Front. Optoelectron. China 2009, 2(1): 61–63
DOI 10.1007/s12200-008-0039-8

RESEARCH ARTICLE

10 W CW ytterbium-doped fiber laser with 4 × 1 fused fiber bundle combiner

Jihuang ZHANG[1], Chao YANG[1], Chuan HUANG[1], Yuhua LI[1], Nengli DAI[1], Peixiang LU (✉)[1], Zuowen JIANG[2], Wei CHEN[2], Jinyan LI[2]

1 Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan 430074, China
2 Fiberhome Telecommunication Tech Co Ltd, Wuhan 430074, China

Abstract An ytterbium-doped double-clad fiber laser with one-end pumped by four 915 nm laser diodes (LDs) combined by a homemade multimode fused fiber bundle combiner is proposed. The combiner, fused by splicing four fiber pigtails from diodes, exhibits a good capability of low-loss and a high efficiency of 92.7%. The fiber laser, which can generate a continuous-wave (CW) up to 10.3 W output power at 1104 nm with a homemade D-shape inner cladding ytterbium-doped fiber, is demonstrated. The slope efficiency is about 65% and the optical-to-optical conversion efficiency with respect to the pump power is 46% at its maximum output laser power.

Keywords fiber laser, multimode fiber coupler, double-clad fiber, pumping

1 Introduction

In recent years, laser diode (LD)-pumped ytterbium (Yb^{3+})-doped double-clad (DC) fiber laser has become increasingly attractive due to its high efficiency, high power and good beam quality, as well as many potential applications in machining, telecommunication and national defense. In the continuous-wave (CW) regime, the Yb^{3+}-doped double-clad fiber laser has shown extraordinary progress in power scaling [1]. Most high-power Yb^{3+}-doped DC fiber lasers adopt end pump technology, which is a conventional method to couple pump lights into the inner cladding. However, this pump method is limited by the single laser diode's power and brightness. Pumping fiber lasers by combining several laser diodes using prism mirrors, polarizing beam splitter and cylindrical lenses has been demonstrated in Ref. [2]. But these pump couplers are tabletop demonstrations and require precise alignment, and also lack compactness and robustness. Several side-pumped methods have been developed for launching pump light, such as V-groove side-coupling combiners [3], angle-polished combiners [4], embedded-mirror combiners [5], and diffraction grating combiners [6]. Nevertheless, a side-pumped fiber laser is limited by the sophisticated fabrication process. Since a multimode fused fiber bundle combiner could replace the bulk-optics coupler to combine multiplex individual laser diodes, it is one of the most important all-fiber components for a monolithic fiber laser system and is convenient for fabrication compared with side-pumped technology.

The multimode fused fiber bundle combiners are used to combine several multimode fiber pigtails into a large diameter output fiber. The combiners are fabricated in a process similar to the fused and tapered fiber coupling by bundling N parallel multimode optical fibers, and the fused structure is spliced to the output fiber. Such combiners that can sustain high power up to 200 W have been reported by Ref. [7]. Benefiting from the multimode fused fiber bundle combiners, fiber lasers now can generate a high power up to kilowatt scale.

In China, hectowatt- and even kilowatt-scale high power Yb^{3+}-doped DC fiber lasers have been realized, and most of these fiber lasers adopt an end-pumped method with a single high-power laser diode [8,]. However, side-pumped technology has been reported to acquire only a few watts with a coupling efficiency of 78.6% by angle-polished method [10]. In this paper, a fiber laser using homemade Yb^{3+}-doped double-clad fibers is developed through one-end pumped method by using four 915 nm LDs with a high efficiency homemade multimode fused fiber bundle combiner. The coupling efficiency of the combiner is about 92.7% and the maximum output laser power is up to 10.3 W, which is beneficial to the good performance of DC fibers.

Received August 10, 2007; accepted November 8, 2007

E-mail: lupeixiang@mail.hust.edu.cn

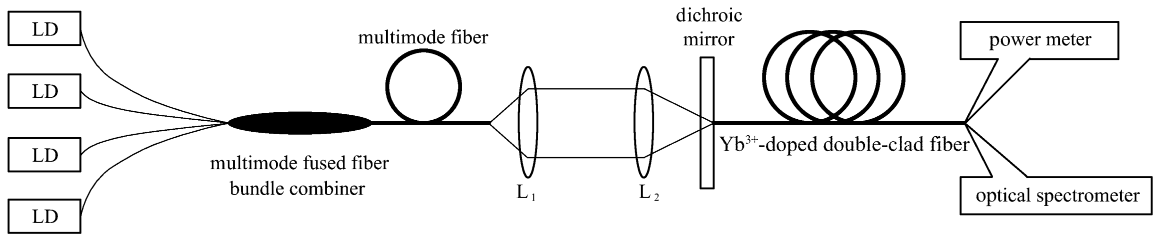

Fig. 1 Schematic diagram of Yb^{3+}-doped fiber laser

2 Experiments and analysis

The experimental setup is shown in Fig. 1. Four LDs operating at 908 to 919 nm related to the diode temperature are used as the pump source, each device is given a maximum optical power of 7 watts and the full width at half maximum (FWHM) of the pump light spectrum is about 3.5 nm. The four fiber pigtails from laser diodes are connected with a multimode fused fiber bundle combiner by fusion splicing, which is produced by Fiberhome Telecom Tech Co Ltd. A multimode fiber with a 200 μm core carries the pump power of the four diodes through out of the combiner, whose numerical aperture (NA) is 0.44. The coupling system comprises L_1, L_2 and dichroic mirror. L_1 and L_2 are both aspheric lenses with focal lengths of 5.5 and 11 mm, and NA are 0.44, 0.22, respectively. The 2 mm thickness dichroic mirror, which is placed on the focal plane of L_2, is attached to the input facet of the gain fiber. The combiner is tested by driving each single diode, and the coupling efficiencies are 85.4%, 90%, 93.5% and 98.6%, respectively. The overall coupling efficiency of the combiner is about 92.7% through experiment, namely the insertion loss is 0.33 dB as shown in Fig. 2. About 2 watts power is dissipated due to its insertion loss at an input power of 28 W, which can lead to a detrimental thermal effect. A heat-sink configuration has been used to cool down the combiner. As illustrated in Fig. 2, the coupling efficiency of the combiner is stable even at the maximum input power.

In this laser system, a D-shape inner cladding Yb^{3+}-doped fiber, also produced by Fiberhome Telecom Tech Co Ltd, is used as the gain material within the Fabry-Perot cavity. The fiber which is coiled as a ring with a diameter of about 40 cm without any special cooling measures has a D-shape 650/600 μm inner cladding with an NA of 0.48 and a core diameter of about 40 μm. Both ends of the fiber are perpendicularly cleaved and polished to connect the fiber axis. The laser cavity is formed between the two facets of the fiber. In order to let the pump light pass through and serve as a high reflector for laser wavelength, a dichroic mirror (905–925 nm, $T > 95\%$, 1040–1200 nm, $R > 99.5\%$) is attached to the input end of the fiber. The other end of the fiber with a 4% Fresnel reflection is used as the output mirror.

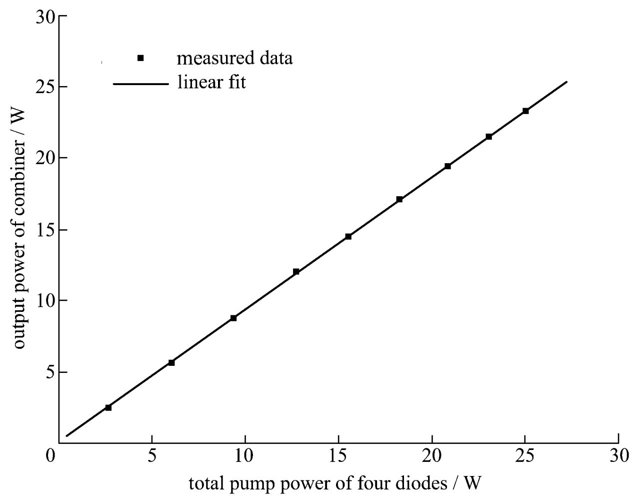

Fig. 2 Coupling efficiency of multimode fused fiber bundle combiner

Figure 3 shows the output power of the high efficiency Yb^{3+}-doped fiber laser pumped at 915 nm. As predicted by theory, above the threshold (about 7 W), the output power grows linearly with launched pump power. A 10.3 W laser power is achieved at the maximum pump

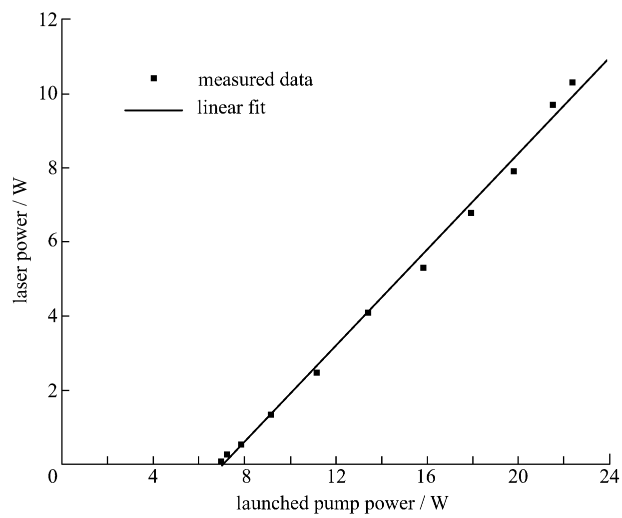

Fig. 3 Fiber laser output power versus launched pump power

power. The output power is almost stable for this fiber and increases linearly at all scales shown in Fig. 3. The slope efficiency with respect to the launched pump power is about 65%. The optical-to-optical conversion efficiency with respect to the pump power is 46% at the maximum output laser power.

As illustrated in Fig. 4, the laser spectrum is centered at 1104 nm, and the spectral width is approximately 8 nm, measured by Ocean Optics USB2000 optical spectrometer. There is a small quantity of unabsorbed pump lights at the 915 nm region in the output radiation. For this fiber laser system, the fiber length is about 24 m, the unabsorbed pump power at 915 nm is less than 2% of the launched pump power, and the optimum fiber length is around 22 m according to the simulation.

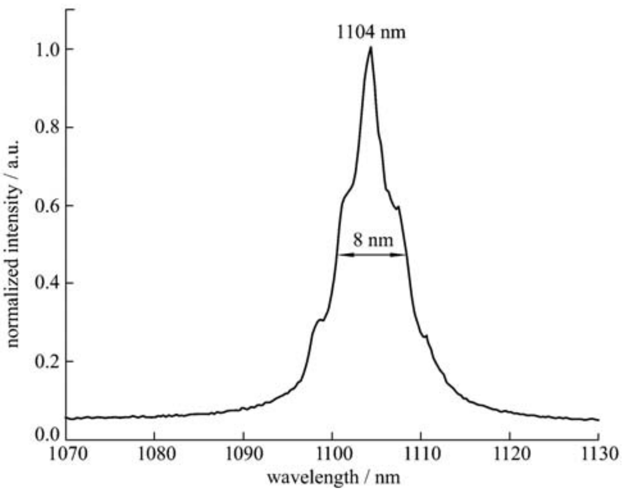

Fig. 4 Output spectrum of Yb^{3+}-doped fiber laser at a laser power of 10.3 W

3 Conclusion

In conclusion, an end-pumped Yb^{3+}-doped double-clad fiber laser with a homemade multimode fused fiber bundle combiner, which combines four individual multimode fiber pigtails from four 915 nm LDs, is presented. The coupling efficiency of the combiner has been demonstrated up to 92.7%. The output laser power is 10.3 W at 1104 nm, and the slope efficiency with respect to the launched pump power is 65%. In the future, high power (hectowatt and even kilowatt) fiber lasers could be realized by increasing the number of laser diodes. Furthermore, the insertion loss of combiners can be reduced to keep away from any detrimental effect by improving the fabrication technique. Future work thus will involve high power fiber laser by combining more pump diodes. In addition, once a fiber grating replaces the dichroic mirror and lens, and serves the function of bulk optics coupler and reflector for the laser cavity, an all fiber-structure fiber laser system could be obtained.

Acknowledgements This work was supported by the National Basic Research Program of China (Grant No. 2006CB806006)

References

1. Jeong Y, Sahu J K, Payne D N, et al. Ytterbium-doped large-core fiber laser with 1.36 kW continuous-wave output power. Optics Express, 2004, 12(25): 6088–6092
2. Kim N S, Hamada T, Prabhu M, et al. Numerical analysis and experimental results of output performance for Nd-doped double-clad fiber lasers. Optics Communications, 2000, 180 (4–6): 329–337
3. Ripin D J, Goldberg L. High efficiency side-coupling of light into optical fibres using imbedded v-grooves. Electronics Letters, 1995, 31(25): 2204–2205
4. Xu J Q, Lu J H, Kumar G, et al. A non-fused fiber coupler for side-pumping of double-clad fiber lasers. Optics Communications, 2003, 220(4–6): 389–395
5. Koplow J P, Moore S W, Kliner D A V. A new method for side pumping of double-clad fiber sources. IEEE Journal of Quantum Electronics, 2003, 39(4): 529–540
6. Herda R, Liem A, Schnabel B, et al. Efficient side-pumping of fiber lasers using binary gold diffraction gratings. Electronics Letters, 2003, 39(3): 276–277
7. Gonthier F, Martineau L, Azami N, et al. High-power all-fiber components: the missing link for high power fiber lasers. Proceedings of SPIE, 2004, 5335: 266–276
8. Zhou J, Lou Q H, Zhu J Q, et al. A continuous-wave 714 W fiber laser with China-made large-mode-area double-clad fiber. Acta Optica Sinica, 2006, 26(7): 1119–1120 (in Chinese)
9. Zhou J, Lou Q H, Kong L F, et al. A 115-W ytterbium-doped fiber laser. Chinese Physics Letters, 2004, 21(6): 1083–1085
10. Ou P, Yan P, Gong M L, et al. Multi-coupler side-pumped Yb-doped double-clad fiber laser. Chinese Optics Letters, 2004, 2(5): 285–287