Asymmetric Very Large Mode Area Fiber with Enhanced Higher Order Mode Delocalization

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Abstract: A novel very-large-mode-area asymmetric rod-type fiber was fabricated and experimentally characterized. The fiber supports effective and robust single-mode operation for a core diameter of 66µm making it attractive for high power amplifier systems.
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1. Introduction

The output power of high power fiber laser and amplifier systems has increased exponentially in recent years. This exceptional increase is largely due to the advances in fiber design and fabrication allowing impressive mode area scaling. However, the performance of high power fiber amplifiers is currently being limited by two intrinsic effects: nonlinear processes and thermal mode instabilities (MI) [1].

A common strategy to overcome detrimental nonlinear processes in optical fibers is scaling the mode field area, and the use of shorter fibers length. Nevertheless, the increase of the core diameter usually comes along with transition from effective single mode to few-mode or multimode guidance. In recent years effective single mode operation in very large mode area (VLMA) fibers has been demonstrated based on novel fiber structures such as large pitch fibers (LPF), chirally coupled cores and distributed filtering fibers [1,2,3] to mention a few. Unfortunately, the HOM discrimination capability of VLMA fibers decrease with larger core sizes. Accordingly, larger cores allow propagation of HOMs, which consequently, have resulted in MI at high power operation. Recently, breaking the cladding symmetry of LMA fibers have been proposed as an interesting approach to enhance the delocalization of HOMs and enable a robust single mode operation of the laser emission [4-6].

In this paper we present a novel asymmetric VLMA passive rod-type fiber with a structure of Ge-doped silica rods judiciously positioned within the cladding lattice to enhance HOM delocalization and assure robust and effective single mode (SM) operation for a core diameter of 66µm with close to diffraction limited beam quality of 1.3 and mode field area (MFA) of 2560µm^2.

2. Asymmetric VLMA Fiber

Figure 1 depicts the cross section of the asymmetric fiber, microscope images of a fabricated fiber as well as the fundamental mode (FM) and the two of the first HOMs. The fibers were fabricated by stack-and-draw. Although we only present passive fibers, we have included an air cladding to study the effects of cladding mode confinement in active fiber designs. Two highly asymmetric passive fibers with different outer diameters (OD) of 1000µm and 800µm outer diameters, Fiber A and B respectively. Fiber A has a 66µm /260µm core /air-clad diameter and Fiber B has 53µm /205µm. The relative hole-diameter (d/ Λ) is 0.42 and 0.469, for Fiber A and B respectively. Figure 1(d-e), shows the calculated FM at 1064 nm and the first two HOMs profiles decoupled to the clad structure.

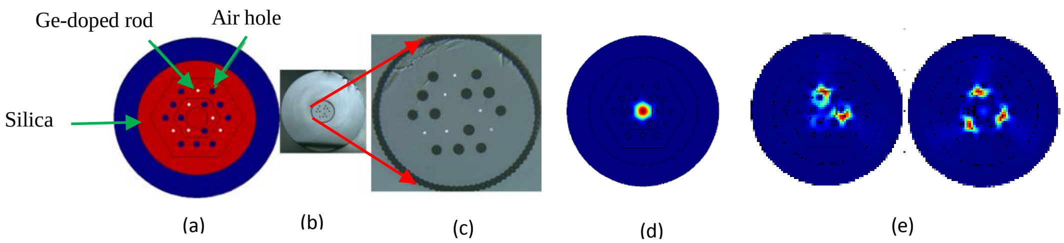

Fig. 1. Asymmetric VLMA rod-type fiber, index profile (a), microscope image of the fabricated fiber (b), enlarged central section (c), simulated FM in the core of the fiber (d), and simulated first two HOMs (e).

3. HOM Delocalization

In order to examine the guidance characteristics of the fabricated fiber as well as its potential to filter out HOMs, we recorded near filed images of the output beam of the passive fiber at several wavelengths by coupling white light delivered from a home-made super continuum source (through launching a pump laser beam to a highly nonlinear fiber (5um core diameter)) into a 52.5/123um core/clad diameter Graded Index Fiber (GIF). The output of GIF was lens-coupled (with 20x magnification) to an InGaAs camera (Xenics XEVA 5191) after passing through Band Pass Filters (BPF- Newport) with 10nm band-pass spectrum. Figure 2(a) exhibits the near field images of the fiber at several wavelengths for two sample fibers (A and B). The S^2 measurement of the fiber that verifies the effective HOMs delocalization as well as its simulation confirmation results, are also shown in Fig.2 (b). The peaks in the FT graph show the coupling of light to the cladding modes.

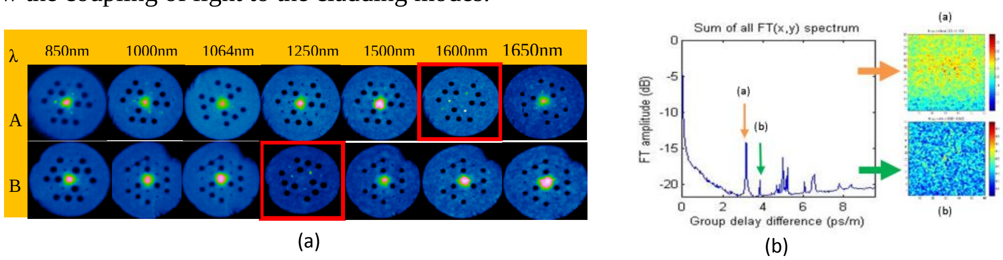

Fig. 2. (a): SM behavior of the asymmetric fibers A and B, (b): S^2 measurement of the fiber A.

Two major specifications of the fabricated fibers are evident from Fig.2 including SM performance of the fibers at broad spectral range (850nm-1650nm, limited to the number of specific BPFs available) and enhanced HOM delocalization due to highly asymmetric pattern using Ge-doped filaments. Both aforementioned properties are beneficial to increase the threshold-like onset of MI in active high power fiber amplifiers. Furthermore, it is also interesting to mention the red-signed selected wavelengths indicate the non-guidance regime of the fiber where the light couples to the Ge-doped resonators. An explicit calculation confirms the 20% change in fiber OD causes the 20% movement of the non-guiding regime due to the phase matching condition of the FM to the resonator modes at some specific wavelengths.

Furthermore, to prove the robust SM behavior of the sample fibers under any launching condition, we translated the input beam along x from -30µm to +30µm attempting to excite any HOM and recorded a series of near field images at 1064nm wavelength. As it is clear from Fig. 3, no HOM was excited which confirms the robust and effective SM operation of the asymmetric rod fiber structure.

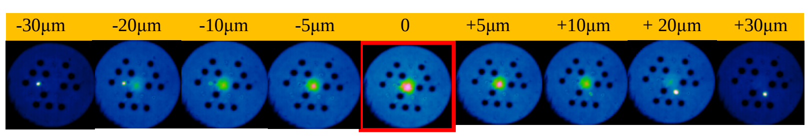

Fig. 3. Near field images of asymmetric fiber at 1064nm under misaligning the lunching condition

Therefore, employing the enhanced delocalization of HOMs through inserting six high index Ge-doped silica filaments in the cladding lattice of a rod-type fiber and breaking the mirror symmetry, demonstrates a broad spectral range of SM operation from 850-1650nm. Moreover, this innovative fiber design with the symmetry-free cladding structure which causes an enhanced preferential gain characteristic, is a promising tool to improve the threshold like onset of MI in high power fiber amplifiers.

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4. References

[1] J. Limpert, F. Stutzki, F. Jansen1, H. Otto1, T. Eidam, C. Jauregui and A. Tu¨nnermann1, "Yb-doped large-pitch fibres: effective single-mode operation based on higher-order mode delocalization," NPG. **1**, (2012).

[2] C. Liu, A. Arbor, G. Chang, N. Litchinitser and D. Guertin, "Chirally coupled core fibers at 1550-nm and 1064-nm for effectively single-mode core size scaling," in CLEO, (Institute of Electrical and Electronics Engineers, Baltimore, 2007), pp. 1-2.

[3] T. Bhutta, J. I. Mackenzie, D. P. Shepherd and R. J. Beach, "Spatial dopant profiles for transverse-mode selection in multimode waveguides," JOSA B **19**, 1539–1543 (2002).

[4] R. Dauliat, D. Gaponov, A. Benoit, F. Salin, K. Schuster, R. Jamier and P. Roy, "Inner cladding microstructuration based on symmetry reduction for improvement of single-mode robustness in VLMA fiber," JOSA. **21**, 18927-18936, (2013).

[5] A. Benoît, R. Dauliat, R. Jamier, G. Humbert,S. Grimm, K. Schuster, F. Salin and P. Roy, "Highly efficient higher-order modes filtering into aperiodic very large mode area fibers for single-mode propagation," JOSA 39, 4561-4564 (2014).

[6] F. Stutzki, F. Jansen, C. Jauregui, J. Limpert and A. Tünnermann, "Breaking the symmetry for enhanced higher-order mode delocalization," in SPIE, (2014).