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Design and Analysis of Modified Photonic Crystal Fiber with Low Confinement Loss

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Abstract— Fluorine doped silica tubes are used instead of air holes to reduce the problem associated with deformities during manufacturing of Photonic Crystal Fiber (PCF). But when fluorine doped silica tubes are used the confinement loss of fiber will be greater than that of air holed one. In this paper, we propose a new structure for this type of modified PCF which gives very low confinement loss. Also, we analyze some of the optical properties of the proposed structure such as effective refractive index, effective area and compared it with the normal hexagonal PCF.

Key words: Photonic crystal fiber, confinement loss, effective area

I. INTRODUCTION

Photonic Crystal Fiber (PCF) is a new class of fiber which shows unique properties. They are made up of array of air holes arranged in particular pattern around silica core. Mainly they guide light either by total internal reflection (TIR) or by photonic band gap (PBG). Conventional photonic crystal fibers are fibers which consist of air holes positioned around a solid core in a particular pattern. The usual geometries of air hole arrangement include hexagonal structures, square lattice, circular ring, honey comb, octagonal etc.

Optical properties of these photonic crystal fibers depends on air hole diameter d, Centre to Centre distance between holes known as pitch Λ, core diameter, number of air hole rings and the geometry of hole arrangement. A minute variation in these parameters may a lead to large variation in the optical characteristics of fiber. Fabrication of Photonic crystal fiber having air holes is a tedious task because it needs to shape the structures of microscopic size by controlling macroscopic parameters such as temperature and stretching rate.

Fluorine doped silica tubes can be used instead of air holes to reduce the difficulties associated with fabrication process. This will avoid the deformities of air holes in conventional PCF. But the main problem associated with this fluorine doped silica structures are increased confinement loss.

In this paper we have analyzed normal hexagonal lattice PCF having air holes and compared it with those having fluorine doped silica tubes instead of air holes. We have proposed a new PCF structure that gives low confinement loss, even in the presence of Fluorine doped silica tubes.

II. NORMAL HEXAGONAL GEOMETRY

To our knowledge hexagonal structures gives less confinement loss than any other geometries. So we are using hexagonal lattice PCF. Fig..1 shows a conventional hexagonal PCF having five air hole rings, diameter of each air hole d, Pitch Λ and Centre core made up of pure silica having refractive index 1.45.

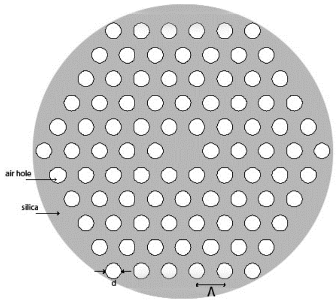

Fig. 1: Normal hexagonal PCF

The main problem with conventional photonic crystal fibers are deformation of the air holes while manufacturing. Even though photonic crystal fibers have a lot of advantages than conventional single mode fibers, we fail to use photonic crystal fibers practically.

One solution to avoid deformation of the structure is to use doped silica tubes instead of air holes. Refractive index of pure silica is 1.45, which can be increased or decreased depending up on the nature of doping. Materials such as fluorine or boron decrease the refractive index of silica. But the confinement loss will be higher for PCF having doped silica tubes.

III. PROPOSED STRUCTURE

Fig. 2 shows the proposed photonic crystal fiber having fluorine doped silica tubes in place of air holes.

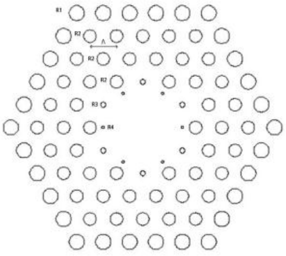

Fig. 2: Proposed PCF structure

The pitch is set as 1.6µm and the outer ring fluorine doped silica tubes named as R1 have a radius of 0.6µm. The tubes named as R2 have a radius of 0.5µm, R3=0.2µm and R4=0.1µm.

Here core is made up of pure silica having refractive index of 1.45 and silica doped with fluorine is used instead of air holes. Doping concentration of fluorine is taken in a level as to reduce the refractive index of silica down to 1.32.

II. CONFINEMENT LOSS

Losses in a PCF occur mainly due to a number of reasons, such as intrinsic loss, Rayleigh scattering loss, structural imperfection loss, confinement loss and so on. Losses during fabrication can be reduced by careful optimization of fabrication process. Confinement loss is an additional form of loss that occurs mainly in single material fibers. It is due to the leakage of power from core to the cladding. Confinement loss in a PCF depends on the number of air holes, diameter of holes *d*, pitch between holes *Λ*.

Confinement loss is calculated from the imaginary part (Im) of complex effective refractive index, n_{eff} using following equation:

$$\text{Conf. Loss} = \frac{40\pi}{\ln(10)\lambda}\,\mathrm{Im}(n_{eff}) \ \ [\mathrm{dB/m}] \qquad (1)$$

Here λ is the wavelength of light.

III. EFFECTIVE MODE AREA

The effective mode area A_{eff} of an optical fiber provides an effective measure of the area over which the fundamental mode is confined during its propagation within the fiber. It is given by the equation:

$$A_{eff} = \frac{\left(\iint_{-\infty}^{\infty} |E|^2 dxdy\right)^2}{\iint_{-\infty}^{\infty} |E|^4 dxdy} \qquad (2)$$

Were E is the transverse component of the electric field. Effective area depends on λ, core diameter & the refractive index difference between core and cladding.

IV. SIMULATION RESULTS

The optical properties of the normal hexagonal PCF of Fig. 1 are analyzed. Fig. 3 shows the variation of effective refractive index as a function of wavelength.

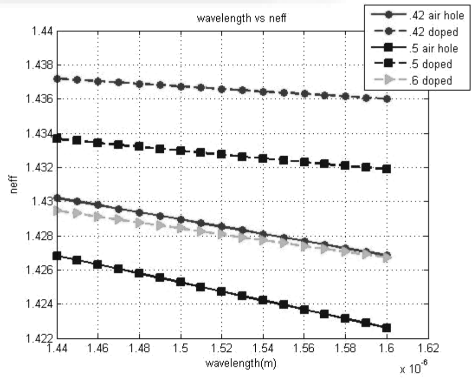

Fig. 3: n_{eff} Vs. wavelength of normal hexagonal geometry of radius .42µm, .5µm, .6µm.

The n_{eff} is less for air holed structure than same having fluorine doped silica tubes. The variation in values of effective refractive index is less in fluorine doped silica geometries. The doped structures .5µm and .6µm hole radius show almost a flat variation in effective refractive index with operating wavelength, and which is a desirable factor for the point of view of optical communication as it leads to lesser dispersion.

Fig. 4 shows effective refractive index variation of the proposed structure having fluorine doped silica tubes for different values of pitch *Λ*.The effective refractive index variation of structures with Λ=2.1µm and Λ=1.6µm shows almost flat variation with operating wavelength.

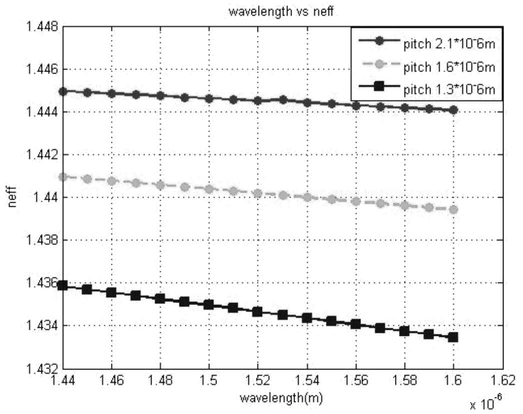

Fig. 4: n_{eff} vs. wavelength for different value of *Λ* for proposed structure.

Fig. 5 and Fig. 6 show the variation of effective mode area of normal hexagonal geometry for air holed and fluorine doped silica geometries respectively.

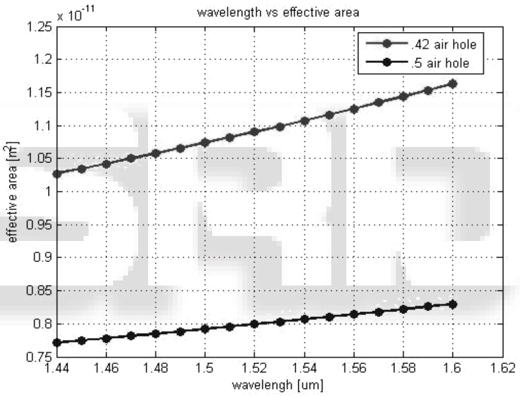

Fig. 5: A_{eff} Vs. λ for normal hexagonal geometry having air holes of radius .42µm and .5µm.

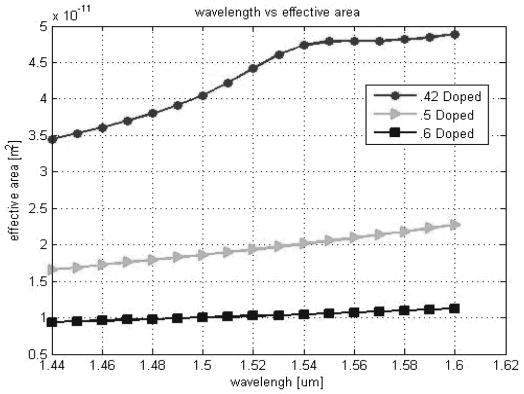

Fig. 6: A_{eff} Vs. λ for normal hexagonal geometry having fluorine doped silica tubes of radius .42µm, .5µm, .6µm.

The variation of effective mode area is increasing linearly with the wavelength from 1440nm to 1600nm. But as the radius of holes increases effective mode area decreases since the core diameter also decreases. Results show that while replacing air holes with fluorine doped silica having refractive index 1.32 the effective mode area increases.

Fig. 7 shows variation of effective mode area of proposed structure for pitches Λ=1.3µm, Λ=1.6µm and Λ=2.1µm.

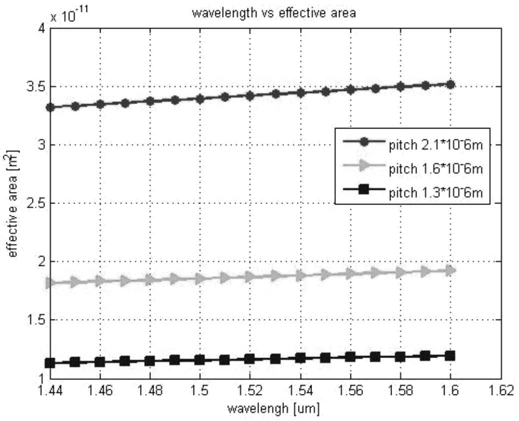

Fig. 7: A_{eff} Vs. λ for different value of Λ for proposed structure.

When the pitch decreases the core diameter of the fiber also decreases, we can see that effective area also decreases with pitch.

The main focus of the proposed geometry is to reduce confinement loss. Fig. 8 and Fig. 9 shows confinement loss as a function of wavelength for normal hexagonal geometry.

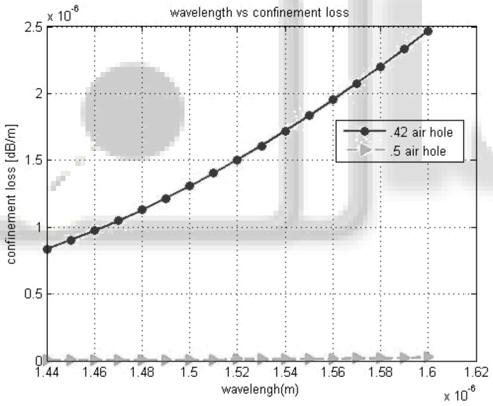

Fig. 8: Conf. Loss Vs. λ for normal hexagonal geometry having air holes of radius .42µm and .5µm.

It is observed that as the radius of holes is increased confinement loss is decreased, because the percentage of silica in the cladding region having same refractive index as that of the core is decreased. This will reduce the leakage of power in to the cladding. But the replacement of air holes with the doped silica tubes has increased the confinement loss; the proposed structure is a solution for this problem.

Proposed structure gives much less confinement loss than normal structure having doped silica tubes. Confinement loss depends on both the radius of the holes and also the filling fraction (d/Λ). For small core fiber the confinement loss will be higher. The structure having Λ=1.6µm gives lesser confinement loss in the operating wavelength.

Fig. 10 shows confinement loss as a function of wavelength for proposed geometry

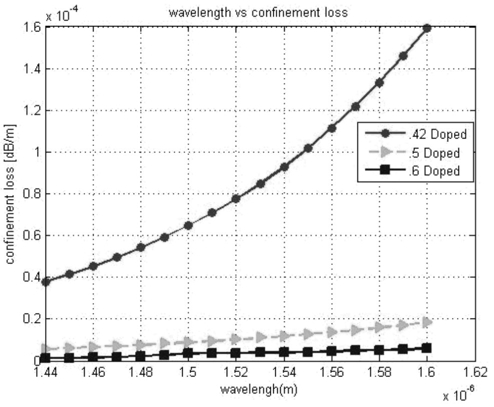

Fig. 9: Conf. Loss Vs. λ for normal hexagonal geometry having fluorine doped silica tubes of radius .42µm, .5µm, .6µm.

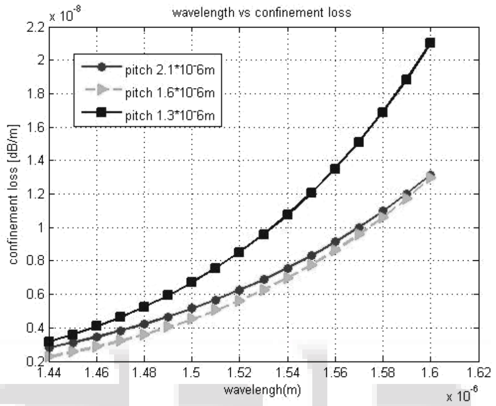

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Fig. 10: Conf. Loss Vs. λ for different value of Λ for proposed structure.

V. CONCLUSION

Confinement loss characteristics of normal hexagonal air holed fiber is studied and compared with those having fluorine doped silica tubes. It is observed that the confinement loss is higher when fluorine doped silica tubes are used instead of air holes. In this paper a new structure that gives low confinement loss even in the presence of fluorine doped silica tube is demonstrated by carefully adjusting the holes in each ring, hole diameter and hole-to-hole spacing. The proposed PCF design will reduce the deformities while manufacturing and at the same time gives low confinement loss.

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