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Investigation of Single mode highly Birefringence Photonic Crystal Fiber for Wide Wavelength Range

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Abstract— **A new design of polarization maintaining index guiding photonic crystal fiber (PCF) was investigated. The proposed PCF is composed of a solid silica core, two large elliptical air holes near core region, two big circular air holes near the core region as well as cladding region with circular air holes. Full vector finite difference time domain (FDTD) method was used for the investigation purpose. Numerous important fiber parameters such as birefringence, dispersion and V parameter have been investigated numerically. The numerical result shows that very high birefringence with magnitude of order of 1.7x10^{-2} has been achieved. The proposed PCF also shows endlessly single mode operation over wide wavelength range.**

Index Terms—**Birefringence, photonic crystal fiber (PCF), polarization, V parameter, single mode fiber, Total dispersion.**

I. INTRODUCTION

As a result of the excellent propagation properties, photonic crystal fibers (PCFs) have created a center of attention from the time when their first fabrication as held in 1996 [1]. All over the world, several research groups are doing their constant effort to set up the advantage of PCFs as compare to conventional fibers. PCFs have numerous novel optical characteristics like highly birefringence [1-7], flexible chromatic dispersion [3] [6] [8], endlessly single mode guiding [9] for large wavelength range, controllable nonlinearity [3], low confinement loss [4] [10] and effective area [3] [11]. In general, PCFs can be categories into two different kinds through their light guiding method. First index guiding PCFs in which light is directed through total internal reflection (TIR) and second one, photonic bandgap fibers in which light is guided through the effect of bandgap [2-3] [5]. Birefringence is generally an unwanted property in the field of fiber optics but on the other hand, highly birefringent photonic crystal fibers (HBFs) are also required [1-7].

The large birefringence fibers have been extensively employed for the polarization control in sensor for fiber optic, accuracy optical instruments as well as for optical communication systems [1-8]. This property can easily realized in photonic crystal fiber because of the refractive index difference among the core region as well as the cladding region is higher as compared to refractive index contrast of the conventional fibers. To realize highly birefringence, there is need to destroy symmetry of the fiber structure as well as increase effective index dissimilarity among two orthogonal polarization modes [1] [7]. Highly birefringence can be achieved through modifying the air hole sizes near the core area [2-5], or through deforming the shape of the air holes for the outer rings [3] [5]. Highly Birefringence can also realize through commencing noncircular defect core or containing a middle elliptical air hole.

In addition to other properties, PCFs also have dispersion properties considerably dissimilar from conventional fibers due to its novel cladding structure which have an array of micrometer diameter air holes that permits to design flexible tailoring of dispersion. Dispersion controlling is very important issue for practical application of optical fiber communications [3], dispersion compensation [3] and nonlinear optics. To realize suitable chromatic dispersion, the parameters in of the PCF require being well premeditated. A number of index guiding PCFs with extraordinary dispersion have been accounted in [1-3] [5-8]. For the numerous applications it is necessary to propose PCFs that show high birefringence, low effective area, endlessly single mode fiber and flattened chromatic dispersion for wide wavelength range.

PCFs that show such properties are not exist. According to Reference [4] [6] [10], highly birefringent PCFs with small confinement loss as well as ultraflatten chromatic dispersion [3] [6] [8] for wide wavelength range were proposed. In Reference [3], flatten dispersion PCFs with low effective mode area were proposed. One Reference [1] also reported anomalous dispersion with highly birefringence. In numerous published papers, merely one of the above properties is showed. Consequently in this paper, a single mode endlessly fiber with highly birefringent and flatten dispersion is offered through commencing two large elliptical air holes and two big circular air hole near core region for deforming the shape of the air holes in the inner ring.

II. THEORETICAL ANALYSIS

To investigate birefringence, chromatic dispersion and endlessly single mode fiber of the proposed highly birefringent photonic crystal fiber, a full-vector finite difference time domain technique [13-14] which is extremely appropriate for the examination of periodic structure is applied which is supported on direct discretization of Maxwell's equations. To absorb out going waves without reflection, special environment are necessitated on the boundaries of the computational domain. To absorb out going

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waves without reflection, transparent boundary condition is used [2].

Initially from a given field allocation, time evolution of the electromagnetic field is computed over a given spatial domain so that's region FDTD technique tool is suitable for examining the electromagnetic wave propagation in complex structures. The FDTD estimate to the fields Hx (x-component magnetic field) and Ex (x-component electric field) obtained from Maxwell's equations in the computational domain [2] [13-14].

A. Birefringence

Birefringence is property of PCF provides the determination of polarization of light which is passing via fiber [1-7] [10-12]. Birefringence characteristics demonstrate physically powerful wavelength addiction. Due to superior flexibility in tuning birefringence, it is possible to design photonic crystal fiber with birefringence of the order of 10^{-2}. Birefringence is defined as a difference between effective refractive indices of two fundamental polarization modes, which can be calculated using equation 1 [1-7] [10-12]:

$$B(\lambda) = |n^{y}_{eff} - n^{x}_{eff}| \tag{1}$$

Where n^{y}_{eff} is the refractive index in x direction and n^{x}_{eff} the refractive index in y direction respectively.

B. Chromatic Dispersion

Chromatic dispersion of the optical fibers is a most important feature causing optical pulse broadening. This dispersion is due to the combined effects of material as well as wavelength dispersion. The chromatic dispersion (D) of the PCF has been achieved from effective refractive index (n_{eff}) values versus the wavelength using equation 2 [1-3] [6] [8]:

$$D = -\left(\frac{\lambda}{c}\right)\frac{d^2}{d\lambda^2}\left[R_e\left(n_{eff}\right)\right] \tag{2}$$

Where Re (η_{eff}) is the real part of n_{eff}, λ is wavelength and c is the velocity of light in vacuum.

The total dispersion can be determined as the sum of the waveguide dispersion (geometrical dispersion) and material dispersion in equation 3 [1-3] [6] [8]:

$$D(\lambda) = D_g(\lambda) + \Gamma D_m(\lambda) \tag{3}$$

Dg(λ) is the waveguide dispersion and Dm(λ) is the material dispersion and Γ is known as the confinement factor in silica and its value is close to 1.

C. V-Parameter

The photonic crystal fiber can be proposed for the endlessly single mode fiber operation. Conventional step index fibers starts to work in the multi mode region beyond the certain cut off frequency. A parameter well known as normalized frequency 'V' is employed to determine the number of guided modes can be calculate by equation 4 [1-2] [9]:

$$V = \frac{2\pi\rho}{\lambda}\sqrt{\left(n^{2}_{core} - n^{2}_{cladding}\right)} \tag{4}$$

Where ρ represents the pitch size, n_{core} represent refractive index of core and $n_{cladding}$ represents the refractive index of cladding.

III. RESULT AND DISCUSSION

In this proposed work, elliptical core photonic crystal fiber was investigated which holds extremely highly birefringence of the order of 1.7×10^{-2}. The birefringence is involvement generally as a result of the presence of elliptical air holes in the innermost ring. The birefringence of the fiber can be modified via varying the length of elliptical air holes size as well as air hole pitch. Silica glass material was used and its refractive index of 1.45 as a core as well as an air hole refractive index 1.0 as a cladding region enclosed to core, to influence the light propagation in fiber.

Fig.1 shows the schematic diagram for the proposed design that contain seven rings of air holes in the cladding region. The innermost ring is created through two elliptical ring which has large diameter on major axis and small diameter on minor axis. A highly stressed core is created through omitting 21 air holes in the innermost ring as well as balanced the two air holes in the center of the y-axis and completed an elliptical air hole. The existence of large elliptic air holes in the first ring is only motivation of elliptic mode field. The mode profile of proposed PCFs is calculated by using FDTD method simulation.

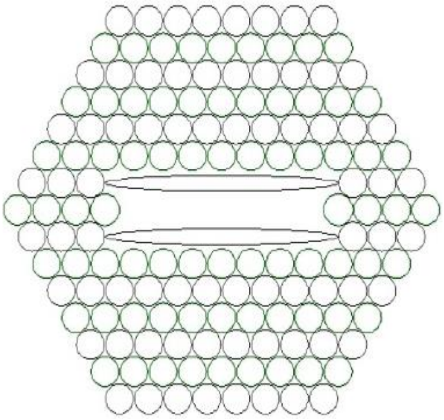

Fig. 1 Schematic diagram for Proposed Design

For the proposed structure innermost ring is invented with two elliptical ring which has width and height d_{major}= 8 x Λ and d_{minor}= 0.25 x Λ correspondingly as well as two big air holes with diameter d_a= Λ and remaining air hole diameter with d= 0.95 x Λ, where Λ is hole pitch.

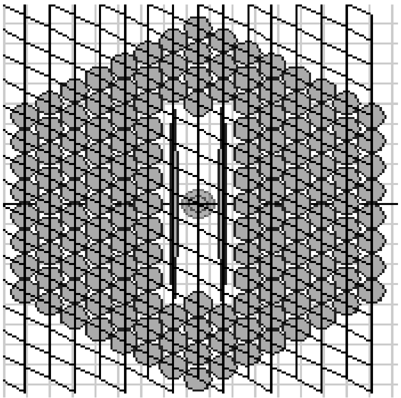

Fig. 2 Cross Section of Proposed PCF Design-5

In the proposed design the investigation based on the control of parameters on birefringence, dispersion as well as V-parameter by modification in pitch. Here fiber birefringences have been calculated for proposed Design-1 to Design-5 as pitch 1.5 µm, 1.6 µm, 1.4 µm, 1.3 µm, 1.25 µm correspondingly and the difference of which has been showing in Fig. 3.

From result it can be conclude that fiber birefringence raises with the decrement in pitch (Λ) and birefringence decrease when pitch increase. Over the wide telecommunication wavelength birefringence is large 1.7×10^{-2}. The birefringence is contributed because of the existence of elliptical air holes in innermost ring. The significance of birefringence of the fiber can be modified by varying the length of an elliptical air holes diameter as well as pitch.

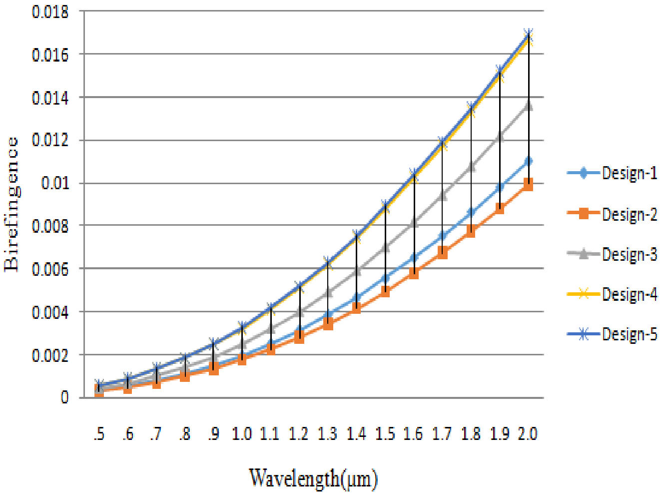

Fig. 3 Birefringence for Design-1 to Design-5

Total dispersion is the wavelength dependence for horizontal polarization as well as vertical polarization modes have been shown in Fig. 4 and Fig. 5 below for Design-1 to Design-5, the fiber is completely flatten dispersive (anomalous dispersive) over a 1.0 µm to 2.0 µm wide wavelength range.

The importance of the dispersion coefficient at first increases with the increment in wavelength, then after decreases with the increase in λ. The variation of dispersion with wavelength is small for the y-direction polarization mode.

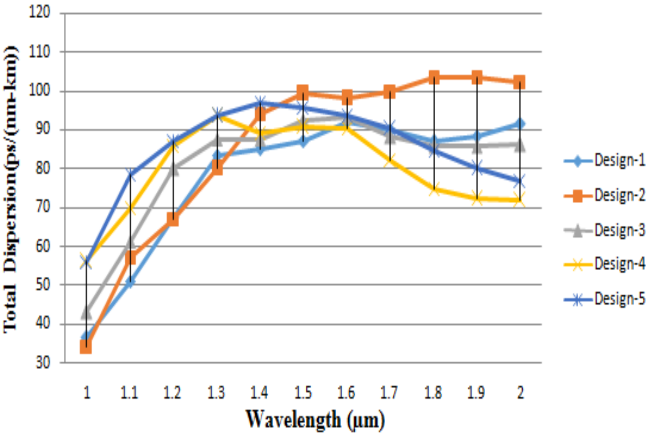

Fig. 4 Total Dispersion X- Polarization for Design-1 to 5

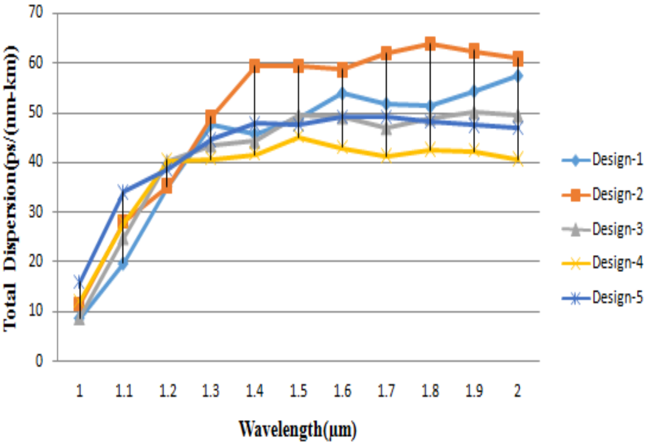

Fig. 5 Total Dispersion Y- polarization for Design-1 to 5

Here Fig. 6 and Fig. 7 represent the effective V-parameter relation of horizontal and vertical polarization mode of all proposed Design-1 to Design-5. The effective V parameter decreases as wavelength raise. For the single mode operation in triangular lattice PCF is $V_{eff}\leq 4.1$, so that it can be conclude that the fiber is endlessly single mode over a wide wavelength range.

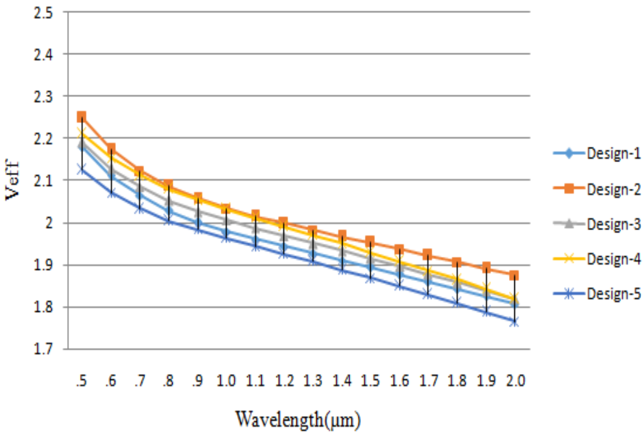

Fig. 6 V-Parameter in X-Polarization for Design-1 to 5

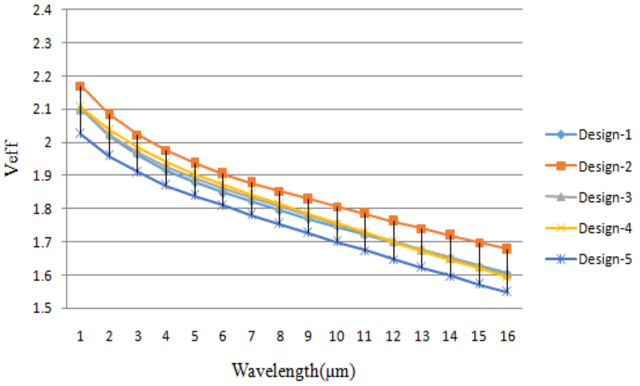

Fig. 7 V-parameter in Y- polarization for Design-1 to 5

IV. CONCLUSION

In the proposed work design as well as investigation was done to get the optical properties of a photonic crystal fiber with hexagonal lattice structure of air holes. Through numerically investigation with finite difference time domain and transparent boundary condition various properties were calculated like birefringence, dispersion, V-parameter and mode field. The proposed PCF offers high birefringence of the order 1.7x10^{-2}. The fiber has anomalous dispersion over 1.0 µm to 2.0 µm for wide wavelength range as well as endlessly single mode fiber.

The suggested fibers can be valuable for the designing purpose of fiber optic sensors. The large significance of birefringence will be helpful to sustain polarization of electric fields. So that these fibers are attractive to design in different fiber optic sensors like as strain sensor, temperature sensor, pressure sensor, humidity sensor, acoustic wave sensor and many more. These fibers may be also useful fabrication of polarization controllers. The most interesting possibilities for PCFs are related to fiber-based signal processing devices with tunable properties, fibers for dispersion management.

REFERENCES

[1] Mohit Sharma, Nitu Borgohain, S Konar "Highly Birefringence Photonic Crystal Fiber with Anomalous Dispersion" *International Conference on Microwave & Photonics (ICMAP), ISBN-9781479921768*, pp.1-4, December 2013.

[2] Rakhi Bhattacharya, S. Konar "Extremely Large Birefringence and Shifting of Zero Dispersion Wavelength of Photonic Crystal Fibers" *Optics and Laser Technology*, Volume 44, Issue 7, pp. 2210–2216, October 2012.

[3] Jian Liang, Maojin Yun, Weijin Kong, Xin Sun, Wenfei Zhang, Sixing Xi "Highly Birefringent Photonic Crystal Fibers with Flattened Dispersion and Low Effective Mode Area" Optik - International Journal for Light and Electron Optics, Volume 122, Issue 23, pp. 2151–2154, December 2011.

[4] S.S. Mishra, Vinod K. Singh "Highly birefringent photonic crystal fiber with low confinement loss at wavelength 1.55 µm" Optik - International Journal for Light and Electron Optics, Volume 122, Issue 22, pp. 1975–1977, November 2011.

[5] Yang Yue, Guiyun Kai, Zhi Wang, Yunfei Lu, Chunshu Zhang, Tingting Sun, Yan Li, Long Jin, Jianguo Liu, Yange Liu, Shuzhong Yuan, and Xiaoyi Dong "Highly Birefringent Elliptical Hole Photonic Crystal Fiber with Two Big Circular air Holes adjacent to Core" *IEEE Photonics Technology Letters*, Volume 18, Issue 24, pp. 2638-2640, ISSN- 1041-1135, December 2006.

[6] Feifei Shi, Yun Wu, Meicheng Li, Yu Zhao, Liancheng Zhao "Highly Birefringent Two-Mode Photonic Crystal Fibers with Near-Zero Flattened Dispersion" IEEE Photonics Journal, Volume 3, Issue 3,ISSN- 1943-0655, December 2011.

[7] Zhu Wu, Dongxiao Yang, Liang Wang, Lei Rao, Le Zhang, Kan Chen, Wenjun He, Su Liu "Achieving both High Birefringence and Low Leakage loss in Double-clad Photonic Crystal Fibers" *Optics & Laser Technology Elsevier*, Volume 42, Issue 2, pp. 387–391, March 2010.

[8] Jingyuan Wanga, Chun Jiangb, Weisheng Hub, Mingyi Gaob, Hongliang Renb "Dispersion and Polarization Properties of Elliptical Air-Hole-Containing Photonic Crystal Fibers" *Optics & Laser Technology*, Volume 39, Issue 5, pp. 913–917, July 2007.

[9] A. Bahrampour, A. Iadicicco, E. foomezhi, Sh. Momeni, A.R. Bhrampour "Analysis of an Endlessly Single-Mode Penrose-Tiling Photonic Quasicrystal Fiber" Third Mediterranean *Photonics Conference*, pp. 1-3, May 2014.

[10] Hongda Tian, Zhongyuan Yu, Lihong Han, and Yumin Liu "Birefringence and Confinement Loss Properties in Photonic Crystal Fibers under Lateral Stress" IEEE Photonics Technology Letters, Volume 20, Issue 22, pp. 1830-1832, ISSN-1041-1135, November 2008.

[11] Shuguang Lia, Yanfeng Lib, Yuanyuan Zhaoa, Guiyao Zhoua, Ying Hana, Lantian Houa "Correlation between the Birefringence and the Structural parameter in Photonic Crystal Fiber" *Optics & Laser Technology Elsevier*, Volume 40, Issue 4, pp. 663–667, June 2007.

[12] Mohit Sharma, Nitu Borogohain, and S. Konar "Index Guiding Photonic Crystal Fibers with Large Birefringence and Walk-Off" *Journal of Lightwave Technology*, Volume 31, Issue 21, pp. 3339 – 3344, ISSN- 0733-8724, November 2013.

[13] Juan Juan Hu, Ping Shum, Guobin Ren, Xia Yu, Guanghui Wang, Chao Lu "Three-Dimensional FDTD Method for the Analysis of Optical Pulse Propagation in Photonic Crystal Fibers" *Optoelectronics and Advanced Materials – Rapid Communications*, Volume 2, Issue 9, pp. 219-524, ISSN- **2065-3824,** September 2008.

[14] Juan Juan Hu, Ping Shum, Chao Lu and Guobin Ren "Generalized Finite-Difference Time-Domain Method Utilizing Auxiliary Differential Equations for the Full-Vectorial Analysis of Photonic Crystal Fibers" *IEEE Photonics Technology Letters*, ISSN: 1041-1135, Volume 19, Issue 24, pp- 1970–1972, December 2007.

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