Increased pulsed amplifier efficiency by manipulating the fiber dopant distribution

J. M. Oh[+], C. Headley, M. J. Andrejco, A. D. Yablon, and D. J. DiGiovanni
OFS Labs, 19 Schoolhouse Road, Somerset, NJ, 08873, USA
[+]*Permanent address Department of Physics, Chungnam National University, Daejeon 305-764, Republic of Korea*
joh@cnu.ac.kr

Abstract: In the pulse application, a significantly increased efficiency of high power large-mode area fiber amplifiers is demonstrated by improving the overlap of the doped region with the fundamental mode of the fiber.

OCIS codes: (060.0060) Fiber optics and optical communications; (060.2320) Fiber optics amplifiers and oscillators

Cladding pumped fiber lasers and amplifiers have emerged as a competing technology for solid state lasers. In order to obtain high powers and mitigate nonlinear effects large mode area (LMA) rare-earth doped fibers have been used [1-3]. In LMA fibers, the area of the fundamental mode of the fiber can be substantially less than that of the core [4]. Recently it was shown that confining the rare-earth dopants in the fiber core to a region where it overlaps with only the fundamental mode leads to an improvement in the efficiency of CW amplifiers, but this advantage decreases as the output signal power increases [4]. It might then be anticipated that the large peak powers and the presence of nonlinearities in pulsed amplifiers might lead to no benefit to the confined dopant fiber. Here, for the first time, we show that a comparable advantage can be obtained even with pulsed amplifiers.

The designs of the two kinds of LMA Yb-doped fibers used are shown schematically in Figure 1. The fully-doped fiber (FDF) shown in Fig. 1 (a) follows the conventional approach and has Yb uniformly distributed throughout the whole core. The novel fiber, referred to as the confined dopant fiber (CDF), has Yb-dopant only in a region approximately equal to the full-width at half-maximum of the fundamental mode of the fiber. Two FDF and two CDF were fabricated and their parameters are summarized in Table 1. The fibers were fabricated so that if the mode field diameter of the pump propagating through the core of each fiber was equal to the diameter of the doped region the absorption in the fibers would be equal. This is reflected in the core absorption measurement. It also means the number of dopants within the mode field diameter (MFD) is different. Thus, the overlap factor between pump and signal modes with the doped regions are different.

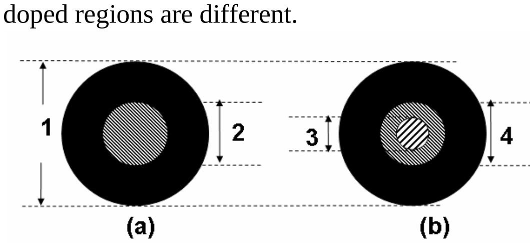

Fig.1. Schematic of the (a) FDF and (b) CDF (1.Cladding diameter, 2.Core & dopant diameter, 3.Dopant diameter, 4.Core diameter)

Table1. The fiber parameters for the four fibers

Fiber	**Core absorption (dB/m)**	**Core diameter (μm)**	**MFD (μm)**	**Dopant diameter (μm)**	**Cladding absorption (dB/m)**	$\frac{A_{MFD}}{A_{Dopant}}$ **(%)**	$\frac{A_{MFD}}{A_{Core}}$ **(%)**	
FDF1	**85**	**29**	**20**	**29**	**1.79**	**43**	**48**	**Fully doped**
FDF2	**80**	**29**	**19**	**29**	**1.68**	**43**	**43**	**Fiber**
CDF1	**73**	**28**	**20**	**21.3**	**0.83**	**88**	**51**	**Confined**
CDF2	**91**	**28**	**20**	**17.4**	**0.69**	**132**	**51**	**dopant Fiber**

Figure 2 is a diagram of the amplifier setup used to test the fibers. The 1082 nm input signal to the test amplifier was generated using a master oscillator power amplifier (MOPA) configuration, and had a repetition rate, pulse width and average power of 10 kHz, 100 ns and 83 mW, respectively. The signal and 975 nm pump light were coupled into the fiber under test using an OFS multimode pump combiner. An all fiber mode converter was used to match the MFD of the standard core size fiber at the output of the mode converter to the 20 µm MFD of the doped fibers to be tested. This minimizes the higher order mode signal light launched, compared to a direct splice.

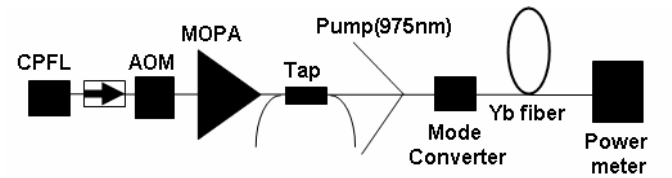

Fig.2. A schematic diagram of the designed YDFA with LMAF

Figure 3(a) shows the optical-to-optical conversion efficiency and Fig. 3(b) the signal output powers of the four fibers as a function of their length, for pump powers of 3.8W, 8W, and 10W, respectively. The ASE, any Stokes light generated, and unabsorbed pump have been filtered out of these measurements. The improvement in efficiency ranges from 7% to 17%. At the 3.8 W pump power, the improvement of output signal power is almost double. The efficiency advantage of the CDF over the FDF decreases with increasing pump power. Two factors contribute to this decrease. First there is an increase in signal power with increasing pump power. The wings of the signal intensity profile can then more efficiently extract energy from the dopants outside of the full-width at half maximum of the MFD, especially for the FDF. The second factor is that the more efficient CDF has more power converted to unwanted wavelengths through various nonlinear effects. Since this power is filtered out of these plots the efficiency decreases.

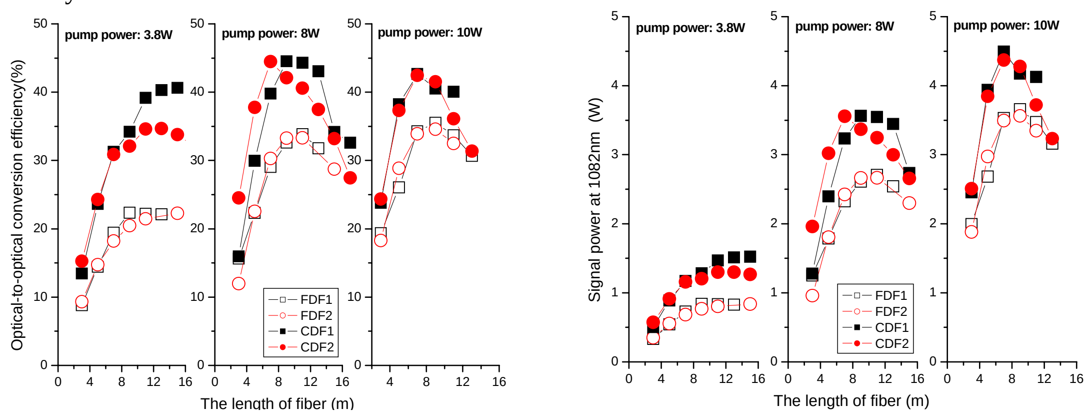

Fig.3. Plot of (a) the optical-to-optical efficiency of the amplifiers and (b) the signal output power at 1082nm as a function of fiber length at 3.8 W, 8 W, and 10 W pump power

It has been shown that increases in efficiency from 7% to 17% can be obtained in LMA high-power pulsed amplifiers by redistributing the rare earth dopant in the fiber so that it overlaps with only the fundamental mode of the fiber.

References

[1] J. Limpert, S. Höffer, A. Liem, H. Zellmer, A. Tünnermann, S. Knoke, and H. Voelckel "100-W average power, high energy nanosecond fiber amplifier" Appl. Phys. B, vol. **75**, pp. 477-479 (2002)

[2] Y. Wang, "Optimization of pulse amplification in ytterbium-doped double clad fiber amplifier" J. Lightwave Technol., vol. **23**, pp. 2139-2147(2005)

[3] J. Nilsson, R. Paschotta, J. E. Caplen, and D. C. Hanna, "Yb3+-ring-doped fiber for high-energy pulse amplification" Opt. Lett., vol. **22**, pp. 1092-1094 (1997)

[4] J. M. Oh, C. Headley, M. J. Andrejco, A. D. Yablon, and D. J. DiGiovanni, "Increased amplifier efficiency by matching the area of the doped fiber region with the fundamental fiber mode" in Optical Fiber Communication Conference, submitted (2006)