Optik - International Journal for Light and Electron Optics 169 (2018) 224–227

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

A 106W Q-switched Ho:YAG laser with single crystal

X.M. Duan[a,*], Y.J. Shen[b], B.Q. Yao[a], Y.Z. Wang[a]

[a] *National Key Laboratory of Tunable Laser Technology, Harbin Institute of Technology, Harbin, 150001, China*
[b] *School of Opto-electronic Information Science and Technology, Yantai University, Yantai, 264005, China*

ARTICLE INFO

Keywords:
2-micron laser
Ho:YAG laser
High power

ABSTRACT

A high power single crystal Ho:YAG laser was reported in this paper. With dual-end pump structure, maximum continuous wave power of 108W was achieved with slope efficiency of 63.2% and optical efficiency of 57.9%. With an acousto-optic Q-switch, maximum average output power of 106W at the pulse repetition frequency of 20kHz was achieved with pulse energy of 5.3mJ and pulse width of 21ns, corresponding to a peak power of approximately 252kW. The output wavelength was 2090.7nm with FWHM linewidth of 0.4nm. The beam quality factor of M^2 was estimated to 1.6.

1. Introduction

Solid-state lasers around 2 μm waveband are significant for many applications in remote sensing [1], medicine [2], material processing [3], and mid-infrared generation via pumping optical parametric oscillators (OPOs) [4]. Due to low quantum defect, 1.9 μm laser pumping of the Ho laser has high conversion efficiency and low thermal load. In addition, Ho^{3+} ion with long upper laser level lifetime are attractive for Q-switched operation. Therefore, Ho-doped laser is a vital approach to obtain the hundreds average power laser at 2 μm. Up to present, many Ho lasers have been demonstrated in various hosts [5–9]. However, there is less report on the Ho laser with 100W-level output. Output power of 83 W was achieved in a Tm,Ho co-doped fiber laser [10]. 101 W average output power at pulse repetition frequency (PRF) of 30 kHz was reported through a Q-switched Ho:YAG oscillator with two rods [11].

Among many host crystals, YAG crystal has high thermal conductivity and great mechanical properties, and good quality YAG crystals are easy to grow. Therefore, the Ho:YAG crystal is very suitable for high power laser. In this paper, by using double-end-pumped structure and single crystal, we demonstrated an output power of as much as 108 W was at continuous wave (CW) mode from the Ho:YAG laser. With Q-switched mode, the output average output power of 106 W was achieved at PRF of 20 kHz. To my best knowledge, this is highest output power in CW and Q-switched Ho laser with single crystal. The output emitting at 2090.7 nm was observed. The beam quality factor was measured to be $M^2 \sim 1.6$.

2. Experimental setup

The experimental setup of the Ho:YAG laser is shown in Fig. 1. Two diode-pumped Tm:YLF lasers at 1908 nm were utilized as the pump source, both of which had a maximum output power of 100 W. One pump laser is *s*-polarized while the another one is *p*-polarized. The pump beam diameter in the crystal was about 900 μm. The thin-film polarizer (TFP) is high reflective (HR) for *s*-polarized pump and high transmission (HT) for *p*-polarized pump. Two TFPs were employed in the setup to avoid the Tm:YLF lasers

* Corresponding author.
E-mail address: xmduan@hit.edu.cn (X.M. Duan).

https://doi.org/10.1016/j.ijleo.2018.05.094
Received 4 April 2018; Accepted 20 May 2018

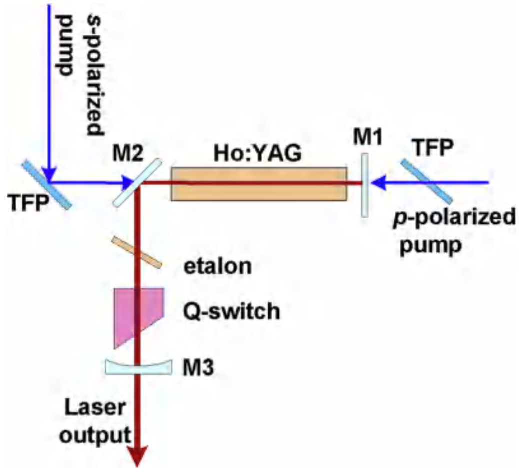

Fig. 1. Schematic diagram of the experimental setup.

being influenced by each other. The Ho:YAG crystal was grown by the Czochralski technique. Both end faces of the crystal were antireflection coated for the laser wavelength and the pump wavelength. Ho:YAG rod with 0.5 at.% doped concentration was a 100 mm in length and 5 mm in diameter. The crystal was wrapped in indium foil and clamped in a copper heatsink held at a temperature of 20 °C with a water cooler. The folded resonator with physical length of 260 mm consists of a 0° flat dichroic mirror (M1), a 45° flat dichroic mirror (M2), and a concave output coupler (M3) with a radius of curvature of 300 mm and transmittance of 68%. All dichroic mirrors provide both high reflection at 2.09 μm and high transmittance at 1.91 μm A 0.5 mm YAG F-P etalon was utilized as a Brewster plate to achieve the single wavelength output. A 50-mm-long acousto-optic modulator (AOM) was used for Q-switch operation. The AOM had a maximum RF power of 100 W.

3. Experimental results

The output power of Ho:YAG laser was measured under CW and Q-switched mode, respectively, as shown in Fig. 2. With CW mode, the maximum output power was 108 W with the incident pump power of 186.5 W. The slope efficiency and optical efficiency were 63.2% and 57.9%, respectively. With Q-switched mode, at PRF of 20 kHz, the maximum average output power of 106 W was achieved with slope efficiency of 62.7%. The Q-switched laser pulse profiles were recorded by a digital oscilloscope (Wavesurfer 64 Xs, Lecroy) with an InGaAs detector. The dependence of laser pulse width on incident pump power was measured and is shown in Fig. 3. The pulse width shortened sharply as the incident pump power increased. As a result, the minimum pulse width of 21 ns and the maximum pulse energy of 5.3 mJ were obtained when the incident pump power was 186.5 W, as shown in Fig. 4, corresponding to a peak power of approximately 252 kW.

The output wavelength of Ho:YAG laser was recorded with the wavemeter Bristol 721 A. At the maximum output average power, the output wavelength is centered at 2090.7 nm with full width half maximum of 0.4 nm as shown in Fig. 5. By using the 90/10 knife edge technique, we have measured the output beam radius at several positions through a waist formed by a lens (f = 150 mm). By fitting the Gaussian beam standard expression to these data, the beam quality factor was estimated to be $M^2 \sim 1.6$. The beam intensity distribution was measured by pyroelectric array camera of Spiricon Pyrocam I, which was shown in Fig. 6.

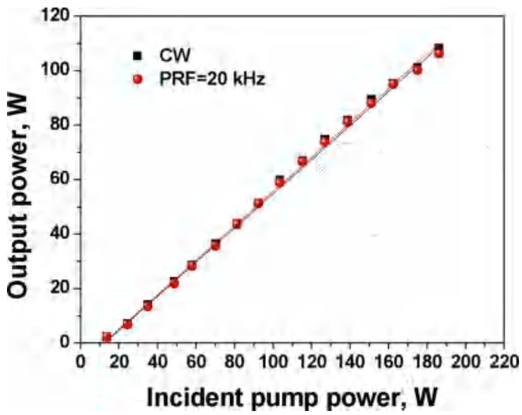

Fig. 2. The output energy of Ho:YAG laser with different PRF.

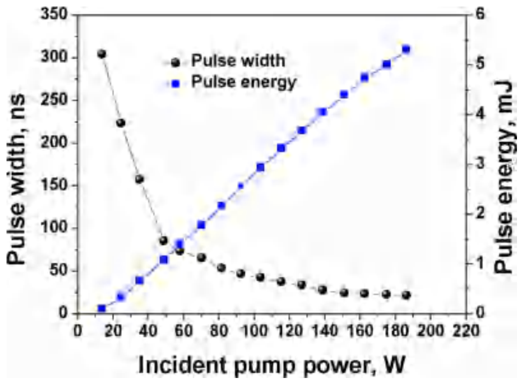

Fig. 3. The pulse width versus incident pump power at the PRF of 20 kHz.

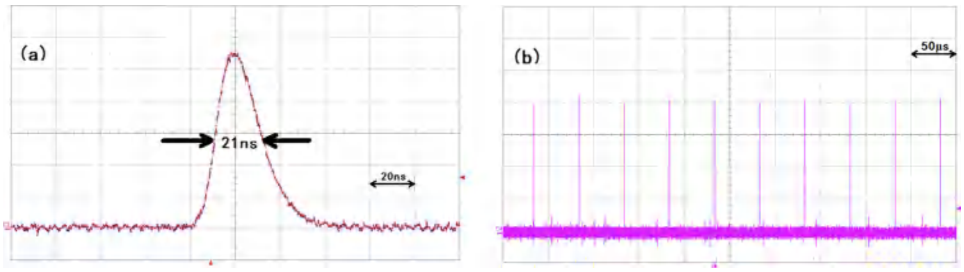

Fig. 4. Minimum pulse profile (a) and pulse train (b) of Ho:YAG laser at PRF of 20 kHz.

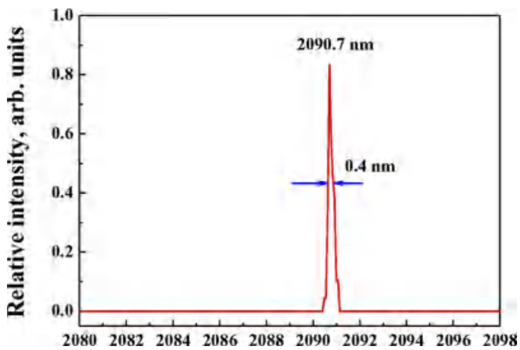

Fig. 5. The output spectrum of the Ho:YAG laser.

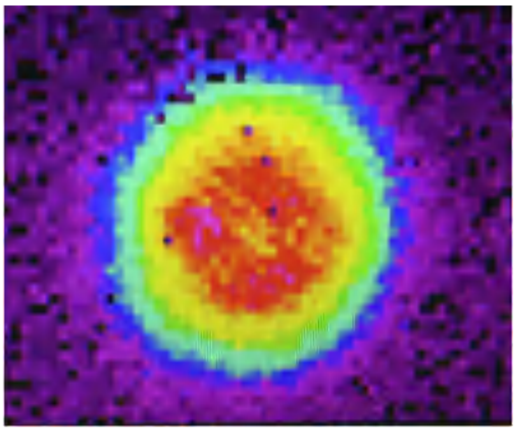

Fig. 6. beam quality factor of Ho:YAG oscillator.

4. Conclusion

In conclusion, we have demonstrated a high power Ho:YAG laser resonantly double-end-pumped by two Tm:YLF lasers at room temperature. In CW mode, the maximum output power of 108 W was achieved with slope efficiency of 63.2%. In Q-switched operation, maximum average output energy of 106 W was obtained at the PRF of 20 kHz. The output wavelength is 2090.7 nm with a FWHM linewidth of 0.4 nm. The minimum pulse width and maximum pulse energy were 21 ns and 5.3 mJ, respectively, corresponding to a peak power of approximately 252 kW. The laser operated with a beam quality factor of $M^2 \sim 1.6$, which was measured by a 90/10 knife-edge method. This Ho:YAG laser is an excellent pump source for mid-infrared optical parametric oscillator.

Acknowledgements

This work is supported by National Natural Science Foundation of China (No. 51572053), Fundamental Research funds for the Provincial Universities (Grant No. WL17B14).

References

[1] T.F. Refaat, U.N. Singh, M. Petros, R. Remus, J. Yu, Appl. Opt. 54 (2015) 7240–7251.
[2] V.S. Serebryakov, É.V. Boĭko, A.G. Kalintsev, A.F. Kornev, A.S. Narivonchik, A.L. Pavlova, J. Opt. Technol. 82 (2015) 781–788.
[3] B. Voisiat, D. Gaponov, P. Gečys, L. Lavoute, M. Silva, A. Hideur, N. Ducros, G. Račiukaitis, Proc. SPIE 9350 (2015) 935014.
[4] L. Wang, T. Xing, S. Hu, X. Wu, H. Wu, J. Wang, H. Jiang, Opt. Express 25 (2017) 3373–3380.
[5] P.A. Budni, L.A. Pomeranz, M.L. Lemons, C.A. Miller, J.R. Mosto, E.P. Chicklis, J. Opt. Soc. Am. B17 (2000) 723–728.
[6] H. Fonnum, E. Lippert, M.W. Haakestad, Opt. Lett. 38 (2013) 1884–1886.
[7] X.M. Duan, B.Q. Yao, G. Li, T.H. Wang, X.T. Yang, Y.Z. Wang, G.J. Zhao, Q. Dong, Laser Phys. Lett. 6 (2008) 279–281.
[8] B.Q. Yao, Y. Ding, X.M. Duan, T.Y. Dai, Y.L. Ju, L.J. Li, W.J. He, Opt. Lett. 39 (2014) 4755–4757.
[9] X. Yang, B. Yao, Y. Ding, X. Li, G. Aka, L. Zheng, J. Xu, Opt. Express 21 (2013) 32566–32571.
[10] S.D. Jackson, A. Sabella, A. Hemming, S. Bennetts, D.G. Lancaster, Opt. Lett. 32 (2007) 241–243.
[11] Y. Shen, B. Yao, X. Duan, G. Zhu, W. Wang, Y. Ju, Y. Wang, Opt. Lett. 37 (2012) 3558–3560.