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Experiment research on optical properties of all microstructure optical fiber laser

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ABSTRACT

We demonstrate a new all-fiber laser with Yb-doped double-cladding microstructure optical fiber (MOF) that is fabricated through non-chemical vapor deposition (Non-CVD) technology. In our experiments, both of the seed laser and amplifier are made of the same kind of Yb-doped MOF by spatial light coupling method. The amplifier output power is 5.03 W with a one-stage amplifier when the seed laser power is 1.07 W. The signal power is amplified about five times. These results can provide motivation for the application of Yb-doped MOF. It indicates that all microstructure optical fiber laser has the great potential to provide enormous output power scaling.

1. Introduction

In recently years, fiber lasers have achieved remarkable development due to their outstanding performance and innate fascinating advantages, for example, excellent beam quality, freedom from alignment, easy thermal management, robust operation, and so on [1,2]. They have facilitated widespread applications of fiber lasers in research, medicine, security, industry, and other areas. There were many investigations on high power fiber laser in the past years [3–7]. The power-scaling of Ytterbium-doped (Yb-doped) fiber lasers even has emerged output power more than 1 kW. In 2009, Jeong et al. [8] demonstrated a cladding-pumped Yb-doped fiber laser generating an output power up to 2.1 kW. In 2015, Xu et al. [9] achieved a high power narrowband all-fiber super-fluorescent fiber source employing three-stage master oscillator power-amplifier chain and obtained the maximal output power of 1.87 kW. In 2016, Beier et al. [10] reported a narrow linewidth, continuous-wave (CW), single mode fiber amplifier emitting a maximum output power of 3 kW.

The gain medium of the above-mentioned fiber lasers is a traditional Yb-doped optical fiber, but the photonic crystal fiber (PCF) [11,12] is a more appropriate one. Remarkable properties of PCF, such as endlessly single mode, low non-linear, large mode area and so on, have been reported for fiber laser. In 2006, Hildebrandt et al. [13] obtained an output power of 148 W in a Yb-doped PCF amplifier. In 2008, Johan et al. [14] reported on a 80 μm core diameter Yb-doped rod-type PCF laser emitting up to 94 W in CW regime when operating at 977 nm. In 2012, Li et al. [15] reported a 980 nm Yb-doped PCF amplifier achieving an output power up to 1.21 W. In 2014, Robin et al. [16] obtained a single frequency Yb-doped PCF amplifier with an output power of 811 W. In 2015, Sidsel et al. [17] achieved an output power of 53 W with a Yb-doped hybrid PCF at 1178 nm. In order to improve laser power, all-fiber laser emerged [18–20]. However, problems, including fusion splice, modes matching and so on, still exist in all-fiber Yb-doped PCF laser [21–24]. Thus, we adopt the spatial light coupling method to investigate optical properties of all MOF laser.

A new all-fiber laser with Yb-doped double-cladding MOF that is fabricated by Non-CVD technology has been demonstrated. In the experiment, both of seed laser and the amplifier are made of the same kind of Yb-doped MOF by spatial light coupling method. Seed source is an independent home-built Yb-doped double-cladding PCF laser. The signal power is amplified about five times. These results can provide motivation for the application of Yb-doped MOF. The optical properties of all MOF laser are discussed. The experiment can implies a potential application for the high power, all-fiber laser in the future.

2. Experiment setup

The temperature of our laboratory is maintained at 25°. The experiment setup of seed laser and amplifier are depicted in Fig. 1. A

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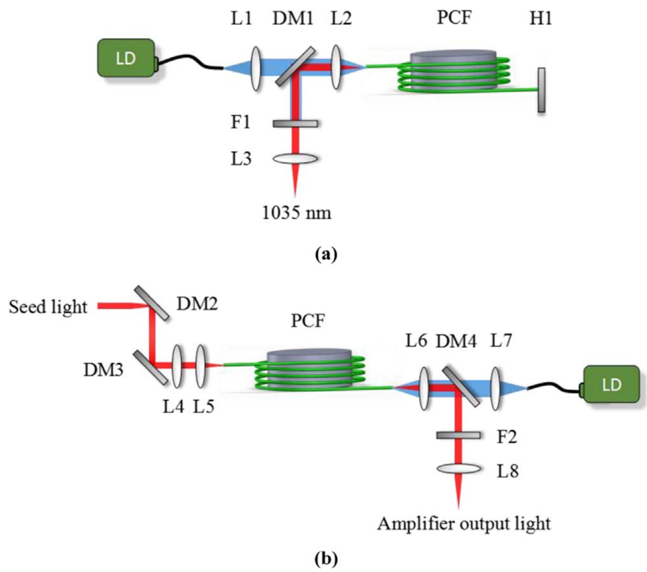

Fig. 1.. Experiment setup of **(a)** seed laser and **(b)** amplifier.

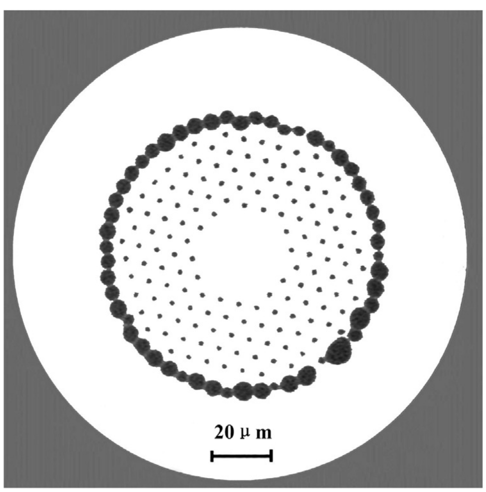

Fig. 2.. Cross-section of the drawn PCF.

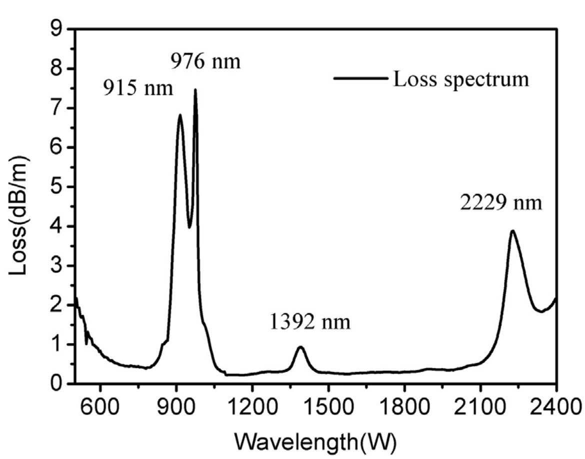

Fig. 3.. Loss spectrum of the PCF.

counter-pumping scheme is used in the amplifier setup. Seed light is provided by the Yb-doped double-cladding PCF laser and its cavity is a Fabry-Perot cavity. The laser comprises LD, L1, DM1, L2, H1 and PCF. Both of the LD in experiment setup are a pump source with core diameter of 105 μm and numerical aperture (NA) of 0.22, whose

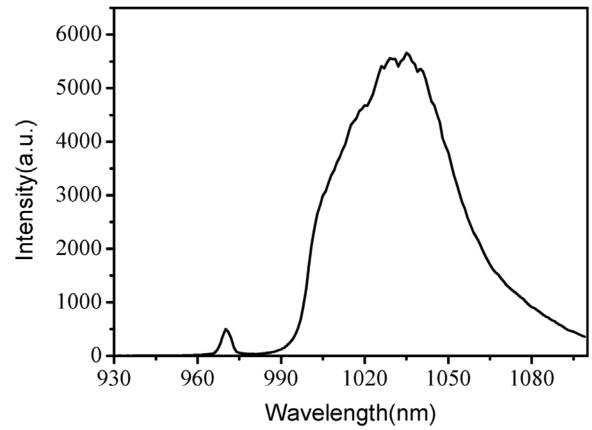

Fig. 4.. Fluorescence spectrum of the 1.87 m length fiber.

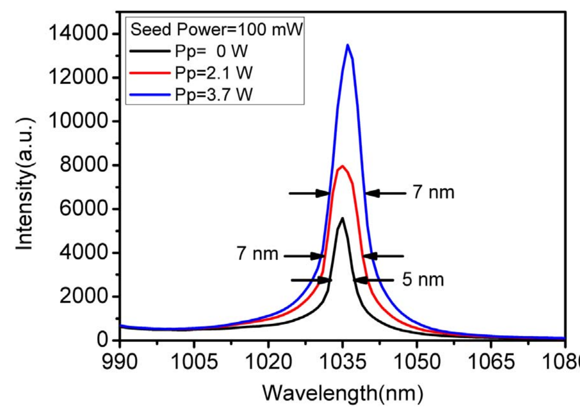

Fig. 5.. Contrast seed light spectra with amplifier light spectra.

emitting at 976 nm. The pump light is injected into the PCF by the two plane convex lenses L1 (f =10 mm) and L2 (f =8 mm). The dichroic mirror DM1 is used for high reflectance at 1035 nm and high transmission at 976 nm for 45° angle of incidence. F1 can filter residual pump light at 976 nm from both sides in order to protect stability of system. Both dichroic mirrors DM2 and DM3 have the same function as DM1 so as to filter residual pump light and change the route of the seed light. L4 (f =20 mm) and L5 (f =10 mm) which are transform beams into tightly focused spot coupling into the gain medium of fiber amplifier, are plane convex lens. The amplifier is comprised of the Yb-doped double-cladding PCF, end-pumped by a LD. The coupling systems composed of L6 (f =6 mm) and L7 (f =10 mm). DM4 is also a 45° dichroic mirror to separate the pump and amplified radiation. Both fiber tails of amplifier are polished at 8° angle to prevent amplified spontaneous emission or even spurious lasing.

The PCF, as gain medium of seed laser and amplifier, is fabricated by Non-CVD technology. The Non-CVD technology is laser sintering technology combined with solution doping method [25,26]. The fabrication process of Yb-doped MOF perform includes two phases. One is preparation of the Yb-doped powder preparation, another is the Yb-doped silica glass sintering. Compared to the conventional CVD, this technology has the superior control of the homogeneity and accuracy of doping concentrations, which can be applicable to the high concentration configurations, large core, and multi-rare earth co-doping to accelerate the development of high power fiber lasers. This type of MOF has potential superiority, such as the low non-linearity, high pump absorption efficiency and bend-insensitive. The cross-section of the drawn PCF is shown in Fig. 2. Nineteen missing air holes define the Yb-doped core area. The diameter of fiber core is 29 μm. There are five layers of air holes between fiber core and air-cladding. PCF has been designed with hole-to-hole distance