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Short Communication

Modeling of capacity enhancement of heterogeneous few mode multi-core fiber

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Abstract

This paper aims targets to make understand the bedrocks and recent advances in Multi-core Fiber Technology using Space Division Multiplexing. Few mode multi-core fiber (FM-MCF) that enable space division multiplexing (SDM) have greater capacity to enhance the transmission capacity compared to (SSMF) Single spatial mode fiber. The concept of Heterogeneous Few Mode Multi-core Fibers has paved it's a way in optical communication system replacing Homogeneous Few Mode Multi-core Fibers which were previously opted. In this paper, we have modeled MCF of different geometries. The uncoupled multi-core fibers (MCFs) which can utilize multiple cores are arranged in a fiber as spatial transmission channels and then is used for the SDM transmission. Design of different structures with different number of cores are also shown. Here, in this paper, the authors use COMSOL Multiphysics (5.2) for carrying out required simulations.

Keywords: SDM (Space Division Multiplexing), MCF (Multi-core Fiber), FMF (Few Mode Fiber), DMD (Differential Mode Delay), (IC-XT) Inter-core crosstalk.

Introduction

Space division multiplexing (SDM) is an efficient and a simple way of facing up a demand for high capacity transmission systems[1-3]. SDM mainly depends on multi-core fibres (MCFs), in which each core constitutes an independent channel or on few mode fibers. We also experienced very high traffic growth every years, and this trend is estimated to proceed further rapidly[4-6]. In SDM transmission systems, several different types of signals are transmitted simultaneously by providing various multiple spatial paths with reasonable cost effective way. Figure-1 shows the basic geometry of MCF.

Multi-core fiber

Different types of cores are present in heterogeneous multi-core fiber whose propagation constants quite differ from each other. In SDM, the combination of multi-core and few-mode, FM-MCF is used a lot[7-9]. The FM-MCF concept has already been suggested a few years ago[10,11,5] and various fabrication results have been demonstrated recently.

$$SC\ C = C\ C \times M\ C \quad (1)$$

$$SC\ C = B.W. \times SE \times N_{ch} \quad (2)$$

Results through analysis of different structures

Simulations: In first step of geometrical modeling, a MCF having Hexagonal, Decagonal, Octagonal, Square, Pentagonal and Rhombic shaped geometry with appropriate different types of parameters are demonstrated. Then in the further next steps, various different appropriate parameters are defined. Then meshing of mentioned structures are performed and various results are interpreted on basis of this.

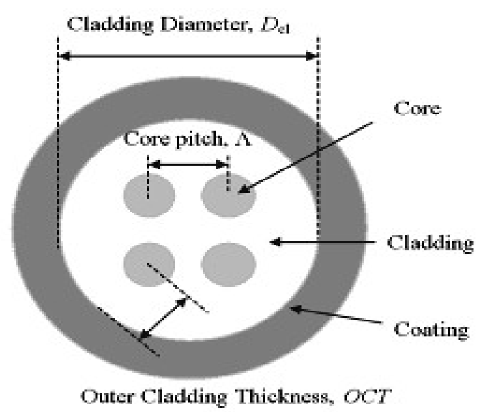

Figure-1: Multi-core fiber geometry.

Designing of different geometries using comsol multi-physics

For the purpose of various analysis, the core radius is taken as 3 µm for Pentagon and Rhombic shaped structure. The value of MFD (Mode Field Diameter) for core radius 3 µm it is 9.8930.

In today's era the silica glass SiO_2 fiber is forming the backbone of modern entire communication systems. Before 1970, optical fibers suffered from very large amount of transmission losses, making optical communication technology merely an academic issue. The different number of cores are arranged in one clad structure in a MCF. The propagation constants of the respective cores are quite different from each other, and also the refractive indices of the respective cores differ from each other in order to reduce crosstalk problem between the respective cores.

Figure-2 represents the rhombic lattice made of SiO_2. The inner core is made of SiO_2 with R.I. n_1 = 1.45 and cladding is doped with the R.I. n_2 = 1.4443 and for other cores it is n_3 = 1.4445, so the relation n_1 > n3 > n_2 is satisfied. Mode analysis is around 1.449 and the effective area is 945.61 μm^2 with SCC (Spatial Channel Count) of 111, CMF (Core Multiplicity Factor) is 0.475, RCMF (Relative Core Multiplicity Factor) is 73.08 and transmission capacity comes out to be 426.43 Tb/s. These values are valid for free- space wavelengths of 1.55 micrometers.

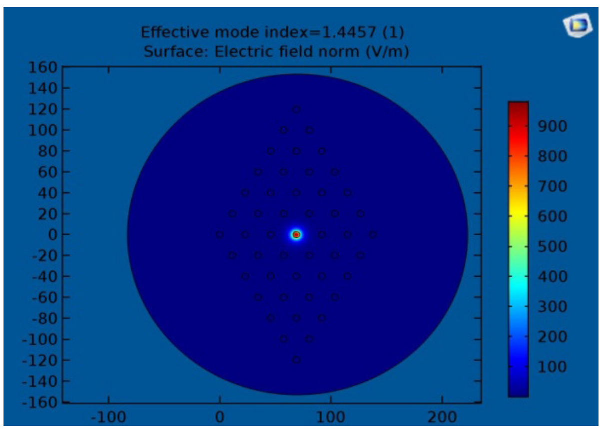

Figure-2: Electric Field Confinement @ 1550 nm (Rhombic Lattice Structure).

Figure-3 is the meshing of Rhombic Structure. The solutions to the proposed figures were obtained using the COMSOL Multiphysics software.

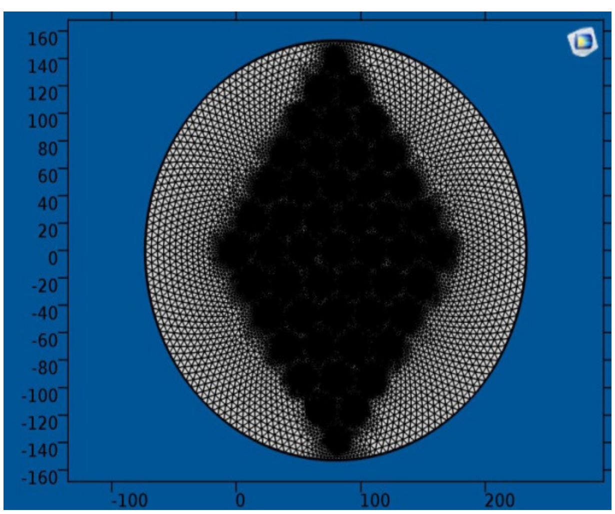

Figure-3: Meshing of Rhombic Shaped Structure.

Figure-4 is the meshing of Pentagon shaped structure with air holes in the outer layer and Figure-8 represents the electric field pattern for it. The inner core is made of SiO_2 with R.I. n_1 = 1.45 and cladding is doped with the R.I. n_2 = 1.4443 and for other cores it is n_3 = 1.4445, so the relation $n_1 > n_3 > n_2$ is satisfied. The total number of cores are 37, after eliminating air holes. The role of the air holes in the basic cell is twofold. Their main function is to isolate cores from each other, thus to eliminate XT and increase core density. The second role is to reduce macrobend induced XT and loss (due to suppression of penetration of the optical field outside the basic cell) making the fiber bend insensitive. The effective area is 1871.2 μm^2 with SCC (Spatial Channel Count) of 111, CMF (Core Multiplicity Factor) is 0.941, transmission capacity comes out to be 426.43 Tb/s and RCMF (Relative Core Multiplicity Factor) is 144.61. For simulation total 3 modes are considered for all structures.

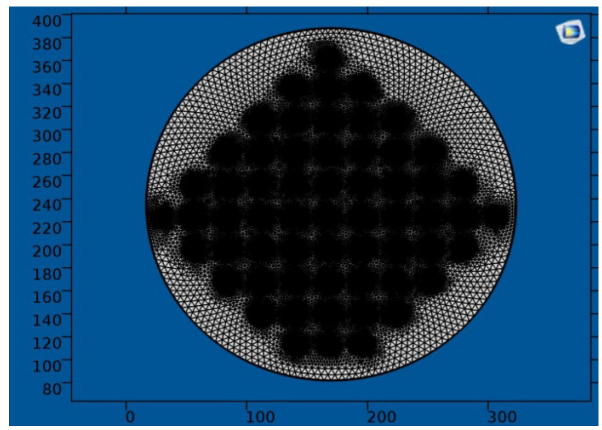

Figure-4: Meshing of Pentagonal Structure.

By raising the index difference or by lowering the distance between cores, it is possible to increase the difference between the effective indices of the fundamental mode and other propagating modes[12-14]. This behaviour is useful when a quasi-single mode fiber is required. Figure-5 gives the plot for core pitch and effective mode index.

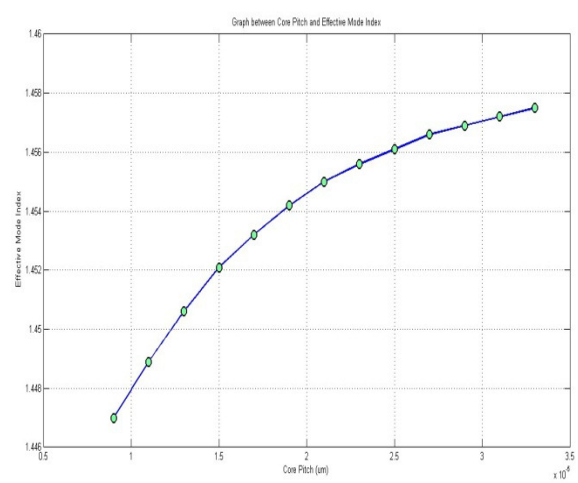

Figure-5: Plot between core pitch and effective mode index.

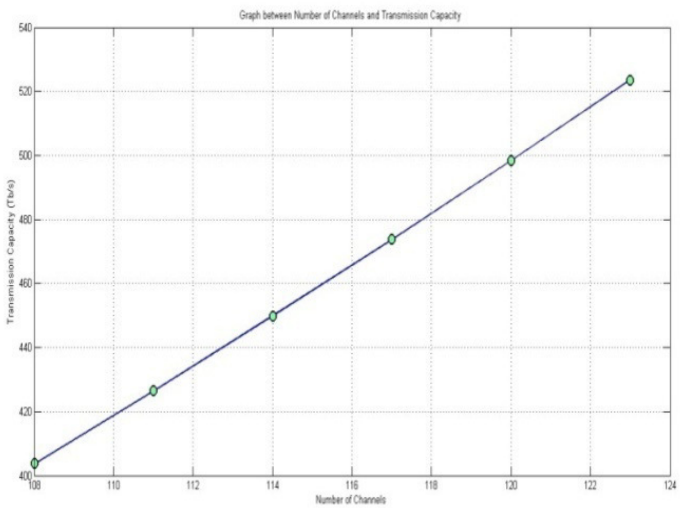

Figure-6: Plot between Number of Channels and Transmission Capacity.

Figure-6 is the relation between number of channels and transmission capacity Tb/s whereas Figure-7 is the relation between number of cores and transmission capacity (Tb/s) Figure-8 is the Electric Field Confinement @ 1550 nm whereas Figure-9 is the 3-D field pattern with proper confinement of electric field for proposed geometry.

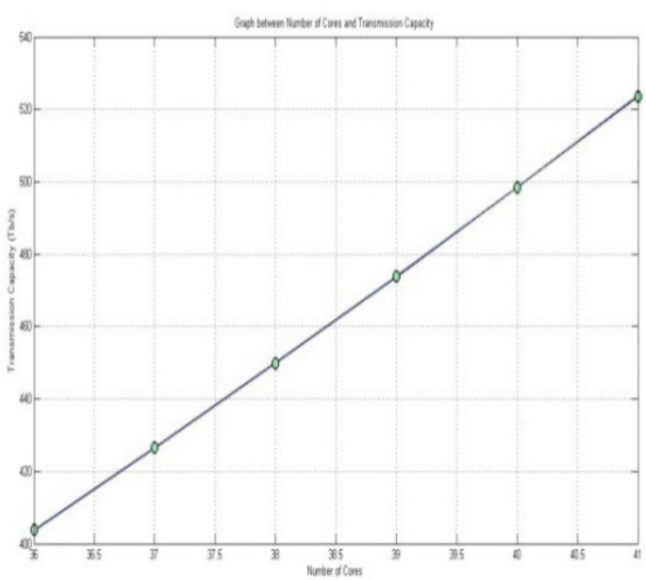

Figure-7: Plot between Number of Cores and Transmission Capacity.

Conclusion

The recent progress on MCF researches to date for high capacity transmission which focusses on uncoupled MCFs is studied in this paper.

The different number of cores and their arrangement have to be carefully determined based on different required factors i.e. transmission distance and modulation format due to the restriction of outer cladding size of MCF which is related to their mechanical reliability. The most promising and advanced approach for realizing high capacity-distance product over Exa b/s/fiber km. The confinement loss for the fiber structure has also been calculated. The cladding thickness (distance between outermost core center and cladding edge) is mainly limited by confinement loss.

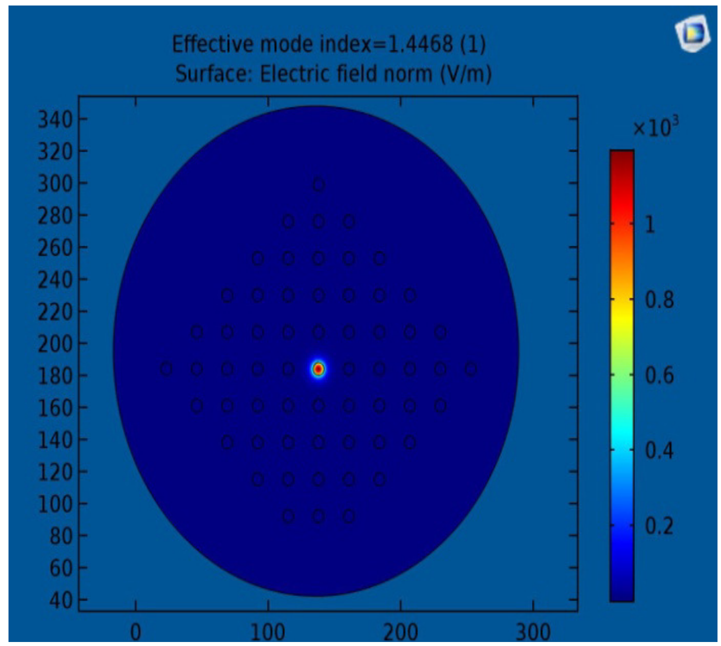

Figure-8: Electric Field Confinement @ 1550 nm (Pentagon Lattice Structure).

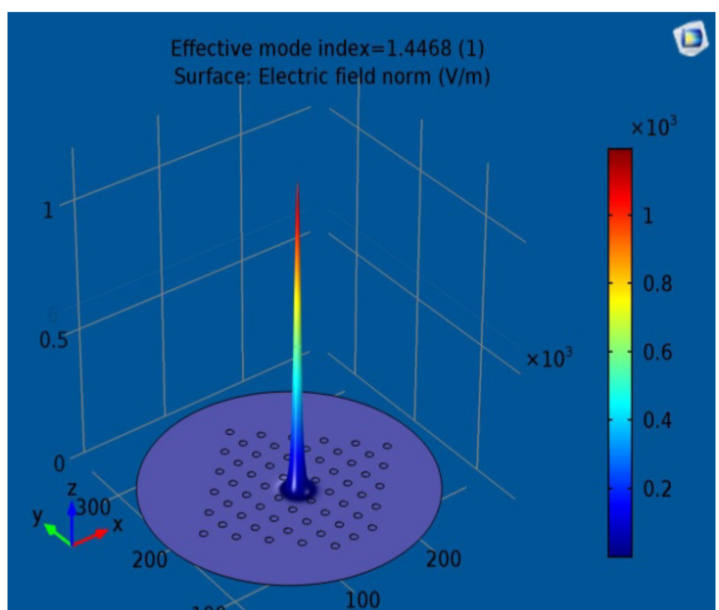

Figure-9: 3-D field pattern for Pentagonal Lattice.

Table-1: Parameters of different geometries of multi-core fiber.

Shape of Structure	No. of cores	No. of air holes	SCC (Spatial Channel Count)	SE (Spectral Efficiency) (bits/sec/hz)	CMF (Core Multiplicity Factor)	TC (Transmission Capacity) (Tb/s)	Effective Area (μm^2)	CMF (Core Multiplici-ty Factor)
Rhombic Lattice Structure	37	12	123	1.5093×10^{-3}	0.475	426.43	945.61	73.08
Pentagon Lattice Structure	37	23	123	1.5093×10^{-3}	0.941	426.43	1871.2	144.61

In order to attain relative spatial efficiency of more than 20, FM-MCF is required and further development on related devices such as amplifier and Fan-in/Fan-out for FM-MCF transmission is highly recommended. Multi-Core Fiber (MCF) based space division multiplexing system can be an answer to the increasing demand for bandwidth. We have simulated multicore fiber with different types of geometries for different values of parameters using finite element method. The simulation results for different parameters of Multi-core fiber are mentioned in Table-1. To enhance the transmission capacity under different scenarios depending on the nature of the cores and separation between them several approaches are studied.

Future development works: To further extend the capacity of MCFs, the combination of MCF and MMF seems to be a must. The utilization of MMF in the form of Few Mode Fibers (FMF) along with MCFs is a promising improvement over the current MCF solutions where mostly single mode fibers are being used. This would allow greatly increasing the resulting capacity and furthermore opening the doors to the development of more resource intensive applications that make use of the new attained capabilities.

In summary, SDM is still a totally new concept and challenge to the different professionals. SDM is totally a new paradigm that promises to guide the evolution of optical communication and still there is very much left to explore.

Furthermore, it is important to develop other devices / techniques concerning spatially-multiplexed transmission. For example connectors, multiplexing / demultiplexing devices, splicing techniques, amplifiers, and transponders are desired to be developed / optimized for spatially-multiplexed transmission networks.

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