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Comparison of Dispersion Properties for Different Lattice of Photonic Crystal Fiber

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ABSTRACT

In this paper the dispersion property of index guided photonic crystal fibers (PCFs) of silica material has been investigated. The modal analysis is done to obtain the complex effective refractive index for: (i) Hexagonal lattice with circular air holes and first ring having elliptical cells (ii) Rectangular lattice with circular air holes and first ring having elliptical cells. The dispersion generated by both the configurations is finally compared in (iii) hexagonal and rectangular lattice with first ring elliptical air holes. A full-vector FDTD method with TE polarization is used to simulate and analyze the dispersion property.

Keywords : Photonic Crystal Fibers (PCFs), Total internal reflection (TIR), Effective Refractive index (neff), Chromatic Dispersion (D), Finite Difference Time Domain (FDTD).

1. INTRODUCTION

A new generation of optical fibers, called PCF (also called holey fiber, holey assisted fiber, or index-guiding), was proposed for the first time in 1996 [1]. A PCF having an internal periodic structure made of capillaries, filled with air, lay to form a hexagonal lattice. Light propagate along the fiber in defects of its crystal structure called core. A defect is realized by removing one or more central capillaries [1].The design of PCFs is very flexible. There are various parameters to design the fiber: lattice pitch (Λ), air hole shape (circular or elliptical) and diameter (d), refractive index of the wafer and type of lattice (rectangular, hexagonal). Freedom of design allows zero, low, or flattened dispersion in visible wavelength range. They can also be designed, fabricated for endlessly single mode property. Such fibers can behave as single mode for all optical range [2].

2. GUIDING MECHANISM

PCFs are divided into two different kinds' of guiding mechanism. The first one is index guided PCF, guiding light by TIR between a solid core and a cladding region with multiple air-holes. Here refractive index is higher than the average refractive index of the cladding.

The second one uses a perfectly periodic structure exhibiting a photonic band-gap (PBG) effect at the operating wavelength to guide light in a low index core-region. Index-guided PCFs, also called holey fibers or micro structured optical fibers, possess especially attractive property of great controllability in dispersion [3].

The variation of electric field is different in both cases as shown in Fig.1 (a) and Fig.1 (b) [4]:

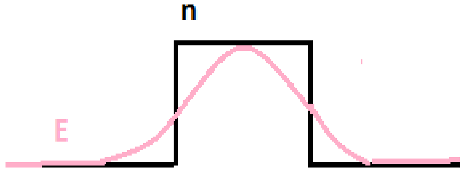

Figure 1 (a) Variation of electric field E in TIR propagation Fiber

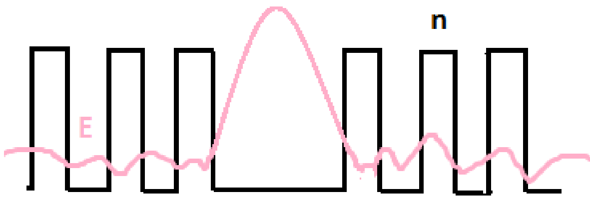

Figure 1 (b) Variation of electric field E in PBG propagation Fiber

3. DISPERSION

The dispersion (*D)* is proportional to the second derivative of the n_{eff}, with respect to the wavelength (λ) obtained as.

$$D = -\frac{\lambda}{C}\frac{d^2 Re[n_{eff}]}{d\lambda^2} \quad (1)$$

Where Re [n_{eff}] is the real part of n_{eff}, λ is wavelength, and c is the velocity of light in vacuum [5].

The total dispersion is calculated as the sum of the geometrical dispersion (or waveguide dispersion) and the material dispersion obtained as:

$$D(\lambda) = Dg(\lambda) + \Gamma Dm(\lambda) \quad (2)$$

Where Γ is the confinement factor in silica, which is close to unity for the most practical PCFs as the modal power is almost confined in the silica with high refractive index. The material dispersion Dm also can be obtained by equation (1). The effective refractive index is directly obtained from the three-term Sellmeier formula given as:

$$n = \sqrt{1 + \frac{A1\lambda^2}{\lambda^2 - \lambda1^2} + \frac{A2\lambda^2}{\lambda^2 - \lambda2^2} + \frac{A3\lambda^2}{\lambda^2 - \lambda3^2}} \quad (3)$$

where λ is operating wavelength in μm and the Sellmeier cofficients for silica are :
A_1=0.69616630,A_2=0.40794260,A_3=0.89747940
λ_1=0.068404300μm,λ_2=0.11624140μm,λ_3=9.8961610μm [6]
secondly the total dispersion is obtained by equation (1).

4. DESIGNING PARAMETERS OF PCF

Since the designed PCF consists of a solid core with a regular array of air holes running along the length of the fiber acting as the cladding. In this type of PCF the mean cladding refractive index is lower than the core index. The wafer chosen is pure silica with refractive index 1.45 and the refractive index of air holes is 1. The pitch (Λ) which is center to center spacing between two nearest air holes is kept as 2.3µm.The circular air hole diameter is 0.7µm. For the elliptical cells the parameters are major axis (a) =0.98 µm, and minor axis (b) = 0.50µm respectively. While choosing the parameter the most important thing was that the air filling fraction was kept same for both circular and elliptical air hole in order to obtain the fundamental space filling mode. Here various configuration of PCF are considered.

Configuration I (A): The PCF layout has hexagonal lattice with circular air holes, number of ring =3, air hole diameter (d) = 0.7µm, lattice constant (Λ) = 2.3 µm.

Configuration I (B): The PCF layout has hexagonal lattice with first ring elliptical cells, number of ring =3, air hole diameter (d) = 0.7µm, lattice constant (Λ) = 2.3 µm and a =0.98 µm, b = 0.50 µm.

Configuration II (A): The PCF layout has rectangular lattice with circular air holes, number of ring =3, air hole diameter (d) = 0.7µm, lattice constant (Λ) = 2.3 µm.

Configuration II (B): The PCF layout has hexagonal lattice with first ring elliptical cells, number of ring =3, air hole diameter (d) = 0.7µm, lattice constant (Λ) = 2.3 µm and (a) =0.98 µm,(b) = 0.50 µm.

The dispersion is numerically simulated by semi vector finite difference method for TE mode (X-polarization). The various layouts designed and investigated using OPTIFDTD mode solver (version8) official license available are shown in fig 5,6,7,8 below:

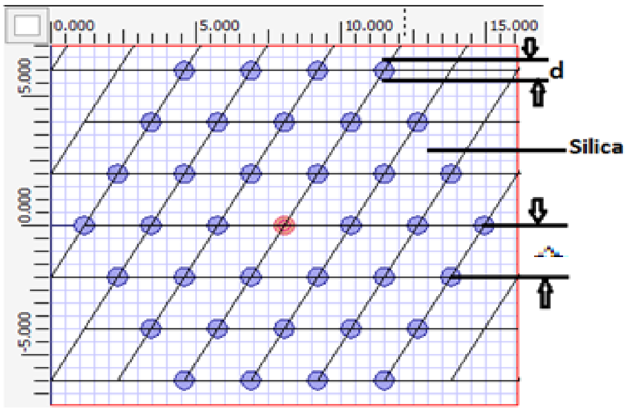

Figure 2. Simulation design (Hexagonal lattice with circular air holes, number of ring =3, air hole diameter (d) = 0.7µm, lattice constant (Λ) = 2.3 µm)

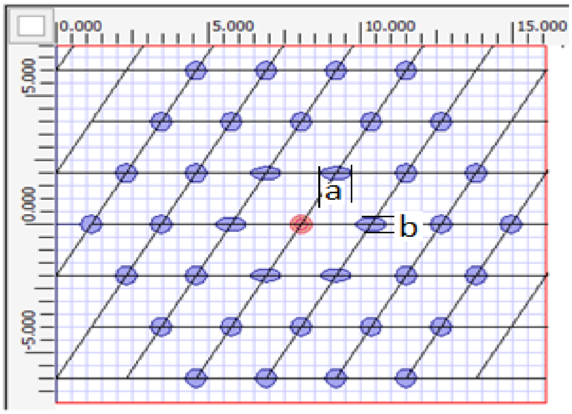

Figure 3. Simulation design (Hexagonal lattice with first ring elliptical cells, number of ring =3, air hole diameter (d) = 0.7µm, lattice constant (Λ) = 2.3 µm and (a) =0.98 µm, (b) = 0.50 µm)

The Mode field pattern is shown in figure 4. It should be flower like arrangement with all the fields being confined in the core region.

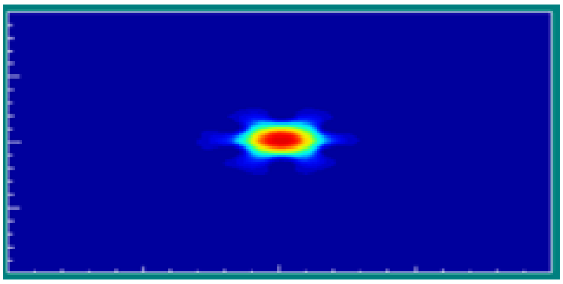

Figure 4. Mode field pattern obtained by mode solver

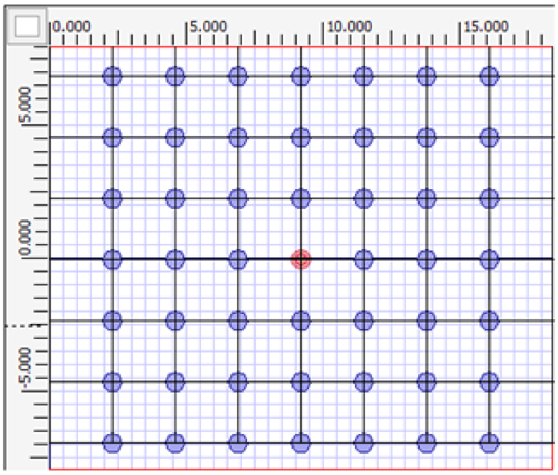

Figure 5. Simulation design (rectangular lattice with circular air holes, number of ring =3, air hole diameter (d) = 0.7µm, lattice constant (Λ) = 2.3 µm)

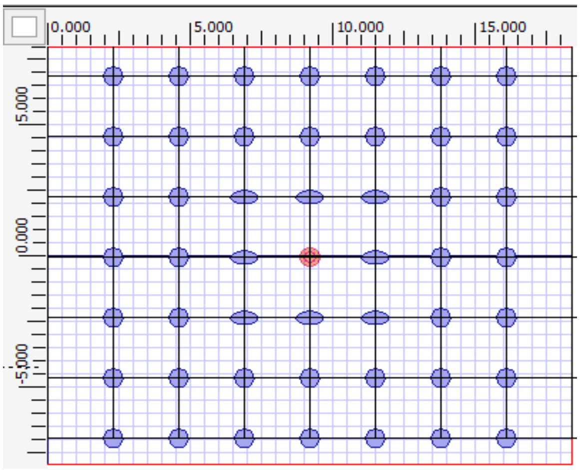

Figure 6. Simulation design (rectangular lattice with first ring elliptical shape, number of ring =3, air hole diameter (d) = 0.7µm, lattice constant (Λ) = 2.3 µm and a =0.89 µm, b = 0.50 µm)

5. RESULTS

The various plots obtained for dispersion are shown in figure 7,8,9. Three rings PCF having circular air-hole and first ring having elliptical cells of hexagonal and rectangular layouts are analyzed and compared.

First, the dispersion is calculated for hexagonal layout with circular air holes having same radius in each ring. The dispersion value obtained is -35ps/km/nm to37ps/km/nm for wavelength ranging from 1.0µm to 2.0µm.

Secondly, the dispersion is calculated for hexagonal layout having first ring, elliptical air holes. The dispersion obtained is -37 ps/km/nm to 20 ps/km/nm for wavelength ranging from 1.0 µm to 2.0µm.

A hexagonal layout having first ring elliptical cells is showing low dispersion.

When the dispersion is calculated for rectangular layout with same dimensions of circular air holes and first ring having elliptical air hole, the first ring having elliptical air holes shows low dispersion.

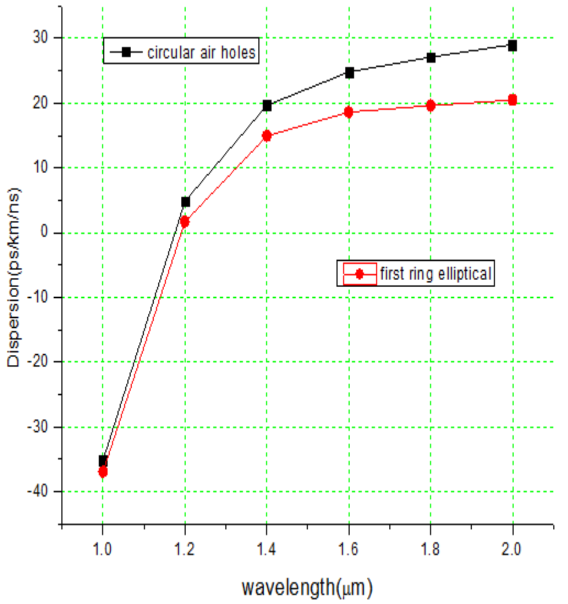

Figure 7.Total dispersion of hexagonal lattice (black curve shows total dispersion of circular air holes and red curve shows first ring elliptical)

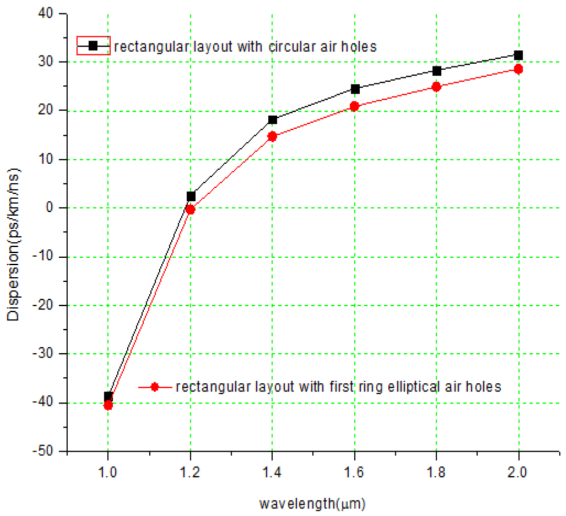

Figure 8.Total dispersion of rectangular lattice (black curve shows total dispersion of circular air holes and red curve shows first ring elliptical)

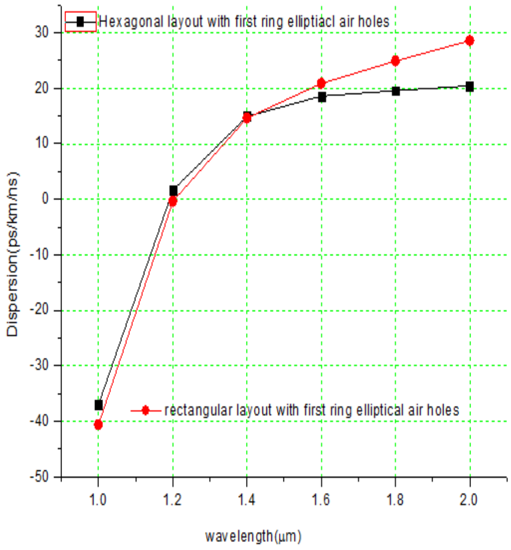

Figure 9.Total dispersion of hexagonal lattice and rectangular lattice with first ring elliptical air holes. (Black curve shows total dispersion of hexagonal lattice and red curve shows rectangular lattice).

6. CONCLUSIONS

On comparison of total dispersion in hexagonal and rectangular layouts with first ring having elliptical air holes, the rectangular lattice is showing low dispersion at shorter wavelength and hexagonal layouts are showing low dispersion at larger wavelength.

7. REFERENCES

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