

Polarization maintaining, very-large-mode area, Er fiber amplifier for high energy pulses at 1572.3 nm

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ABSTRACT

We demonstrate the first polarization maintaining, very-large-mode-area Er-doped fiber amplifier with $\sim 1000 \mu\text{m}^2$ effective area. The amplifier is core pumped by a Raman fiber laser and is used to generate single frequency one microsecond pulses with pulse energy of $368 \mu\text{J}$, M^2 of 1.1, and polarization extinction $> 20 \text{ dB}$. The amplifier operates at 1572.3 nm , a wavelength useful for trace atmospheric CO_2 detection.

Keywords: Er fiber laser, very-large-mode area, polarization maintaining fiber

Very-large-mode area (VLMA) Er-doped fiber amplifiers [1], core pumped by high-power 1480 nm , Raman fiber lasers [2], generate diffraction limited, high energy pulses at 1.5 micron wavelengths, and have applications in femtosecond fiber chirp-pulse amplifiers [3] and high-energy soliton generation [4], for example. They have been demonstrated with core diameters greater than 50 microns and effective areas greater than $1100 \mu\text{m}^2$.

In spite of the success of VLMA Er amplifiers, there have been few results on making polarization maintaining large-mode area Er-doped fibers. A $26 \mu\text{m}$ mode-field diameter ($\sim 530 \mu\text{m}^2 A_{\text{eff}}$) polarization maintaining, Er-Yb doped photonic crystal fiber laser was previously demonstrated [5]. In this work, we demonstrate for the first time, a polarization maintaining, Er-doped VLMA amplifier with greater than $1000 \mu\text{m}^2$ effective area. We then use this amplifier to demonstrate high energy, one microsecond pulse amplification at 1572.3 nm . The CO_2 absorption line centered at 1572.3 nm has been chosen due to confluence of several spectroscopic properties. It is relatively insensitive to temperature changes compared to other lines in the absorption band, free of absorption features from other atmospheric constituents, and has a convenient peak absorption amplitude that allows measurement of the full atmospheric column that optimizes SNR (i.e - it does not saturate, but is a large enough feature that it is easy to

distinguish from background variations.) [6,7]. Single frequency, 1572.3 nm , $1 \mu\text{s}$ pulses at 7.2 kHz repetition frequency were amplified to 400 W peak power with a pulse energy of $368 \mu\text{J}$. Polarization extinction ratio of the signal was better than 20 dB , and $M^2 = 1.1$.

A microscope image of the fabricated fiber is shown in Fig. 1a. The core diameter was approximately $50 \mu\text{m}$ and the fiber OD $330 \mu\text{m}$. The designed birefringence beat length was 15.8 mm , and the measured beat length was 14.1 mm . Er absorption was approximately 50 dB/m at 1530 nm .

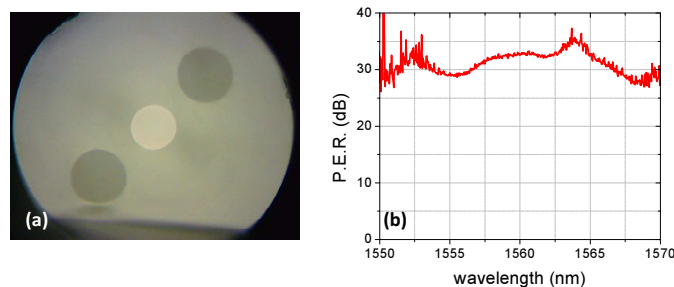


Figure 1. (a) Microscope image of the PM-VLMA Er-doped fiber. (b) Polarization extinction ratio measurement made at 100 mW output power.

To fabricate an amplifier, a 3 m length of PM-VLMA-Er fiber was fusion spliced to a PM $1480/1550 \text{ WDM}$. A 20 W , 1480 nm Raman fiber laser was used as a pump source. The polarization extinction ratio was first characterized at low CW output powers. For approximately 100 mW output the polarization extinction ratio was measured to be greater than 30 dB over a broad wavelength range, see Fig. 1b.

Next a 7.2 kHz pulse train with $1 \mu\text{s}$ pulses and 10 mW average power was amplified in the PM-VLMA-Er amplifier. The seed laser linewidth was approximately 400 kHz . Because the target wavelength of operation was 1572.3 nm , a longer 3.75 m length of fiber was used, compared to the usual 2 to 2.5 m length for a VLMA fiber with this Er absorption level [1].

Operating characteristics of the PM-VLMA-Er amplifier are shown in Fig. 2. Output spectra are shown for a seed laser wavelength of 1560 nm, compared to 1572.3 nm, for 2 W average power. When operating at longer wavelengths ASE tends to build up at 1560 nm. This shorter wavelength ASE build-up could potentially be suppressed with even longer amplifier lengths, however at the expense of a lower stimulated Brillouin threshold. Fig 2b shows output pulse energy vs. pump power at 1572.3. Only in-band 1572.3 nm signal power was used to calculate pulse energy. The maximum pulse energy was 368 μJ . The output pulse temporal pulse shape is shown in Fig. 2c. The input pulse to the amplifier (inset, Fig. 2c) was shaped to pre-compensate some of the gain induced pulse tilt and maximize the output pulse energy. A maximum peak power of 400 W was achieved. Further pulse energy scaling was limited by the onset of stimulated Brillouin scattering. Measured $M^2 = 1.1$ and the beam profile are shown in Fig. 2d. Fig. 2e shows the polarization extinction ratio (PER) measurement. While the ASE was largely unpolarized, the signal P.E.R. was better than 20 dB at maximum pulse energy.

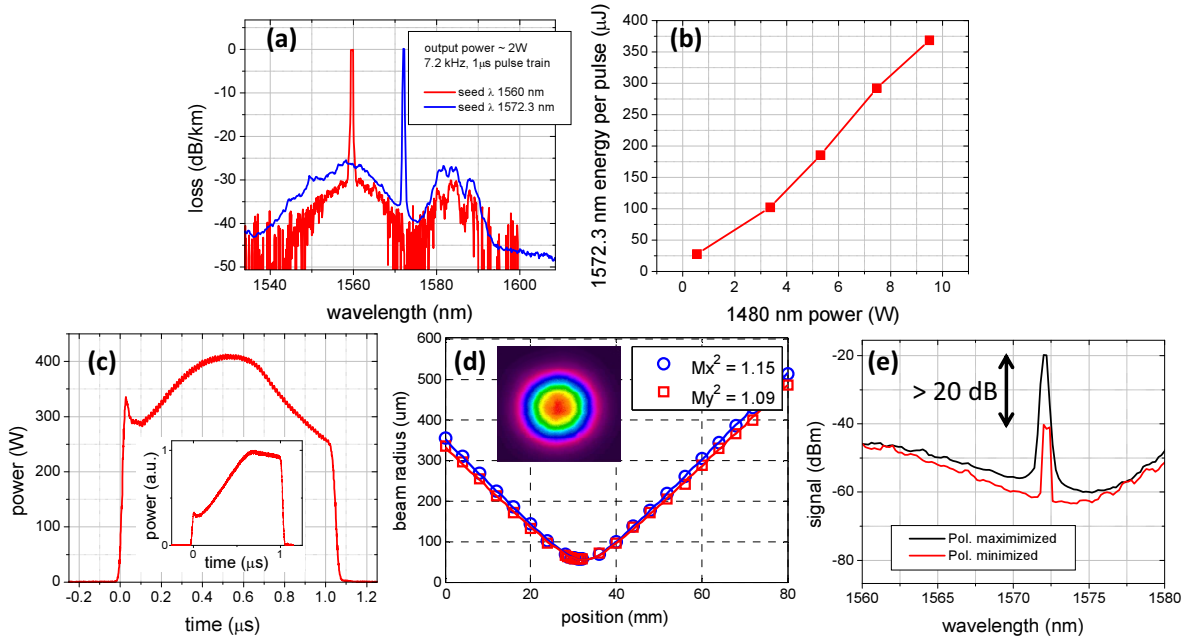


Figure 2. (a) Output spectrum for 1560 nm vs. 1572.3 nm operation. (b) Output pulse energy vs. pump power. (c) Output pulse shape for 368 μJ pulse energy. Inset, input seed pulse (d) beam profile and M^2 measurement for CW operation at 1572.3 nm. (e) Polarization extinction ratio measurement

In conclusion we have demonstrated the first polarization maintaining, very large mode area, Er-doped fiber amplifier with effective area greater than $1000 \mu\text{m}^2$. Using this amplifier we demonstrated amplification of 1572.3 nm, 1 μs pulses to 368 μJ pulse energy, $M^2 = 1.1$ and signal P.E.R. greater than 20 dB. We expect this amplifier to be a useful source for atmospheric trace gas detection.

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