MODAL ANALYSIS OF HOLEY FIBER MODE-SELECTIVE COUPLERS

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Abstract

Mode Division Multiplexing is currently investigated as a possible way to increase fiber system capacity. With this approach, different modes of the same fiber carry distinct information. One of the problems to be solved in these systems concerns coupling/decoupling of the various modes to/from the same fiber. In this presentation, the mode features of a mode mux/demux based on holey fibers are investigated, with particular emphasis on optimal device design. Some preliminary experimental results will also be presented.

Index Terms – Mode Division Multiplexing, Holey Fibers, Modeling.

I. INTRODUCTION

The need to increase the capacity of optical transmission systems has pushed research to investigate new solutions. After trying to increase the system capacity using WDM, Polarization Division Multiplexing, Orthogonal Frequency Division Multiplexing (OFDM) and Multilevel Modulation, the Non Linear Shannon Capacity Limit [1] is soon to be reached. To overcome this problem, and to raise the available bandwidth, Spatial Multiplexing Techniques (namely Mode Division Multiplexing in few mode optical fibers and multicore optical fibers) are currently being investigated [2]. The former approach considers different modes propagating in a single fiber core, each mode carrying distinct information. The latter, on the contrary, uses many single mode cores within the same cladding. Both solutions allow space saving, which is crucial in data centers or other environments where space is a constraint. Both of them, however, present a serious problem: coupling among modes in the same fiber, or between adjacent cores, which creates channel interference effects. Such a problem can be overcome by using classical MIMO techniques [3] in the former case, or careful core topological choices [4] in the latter one. The separation of the closely spaced fiber cores or the different modes propagating in the same fiber core is a further challenging task.

This work concentrates on the design of mode coupling/decoupling devices to/from a few-mode fiber. Some solutions have been proposed so far. Selective mode decoupling can be done, for example, by looking for synchronous conditions between the multimode waveguide and a single mode one. This can be met in longitudinally varying devices, where synchronicity is obtained by varying the angle between the coupled waveguides [5], or in suitably designed cylindrical structures with different transversal size, so that two different modes have the same longitudinal propagation constant [6].

In this work, theoretical and preliminary experimental results of mode selective coupling in Holey Fiber couplers will be reported.

II. SELECTIVE MODE COUPLER STRUCTURE

The cross-sections of the two separate fiber cores as well as of the overall coupler are shown in Fig. 1. The structures have been chosen after a numerical study that considered many possible geometries via both a Finite Difference package and a commercial FEM code [7]. Two rings of holes for each fiber core resulted in an optimal trade-off between high coupling strength and low overall device radiation loss.

The two separate fiber cores have been designed to be synchronous for two different modes: the LP_{11} mode of the large-core and the LP_{01} mode of the small-core. To put the two cores close enough to guarantee coupling, a slight change in the fiber structure had to be made, as shown in Fig. 1c, where the radius of the hole in the coupling region has also been suitably tailored.

The LP_{11} mode has two orthogonal linear degenerate polarizations, generally denoted as LP_{11a} (two intensity lobes with vertical zero line) and LP_{11b} (two intensity lobes with horizontal zero line). In the coupler, supermodes exist. Two of them, whose components are shown in Fig. 2, exhibit symmetry compatible with a Perfect Magnetic Conductor, PMC, placed along the horizontal axis. The remaining two, whose components are shown in Fig. 3, exhibit symmetry compatible with a Perfect Electric Conductor, PEC, placed along the horizontal axis. The small complex part of the calculated propagation constant of the supermodes implies the existence of some losses in the coupler.

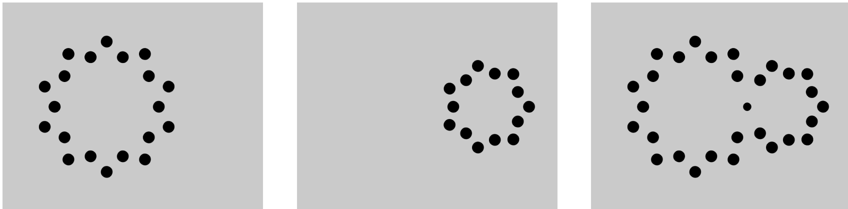
III. SELECTIVE MODE COUPLER BEHAVIOUR

When the large fiber core gets closer to the smaller one, coupling between LP_{11a} and LP_{11b} and the supermodes occurs. However, the field shapes allow only the LP_{11a} large components to couple efficiently with the large components of the supermodes. The LP_{11b} large components couple in fact with the small ones of the supermodes, so coupling does not practically occur in this case.

The overall behavior of the coupler was numerically tested using a Finite Difference BPM full vectorial code [8]. A prototype of the device has been realized by drilling and drawing of a solid PMMA preform rod [9]. The excellent agreement between the calculated and measured field intensities in the 3 dB coupling section is shown in Fig. 4.

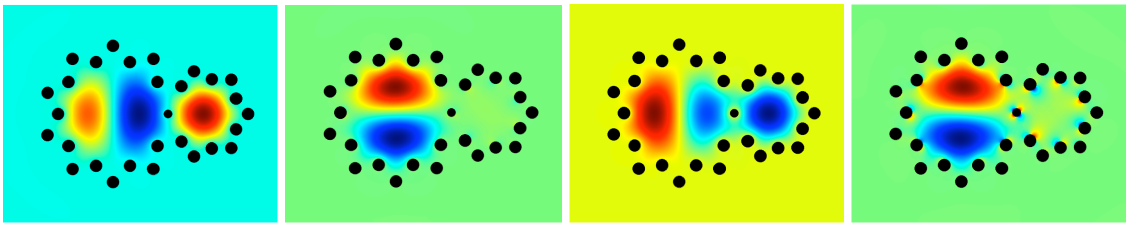
The power evolution calculated along the propagation distance confirms that the radiation losses are very small.

The calculated coupling efficiency spectral behavior of the proposed coupler is shown in Fig. 5. As one can see, coupling is not very sensitive to wavelength. This is a further feature that can be exploited in the device design, for example for applications at different wavelengths.



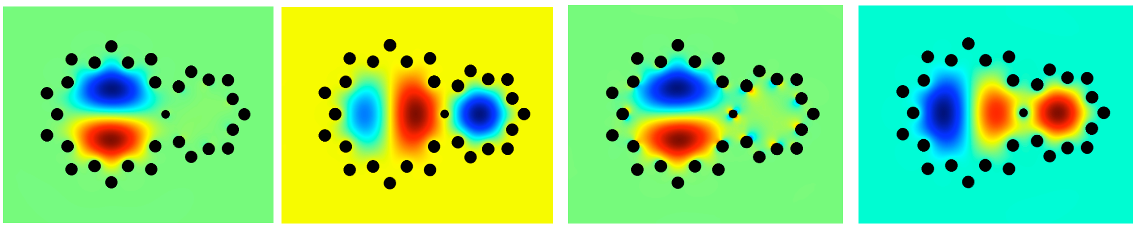
(a) (b) (c)

FIG. 1 – (a) Large-core fiber guiding LP_{11} mode, (b) Small-core fiber guiding LP_{01} mode, (c) Coupler. All the figures show a 50×40 μm area.



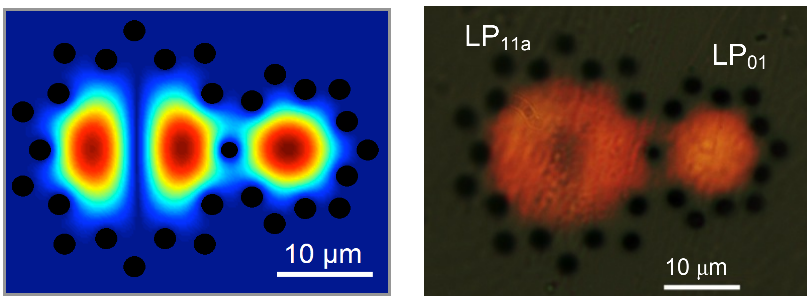
(a) (b) (c) (d)

FIG. 2 – Supermodes with symmetry with respect to a horizontal PMC plane: (a,b) E_x (larger) and E_y components of the first one; (c,d) E_x (larger) and E_y fields of the second one.



(a) (b) (c) (d)

FIG. 3 – Supermodes with symmetry with respect to a horizontal PEC plane: (a,b) E_x and E_y (larger) components of the first one; (c,d) E_x and E_y (larger) fields of the second one.



(a) (b)

FIG. 4 – Intensity distribution at the 3 dB coupling section: (a) BPM simulation, (b) Experimental result (broadband excitation).

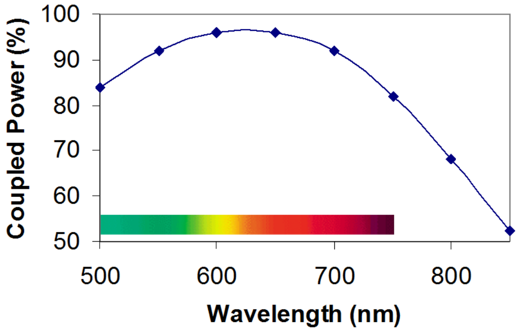


FIG. 5 – Spectral response of the proposed coupler.

IV. CONCLUSION

A selective mode coupler realized using Holey Fibers has been investigated. Experimental results are in excellent agreement with theoretical predictions. The device is suited for mux/demux operations in mode multiplexed systems for high transmission bandwidth. Its features (high coupling efficiency, low loss, low wavelength sensitivity) make it a promising solution worthy of further analysis.

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