A Novel Design of a Honeycomb PCF with Flattened Dispersion for Wideband Transmission Systems

Ankita Bapna, Shivpratap Pandey

Abstract— **A new type of flattened dispersion Honeycomb photonic crystal fiber along three distinct diameters of air hole in cladding area is investigated. The dispersion is examined using a 2-D finite difference time domain full vector modal analysis with the anisotropic perfectly matched layers (PML). Over the numerical simulation and optimizing the geometrical parameters, the proposed photonic crystal fibers can conceive flattened dispersion of 0±0.28 ps/(km-nm) in wide wavelength range of 1.28 µm to 1.71 µm, which is flatten than the other PCFs structure. Due to this wide wavelength range of low dispersion, the proposed honeycomb structure can be used for second and third telecom windows.**

Index Terms— **Effective Refractive Index (n*eff*), Photonic Crystal Fiber (PCF), Transparent Boundary Condition (TBC), Perfectly matched layers (PML).**

I. INTRODUCTION

Photonic crystal fibers (PCFs) have engrossed right smart consideration since the first fabrication of PCF in the year of 1996 [1]. Photonic crystal fibers (PCFs) have advantages like as endlessly single-mode [1], tailorable effective modal areas [2], anomalous dispersion [3] and highly birefringent [1]. To achieve flattened dispersion in PCFs, several intriguing designs have been proposed [1-8]. In all cases, essentially flattened fiber-dispersion behavior becomes a imperative issue. PCFs possess dispersion properties significantly different from those of conventional fibers because the cladding structure consisting of an array of micrometer-sized [3], [6] air holes allows for adjustable tailoring of the dispersion curves. The light propagation is done by total internal reflection (TIR) mechanism so that air holes in the cladding organize sufficient index diversity between the core and the cladding [6-8].

The other important parameter in PCF is confinement loss [1-5], [6-7], [9-10]. For designing of particular guiding properties, it can be done by changing the parameters of the holey cladding. On the other hand, designs are based on triangular [1], [5-6], [10-11] and square lattice [3] PCFs as shown in fig 1 and fig. 2.

In recent time the elliptic waveguide [1], [5-6], [10-11] property also is used to fabricate the crystal structure. The Silica as a core material is extensively used for most of PCF structure and the cladding is surrounded by the air holes and the shape of the air holes can be designed by the elliptic waveguide, linear waveguide and arc waveguide.

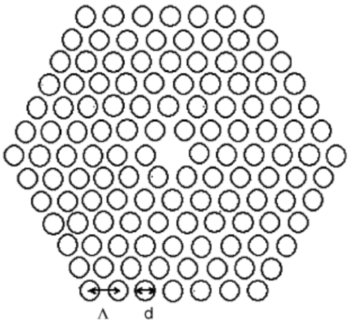

Fig. 1 Traditional Triangular lattice high index core PCF [6]

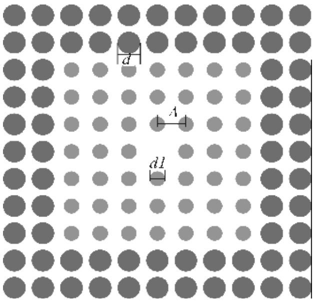

Fig. 2 The Cross Section of square lattice PCF [3]

In particular, when the defect is formed by removing several air holes in cladding region of PCF the structure becomes honeycomb PCF [2], [4], [9] as shown in fig 3. In addition, a modified honeycomb structure has been investigated by Broeng et al. [9].

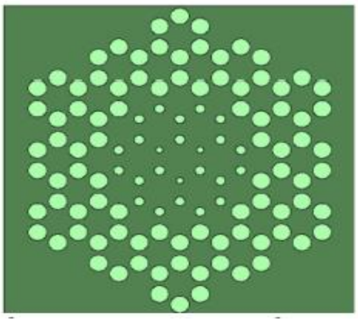

Fig. 3 Index-guiding honey comb PCFs [2]

Due to complex structure of PCF, different numerical techniques has been used to study different properties of PCF such as Finite Difference Time Domain Method [2-5], [10], Finite Element Method [7-9] , the plane wave expansion (PWE) method [1], [6].

By manipulating circular air hole diameter d, pitch Λ and air core diameter, it is possible to control the properties of PCF such as real effective refractive index, imaginary

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effective refractive index, confinement loss, at wide wavelength.

In this research we investigate that it is possible to design a honeycomb PCFs with nearly zero flattened chromatic dispersion over second and third telecom window. The productive full vector modal based on the finite difference time domain method (FDTD) for analyzing the various properties of PCFs is used. Anisotropic perfectly matched layers (PMLs) absorbing boundary are positioned outside the outermost ring of holes in order to reduce the simulation window.

II. ADVANTAGES OF PCFS

There are many advantages against a conventional optical fiber. The biggest ones are possibility to control optical properties and confinement characteristics of material. Allow for guidance through hollow fibers (air holes). Smaller attenuation than with fiber with solid core. PCFs with larger cores may carry more power than conventional fibers. Control over dispersion: size of air holes may be tuned to shift point of zero dispersion into visible range of the light.

III. APPLICATION OF PCFS

PCF can be used to design various sensors like Curvature/Bend Sensors, Displacement/Strain, Electric and Magnetic Field Sensors, Pressures Sensors, Temperature Sensors. As a nonlinear devices, e.g. for super continuum generation (frequency combs) Raman conversion, constant amplification, or pulse compression. In numerous telecommunication parts, e.g. prefer to dispersion management, filtering or switch, high-birefringent photonic as a refraction part.

IV. LOSSES IN PCFS

In the case of optical fiber, There are mostly factors have been analyzed as dispersion arises due to a variety of causes are:

I. Material dispersion depends upon material.
II. Waveguide dispersion depends upon structure.
III. Differential group delay or Intermodal dispersion depends upon types of Different frequency component.

The material dispersion is depend up on the profile of the wavelength, is also an imperative factor in introducing dispersion in fiber. The unit of chromatic dispersion of a fiber is defined in ps/ (km-nm) by the equation [1-3], [6-8], [10].

The dispersion (D) is proportional to the subsequent derivative of the n_{eff}, with esteem to the wavelength (λ) obtained as [1-3], [6-8], [10]:

$$D = -\frac{\lambda}{c}\frac{d^2 Re(n_{eff})}{d\lambda^2} \qquad \text{Eq. 1}$$

Where, Re (n_{eff}) = Real part of n_{eff}, λ = Wavelength and c=Velocity of light in vacuum.

Sellmeier Equation

The material dispersion D_m also can be obtained by Eq. (2). The effective refractive index is straightforwardly obtained from the three-term Sellmeier formula known as:

$$n = \sqrt{1 + \frac{A_1\lambda^2}{\lambda^2-\lambda_1^2} + \frac{A_2\lambda^2}{\lambda^2-\lambda_2^2} + \frac{A_3\lambda^2}{\lambda^2-\lambda_3^2}} \qquad \text{Eq. 2}$$

Where λ = Operating wavelength in μm and the Sellmeier coefficients for Fused silica (fluorine-doped silica 1 mole %) Sellmeier constants are:

$A_1 = 0.696166300$, $A_2 = 0.407942600$, $A_3 = 0.897479400$
$\lambda_1 = 4.67914826\times10^{-3}\,\mu m^2$, $\lambda 2 = 1.35120631\times10^{-2}\,\mu m^2$
$\lambda_3 = 97.9340025\ \mu m^2$

Total Dispersion

The total dispersion (chromatic dispersion) is depends upon the calculation of the sum of the geometrical dispersion (or waveguide dispersion) and the material dispersion obtained as [1-3], [6-8], [10]:

$$D(\lambda) = D_g(\lambda) + \Gamma D_m(\lambda) \qquad \text{Eq. 3}$$

Where Γ is the confinement factor in silica, which is close up to unity for a large amount practical PCFs as the modal power is approximately constrained in the silica with high refractive index. Secondly the total dispersion is obtained by Eq. 3.

V. PROPOSED DESIGN AND SIMULATION RESULT

The proposed honeycomb PCF is made up of fused silica and has an array of air holes running along its length. Now here we will analyze the dispersion properties of photonic crystal fiber. For the entire configurations analyzed the mean cladding refractive index is lower than the core index. The core material is silica glass which refractive index is 1.458 and the refractive index of cladding air holes is 1. The pitch difference (Λ) which is center to center spacing between two nearest air holes is kept as 1.65μm for the entire configuration. The lattice structure is in triangular lattice. Here various configurations of PCF are considered. The dispersion property is numerically simulated by full vector analysis method.

The finite difference time domain method and the TBC boundary condition are used for the simulation boundaries. The software is used for various layouts designed and investigated is Optiwave System-FDTD mode solver tool.

Design-1

The PCF structure is made up of seven layer triangular lattice structure with inner most ring is circular holes which has diameter d1 = 0.6 μm, second and third layer has elliptical holes with diameter d2 = 1.0 μm, forth to seventh layer diameter is d3 = 1.44 μm and pitch (Λ) is 1.65 μm.

Design-2

The PCF structure is made up of seven layer triangular lattice structure with inner most ring is circular holes which has diameter d1 =0.6 μm, second and third layer has elliptical holes with diameter d2 = 0.8 μm, forth to seventh layer diameter is d3 = 1.44 μm and pitch (Λ) is 1.65 μm.

Design-3

The PCF structure is made up of seven layer triangular lattice structure with inner most ring is circular holes which has diameter d1 = 0.665 μm, second and third layer has elliptical holes with diameter d2 = 0.704 μm, forth to seventh layer diameter is d3 = 1.44 μm and pitch (Λ) is 1.65 μm as shown in fig 4.

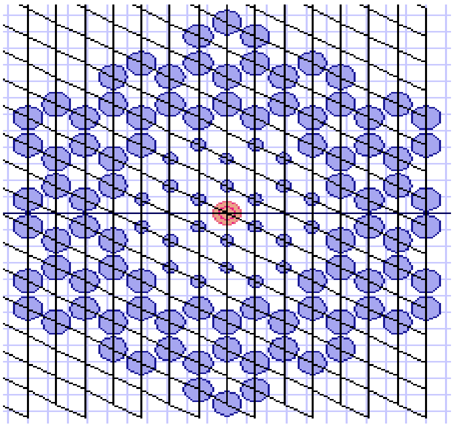

Fig. 4 Air-hole distribution of the Proposed Hybrid Structure for Design-3

Design-4

The PCF structure is made up of seven layer triangular lattice structure with inner most ring is circular holes which has diameter d1 = 0.6 µm, second and third layer has elliptical holes with diameter d2 = 0.7 µm, forth to seventh layer diameter is d3 = 1.44 µm and pitch (Λ) is 1.65 µm.

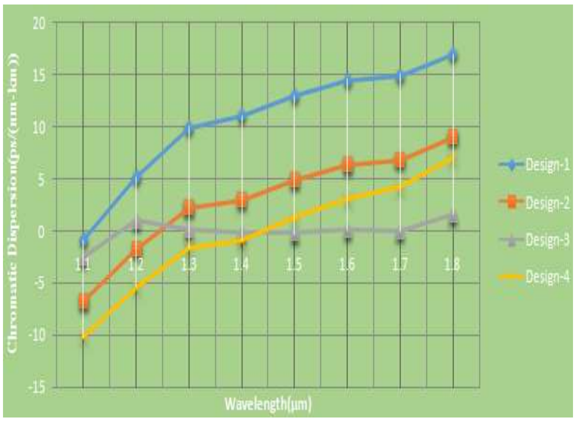

Fig. 5 Comparison of Chromatic dispersion for Design-1 to Design-4

In the proposed work there is a comparison between all the four designs is based on Total dispersion (chromatic dispersion) as shown in Fig 5. For above all the Design-1 to Design-4, we can conclude that Design-3 gives more flatten dispersion for a wide µm wavelength range from 1.28 µm to 1.71 µm as compare to other three designs.

Table 1 Comparison of various properties of proposed PCF with reference papers

PCF	Comparison of Model properties			
	Wavelength Range	**Dispersion ps/ (km-nm)**	**Flat Band (nm)**	**N_r, N_Λ, N_d**
Ref. [6]	1.3 µm to 1.87 µm	0 ± 0.8	580	**6,1,7**
Ref. [7]	1.25 µm to 1.70 µm	0 ± 1.2	450	**6,1,3**
Ref. [8]	1.3 µm to 1.6 µm	0 ± 0.6	300	**5,1,2**
Proposed Design-3	1.28 µm to 1.71µm	0 ± 0.28	430	**7,1,3**

At the Final, there is a comparison between various properties of the PCFs for telecom and nonlinear optics applications. Therefore, the proposed fiber with a modest number of design parameters, near-zero ultra-flattened dispersion may pave the way for various applications in optics including for some nonlinear applications, like as super continuum generation, soliton pulse transmission as well as in wavelength division multiplexing systems. Table 1 compares those fibers taking into flat dispersion, wavelength range and number of design parameters including like number of rings (N_r), number of pitch (N_Λ) and number of different diameter of holes (N_d) which are used in PCF design respectively.

VI. CONCLUSION

We proposed and numerically investigated honeycomb index guiding PCFs. The proposed honeycomb PCFs has flattened zero dispersion over a wide wavelength range can be efficiently designed. In comparison with several previously research work presented dispersion-flattened PCFs, the design procedure for this proposed structure would be more efficient and easier because relatively minimized geometrical parameters are required to be optimized and simple for fabrications considering less number of air holes, It has been shown that the proposal of honeycomb index-guiding PCFs has nearly zero ultra-flattened chromatic dispersion of 0±0.28 ps/(nm,km) in second and third optical window. In this research, it is found that the dimension of the inner ring of holes is particularly important in controlling the dispersion flatness, It is also important to accurately define the pitch to control the dispersion slope.

As the final conclusion of this research work, the honeycomb PCFs may be suitable for chromatic dispersion management applications as a chromatic dispersion controller, dispersion compensator, or as a candidate for nonlinear optical systems if effective area would be reduced by appropriate pitch values.

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