50-watt ytterbium-doped double-clad fiber laser

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A ytterbium-doped double-clad fiber laser with more than 50-W output, near diffraction-limited is demonstrated in SIOM. The optical-to-optical efficiency is about 44% with respect to incident pump power and the slope efficiency is 69% against launched pump power.

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Applications in printing technology, metrology and micromachining require compact, efficient and powerful lasers with excellent beam quality. Diode pumped solid state lasers meet these requirements, however thermal effects in conventional bulk laser materials complicate the scaling of the output power with constant beam quality. With fiber lasers these problems can be overcome. But the output power of diode pumped fiber lasers is limited to the same order of magnitude as the power of single mode diode lasers[1]. To scale the output power beyond a few hundred milliwatts, Snitzer and co-workers demonstrated a clever solution to this problem, it involved what they called a double-clad fiber[2]. Since the mid-1990s, with the development of the fabrication technics of double-cladding fiber and high-power laser diode bar (including its beam shaping techniques), high-power double-clad Yb^{3+}-doped fiber lasers have progressed rapidly, from 2 W in 1995[3], 35 W in 1997[4], 110 W in 1999[5], 150 W in 2002[6], and more than 200 W in 2003[7].

In China, the CW output powers of 4.9[8], 10[9] and 20 W[10] from rectangle-shaped double-clad fiber have been realized in our institute (Shanghai Institute of Optics & Fine Mechanics, CAS), and a practical model fiber laser with output of 20 W has been developed. The CW output powers of 6.5- and 10-W[11,12] fiber lasers are reported by Nankai University and Tsinghua University in 2002 and in 2003. In this letter, we reported output power of 50 W from a double-clad fiber laser.

In our laser system, a D-shape inner cladding Yb-doped fiber is used as the gain material within the Fabry-Perot cavity, which is manufactured by Institute for Physical High Technology (IPHT) in Jena, Germany. The fiber had a D-shape 350/450 μm inner cladding with a numerical aperture (NA) of $\sim$ 0.37 and the core diameter is 12 μm with a NA of $\sim$ 0.15. The doping Yb-concentration is about 6500 mol ppm. The length is 39 m and the pump power will be absorbed sufficiently when pump wavelength at 975 nm. The fiber is coiled by 32-cm diameter cylindrical mandrel in air, and without any special cooling device. The pump source is a high-power laser diode, central wavelength is about 975 nm with 5-nm spectral width (FWHM). The laser diode is water-cooled and the operating temperature varies from 16 to 22°C. The pump power was coupled into the inner cladding of the input end of the fiber by a special designed spherical coupler system. The focused beam spot is smaller than 300×300 μm^2, and the NA is about 0.35, with these values, the spread angle of the pump beam matches well with the NA of the double-clad fiber inner cladding. In order to pass the pump light and serve as a high reflector for the laser wavelength, a dichroic mirror (975 nm, T ~90%, 1060 − 1150 nm, $R > 99.8\%$) is attached to the fiber input end. The other end of the fiber was polished and the 4% Fresnel reflection was used as the output mirror.

Figures 1 and 2 show the measured total output power from the fiber laser as a function of the incident and the launched pump power. The incident pump power means the power in front of the dichroic mirror, and the launched pump power means the power in the input end of the fiber, which is detected using the truncation method. A maximum output power of 50.3 W was measured at 114 W incident pump power, corresponding launched pump power is 75.9 W. The incident laser pump threshold power is about 2 W. As far as we know, this is the highest output power generated by a double-clad fiber laser now in China. Noting that at 50 W of average power, the average optical intensity in the core is more than 65 MW/cm^2. The fiber laser output spectrum is centered at 1099 nm and the measured optical-to-optical conversion efficiency is 44%. This efficiency is based on pump power incident on the dichroic mirror and output power of the fiber laser. The slope efficiency is about 69% with respect to launched pump power. From Figs. 1 and 2, we can see that the output power is linearly

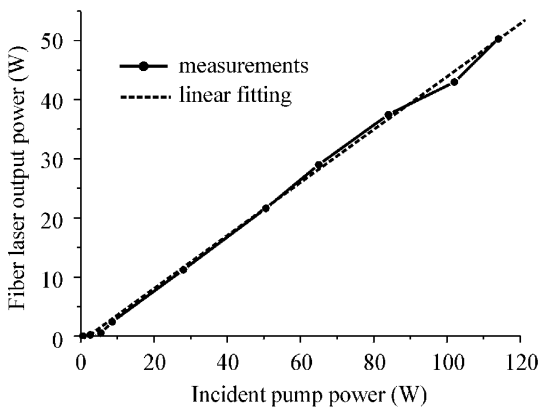

Fig. 1. Output power of the fiber laser against incident LD pump power.

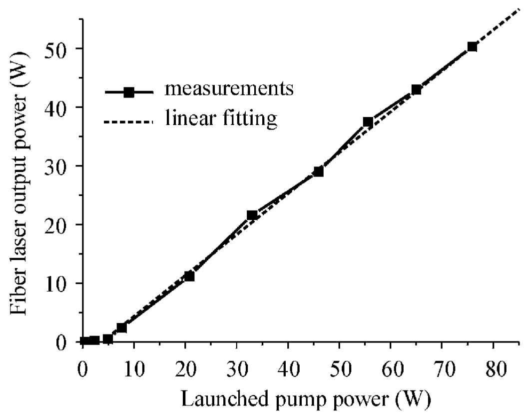

Fig. 2. Output power of the fiber laser against launched LD pump power.

increasing with the incident pump power, the output power can be further improved by increasing pump power and optimizing coupling system.

In our experiments, the fiber was tested in fiber laser systems with an output power of about 50 W without serious thermal problems. But the glass dichroic mirror attached to the fiber input end can be damaged when the incident pump power over 120 W. For this fiber, in order to increase the output power, it is necessary to choose quartz dichroic mirror which has a higher transmission for the pump wavelength.

In summary, we have demonstrated 44% optical-to-optical conversion efficiency against incident pump power and 69% slope efficiency against launched pump power in a D-shape inner cladding double-clad fiber laser operating at 50 W power. Although the average optical density in the fiber core is about 65 MW/cm^2, serious thermal problems and catastrophic fiber failure are not observed in the fiber. Higher output power fiber laser will be realized through increasing the pump power and optimizing coupling system.

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