Laser output of radial-slab solid-state laser

Zhaoshuo Tian (田兆硕), Hongling Cheng (成洪玲), Ping Xu (许 平), Xingbao Zhang (张兴宝), and Shiyou Fu (付石友)*

Information Optoelectronics Research Institute, Harbin Institute of Technology, Weihai 264209, China

**Corresponding author: fsytzs@126.com*

Received September 28, 2012; accepted December 13, 2012; posted online March 20, 2013

In this letter, numerical simulation and experimental study of a radial-slab solid-state laser are presented. The laser includes four crossing-slabs pumped by four Xe flashlamps. The numerical simulation of coherent intensity in the near field and the far field indicates that the laser with the structure can improve the quality of output beam compared with incoherent beam combination. The radial-slab solid-state laser is fabricated, and initial experiments are carried out at a pulse repetition of 1 Hz. Nine beams in the near field and one combined beam in the far field are obtained in our initial experiment. The experimental results are consistent with the numerical analysis in the coherent condition. The results show that coherent beam combination is obtained by this laser.

OCIS codes: 140.3580, 140.3298.

doi: 10.3788/COL201311.041404.

High power solid-state lasers with high efficiency, small volume, and high reliability are widely applied in the fields of industrial machining, material processing, military, etc.. The improvements in power and beam quality for solid lasers are greatly limited because of the effects of thermal lens, stress birefringence, and statistical phase distortions.

Problems existing in high power lasers with a single slab or rod, such as the decline of beam quality, the stability of the laser system, the difficulty of heat dispersing, the optical and thermal damages to the gain medium, and the optical nonlinear effects are often ignored in low power solid-state lasers[1−4]. However, they should be considered in high power lasers. Nowadays, adopting gain medium series connection or master oscillator power amplifier laser systems are the main methods of obtaining high output power in solid-state lasers. Nevertheless, the output power is unstable and affected by gain saturation because of large thermal effect and difficulty in laser alignment. Thus, the number of gain medium is limited in gain medium series connection laser systems.

The use of multi-slabs parallel connection to achieve coherent beam combination is a hot research area internationally; this method can also be applied to obtain high power lasers[5−8]. Some experimental results and computational numerical simulations also demonstrated high feedback efficiency, high power, and high brightness using this method[9−12]. To obtain high quality, phase control and phase compensation technologies such as self-phase modulation and stimulated Brillouin scatering mirrors are widely used[13−15]. In our research, the radial construction of a radio frequency (RF)-excited multi-channel slab discharge CO_2 laser is introduced into a solid-state laser. The solid gain medium can be made by radial construction and output N laser beams. Ideally, the maximum intensity of combinations of N coherent beams at the focal spot increase the far-field intensity profile by a factor of N^2, with a corresponding reduction of the far-field focal spot size by $\sqrt{N}$. One of main advantages is that the center of gain medium can be efficiently cooled, and the pump uniformity can also be improved. Thus, the effect of thermal lens and thermal stress of gain medium could be greatly reduced. This type of laser gives a new research direction for high power, high beam quality, and compact and scale power solid-state lasers. With a suitable design, yielding ten or hundred thousands of Watt laser with high beam quality is possible.

We simulated the near-field and far-field intensity profiles of double-slab laser and triple-slab laser under non-phase-locking and phase-locking conditions. Our previous theoretical calculation and computer simulations of the crossing slabs were discussed in Refs. [16-18]. The simulation results show that no high beam quality laser can be obtained under double- and triple-slab conditions. In this letter, compared with the simulations, we provide the initial experimental results for eight radial-slab solid-state lasers.

The radial-slab solid-state laser is proposed based on the radial configuration of a RF-excited multi-channel slab discharge CO_2 laser. Figure 1 shows a schematic of the end structure for the radial slab. It is made of precisely cut Nd-doped glass rods. The radial slab with a diameter of 30 mm includes four 100-mm-long and 5-mm-wide crossing-slabs. One face of two ends is anti-reflected. and the other is highly reflected at 1.06 μm. The four crossing-slabs are pumped by Xe flashlamps, and a plano-plano resonator is adopted in this laser system. For coherent combination, we obtain the near-field and far-field intensity profiles through the fast Fourier-transform iterative solution method. The output laser intensities in the near field can be assumed as elliptical Gaussian beams, in the case of single fundamental transverse mode emission for the nine slabs. The spatial distribution is described by

$$E(x,y)=\sum_{j=1}^{9}E_0\mathrm{e}^{-(x/\omega_x)^2}\mathrm{e}^{-(y/\omega_y)^2}\mathrm{e}^{\mathrm{i}\varphi_j}, \qquad (1)$$

where ω_x, ω_y are the elliptical Gaussian beam waists at the output mirror in x and y directions, φ_j is the phase difference of nine output beams. The experimental results demonstrated that the electric fields in the near-field zone are near Gaussian. Thus, a Gaussian model was used in our theoretical calculation and simulation.

In the simulation, the ideal conditions were considered, and the phase shifts were assumed to be zero. If the phase shifts are not the same, we can obtain partial coherent or incoherent beam combination. The near-field intensity (3 m) profile of the radial-slab laser output coherent combination is shown in Fig. 2. According to the experimental observation, the intensity profile for each of the nine beams is Gaussian distribution, with the center one weaker and the other ones stronger for the medium absorption and optical field distribution of pump flash lamps. In the case of coherent combination simulation, the nine beams overlap completely in the far field (30 m), producing a single output beam with better quality than that in the case of incoherent (Fig. 3). The numerical simulations illustrate that the laser with the structure of a radial slab can greatly enhance the beam quality in terms of peak power and beam waist, making

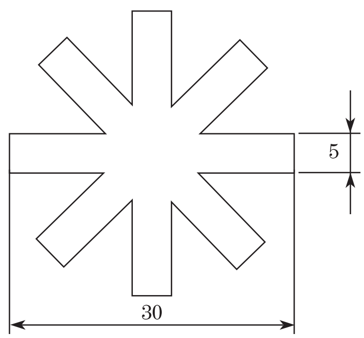

Fig. 1. End structure of the radial slab.

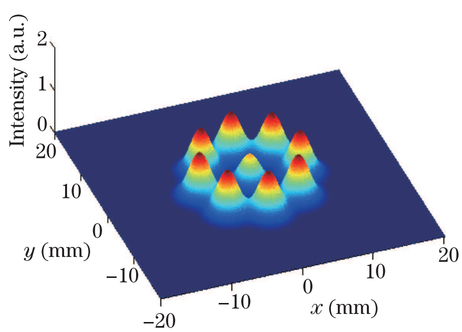

Fig. 2. Near-field intensity profile of the radial-slab laser output at 3 m (coherent).

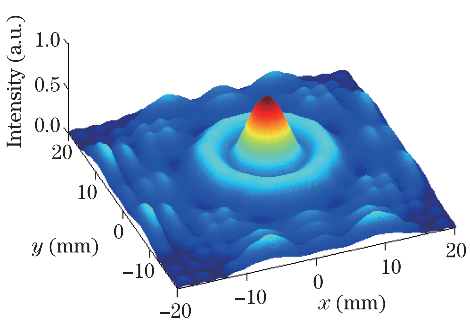

Fig. 3. Far-field intensity profile of the radial-slab laser output at 30 m (coherent).

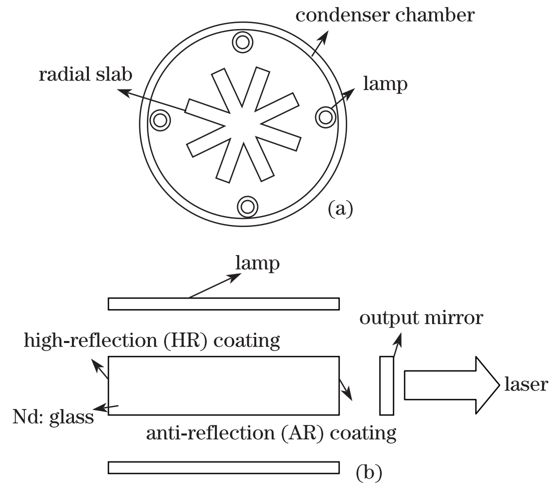

Fig. 4. Schematic of the radial-slab solid laser. (a) Cross-sectional view of the radial slab; (b) side view of laser.

it a promising way to achieve high power, high beam quality, and compact and scale power solid-state laser.

The experiments were performed based on the structure presented in Fig. 4, in which a diffuse reflecting pump chamber was used. In our initial experiment, four Xe flashlamps were arranged around the radial slab to produce a relatively homogeneous pumping profile. One end of the radial slab was coated with anti-reflection film and the other side with high-reflection film. The output mirror, having a 10% transmission, was placed 0.4 m in front of the radial slab. One fan placed 0.5 m in front of the high-reflection coating was used for cooling the radial slab and flashlamps. Two power supplies were connected to four flashlamps, each for two lamps. A pulse signal generator externally triggered the power supply, igniting the lamps simultaneously. We used a charge-coupled device (CCD) camera with a 640×480-pixel resolution to record the beams in the near and far field. The shutter speed is 1/25 s. Using a high-speed avalance photodiode, the laser pulse duration was determined to be 200 μs. The shutter time is much longer than the pulse duration; hence, all laser energy is input into the CCD during the shutter time. When the experiments are performed at a pulse repetition of 1 Hz, the laser output pulse energy is 67 mJ. The near-field pattern in Fig. 5(a) was observed ~3 m from the output mirror by a CCD. The image presented three dimensionally in Fig. 5(b), was processed using Matlab.

The result is slightly different from the theoretical analysis, because we assumed that the slabs were uniformly pumped and neglected the thermal effects. The far-field intensity profile was recorded using an infrared camera ~30 m away from the output mirror. Coherent, partial coherent, and incoherent beam combination could be observed. In the coherent situation, the far-field beam profile and its three-dimensional image are presented in Figs. 6(a) and (b). The nine beams overlap completely and produce one strong output beam (Fig. 6(b)). The result is consistent with the theoretical analysis for coherent multi-beams combination, showing that we have obtained coherent beam combination using the radial-slab laser.

In conclusion, we conduct numerical simulation and experimental studies for a radial-slab solid-state laser.

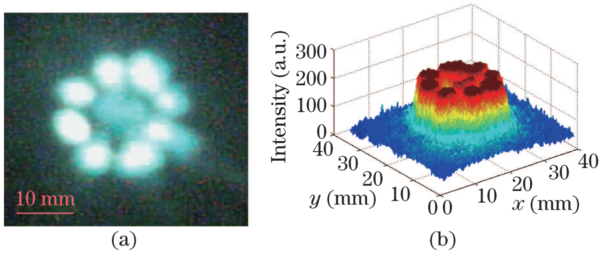

Fig. 5. (a) Near-field beam pattern; (b) near-field intensity profile.

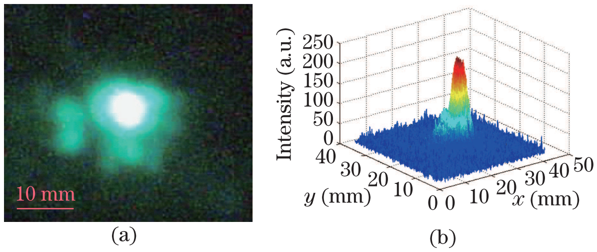

Fig. 6. (a) Far-field beam pattern; (b) far-field intensity profile.

Nine beams in the near field and one coherent beam in the far field are obtained in our initial experiment, which is consistent with the numerical analysis. The results show that we obtain coherent beam combination using the radial-slab laser. In future exteriments, eight pump flash lamps will be used to provide more uniform pumping light field and obtain better beam quality and higher power. Experiments are currently underway, and futher results will be reported.

This work was supported by the Fundamental Research Funds for the Central Universities (Nos. HIT. BRET. 2010014 and HIT.NSRIF.2013139), the Science and Technology Planning of Shandong Province, China (Nos. 2011GHY11514), and the Key Laboratory of Functional Crystals and Laser Technology, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences.

References

1. A. Giesen and J. Speiser, IEEE J. Sel. Top. Quantum Electron. **13,** 598 (2007).
2. S. Lee, M. Yuan, B. H. Cha, C. J. Kim, S. Suk, and H. S. Kim, Appl. Opt. **41,** 5625 (2002).
3. P. Zhu, D. J. Li, B. S. Qi, A. Schell, P. Shi, C. Haas, S. J. Fu, N. L. Wu, and K. M. Du, Opt. Lett. **33,** 2248 (2008).
4. Y. Wang, F. Chen, M. J. Wang, and J. Q. Xu, Chin. Opt. Lett. **9,** 021402 (2011).
5. E. M. Philipp-Rutz, Appl. Phys. Lett. **26,** 475 (1975).
6. D. R. Scifres, R. D. Burnham, and W. Streifer, Appl. Phys. Lett. **33,** 1015 (1978)
7. C. J. Corcoran and R. H. Redike, Appl. Phys. Lett. **59,** 759 (1991).
8. Y. Zhou, L. Liu, C. Etson, Y. Abranyos, A. Padilla, and Y. C. Chen, Appl. Phys. Lett. **84,** 3025 (2004).
9. L. Shimshi, A. A. Ishaaya, N. Davidson, and A. A. Friesem, Opt. Commun. **275,** 389 (2007).
10. G. D. Goodno, H. Komine, S. J. McNaught, and S. B. Weiss, Opt. Lett. **33,** 1247 (2006).
11. E. C. Cheung, J.G. Ho, G. D. Goodno, R. R. Rice, J. Rothenberg, P. Thielen, M. Weber, and M. Wickham, Opt. Lett. **33,** 354 (2008).
12. C. Bellanger, A. Brignon, J. Colineau, and J. P. Huignard, Opt. Lett. **33,** 2937 (2008).
13. S. Jiang, M. Hanna, F. Druon, and P. Georges, Opt. Lett. **35,** 1293 (2010).
14. R. Xiao, J. Hou, M. Liu, and Z. F. Jiang, Opt. Express **16,** 2015 (2008).
15. L. R. Taylor, Y. Feng, and D. B. Calia, Opt. Express **18,** 8540 (2010).
16. S. Y. Fu, Z. S. Tian, X. L. Shi and Z. H. Sun, Chin. Phys. B **17,** 628 (2008).
17. S. Y. Fu, Z. S. Tian, Y. Z. Pan, and X. J. Chen, Proc. SPIE **6823,** 682303 (2007).
18. Z. S. Tian, H. L. Cheng, S. Y. Fu, Z. H. Sun, and Q. Wang, in *Proceedings of CLEO/Europe–EQEC* CA_P42 (2009).