A 110-W fiber laser with homemade double-clad fiber

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Received October 13, 2004

A high-power ytterbium-doped fiber laser (YDFL) with homemade double-clad fiber (DCF) is introduced in this letter. The geometric parameter and laser characteristics of the fiber have been studied. With one-end-pumping scheme, pumped by a high-power laser diode with launching power of 280 W, a maximum continuous wave (CW) output of 110 W is obtained with an optical-to-optical efficiency of 40%.

OCIS codes: 060.2320, 140.3510, 140.3480.

High-power fiber lasers are now mature products and have numerous applications in medical, military, industrial processing, and modern telecommunication because of some unique advantages including high conversion efficiency, excellent beam quality, less thermal effect, and small volume and weight, etc.. Usually single mode fiber lasers are pumped by single mode diode with low output power. Double-clad fiber lasers (DCFLs) overcome the problem of launching the power from multimode pumps into single mode core by a large multimode section surrounding the doped core which propagates the pump light. Improvement in high power multimode diode combined with double-clad fiber (DCF) technology permits DCFLs to be very efficient and promising. They are mainly operating in continuous wave (CW), Q-switch, or mode lock regimes. Ytterbium-doping is attractive for high-power cladding-pumped fiber lasers for its high efficiency and high pump absorption[1]. The output power of Yb^{3+}-doped fiber laser (YDFL) reaches more than 100 W due to the high damage threshold of the silica host[2]. Ytterbium DCFL is largely used as a pump source for Raman fiber laser (RFL), which is used for testing components, pumping erbium-doped fiber amplifier (EDFA) and Raman amplifier.

Dominic *et al.* first demonstrated 110-W fiber laser in 1999, which was pumped from both ends of the Yb^{3+}-doped double-clad fiber (DCF) by four beam-shaped 915-nm diode bars[2]. CW output powers of 610 W[3] and 1 kW[4] from a large-core Yb^{3+}-doped DCFL were reported by Jeong *et al.* in this year by using one diode laser at one end and two at each, respectively. Combining the output beams of several 100-W-class fiber lasers[5], fiber laser with output power of more than 2 kW was developed in IPG Photonics. In China, the fiber lasers with CW output powers of 6.5[6], 30[7], and 115 W[8] were reported.

The above mentioned fibers are all imported Yb^{3+}-doped DCF. 110-W CW output power is obtained from a homemade Yb^{3+}-doped DCF (Fiberhome Telecommunication Tech Co. Ltd.). The fiber was pulled from a D-shape performance which was fabricated by the modified chemical-vapor deposition (MCVD) and solution doping techniques. The geometric parameter and the fluorescence characteristic of the fiber were measured. This fiber had a 16-μm Yb-doped core diameter with a numerical aperture (NA) of 0.18, and the inner cladding had a 400/450 μm diameter for the shorter/longer axis with a NA of 0.36. The performance was milled to D-shape before being drawn to fiber, so as to improve the cladding-mode overlapping with the Yb-doped core. Fluorescent lifetime of the fiber is 840 μs, and the fluorescence spectrum of 6-m Yb^{3+}-doped DCF is presented in Fig. 1.

The experimental setup is shown in Fig. 2. Both ends of the fiber are perpendicularly cleaved relative to the fiber axis. The laser cavity is formed between the two facets of the fiber. The fiber is cladding-pumped with one-end-coupling scheme by a diode stack emitting at ~ 975 nm with 5-nm spectral width. The collimated output beam dimension is 40 × 40 (mm), so the beam from this kind of source is necessarily rather large when

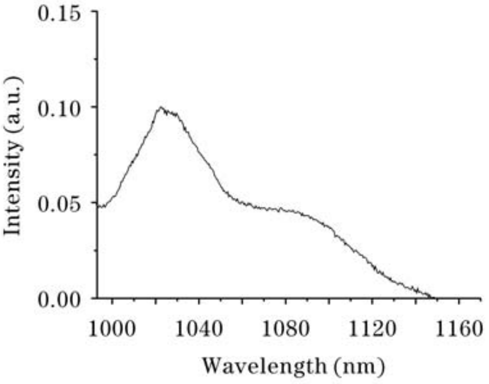

Fig. 1. The fluorescence spectrum of 6-m Yb-doped DCF.

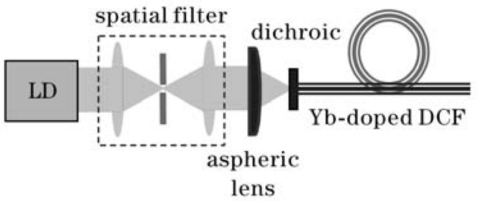

Fig. 2. Experimental setup.

1671-7694/2005/060345-03 http://www.col.org.cn

focused, and the pump launch optimization is critical. We use a spatial filter to improve the beam quality of the high power pump light and a special designed aspheric to focus the pump light on the inner cladding. In order to transmit the pump light and reflect the laser light, a dichroic mirror (975 nm, $T \sim 95\%$; 1080—1150 nm, $R > 99.8\%$) is attached to the input end of the fiber. At the other end of the fiber, 4% Fresnel reflection is used as the output mirror.

The output power is a function of fiber length when the injected pump power is fixed. Optimum length of 20 m was achieved theoritically[9] and experimentally as shown in Fig. 3. The experiment results of 6-, 21-, and 52-m fibers are presented in Fig. 4.

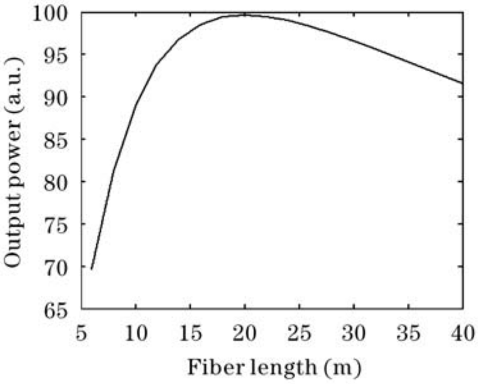

Fig. 3. Output power as a function of fiber length.

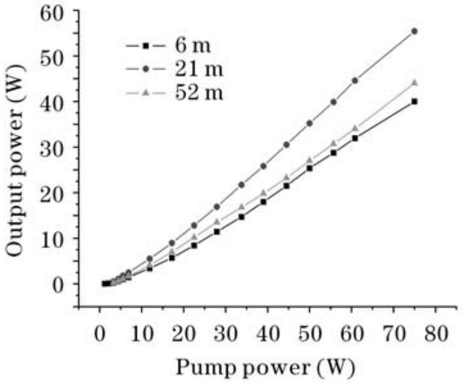

Fig. 4. Output power of different fiber lengths.

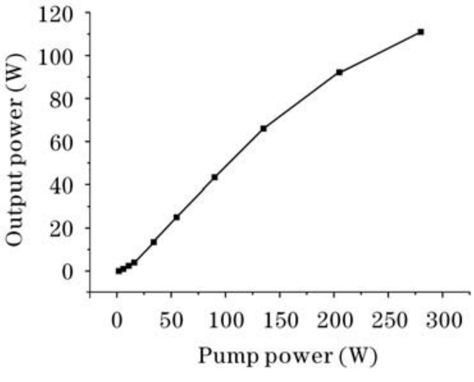

Fig. 5. Laser output power with respect to the launched pump power.

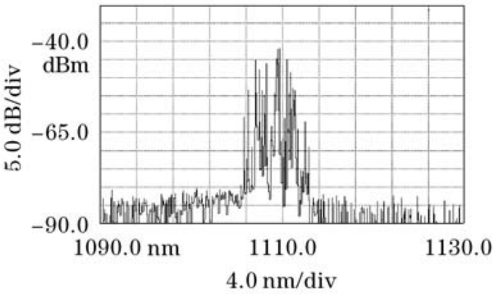

Fig. 6. Laser output spectrum.

In Fig. 5, the maximum laser output power of 20-m DCF is 111 W corresponding to the launched pump power of 280 W with an optical-to-optical efficiency of 40%. The output power increases linearly at low power with slope efficiency of 50%, but there is a roll over at high pump powers. The slope efficiency is only 25% at the maximum output power. Figure 6 is the output spectrum centered at ~ 1108 nm with a spectral width of ~ 10 nm, which is which is measured by MS9710B optical spectrum analyzer.

The slope efficiency of this system is lower than that in Ref. [8] (see Figs. 4 and 5). The reason is probably that the inherent loss of the DCF is high, and the NAs of pump light source and DCF inner cladding are not matching very well.

The roll over of slope efficiency at high pump powers also happened in previous experiments using imported fibers, which is possibly because of the thermal effect caused by the high pump power[8]. This fiber laser gives an output power of about 70 W without any thermal problems. But at higher pump power, the power density of the laser radiation increases, the absorption of the silicone rubber used for the outer cladding of the DCF is much higher than that of the inner cladding pure silica cladding. Hence, the heating of the fiber is significant, and the pump power absorption efficiency decreases. In addition, through an infrared telescope, we found that the first several meters of the DCF in pump end is very bright, which indicates that the pumping leakage from the fiber coating is high. The more the pump power added, the more the pump light leaked, which also attributes to the roll over of slope efficiency at higher pump power.

In summary, we have demonstrated a high Yb^{3+} ions concentration, double-clad YDFL with a CW output power of 110 W at 1.08 μm. The slope efficiency is 40% with respect to the launched pump power. To our knowledge, this is the highest output power obtained by homemade fiber at present. The experimental setup looks something like that in Ref. [8], but we changed almost everything in it, such as the fiber, the aspheric lens, the dichroic mirror, and even the pump source, to satisfy our homemade DCF. The slope efficiency and output power can be further improved by optimizing focal length of the aspheric lens so as to ensure that the NA of pumping light is a little smaller than that of inner cladding. In addition, using both-end pump scheme, large core and inner cladding fiber, or temperature-controlled structure, can also improve the output power greatly[4].

This work was supported by the National Natural Science Foundation of China (No. 60244005), the Chinese Academy of Sciences, and Shanghai Science & Technology Foundation (No. 036105034). D. Xue's e-mail address is xuedong@siom.ac.cn.

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