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Israelsen, Stine Møller; Rottwitt, Karsten

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Effect of Aircladding on Bessel-Like Modes

Stine H. M. Larsen[1], and Karsten Rottwitt[1]
[1]DTU Fotonik, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark
shml@fotonik.dtu.dk

The effect of an aircladding in a double cladding fiber designed to guide higher order modes is examined. For very high order symmetrical modes we find that the circular symmetry of the modes is broken.

Micro-structured fiber; Higher order modes;

I. ABSTRACT

Higher order modes (HOMs) have recently attracted much attention. Especially Bessel-like modes, the LP_{0X} modes, are interesting due to their properties such as diffraction free propagation and self-healing [1]. We investigate the effect of an air cladding on LP_{0X} modes in a double cladding structure both numerically and experimentally to document the break of circular symmetry caused by aircladding and the impact of this effect on the diffraction free propagation distance. We excite the HOMs in a double cladding fiber with an aircladding as the outer cladding using a long period grating (LPG) [2]. A microscope image and a sketch of the refractive index are seen in Fig. 1.

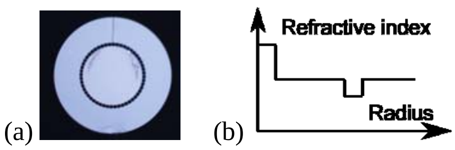

Fig. 1: (a): Microscope image of the fiber. The core is single-moded with a cutoff at 760 nm. The aircladding contains 60 holes. (b): Sketch of the refractive index profile of the investigated fiber.

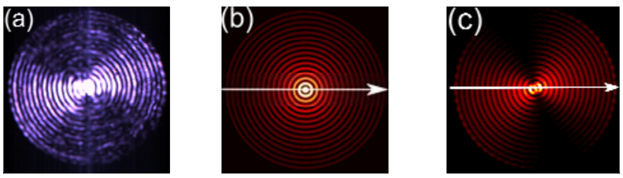

Fig. 2: a) Image of LP_{016} generated with a LPG in the aircladding fiber. The camera is slightly saturated to image the outer rings of the mode. b) An ideal LP_{016} generated with a scalar mode solver. c) One of two LP_{016} modes generated with a full vectorial mode solver.

We have excited LP_{016} with 90 % conversion efficiency. An image of the mode is depicted in Fig. 2a. Notice the bowtie shape in the mode which breaks the symmetry of LP_{0X}-mode. This effect is not seen in the ideal solution, see Fig. 2b. The mode in Fig. 2a is one of two eigenmodes in between which one can shift by a slight perturbation of the fiber. The break of circular symmetry is verified with a full vectorial mode solver, see Fig. 2c. The effect is only observed for very high order HOMs. The onset of the effect is found using the full vectorial mode solver at LP_{010}. A second effect observed in Fig. 2a is the ripples in the outer rings; this effect sets in for slightly higher order modes compared to the break of circular symmetry with an onset at LP_{012}. Both effects may be caused by the shape of the aircladding. The free space propagation of the non-symmetric LP_{016} and the ideal LP_{016} is investigated using a non-commercial Fourier propagation routine. The diffraction free propagation distance is defined as the distance where the maximum intensity has dropped to e^{-1} compared to the intensity at the end facet of the fiber. The simulated free space propagation along the axes indicated in Fig. 2b and Fig. 2c is plotted in Fig. 3.

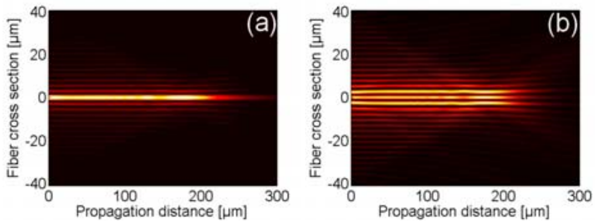

Fig. 3: (a) Free space propagation simulation of the ideal LP_{016} which has a propagation distance of 216 μm and (b) of the one found with the full vectorial mode solver which has a propagation distance of 218 μm.

In summary, we have shown that the aircladding in a double cladding fiber breaks the circular symmetry of high order LP_{0X} modes. However the break of circulcar symmetry happens without reducing the diffraction free propagation distance.

A. Acknowledgement

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