# 10-W cladding-pumped fiber laser with single transverse mode output

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A Yb-doped double-clad fiber laser is demonstrated with a measured power output of 10.6 W and a fundamental spatial mode. The optical-to-optical conversion efficiency is 44% and the slope efficiency is 86% closed to quantum efficiency of optical conversion. In our laser system, a D-shape (340 $\mu$m/400 $\mu$m) inner cladding Yb-doped fiber is used as the gain material within the Fabry-Perot cavity. Multimode diode pump radiation is injected into the cladding through an end facet of the composite fiber.

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Double clad fiber (DCF) lasers have some unique advantages over traditional solid-state laser systems, such as unparalleled conversion efficiency, excellent beam quality, small volume and weight, and robust laser cavity. The jump to watt-level fiber laser output around 1.1-$\mu$m wavelength occurred in 1993, when a 5-W neodymium-doped fiber laser was reported[1]. This development laid the groundwork for ten-watt and higher single-mode fiber lasers suitable for micro-machining and other applications. Until 1999, CW output power of 110 W from a single-mode fiber laser was reported using two ends facet pumping[2]. Further, in order to scaling of total fiber-laser output power, the first 100-W-class diffraction-limited fiber laser was introduced in 2000 using the basic multi-fiber side-coupling technology[3,4], and the low-order multimode outputs was up to 2 kW by the year of 2002.

In China, the CW output power of 4.9 W from rectangle-shaped DCF laser was reported by Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences in April, 2002[5]. Soon after, the CW output power of 6.5 W from D-shaped DCF laser was reported by Nankai University in October, 2002[6]. In this paper, the fundamental spatial mode 10.6 W cladding-pumped fiber laser is presented.

The DCF laser consists of a multi-mode LD pumping source, the coupling lens and a Fabry-Perot cavity. The Yb-doped DCF is manufactured by Institute for Physical High Technology in Jena, Germany and has a D-shape (340 $\mu$m/400 $\mu$m) inner cladding with a numerical aperture (NA) of 0.37. The fiber core diameter is 12 $\mu$m with a NA of 0.17. The doped Yb-concentration is 6500 mol ppm. The fiber length gives more than 13 dB of pump absorption at 975 nm and makes the pumping power to be absorbed sufficiently. The LD pumping source made by Hi-Tech Optoelectronics Co., LTD is fiber coupled 26 W output with the output fiber diameter of 1.1 mm and a NA of 0.11. The LD is cooled by water to match the absorption of Yb-dopped fiber. Multimode diode pump radiation is injected into the pump cladding through an end facet of the composite fiber, propagates along the fiber structure, periodically traversing the doped fiber core, and produces a population inversion in the core fiber. In order to realize the efficient conversion of multimode output radiation from the fiber coupled laser diodes into inner pump cladding, a set of optical coupling lens is used. A dichroic mirror (910 – 980 nm, $T > 85.0\%$; 1050 – 1150 nm, $R > 99.8\%$) which passes the pump light and severs as a high reflector for the laser radiation is attached to one end of the fiber. The output end of the fiber is the air/glass interface ($R \approx 3.5\%$) served as the laser output coupler. The fiber is coiled by 32-cm diameter cylindrical mandrel.

Figure 1 shows the measured total output power from the fiber laser versus the input pump power from the fiber coupled LD source. A maximum output power of 10.6 W is measured at 25.6-W LD pump power by Molectron EPM2000 power meter. The measured total optical-to-optical conversion efficiency is 44% and the laser pump threshold power is around 1 W. We have not found any decrease in total output power (see Fig. 1) when the pump power is increased. The measurement shows that the pump power has been absorbed sufficiently and the left pump power from the output end of the fiber is lower than 50 mW. The measured slope efficiency of the fiber laser is 86% and near to quantum efficiency of optical conversion. This slope efficiency is based on the pump power incident on the fiber and the output power of the fiber laser.

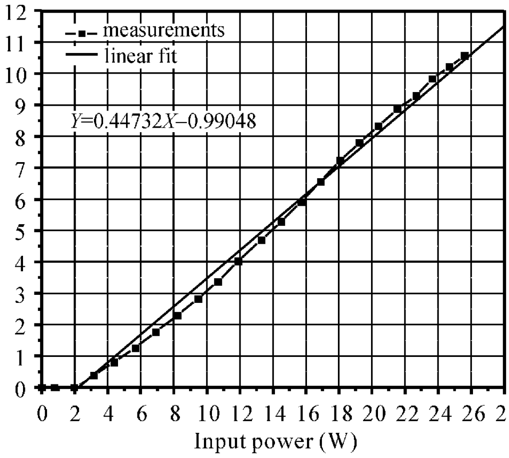


Fig. 1. Output power of the fiber laser against input power of LD pump source.

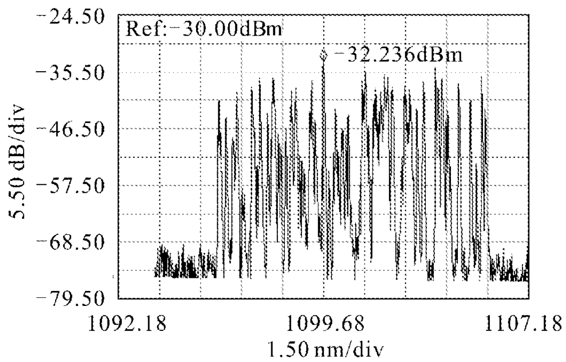


Fig. 2. Output spectrum of the fiber laser.

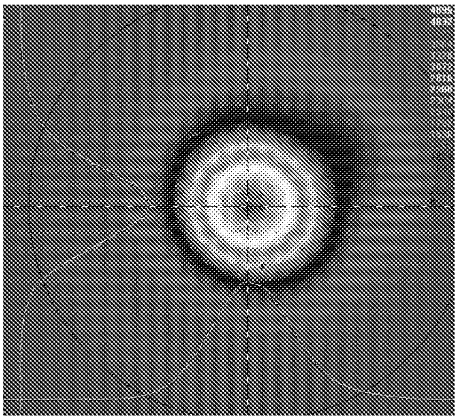

Fig. 3. Spatial mode distribution of the fiber laser.

As shown in Fig. 2, the output spectrum of the fiber laser measured by Agilent86142B spectrum analyzer, is centered at 1.1 $\mu$m and spectral width is about 10 nm. The spatial mode is measured by Spiricon LBA-500PC spatial mode analyzer, as shown in Fig. 3. Figure 3 shows that the fundamental spatial mode is obtained in this DCF laser. The beam quality of the fiber laser is insensitive to the power operating point of the laser.

In summary, we have demonstrated 44% optical-to-optical conversion efficiency and high slope efficiency in a DCF laser operating at 10.6-W CW power. Fundamental spatial mode is obtained in the fiber laser. The output power and the optical-to-optical conversion efficiency can be further improved by increasing pump coupling efficiency. The current limitation to attaining higher power is the availability of higher brightness pump sources. In achieving these 10-W-class powers, we have shown that the DCF laser has good performance and has great potential for many applications.

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