All-solid VLMA Yb-Doped Single-Mode PM Fiber with 10dB/m Absorption for High Power Compact Laser Applications

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We report the design and manufacturing of a truly single-mode VLMA (Very Large Mode Area) fiber basis on a simple bend oriented all-solid step index principle, presenting an measured absorption about 10 dB/m and an optical efficiency above 73%.

Motivations

- Growing demand for large-mode-area doped fiber for the development of high-power fiber amplifiers, especially for laser dicing applications.
- Challenges in manufacturing single-mode fibers with large core diameter (>15µm) for 1µm emission using rare-earth dopant and MCVD process [1].
- The use of ytterbium-doped VLMA microstructured fibers addresses the need [2], but those fibers are expensive and harder to be integrated in a monolithic robustness system.

Preform and Fiber achievement

- Preform with nearly 1:1 molar Al_2O_3/P_2O_5 ratio [3] used as core-glass with core/clad index difference ~7x10-4 showing negligible longitudinal index variation (Fig 1)

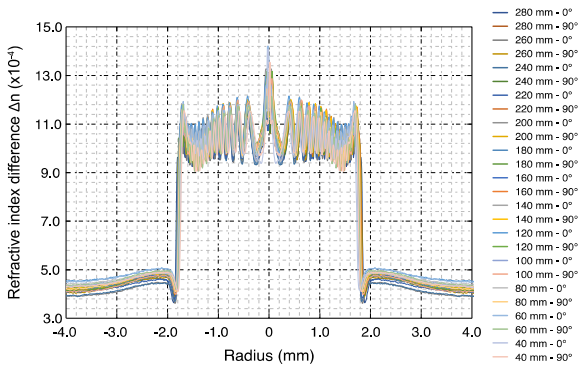

Fig 1: Refractive index profile on preform at different positions.

- Panda-like fiber (Fig 2) with the following patented geometry :
  - Cladding diameter of 224 µm
  - Core diameter close to 41 µm for a MFD about 32 µm and an effective area of 800 µm² on a straight fiber
  - Core numerical aperture of 0.05
  - Non-circularity fiber and auto-orientation by mechanical flats shape
  - Birefringence level reaching 1.10^{-4}

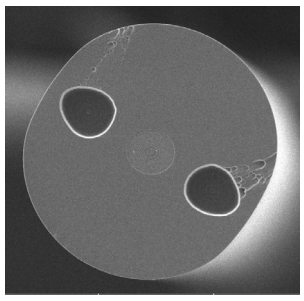

Fig 2: SEM picture of the manufactured fiber

- Finite elements simulations promoting truly single-mode regime for fiber similar to [4] :
  - Predicting both the birefringence and guiding modal properties, including stress-induced refractive index change
  - Confirming the higher-order modes filtering by bending the fiber in a preferential direction of curvature.
- The absorption spectrum of the fabricated fiber was measured on Fig 3 (a) by using the small-signal cutback method for various fiber lengths.

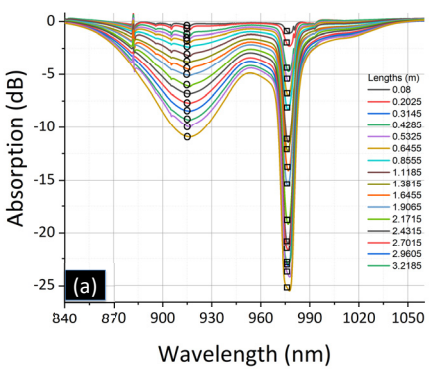

Fig 3 : (a) Absorption spectrum from 'cutback' method measurement

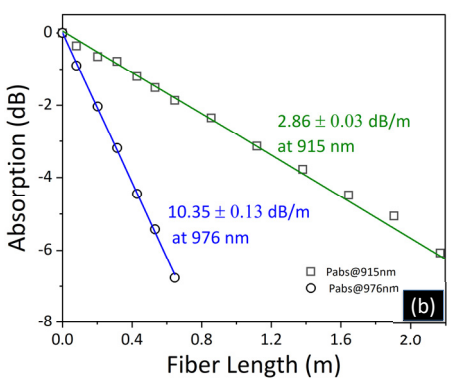

Fig 3 : (b) Cladding absorption at 915 nm and 976 nm in PM-VLMA double clad fiber versus fiber length

- Based on the absorption spectra, the cladding-absorption was calculated for the wavelengths of 915nm and 976nm, as shown in Fig 3 (b). The linear cladding-absorption of the pump in this present case, @ 915 nm and 976 nm are 2.86 dB/m et 10.4 dB/m respectively. The absorption ratio @ 976nm versus @ 915 nm is close to 3.6.

- A flat-shape cladding, combined with the presence of stress rods, ensures good mode mixing with the doped core, then the way the fiber is coiled has no significant influence on pump absorption (see experiment on Fig 4).

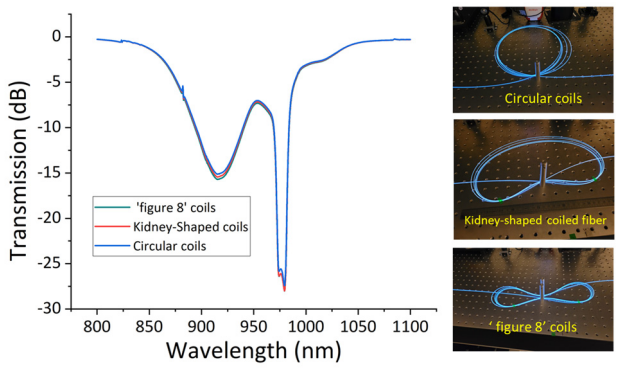

Fig 4: Absorption spectra for the Yb-VLMA fiber in circular (blue), 'kidney-shaped' (red) and 'figure 8' (green) coils.

Laser integration

- The fiber is implemented in a laser configuration described on Fig 5 in pulsed regime. The FCPA laser operating at 1040 nm is seeded by an in-house developed all fiber mode-locked oscillator and delivering a stable pulse train at 20 MHz repetition rate. The VLMA fiber is pumped with two 30 W/976 nm multimode laser diodes through a pump combiner and the MFA.

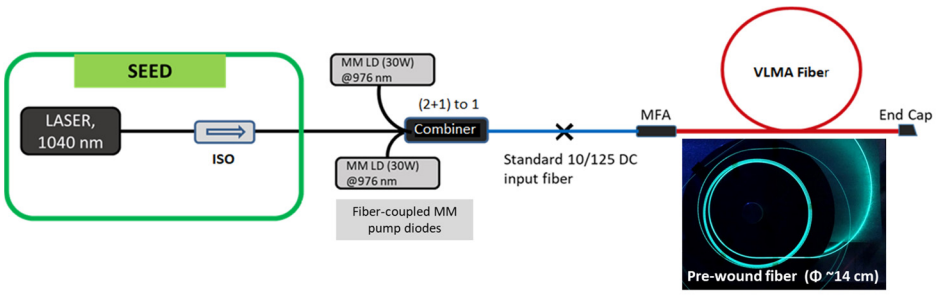

Fig 5: Setup for laser configuration testing

- As showed on Fig 6 (a), stable performances were reached in pulsed regime, with closed to 75% efficiency at 50W in a CPA forward amplifier configuration and with a coiling diameter about 14 cm. Similarly, the beam diagnostic analysis as on Fig. 6 (b) confirms single-mode regime with M^2 below 1.2 at 30 W output power as well as PER above 17 dB.

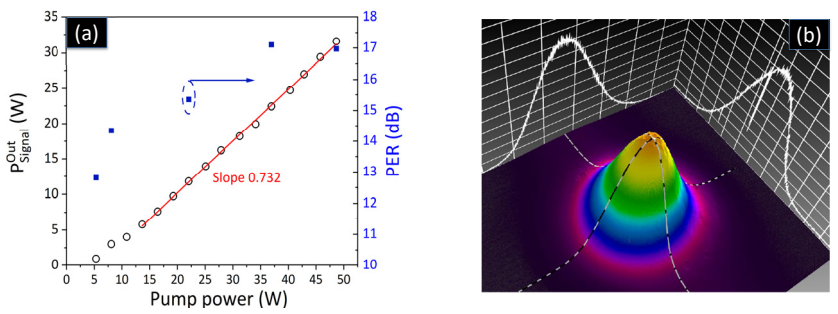

Fig 6: (a) Laser bench output power and Polarization Extinction Ratio (PER) vs absorbed pump power. (b) Output spot shooting for M^2 measurement.

Conclusion

A truly single-mode behavior was demonstrated in Yb-doped step-index PM fiber with effective area 800 µm2 and 10dB/m of absorption.
Through a careful dimensioning of the birefringence parameters, it is possible for small bending radii to reduce the confinement loss for the LP01 mode. It paves the way to design a new generation of lasers with high efficiency and compactness for easier integration in embedded applications as Lidar.

Acknowledgements

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