High efficiency, high power QCW diode-side-pumped Nd:YAG ceramic laser at 1064 nm based on domestic ceramic

Yuanbin Wang (王元斌)[1,3], Baoshan Wang (王保山)[1*], Yong Bo (薄 勇)[1], Jialin Xu (许家林)[1], Song Song (宋 松)[1], Qinjun Peng (彭钦军)[1], Zuyan Xu (许祖彦)[1], Wenbin Liu (刘文斌)[2], Yubai Pan (潘裕柏)[2], and Jinghe Liu (刘景和)[3]

[1]*Key Lab of Functional Crystal and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, China*

[2]*Shanghai Institute of Ceramics, Chinese Academy of Sciences, Shanghai 201800, China*

[3]*School of Materials Science and Engineering, Changchun University of Science and Technology, Changchun 130022, China*

**E-mail: baoshan002@126.com*

Received June 28, 2010

A high efficiency, high power diode-side-pumped quasi continuous wave (QCW) Nd:YAG ceramic rod laser at 1064 nm based on the domestic transparent ceramic is reported. The average output power of 961 W is achieved with double ceramic rods by means of a symmetrical convex-convex cavity. The optical-to-optical conversion efficiency is 38.3% and the slope efficiency is 45.3%. To the best of our knowledge, this is the highest level of efficiency achieved for the domestic Nd:YAG ceramic rod laser.

OCIS codes: 140.3460, 140.3480, 140.3580.

doi: 10.3788/COL20100812.1144.

Many recent studies on laser active materials have focused on polycrystalline ceramics, which have numerous advantages over single crystals, including ease of fabrication, low cost, larger size, multi-functional structure, higher doping concentration with controlled profile, and mass production[1−5] . Since 1995, when the first transparent polycrystalline ceramic Nd:YAG was synthesized and laser output was obtained, the use of polycrystalline ceramic has developed rapidly and a number of scientists have concentrated on the improvement of its growth technique and the production of higher output power[6].

In the area of domestic ceramic laser, Pan *et al.* reported a continuous wave (CW) diode-end-pumped laser output power of 1 W level in 2006[7] . Chen *et al.* achieved 10 W with a doubled end-pumped ceramic laser in 2007[8] , and Tang *et al.* reported a diode-side-pumped quasi CW (QCW) laser output of 23 W in 2008[9] . Recently, Zong *et al.* obtained an output power of 76 W from an end-pumped ceramic laser using direct pump technology[10]. To our knowledge, a domestic ceramic laser output power over 100 W has not been reported yet. In this letter, we present a high efficiency, high power QCW diode-side-pumped Nd:YAG ceramic rod laser at 1064 nm based on domestic ceramic. The average output power is up to 961 W with an optical-to-optical conversion efficiency of 38.3%, the highest power for domestic Nd:YAG ceramic rod laser.

The cross section schematic drawing of the laser module is shown in Fig. 1. The laser module consists of a Nd:YAG ceramic rod, a cooling sleeve, five laser-diode (LD) arrays, and a diffusive optical cavity. The Nd:YAG ceramic rod has a diameter of 6 mm and a length of 100 mm with 1 at.-% Nd^{3+} doping concentration. Both end faces of the rod were coated with anti-reflection (AR) at 1064 nm ($R < 0.2\%$). The Nd:YAG ceramic rod was cooled with water through a glass tube intended purposely for cooling the laser rod. Five QCW LD arrays surrounded the Nd:YAG ceramic rod symmetrically. The total pump power of a single 808-nm laser module can be over 1200 W. To increase the absorption efficiency, five polished brass reflectors coated with gold were also placed around the Nd:YAG ceramic rod symmetrically to reflect

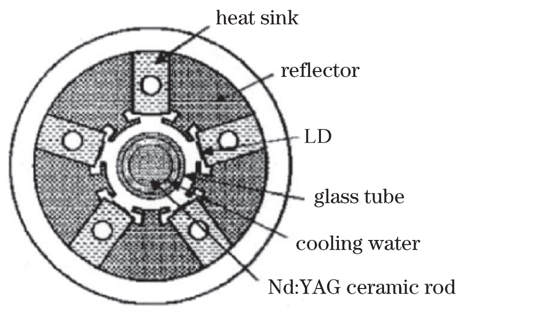

Fig. 1. Schematic diagram of a laser pump module.

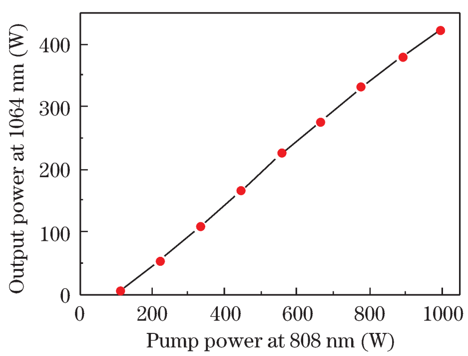

Fig. 2. Average output power versus LD pump power for a single module laser.

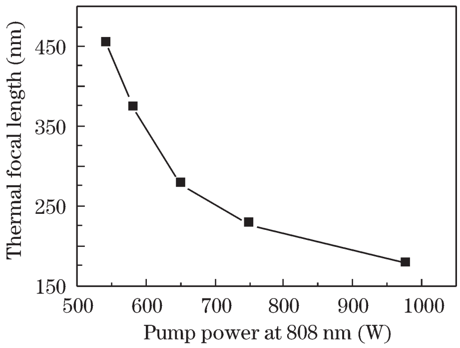

Fig. 3. Thermal focal length versus LD pump power.

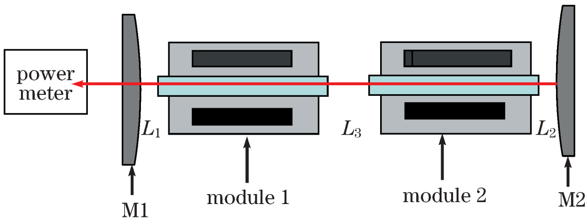

Fig. 4. Experimental setup for two modules Nd:YAG ceramic laser.

unabsorbed pump light back into the Nd:YAG rod.

We first studied the laser performance of a single module in plane-plane short cavity with an output coupler of 20% transmission at 1064 nm and a rear mirror coated with high reflectance at 1064 nm. The average output power as a function of the LD pump power is shown in Fig. 2. The maximum output power obtained was at 425 W at LD pump power of 1000 W, corresponding to an optical-to-optical conversion efficiency of 42.5% and a slope efficiency of 48.3%. The optical-to-optical conversion efficiency was equivalent to that of the ceramic laser demonstrated by Toshiba Corporation in Japan[6].

The thermal effect of the laser rod can affect laser performance seriously. Thus, we also measured the thermal focal length of a single Nd:YAG ceramic rod using the method suggested by Lancaster *et al.*[11]. Figure 3 shows the measured results of the thermal focal length under different pump powers. The thermal focal length decreases with the increase in pump power. The thermal focal length is about 170 mm at 1000-W pump power.

Two identical laser modules were employed for power scaling. The experimental setup is shown in Fig. 4. The convex mirror M1 was an output coupler with a transmission of 30% at 1064 nm. The rear convex mirror M2 was coated with high reflectance at 1064 nm ($R > 99.8\%$). M1 and M2 have the same radius of curvature (ROC), which is 1000 mm. In our experiment, L_1 and L_2 represent the distance between the laser rod and the mirrors, respectively; L_3 represents the distance between the two rods. Here, $L_1 = L_2 = L_3/2 = 5$ mm. Hence, the laser cavity had a symmetrical convex-convex configuration with a total cavity length of 220 mm.

Figure 5 shows the average output power of the Nd:YAG ceramic laser as a function of LD pump power with solid squares for the convex-convex cavity. A maximum output power of 961 W at 1064 nm was obtained

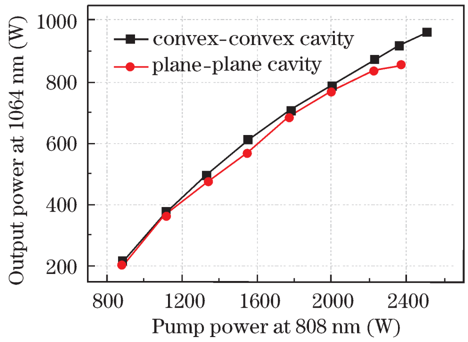

Fig. 5. Average output power versus the LD pump power for two modules laser.

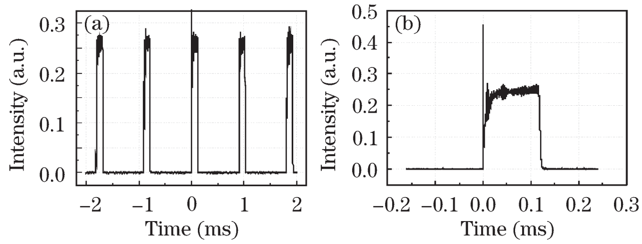

Fig. 6. Observed oscilloscope traces. (a) Laser pulse train and (b) single pulse envelope.

under pump power of 2511 W, which corresponded to an optical-to-optical conversion efficiency of 38.3% and a slope efficiency of 45.3%. To our knowledge, this is the highest output power obtained for a domestic Nd:YAG rod ceramic laser. The laser pulse characterization was recorded on a Si-photodiode detector (Thorlabs Inc., DET200) and a digital oscilloscope (Tektronix, DPO4104, 1-GHz bandwidth). The typical laser pulse train and single pulse envelope are shown in Figs. 6(a) and (b), respectively. The laser pulse repetition frequency (PRF) was 1.1 kHz and pulse width was 170 μs.

To conduct a comparison, we also worked on two Nd:YAG ceramic laser rods with the plane-plane cavity. Its output power versus LD pump power is depicted with solid circles as shown in Fig. 5. The laser output power for the convex-convex cavity was obviously higher than that for plane-plane cavity, particularly in the higher pump power range. Through a convex-convex resonator, a larger fundamental mode size in the Nd:YAG ceramic rods can be obtained, contributing to the production of a higher output power[12,13].

In conclusion, we have demonstrated a high efficiency, high power LD side-pumped QCW Nd:YAG ceramic rod laser at 1064 nm. A maximum average output power of 961 W is obtained under pump power of 2511 W, corresponding to an optical-to-optical conversion efficiency of 38.3 % and a slope efficiency of 45.3%. To the best of our knowledge, this is the highest output power that has been obtained for the domestic Nd:YAG ceramic rod laser.

This work was supported by the Major Program of the National Natural Science Foundation of China (No. 50990304) and the National High Technology Research and Development Program of China.

References

1. S. Lee, D. Choi, C.-J. Kim, and J. Zhou, Opt. Laser Technol. **39,** 705 (2007).
2. J. Lu, J. Lu, T. Murai, K. Takaichi, T. Uematsu, and K. Ueda, in *Proceedings of OSA/ASSL 2002* **68,** 507 (2002).
3. Y. Xu, H. Yu, Y. Wu, B. Jiang, J. Li, Y. Pan, X. Liang, J. Guo, and J. Xu, Chinese J. Lasers (in Chinese) **34,** 1171 (2007).
4. Y. Qi, Q. Lou, J. Dong, Y. Wei, and J. Zhou, Acta Opt. Sin. (in Chinese) **26,** 797 (2006).
5. J. Ji, Y. Qi, X. Zhu, and Q. Lou, Acta Opt. Sin. (in Chinese) **26,** 415 (2006).
6. J. Lu, K. Ueda, H. Yagi, T. Yanagitani, Y. Alexander, and A. A. Kaminskii, J. Alloys Compd. **341,** 220 (2002).
7. Y.-B. Pan, J. Xu, Y.-S. Wu, J. Li, J.-D. Li, B.-X. Jiang, W.-B. Chen, X.-Q. Feng, Y.-P. Zeng, L.-P. Huang, and J.-K. Jing, J. Inorg. Mater. **5,** 1278 (2006).
8. Y. Chen, Y. Zhou, N. Zong, G. Wang, Y. Bo, Q. Peng, D. Cui, Z. Xu, Y. Wu, J. Li, X. Feng, Y. Pan, J. Li, F. Fan, A. Yu, Y. Zhou, and Z. Hu, Chinese J. Lasers (in Chinese) **34,** 660 (2007).
9. H. Tang, X. Zhu, B. Jiang, and Y. Pan, Chinese J. Lasers (in Chinese) **35,** 2001 (2008).
10. N. Zong, X. Zhang, F. Li, Q. Ma, B. Wang, Y. Bo, Q. Peng, D. Cui, Z. Xu, W. Liu, X. Feng, and Y. Pan, Chinese J. Lasers (in Chinese) **36,** 1889 (2009).
11. D. G. Lancaster and J. M. Dawes, Opt. Laser Technol. **30,** 103 (1998).
12. Y. Bo, A. Geng, Y. Bi, Z. Sun, X. Yang, Q. Peng, H. Li, R. Li, D. Cui, and Z. Xu, Appl. Opt. **45,** 2499 (2006).
13. F. Salin, J. Squier, and D. J. Harter, in *Proceedings of OSA/ASSL 1992* **13,** 238 (1992).