Improved Dispersion and Birefringence Property of Photonic Crystal Fiber by Creating Asymmetry around the Core

Priyanka Sharma, Kirti Vyas

***Abstract*— This paper presents a defected core design of photonic crystal fiber, which is promise to improved dispersion property as well as provided a flattened dispersion in the 1.4 µm to 2.0 µm wavelength range. The FDTD method has been employed for characterization of its optical parameters. The above dispersion is even investigated by converting air hole into large elliptical air hole around the core. A full-vector TE, FDTD method is used to simulate and analyze the dispersion and birefringence property.**

***Index Terms*— Photonic crystal fiber, Dispersion, Birefringence.**

I. INTRODUCTION

PHOTONIC crystal fibers (PCFs) have attracted significant attention recently. A PCF consists of a central core of air or pure silica surrounded by an array of air holes running along its length. PCFs may be divided into two categories: the index guiding PCF, where light is guided by modified total internal reflection and the bandgap guiding PCF, where light guiding is based on the effect of photonic bandgap (PBG) within which light propagation is prohibited [1]. Photonic crystal fibers (PCFs) possess dispersion properties significantly different from those of conventional fibers because the novel cladding structure consisting of an array of micrometer-sized air holes allows for flexible tailoring of the dispersion curves. Inclusion of air-holes in the cladding creates sufficient index difference between the core and the cladding to guide light by the mechanism of total internal reflection (TIR). Recently, photonic crystal fiber (PCF) has received increasing attention because of its novel optical characteristics [2]. Photonic crystal fiber also known as holey fiber or microstructure fiber is new types of optical fibers based on the properties of photonic crystal. A PCF having an internal periodic structure made up of capillaries which is hexagonal lattice. The light is confined and propagates along the length of fiber in defects of its crystal structure called core, which can be a solid core or hollow core. The design PCFs is very flexible. There are various parameters to design the photonic crystal fiber like lattice pitch (Λ), air hole diameter (d) & shape (circular or elliptical), refractive index of the wafer and types of lattice (Rectangular, hexagonal etc.) Birefringent PCFs have many applications such as coupling between optical fibers and CO2 laser transmission, coherent communication systems, fiber optic interferometric sensors and gas sensing etc. Several authors like Rakhi et. al. have reported ~ 5.45×10^{-2} in a bandgap fiber [3]. Liang Wang et al and Dingjie Xu et al demonstrated only high birefringence without dispersion at the magnitude of 10^{-3} . Jian Liang et al designed a PCF that offered birefringence at the magnitude of 10^{-3} and dispersion (5 to 30) ps/(km-nm) for wavelength range 1.0 to 2.05 µm [4]. Last decade has created strong requirements for novel optical components that can handle functions such as dispersion compensation, flattened dispersion and exhibit endlessly single-mode property. Their artificial crystal-like structure results in a number of unique and unusual properties, such as single-mode operation from UV to IR spectral regions, large mode areas with core diameters larger than 20 μm^2, highly nonlinear performance, and tunable dispersion [5]. Et-al Mohit present the PCF with hexagonal lattice of air holes. The designed fiber promises very large birefringence 1.2×10^{-2} at 1.55 µm. The fiber has anomalous dispersion over a wide range of wavelength

In this paper, we proposed a 7 rings hexagonal PCF structure that is suitable in low and flattened dispersion over a wide range of wavelength ranging from 1.4 µm to 2.0 µm. The attractive feature of our proposed PCF is the design flexibility with very low negative & flatted dispersion of -8 ps/(nm.km) and high birefringence property.

II. ANALYSIS METHOD AND EQUATIONS

Chromatic dispersion is the main contribute to the Optical pulse broadening. Chromatic dispersion is caused by combined effects of material and waveguide dispersion Control of the chromatic dispersion in PCFs is essential for practical applications in optical communication systems, dispersion compensation and linear or nonlinear optics .In the short wavelength range, the guided mode is well confined into the PCF core region and the dispersion property is affected by the inner air-hole rings. In the long wavelength range The PCF effective core area is increased and the dispersion is affected not only by inner rings but also by the outer rings, particularly when the hole to hole spacing is small. The chromatic dispersion D of the PCF is obtained from the n_{eff} values against the wavelength using:

$$D = -\frac{\lambda}{c}\frac{d^2 \operatorname{Re}[n_{eff}]}{d\lambda^2}$$

Where c is the velocity of light and Re (n_{eff}) is the real part of the n_{eff}. Material dispersion refers to the wavelength dependence of the refractive index of material caused by the interaction between the optical mode and ions, molecules or electrons in the material. Waveguide dispersion depends on the core diameter and on the refractive index contrast between the core and cladding. Total chromatic dispersion D consists of two components: material dispersion and waveguide dispersion:

$$D = D_m + D_w$$

The material dispersion given by Sellmeier formula is directly included in the calculation. Therefore, *D is* the total dispersion of the PCF [6]

Highly birefringence fibers are widely used for polarization control in fiber optic sensors, precision optical instruments, and optical communication systems. Birefringence is defined as a difference between effective refractive indices of two fundamental polarization modes and can be written as

$$B = | n_x - n_y |$$

Where n_x and n_y are the effective refractive indices of each fundamental mode [7].

III. SIMULATION & RESULTS

In this present investigation, we have designed elliptical core by omitting 21 air hole around the core and converted single air hole into elliptical by changing the parameter (Major axis a_1=5, minor axis b_1=0.1) in first ring around the core. Same as we converting second ring into elliptical by the same concept. In previous work have seven rings of air holes in the cladding region. The innermost ring is composed with two elliptical rings. We made a highly stressed core by omitting 21 air holes in the innermost ring and offset the two air holes in the center of the *y-axis* and made an elliptical air hole [3]. In this paper, in first configuration we change the parameter of innermost ring is composed with two elliptical rings and obtains an optimum parameter which shows an improvement in dispersion property. Then after in configuration-II, we design two innermost ring is composed with two elliptical ring with same parameter (Major axis a_1=5, minor axis b_1=0.1) .we also calculated the mode profile of proposed PCF by using FDTD method simulation. The TBC boundary condition is used. The layout of configuration- II is shows in fig 1.

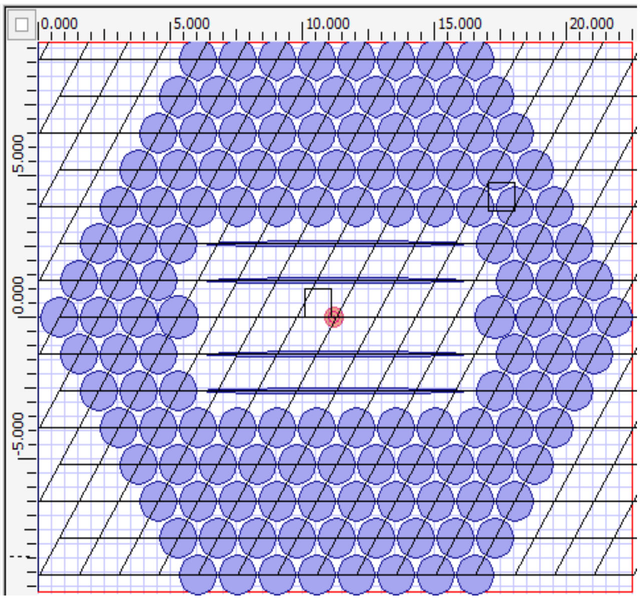

Fig 1. Configuration- II PCF design with two innermost ring is composed with two elliptical ring.

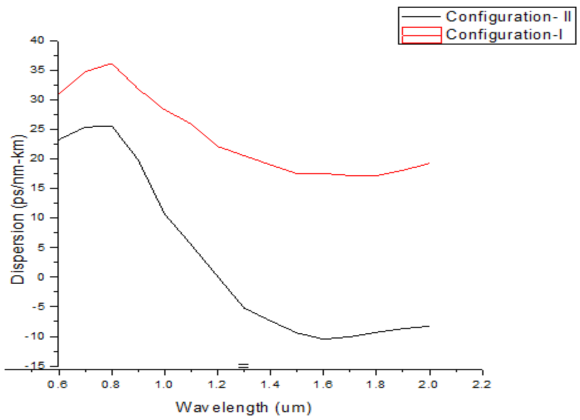

Fig 2. Graph between dispersion and wavelength.

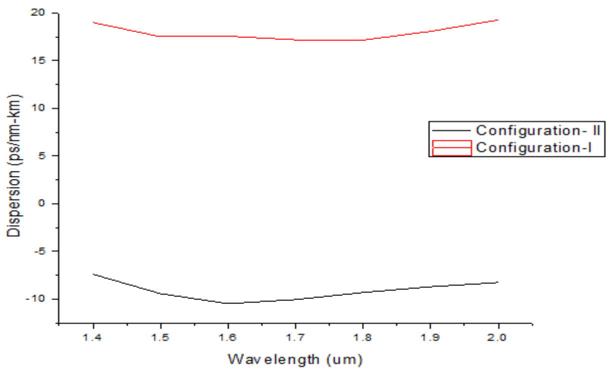

Fig 3. Graph between dispersion and wavelength.

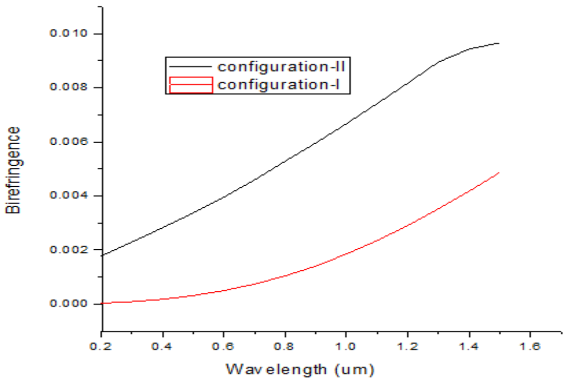

Fig 3. Graph between Birefringence and wavelength.

Fig 2 shows the dispersion characteristics of X-polarization for optimum design parameter ʌ=1.5 µm, and two big air hole with diameter d_1=ʌ and rest air hole diameter d=0.95×ʌ [3]. We made a highly stressed core by omitting 21 air hole in configuration-I and in configuration-II omitting 35 air hole.

From the curve it is seen that, proposed PCF have a very small dispersion over the 0.2 µm to 2.0 µm wavelength range. It has -8 (ps/nm-km) at 1.55 µm. In fig 3, shows that this PCF is have flattened dispersion in the 1.4 µm to 2.0 µm wavelength range.

In fig 4, shows that the birefringence property of this PCF, in configuration-II has much improvement in birefringence property as compare with configuration –I.

IV. CONCLUSION

In this article, we have investigation dispersion and birefringence property of defected core PCF by using FDTD method. It was found from numerical simulation proposed PCF have a very small dispersion over the 0.2 µm to 2.0 µm wavelength range. It has -8 (ps/nm-km) at 1.55 µm. PCF also have flattened dispersion in the 1.4 µm to 2.0 µm wavelength range. The proposed fiber exhibits birefringence as high as 1×10^{-2}. Hence, the fiber is a promising candidate for sensing applications, can be used to eliminate the effect of PMD in transmission systems, optical amplification applications, fiber loop mirror, etc. these fiber also may be also useful fabrication of polarization controllers

ACKNOWLEDGMENTS

The concept of this work is inspired by paper "highly birefringence photonic crystal fiber with anomalous dispersion" et-al Mohit Sharma.

REFERENCE

[1] Takashi Matsui, Jian Zhou, Kazuhide Nakajima, And Izumi Sankawa," Dispersion-Flattened Photonic Crystal Fiber With Large Effective Area And Low Confinement Loss", JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 23, NO. 12, DECEMBER 2005.

[2] Jian Ju, Wei Jin, *Senior Member, IEEE*, and M. Suleyman Demokan, "Design of Single-Polarization Single-Mode Photonic Crystal Fiber at 1.30 and 1.55 μm"

[3] Mohit Sharma*1, Nitu Borgohain2, S Konar3 "Highly Birefringence Photonic Crystal Fiber with Anomalous Dispersion" 978-1-4799-2174-4/13/$31.00 ©2013 IEEE

[4] R. R. Mahmud S. M. A. Razzak, M. Salim Habib, M. Samiul Habib" Low Dispersion Nonlinear Polarization Maintaining Photonic Crystal Fiber Using Hybrid Cladding" 978-1-4799-4819-2/14/$31.00 ©2014 IEEE

[5] Sanjaykumar Gowrea, Sudipta Mahapatraa, S.K. Varshneya, P.K. Sahub "Dispersion characteristics of all-glass photonic crystal fibers" Optik 124 (2013) 3730– 3733

[6] Chengcheng Gui Jian Wang, Member, IEEE, "Elliptical–Spiral Photonic Crystal Fibers With Wideband High Birefringence, Large Nonlinearity, And Low Dispersion", Volume 4, Number 6, December 2012.

[7] D. C. Tee, M. H. Abu Bakar, Tamchek, And F. R. Mahamd Adikan," Photonic Crystal Fiber In Photonic Crystal Fiber For Residual Dispersion". Compensation Over E+S+C+L+U Wavelength Bands", Vol. 5, No. 3, June 2013, IEEE Photonics Journal.

[8] E.K. Akowuah, H.Ademgil, And S.Haxha,"Design And Analysis Of Photonic Crystal Fibres (Pcfs) For Broadband Applications"

[9] Feifei Shi, Yun Wu, Meicheng Li, Yu Zhao, And Liancheng Zhao," Highly Birefringent Two-Mode Photonic Crystal Fibers With Near-Zero Flattened Dispersion", Volume 3, Number 6, December 2011.

[10] Fei Liua, Hongyan Gaob, Yani Zhangc, Qiang Xud," Optical Birefringence And Polarization Dependent Loss Of Elliptical-Hole Rectangular Lattice Photonic Crystal Fibers Based On Polymer.

[11] Feroza Begum , Yoshinori Namihira , S.M. Abdur Razzak , Shubi Kaijage , Nguyen Hoang Hai , Tatsuya Kinjo , Kazuya Miyagi , Nianyu Zou ," Design And Analysis Of Novel Highly Nonlinear Photonic Crystal Fibers. With Ultra-Flattened Chromatic Dispersion", Optics Communications 282 (2009) 1416–1421.

[12] H. Ademgil, S. Haxha "Highly Nonlinear Birefringent Photonic Crystal Fiber", Optics Communications 282 (2009) 2831–2835

[13] H. Ademgil, S. Haxha, *Senior Member, IEEE*, T. Gorman, And F. Abdelmalek, "Bending Effects On Highly Birefringent Photonic Crystal Fibers With Low Chromatic Dispersion And Low Confinement Losses" JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 27, NO. 5, MARCH 1, 2009

[14] H. Ademgil And S. Haxha*, Senior Member, IEEE, Member, OSA,"* Highly Birefringent Photonic Crystal Fibers With Ultralow Chromatic Dispersion And Low Confinement Losses*",* JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 26, NO. 4, FEBRUARY 15, 2008

[15] H. Ademgil, S. Haxha, *Senior Member, IEEE*, T. Gorman, And F. Abdelmalek," Bending Effects On Highly Birefringent Photonic Crystal Fibers With Low Chromatic Dispersion And Low Confinement Losses", JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 27, NO. 5, MARCH 1, 2009

[16] I. Abdelaziz, F. Abdelmalek, S. Haxha, *Senior Member, IEEE*, H. Ademgil, And H. Bouchriha," Photonic Crystal Fiber With An Ultrahigh Birefringence And Flattened Dispersion By Using Genetic Algorithms", Journal Of Lightwave Technology, Vol. 31, No. 2, January 15, 2013

[17] Jian Ju, Wei Jin, *Senior Member, IEEE*, And M. Suleyman Demokan, *Senior Member, IEEE,"* Design Of Single-Polarization Single-Mode Photonic Crystal Fiber At 1.30 And 1.55 *M*m*",* JOURNAL OF LIGHTWAVE TECHNOLOGY, VOL. 24, NO. 2, FEBRUARY 2006.

[18] K. S. Yeoa,B, D. M. C. Chowa, D. C. Teea, W. R. Wonga, S. R. Sandoghchia, M. A. Mahdib And F. R. Mahamd Adikan, "Dispersion Modeling Of Solid Core".

[19] K. P. Hansen," Dispersion Flattened Hybrid-Core Nonlinear Photonic Crystal Fiber", 30 June 2003 / Vol. 11, No. 13 / OPTICS EXPRESS 1503.

[20] Ming Chen, Qingyang,Tiansongli, Mingsongchen, Ninghe," New High Negative Dispersion Photonic Crystal Fiber", Optik 121 (2010) 867–871.