International Journal of Engineering and Applied Sciences (IJEAS)
ISSN: 2394-3661, Volume-3, Issue-7, July 2016

Study and Analysis of Photonic Crystal Fiber in Honey Comb Structure with Ultra-Flattened Dispersion

Ankita Singh, Himanshu Joshi, Khushbu Sharma

***Abstract*— A new class of Honey Comb Photonic Crystal Fibres (PCFs) structure that has a high-index core surrounded by air holes is proposed. For the proposed design four different air-hole diameters surrounding core region is used. A full vector Finite Difference Time Domain (FDTD) analysis with the Transparent Boundary conditions (TBC) absorbing boundary conditions is effectively applied to investigate the model characteristics of Photonic Crystal Fibres (PCFs) Through the numerical simulation and optimizing the geometrical parameters like changing the pitch (Λ) for photonic crystal fibers in Honey Comb structure, it has been demonstrated that it is possible to obtain ultra flatten dispersion over a wide wavelength range. The designed index-guiding Honey Comb PCFs has a nearly zero ultra-flattened dispersion of O±O.11ps/(nm.km) in a wavelength range of 1.4 µm to 1.6µm. The proposed structure is designed using seven rings in which circular air holes are used. The background material for the designing purpose is silica with refractive index 1.458. Moreover, a detailed study of PCF with honeycomb lattice has been carried out with the purpose of optimizing the chromatic dispersion.**

***Index Terms*— Chromatic Dispersion, Confinement Loss, Effective Refractive Index (η_{eff}), Honey Comb, Photonic Crystal Fiber (PCF)**

I. INTRODUCTION

Photonic crystal fiber (PCF) [1-2] is a particular class of fiber using various new designing application. PCFs are designed for special-purpose applications that do not require large volume of fibers. PCF can be fabricated by the use of Photonic crystals which are composed of periodic dielectric or metal-dielectric nanostructures that influence the propagation of electromagnetic waves (EM). Photonic crystal fibers (PCFs) have attracted much interest in recent time because of their inimitable dispersion properties. Especially, index-guiding PCFs, also called holey fibers **(HFs)** consists a series of air holes that runs throughout the length of the fiber [3]. Characteristics of PCFs such as, effective index mode confinement loss, dispersion are measured by varying the structural parameters (air hole diameter, lattice pitch) [4].

PCFs, also called endlessly single mode fibers [5] generally classified into two special kinds of fibers by their light-guiding mechanism [6]. The first experimentally realized-type guides by a modified form of total internal reflection (M-TIR) between a solid core and a cladding region with multiple air-holes and fibers of this type are also known as index-guiding PCFs [2]. On the other hand, the second one uses a enormously periodic structure exhibiting a photonic band gap effect at the operating wavelength that allowing for novel features such as light confinement to a low- index core [2] [6-8] known as photonic band gap fiber and investigated in [9].The diameter of the air holes is indicated by d which is termed as the structural parameter of the PCF [10]. The lattice pitch (distance between the holes) is denoted by Λ and the ratio *d/Λ* is called air filling fraction.

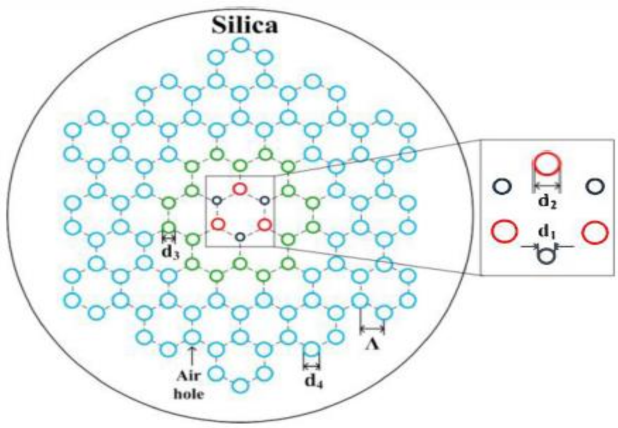

Fig.1 Schematic cross-section of conventional Honey Comb PCFs with seven air hole rings and the geometrical Parameters of the air hole diameter d, pitch Λ

In PCFs, due to presence of finite number of air hole in the cladding, the guided mode becomes intrinsically leaky, so confinement loss exists. In Holey Fibers PCFs, since the periodicity in the cladding region is not essential to confine the guiding light into the core region, so by varying the air hole diameter of each air hole ring, air hole pitch and cladding structure it becomes possible to control both dispersion and confinement loss in wide wavelength range [11]. Because of its capability to confine light in hollow or solid cores, PCF is now finding applications in fiber optic communications, fiber lasers, nonlinear devices, high-power transmission, and highly sensitive gas sensors [4].

Index-Guiding fibers allow an accurate control of the dispersion features that can results in a single mode transmission fiber for enormously wide range of wavelengths, starting from a very short wavelength to some micrometers [1]. It is also observed that, the flattened symmetry can lead to

Ankita Singh, M.Tech. Scholar, Department of Electronics and Communication, Jagannath University, Jaipur, India
Himanshu Joshi, Assistant Professor, Department of Electronics and Communication, Jagannath University, Jaipur, India
Khushbu Sharma, Assistant Professor, Department of Electronics and Communication, Maharani Girls Engineering College, Jaipur, India

a long range transmission without chromatic dispersion [12]. On the practical point of view, Due to flexibility of Stack and Draw technique there are no worries to fabricate complicated PCFs.

Numerous designs like PCFs with two-defected air hole rings [13], a modified hexagonal PCFs [14], nonlinear PCFs with several kinds of air hole diameters [15], and square PCFs [16] have been proposed to attain nearly zero ultra-flattened chromatic dispersion properties for the PCFs. Some of them become complicated to attain nearly zero ultra-flattened dispersion. Many preceding designs do not have better dispersion as compare to other design so it is very necessary to scrutinize ultra-flattened dispersion in honeycomb PCFs. In recent times honeycomb [11] seven rings PCFs with multiple designing parameters such as diameter of air holes, shape of the holes (like circular, square, elliptical) and pitch difference was proposed to achieve ultra-flattened dispersion and the spacing between these holes facilitates development of PCFs with improved properties.

In this paper we numerically examine and proposed a new type of honeycomb Photonic crystal fiber structure. According to proposed structure, it is possible to design a honeycomb PCFs with nearly zero ultra-flattened chromatic dispersion by optimizing the geometrical parameter- pitch Λ. For the designing purpose, We use a efficient full vector modal solver based on the finite difference time domain method (FDTD) and Transparent Boundary conditions (TBC) absorbing boundary to investigate the various properties of PCFs. Numerical results shown that the PCFs has nearly zero ultra-flattened chromatic dispersion of 0±0.11 ps/ (nm.km) in all C, S, L band which are found to be more flat than those of reported triangular and honeycomb PCFs [11, 17].

II. Theoretical Analysis

To analyze the ultra-flattened dispersion in Honey Comb photonic crystal fiber, a full-vector finite difference time domain technique [18] is used which is appropriate for the examination of periodic structure and supported on the discretization scheme that can be derived from the Maxwell's equations [19]. FDTD technique tool is suitable for examining the electromagnetic wave propagation in complex structures and it estimate to the fields Hx (x-component magnetic field) and Ex (x-component electric field) obtained from Maxwell's equations [18-19].

The schematic cross-section view of the PCFs with honeycomb structure containing seven rings is shown in figure1. The proposed PCFs consists circular air holes in the cladding region that are arranged in hexagonal arrangement, Here d is the air hole diameter, '∧' is the center-to-center spacing between the air holes known as pitch, and d/∧ is the ratio of normalized diameters of the air holes in the cladding. The background material is silica with refractive index 1.458 and air refractive index 1.0. In the structure of the proposed honeycomb PCFs design (see Figure 1), there are four degrees of freedom as inner ring air hole diameter d_1, d_2 and outer rings air hole diameter d_3, d_4 and hole to hole spacing is pitch (∧). By suitable design of these parameters d_1, d_2, d_3, d_4 and pitch ultra- flattened dispersion can be obtained. The outer rings air hole is kept large enough to improve the c dispersion as well as controlling of confinement loss. After careful selection of the all these parameters, it is possible to achieve desired dispersion properties because the dispersion characteristics are dominantly affected by the air hole sizes of the inner rings as well as pitch. In optical communication dispersion plays an important role as it determines the information carrying capacity fiber. Therefore, it becomes necessary to investigate the dispersion properties of an optical fiber especially for Photonic Crystal Fibers.

Information is transmitted in the form of light pulses in optical fibers. So Dispersion is the phenomenon that may occur during propagation and cause pulses to spread, it occur because spectral component travel with different velocity. It limits the communication capacity of the system. Chromatic dispersion is caused by the combine effects of material and Waveguide dispersion. Waveguide dispersion depends on the core diameter and on the refractive index contrast between the core and the cladding. 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. The chromatic dispersion D of a PCF is easily calculated from the second derivative of the mode index, $\eta_{eff} = ß / k_0$ using equation (1)

$$D = -\left(\frac{\lambda}{c}\right)\frac{d^2}{d\lambda^2}\left[R_e\left(n_{eff}\right)\right] \quad (1)$$

in [ps/(km.nm)],Where Re (η_{eff}) is the real part of n_{eff} and λ is wavelength , c is the velocity of light in vacuum, ß is the Propagation constant, $k_0 = 2\pi/\lambda$ the wave number in the free space [14] [20]. Total chromatic dispersion D is given by the addition of two components: material dispersion D_m and waveguide dispersion D_w

$$D(\lambda) = D_m(\lambda) + D_w(\lambda) \quad (2)$$

The material dispersion given by Sellmeier's Formula is directly included in the calculation (equation 3).

$$\eta 2 = 1 + (\beta 1\lambda^2)/(\lambda^2 - C_1^2) + (\beta 2\lambda^2)/(\lambda^2 - C_2^2) + (\beta 3\lambda^2)/(\lambda^2 - C_3^2) \quad (3)$$

Sellmeier constants are:

ß1 = 0.696166300, ß2 =0.407942600, $ß_3$ = 0.897479400
C1= 4.67914826×10−3μm^2, C2= 1.35120631×10−2μm^2,
C3= 97.9340025 μm^2.

Due to the finite nature of the photonic crystal lattice in PCF, all modes are leaky and the resulting confinement loss, L_c, can be calculated from the imaginary part of the mode index using the equation (4).

$$L_c = 8.686 k_0 \, \mathrm{Im}\,[\eta_{eff}] \quad (4)$$

Where (η_{eff}) is effective mode index. The confinement loss is a significant parameter to design a PCF with a finite number of air holes.

III. Result and Discussion

The structure of the proposed honeycomb PCFs design is shown in Figure 2. The designed honey comb PCF consists of a solid core region with a regular array of air holes running along the length of the fiber acting as the cladding. The core material is silica glass having refractive index 1.458 and the refractive index of cladding air holes is 1. The refractive index of cladding is lower than the refractive index of core region.

ISSN: 2394-3661, Volume-3, Issue-7, July 2016

This seven ring honeycomb structure is in triangular lattice structure.

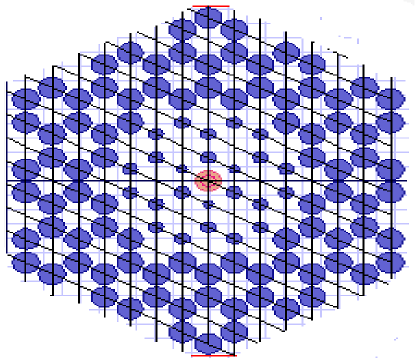

Fig. 2 Cross Section of Proposed PCF Design-3

The proposed honeycomb seven ring PCFs structure consists four air hole diameters d_1, d_2, d_3, d_4. In which inner ring with hole diameter d_1/Λ = 0.3 and d_2/Λ =0.44. Other diameters are d_3/Λ =0.434 and $d_{4/}\Lambda$ =0.8. For the proposed structure pitch Λ is = 1.625µm.

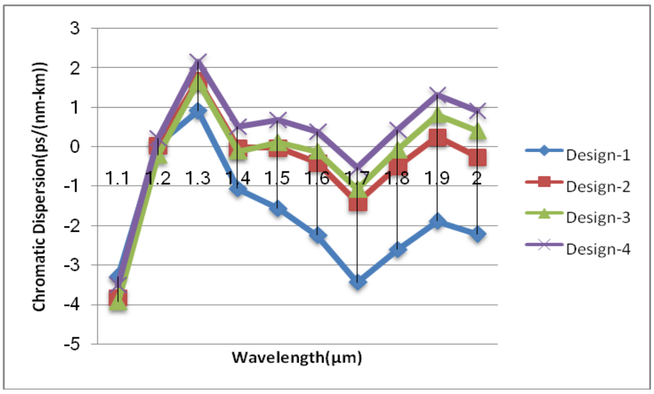

Fig 3: Effective of varying the pitch while keeping diameter d1, d2, d3and d4 constant

Figure 3 shows the Chromatic dispersion dependence with wavelength for design 1 to design 4. Here, the diameter of air holes for all these four designs remain same and that is d1 = 0.54, d_2 = 0.792, d3=0.7812, d_4 =1.44 and only pitch is varied. The value of pitch for design 1 is 1. 6µm,for design 2 pitch Λ = 1.62µm, design 3 pitch Λ = 1.625 and for design 4 pitch Λ = 1 .63 µm. Design 3 is our proposed design structure and it shows all most flat dispersion in the wavelength range 1.4 µm to 1.6 µm.

Confinement loss dependence with wavelenght is shown in figure 4.We analysis that the confinement loss and dispersion are reciprocal to each other. For the lower wavelengths we get less confinement loss as compare to higher wavelengths. The outer four rings air hole is kept large enough to improve confinement loss also controlling the chromatic dispersion.

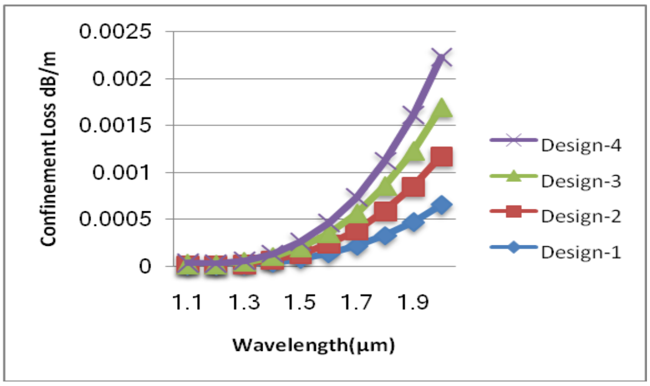

Fig. 4 Confinement loss dependence with wavelength

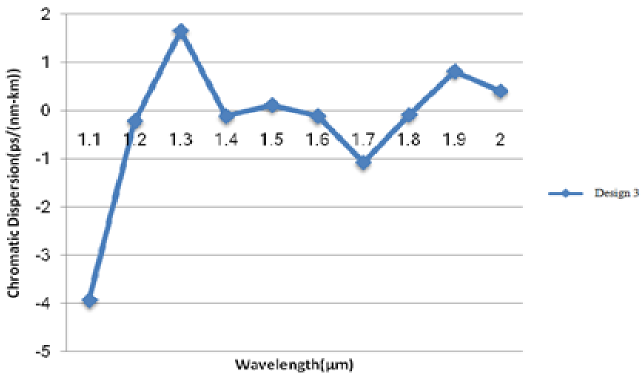

Fig 5: Chromatic dispersion dependence with wavelength for proposed design 3

Figure 5 shows the Chromatic Dispersion dependence with wavelength. In the proposed designs of Honey Comb Photonic Crystal Fiber while keeping the diameter as constant and wafer dimensions are also constant, only pitch is varied. At the pitch 1.625 µm. we observe that Honey Comb PCF shows better dispersion at the wavelength range 1.4µm to 1.6µm.

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

PCF	Wavelength Range (µm)	Dispersion [ps/km. nm]	Flat band (nm)	Nr, NΛ, Nd
Ref. [11]	1.30 to 1.60 µm	0 ± 0.6	300	5,2,3
Ref. [17]	1.39 to 1.70 µm	0 ± 0.2	310	7,1,4
Proposed design - 3	1.4 to 1.6 µm	0 ± 0.11	200	7,1,4

At the Final, above table shows the comparison between various properties of the PCFs for telecom and nonlinear optics applications. Therefore, the proposed PCF with a modest number of design parameters, near-zero ultra-flattened dispersion may pave the way for various applications in optics. Above stable shows the comparison of those fibers taking into flat dispersion, wavelength range and number of design parameters including like number of rings (Nr), number of pitch (NΛ) and number of different diameter of holes (Nd) which are used in PCF design respectively.

IV. Conclusion

In the proposed work design as well as investigation was done to get the optical properties of a Honey Comb photonic crystal fiber with triangular lattice structure of air holes. Through numerically investigation with finite difference time domain and transparent boundary condition various properties were calculated like Waveguide dispersion, Chromatic dispersion and Confinement loss. The proposed index-guiding honeycomb PCFs has flattened zero dispersion over a wide wavelength range. In comparison with several other previously research work presented on dispersion-flattened PCFs, It has been shown that the proposal of honeycomb PCFs has nearly zero ultra-flattened chromatic dispersion of 0±0.11ps/(nm.km). As the final conclusion of this research work, the honeycomb PCFs may be suitable for chromatic dispersion management applications as a chromatic dispersion controller, nonlinear optical system or as a dispersion compensator.

References

[1] T. A. Birks, J. C. Knight, and P. St. J. Russell, "Endlessly single-mode Photonic Crystal Fiber," *Optics Letters*., Volume. 22, pp. 961–963, July1997.

[2] J. Broeng, D. Mogilevtsev, S. E. Barkou, and A. Bjarklev, "Photonic Crystal Fibers: A new class of optical waveguides,"*Optical Fiber Technoogy*." Volume 5, pp. 305–330, July 1999.

[3] Ming-Yang Chen, Rong-Jin Yu, Member, OSA, and An-Ping Zhao, Senior Member, IEEE "Confinement Losses and Optimization in Rectangular-Lattice Photonic-Crystal Fibers," *journal of lightwave technology*,Volume.23,no.9, september 2005.

[4] Md. Mahbub Hossain and Md. Maniruzzaman Electronics and Communication Engineering Discipline Khulna University, Khulna, Bangladesh "Analysis of Dispersion and Confinement Loss in Photonic Crystal Fiber," *International Conference on Electrical Engineering and Information & Communication Technology (ICEEICT)* 2014.

[5] P. S. J. Russel, "Photonic-crystal fibers", *Journal of Lightwave Technology*, Volume. 24, no. 12, pp. 4729-4749, 2006.

[6] R. P. Feyman, The Feyman Lectures on Physics, Volume. 2, Addison-Wesley, 1969. J. C. Knight, T. A. Birks, P. S. J. Russell, and D. M. Atkin, "All silica single mode optical fiber with photonic crystal cladding", *optics letters*, Volume 21. pp. 1547- 1549, 1996.

[7] J. C. Knight, J. Broeng, T. A. Birks, and P. St. J. Russell, " Photonic band
gap guidance in optical fibers," Science, Volume 282, pp. 1476–1478, Oct. 1998

[8] J. Broeng, S. E. Barkou, and A. Bjarklev, "Analysis of air guiding photonic bandgap fibers," *optics letters*, Volume 25, Jan. 2000.

[9] A. Ortigosa-Blanch, J. C. Knight, W. Wadsworth, J. Arriaga, B. J. Mangan, T. A. Birks, and P. St. J. Russell, "Highly Birefringent Photonic Crystal Fibers," *optics letters* Volume 25, pp. 1325–1327, Sept. 2000.

[10] M. D. Nielsen, N. A. Mortensen, J. R. Folkenberg, A. Petersson and A. Bjarklev, "Improved All-Silica Endlessly Single-Mode Photonic Crystal Fibers," Optical Fiber Communication Conference Volume 2,pp. 701-702, March 23-28, 2003, Atlanta, Georgia (USA).

[11] Nghiem Xuan Tam, Nguyen Xuan Son, Pham Hong Thai Nguyen Hoang Haia "New Proposal of Chromatic Dispersion Control in Honey Comb Photonic Crystal Fiber for Broadband Communication." *International Conference on Communications and Electronics (ICCE)*, 2014, IEEE, *ISBN-9781479950492*, July 30 2014-Aug.2014.

[12] W. H. Reeves, J. C. Knight, and P. St. J. Russell, "Demonstration of ultraflattened dispersion in PCFs," optics Express 10, 609-613 (2002).

[13] Sejin Lee, Woosung Ha, Hong-gu Choi, Jiyoung Park, Soan Kim and Kyunghwan Oh "Ring Defect Photonic Crystal Fibers for Low loss and Flattened Dispersion" 15th Opto Electronics and Communications Conference (OECC2010) Technical Digest, July 2010, Sapporo Convention Center, Japan.

[14] JingyuanWanga, Chun Jiangb, Weisheng Hub, Mingyi Gaob Hongliang Renb "Dispersion and polarization properties of elliptical airhole-containing photonic crystal fibers," *Optics & Laser Technology*, Elsevier Ltd. 2007.

[15] Md. Sharafat Ali, Aminul Islam, Redwan Ahmad, A. H. Siddique, K M Nasim, M A G Khan, M Samiul Habib "Design of Hybrid Photonic Crystal Fibers for Tailoring Dispersion and Confinement Loss" International Conference on *Electrical Information and Communication Technology(EICT)* IEEE, *ISBN-978147992299,* 2013.

[16] TAN Xiao-ling, GENG You-fu, TIAN Zhen, WANG Peng and YAO Jian-quan "Study of ultra flattened dispersion square-lattice photonic crystal fiber with low confinement loss" *Optoelectronics Letters*, Vol.5 No.2, 1 March 2009.

[17] M. Samiul Habib, M. A. Motin, M. I. Hasan, M. Selim Habib, S.M Abdur Razzak, and M. A. Goffar Khan "Dispersion and Confinement Loss Control with Decagonal Photonic Crystal Fibers for Wideband Transmission Systems" *International Conference on Informatics, Electronics & Vision* (*ICIEV*), IEEE, *ISBN-978147990400*, 2013.

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

[19] Zhu Z and Brown T G, "Analysis of the fundamental space-filling mode of photonic crystal fibers: a symmetry point of view," optical Express no.10, pp.853-64, 2002.

[20] 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.

Ankita Singh M.Tech Scholar, Department of Electronics and Communica- tion, Jagan Nath University, Jaipur. I am pursuing M.Tech (Digital communication) from Jagan Nath University and completed B.Tech in year 2014 from Rajasthan Technical University. I am currently working in the communication field.

Himanshu Joshi, Assistant Professor, Department of Electronics and Comm- unication, Jagannath University, Jaipur, India. He has completed his M.Tech (VLSI and Embedded system) in 2011 from Gyan Vihar University, Jaipur, and B.E degree in 2007 from Rajasthan University. He is currently working in the VLSI and Communication Field.

Khushbu Sharma received the M.Tech. degree in Digital Communication in 2015 from RTU, kota and B.Tech degree in Electronics & Communication Engineering in 2011 from Rajasthan Technical University, Kota Rajasthan. She is currently working as Assistant Professor in the department of E&C, Maharani Girls Engineering college, Jaipur. Her current research includes communication field.