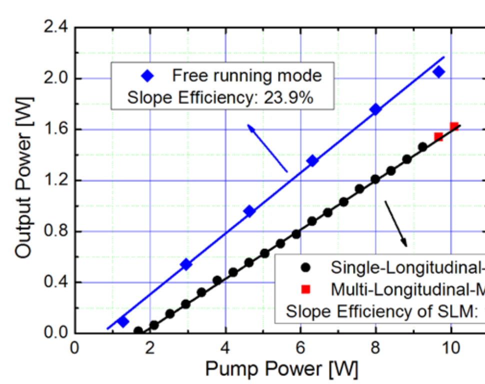

Fig. 2 Output power as a function of the pump power for the twisted-mode-cavity Tm:YAG laser ■ free running mode ● single frequency mode

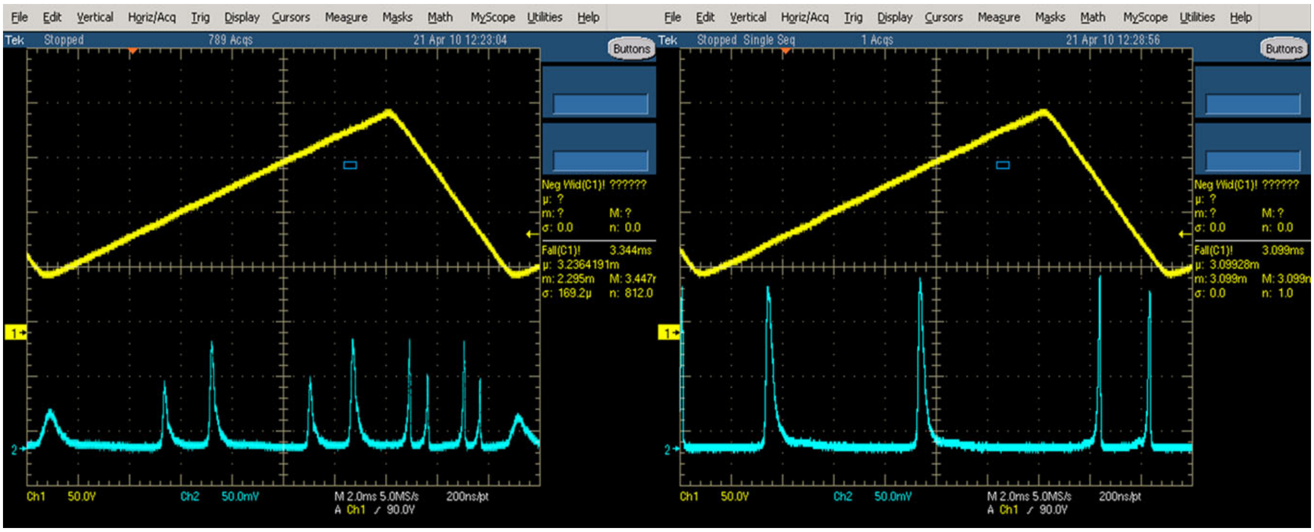

Fig. 3 Spectra of the L-shaped twisted-mode-cavity Tm:YAG laser at different conditions: (*left*) spectrum of the L-shaped Tm:YAG laser in free running mode; (*right*) spectrum of the L-shaped Tm:YAG laser in single-frequency mode

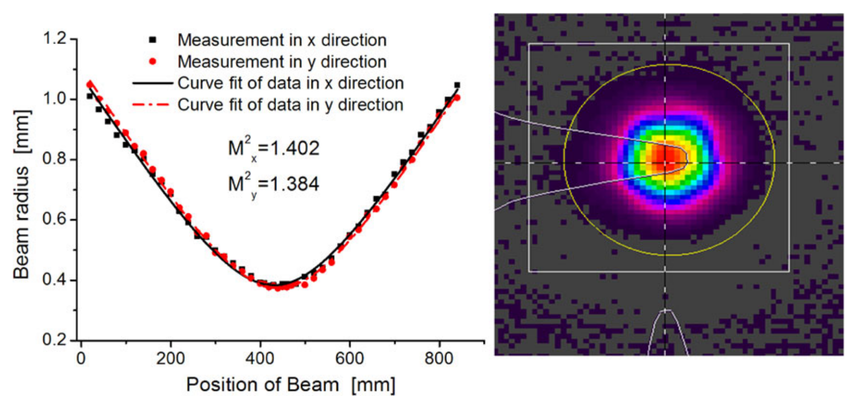

Fig. 4 Beam quality measurement of the twisted-mode-cavity Tm:YAG laser: (**a**) propagation of the second order beam radii; (**b**) beam profile

was the signal of the Tm:YAG laser transmitted through the F–P interferometer. Figure 3 (right) shows the Tm:YAG laser in the single-longitudinal-mode. When we increased the current of the laser diode, the pumping power was increased and the mode jumping occurred in the twisted-mode-cavity Tm:YAG laser.

The beam quality of the Tm:YAG laser was measured by using a Pyro-III infrared CCD camera (Spricon Inc.) when the single-frequency output power was 1.46 W. The M^2 factors of the Tm:YAG laser were determined by measuring the beam radii of the Tm:YAG laser in the x- and y-directions along the beam propagation. The experimental results are shown in Fig. 4. The beam profile of the Tm:YAG laser is shown in Fig. 4(b). The M^2 factors were calculated to be 1.402 and 1.384 in the x- and y-directions, respectively.

4 Conclusion

In summary, a diode-pumped 2 μm single-frequency Tm:YAG laser with an L-shaped twisted-mode-cavity was demonstrated. The maximum single-frequency output power was 1.46 W, with a slope efficiency of 19.2%. The M^2 factors of the 2 μm laser at the maximum output power were 1.402 and 1.384 along the x- and y-directions, respectively. A Fabry–Perot interferometer illustrated that the twisted-mode technique in the 2 μm region can realize high power output.

Acknowledgements This work is partly supported by the National Natural Science Foundation of China (61178027) and the Doctoral Fund of Ministry of Education of China (20101101110015).

References

1. L.E. Batay, A.A. Demidovich, A.N. Kuzmin, A.N. Titov, M. Mond, S. Kuck, Appl. Phys. B **75**, 457 (2002)
2. G. Galzerano, E. Sani, A. Toncelli, S. Taccheo, M. Tonelli, P. Laporta, Appl. Phys. B **78**, 733 (2004)
3. D. Gatti, G. Galzerano, A. Toncelli, M. Tonelli, P. Laporta, Appl. Phys. B **86**, 269 (2007)
4. G.J. Koch, J.Y. Beyon, B.W. Barnes, M. Petros, J. Yu, F. Amzajerdian, M.J. Kavaya, U.N. Singh, Opt. Eng. **46**, 116201 (2007)

5. S. Ishii, K. Mizutani, H. Fukuoka, T. Ishikawa, B. Philippe, H. Iwai, T. Aoki, T. Itabe, A. Sato, K. Asai, Appl. Opt. **49**, 1809 (2010)
6. Z. Lin, C. Gao, M. Gao, Y. Zhang, H. Weber, Appl. Phys. B, Lasers Opt. **94**, 81 (2009)
7. C. Nagasawa, T. Suzuki, H. Nakajima, H. Hara, K. Mizutani, Opt. Commun. **200**, 315 (2001)
8. N. Coluccelli, G. Galzerano, D. Parisi, M. Tonelli, P. Laporta, Opt. Lett. **33**, 1951 (2008)
9. J. Li, S.H. Yang, H.Y. Zhang, D.X. Hu, C.M. Zhao, Laser Phys. Lett. **7**, 203 (2010)
10. C.T. Wu, Y.L. Ju, B.Q. Yao, L. Ke, Y.Z. Wang, Laser Phys. **21**, 356 (2011)
11. C.T. Wu, Y.L. Ju, R.L. Zhou, X.M. Duan, Y.Z. Wang, Laser Phys. **21**, 372 (2011)
12. C. Svelto, I. Freitag, Electron. Lett. **35**, 152 (1999)
13. B.Q. Yao, X.M. Duan, D. Fang, Y.J. Zhang, L. Ke, Y.L. Ju, Y.Z. Wang, G.J. Zhao, Opt. Lett. **33**, 2121 (2008)
14. C.Q. Gao, M.W. Gao, Y.S. Zhang, Z.F. Lin, L.N. Zhu, Opt. Lett. **34**, 3029 (2009)
15. Y. Zhang, C. Gao, M. Gao, Z. Lin, R. Wang, Laser Phys. Lett. **7**, 17 (2010)