# Study and Analysis of Low-Dispersion Photonic Crystal Fiber

[1] Laxmi Chaudhary, and [2]Arun JB
[1]PhD. Scholar, Bhagwant University,Ajmer
[2]PhD. Supervisor, Bhagwant University

***Abstract***: The dispersion is the parameter to investigate the performance of the PCFs similarly conventional optical fibers in the optical systems. This paper discusses several optimum designs wavelength ranging from 0.5 µm to 2.0 µm wavelength. In this paper we investigate the method for chromatic dispersion of Borosilicate crown glass from the scalar effective index method using transparent boundary condition with linear and elliptic waveguide. The chromatic dispersion is evaluated based on the result obtained due to the influence of the PCF structure parameters deviation. It has been demonstrated that nearly zero dispersion is possible to achieve in a range from 1.5 to 2.0 µm wavelength.

***IndexTerms* - Photonic Crystal Fiber (PCF), Effective Refractive Index (neff), Chromatic dispersion. FDTD (Finite Difference Time Domain)**

## I.INTRODUCTION

Photonic crystal fibers (PCFs) are designed to influence the modern optical fiber optics which has been progressing right since 1970's and are also observed as most active fields of optics research.As compare to the conventional fibres the PCFs are the design are flexible that give the advantage of attaining a variety of special optical properties, and this make the PCF to be used for large range of applications.[1-4] PCF are the optical fibres which are micro structured and in which the air holes are arranged alongside the length of the fibre and with the different refractive index background material.The dielectric material of photonic crystal contain of dielectric materials that function as electrical insulators or in which there is low loss propagation in electromagnetic field. There is lattice like structure arrangement of holes in the dielectric and which are repeated at regular intervals, and this is described as a photonic band gap arrange of frequencies in which a light with a specified wavelength is blocked [4, 6].The holes may have different diameter or different shape in the lattice structure .Currently the elliptic waveguide properties are used to construct the crystal structure. For designing the holes with square shape the linear waveguide is used. By introducing defects energy levels can be produced within the photonic band gap[11.] The defects may for example, in which the size of some of the holes is changed in a photonic crystal that is equal to perfect periodicity of the silicon-crystal lattice is broken.The PCF can be design efficiently and can be provide the modifying several guiding properties for example , birefringence, nonlinearity, chromatic dispersion and effective mode area [2-3]. The parameters for different design such as air-hole rings, air-hole diameter d, spacing between holes, and pitch (Λ). PCFs due to the different optical properties such as, flexibility in design, single mode operation, very small loss and characteristics of flattened dispersion have been use for developing the optical communication systems [4-5]. The Borosilicate crown glass is used as optical material and it is used in large section OPTICS products. The Refractive Index of BK7 & is 1.5168 whereas of Silica is 1.456 .The density (g/ cm3) is 2.51 of Bk7 & and 2.2 of the silica. The Bk7 is very efficient in transmission down to 350 nm, it is relatively hard glass. Another and widely used in the optics industry [9,10].The material chosen as the Borosilicate crown glass as wafer with refractive index of 1.5168 and 1.0 as the air hole refractive index. Basically the use of silica material is in various application of the optical fiber, but in recent times Borosilicate material is more preferred than silica material with its unique and different properties. For any kind of lattice structure (square,hexagonal or Rectangular)the material remains unchanged .The structure parameter such as air hole diameter "d"and pitch "Λ" also do not affect it.[8-10].

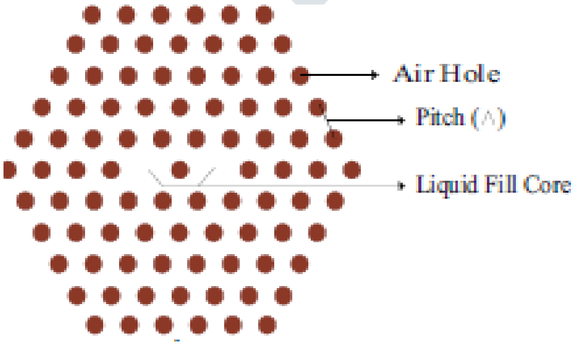

Fig. 1.Photonic Crystal Fibre.

## II. ADVANTAGES OF PCF

The PCF allow for guidance through hollow core (air holes) and smaller attenuation available than with solid core fiber. Large cores PCF can carry more power attenuation effects not worse than conventional fibers. Various applications have used PCF in the multiplier, de-multiplier, logic gates, polarization splitter, optical couplers, optical sensors and detection in medical field etc. [6]. The dispersion can be controlled in PCF if the air hole sizes are modified to shift point to zero dispersion in visible kind of the light ranges. Other exclusive properties for example high nonlinearity ,high birefringence , single mode guiding to endlessly ,fiber sensors and lasers which cannot be achievable by ordinary optical fiber [7-8]. The PCF is very suitable in optical telecommunications and as laser applications with its feature of frequencies and directions of propagating magnetic force[14].

## II. CHROMATIC DISPERSION TAILORING

The PCF have the property to control chromatic dispersion profile by changing the hole diameter and the hole pitch. The feature of the controlling of chromatic dispersion within the PCFs is a significant issue in practical applications to nonlinear optics, dispersion compensation and in optical communication systems.

Calculation of the chromatic dispersion (D) is done with fundamental mode's effective index(*n*eff) vs. the wavelength where velocity of light (c ) in a vacuum[13-17].

Using

$$D_w = -\left(\frac{\lambda}{c}\right)\frac{d^2}{d\lambda^2} n_{eff}$$

The curve of dispersion is near to the pure silica's material dispersion. , when the ration of diameter of hole to pitch is small and large is the hole to pitch. By increasing the air-hole diameter of the waveguide, the waveguide dispersion may influence more with the increase of air-hole diameter[20]. We can see that by properly changing the parameters such as hole diameter and hole pitch and design a PCF structure with a large air-hole diameter and small hole pitch, It is very likely to modify the zero dispersion wavelength to visible to near-infrared (IR) regions and obtain the large normal dispersion in the 1.55-$\mu$m wavelength range [12-14].The air holes with similar diameter in array with is used to form the cladding structure of PCF regular triangular Lattice. Though, with similar diameter of air-hole inside the cladding region, using a PCF it is very tough to control both the dispersion in a large wavelength range. Since in index-guiding PCFs, in the cladding region it is not necessary to restrict the light into the core region with higher-index and several effective refractive index profiles can be obtained [18].

## III.STRUCTURE PARAMETER

The proposed the structure is designed with hexagonal lattice having solid core to make the refractive index (RI) of the core higher than cladding and the light will propagate through the cladding which is characterized by different air holes, pitch with different diameters[9,10]. For creating the circular holes the elliptic waveguide is used by changing the distance between major axis and minor axis whereas for the square holes the linear waveguide is used by changing the starting and ending point in horizontal and vertical axis of holes. The two structures of Design-1 and 2 PCF proposed by using six rings in which inner three rings consist of circular air holes and square holes in the outer three rings. The other two structures of Design-3 and 4 PCF are proposed by accumulation of additional ring of circular air holes. Further the dispersion for different air hole diameter of inner and outer ring can be investigated.

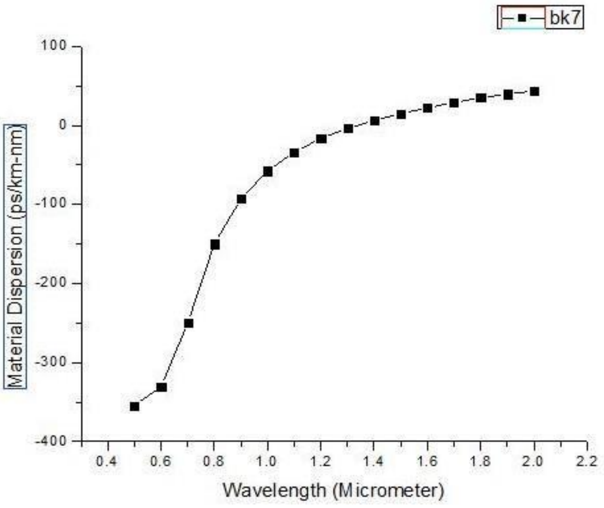

*Fig.* 2: Material dispersion of Borosilicate crown glass[6,8]

## Cladding layers

1. Design 1: Six Rings : $d_1$=0.6 µm(diameter of inner three ring of circular holes ), L=1 µm, w=1µm(length and width of outer three rings of square holes), Pitch($\Lambda$) = 2.0 µm

2.Design 2: Six Rings : $d_1$=0.6 µm(diameter of inner first ring circular holes) ,$d_2$=0.8 µm(diameter of second and third ring of circular holes) , L=1 µm, w=1µm(length and width of outer three rings square holes), Pitch($\Lambda$) = 2.0 µm

3.Design 3: Seven Rings : $d_1$=0.6 µm(diameter of first three rings are circular holes),$d_2$=1.2 µm(diameter of the fourth ring of circular holes) , L=1 µm, w=1µm(length and width of outer three rings square holes), Pitch($\Lambda$) = 2.0 µm.

4.Design 4: Seven Rings : $d_1$=0.6 µm(diameter of first three rings are circular holes) ,$d_2$=0.8 µm (diameter of the fourth ring of circular holes ), L=1 µm, w=1µm(length and width of outer three rings square holes, Pitch($\Lambda$) = 2.0 µm.

## IV.SIMULATION RESULTS

By using the software Opti-FDTD software for simulation effective refractive index is obtained .In fig. 3.effective refractive index of range from 0.5 µm to 2.0 µm wavelength for the selected PCF structure .It is observed that, the refractive index value declines due the addition of ring in the structure. Also with increase of wavelength range there is declination in refractive index and with increases of the air holes size the refractive index increases. Refractive index value is 1.51391 at 0.5 µm wavelength for selected design-1 and for design-2 is 1.51315 and in both case there were six rings. With seven rings in design-3 refractive index value varies as 1.51322 and design-4 it .is 51313.So as the wavelength increases the refractive index value decreases correspondingly.

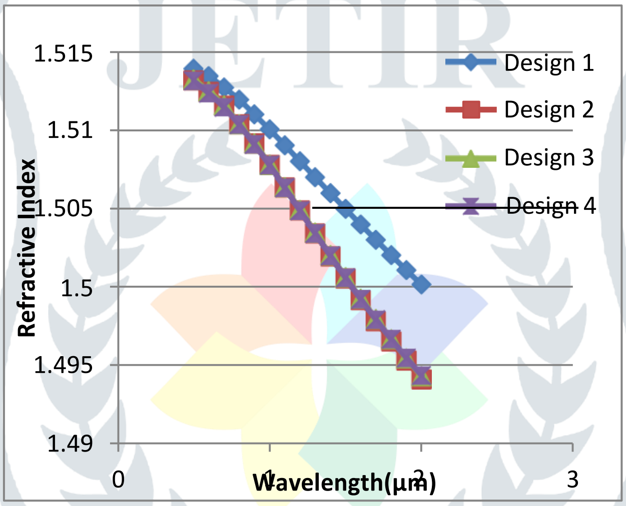

Fig.3. Refractive index (Design-1 to Design-4)

We observed that chromatic dispersion for design-3 is -5.4813 (ps/nm-km) and for design-4 is -8.13062 (ps/nm-km) at wavelength 1.5 µm. The value of chromatic dispersion for design-3 is 1.14613 (ps/nm-km) and for design-4 is -4.16955 (ps/nm-km) at wavelength 1.6 µm. So we can conclude from above result, designs-3 and 4 give more flattened dispersion as compare to design-1 and 2. We observed that chromatic dispersion for design-3 is -5.4813 (ps/nm-km) and for design-4 is -8.13062 (ps/nm-km) at wavelength 1.5 µm. The value of chromatic dispersion for design-3 is 1.14613 (ps/nm-km) and for design-4 is -4.16955 (ps/nm-km) at wavelength 1.6 µm.

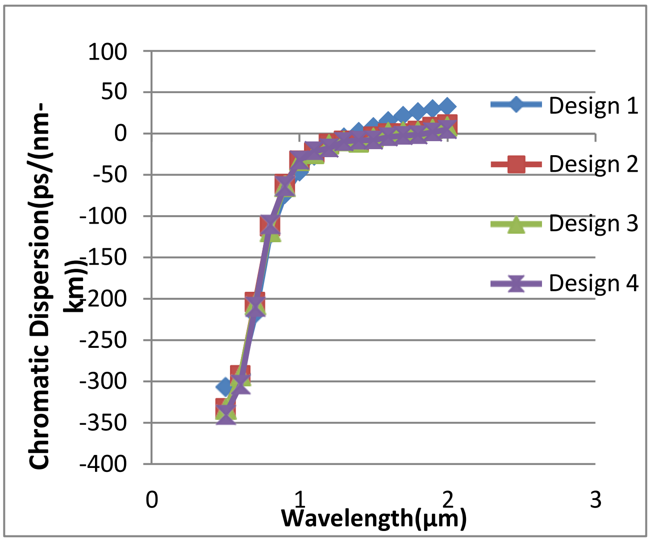

Fig.4.Comparison of chromatic dispersion of proposed PCF

And also by increasing the number of rings in the PCF structure the chromatic dispersion value decreases and also achieved flat dispersion near zero in wide wavelength range. We observe that design-3 & 4 with number of ring seven that design give more flattened dispersion as compared to design-1 and 2 with the number of ring six. And also as the wavelength increase gives the almost flat dispersion.

## V.CONCLUSION

PCF design of borosilicate crown glass with circular and square holes and along with the number of rings altered and air hole diameter and pitch also changed. We this we can determine that dispersion decreases and also it is observed that increase in holes spacing can also lower dispersion at different wavelength and so we obtained the flattened dispersion, which is main aim concern in designing the PCF. So the PCF based solutions are much preferred in sensor classes such as strain sensor, pressure sensor and temperature sensors [16-19]. Further PCF is also used in many applications in biology, imaging, spectroscopy, medical science, etc. and in radiation guidance terahertz range.

## REFERENCES

[1]J.C. Knight, T.A. Birks, P. St. J. Russell, D.M. Atkin.. All-silica single-mode fiber with photonic crystal cladding. Opt. Lett. 21, pp. 1547-1549, 1996.

[2]J. Broeng, D. Mogilevstev, S. E. Barkou, and A. Bjarklev.. Photonic crystal fibres: A new class of optical waveguides. Opt. Fiber Technol. 5, pp. 305- 330, 1999.

[3]K. Saitoh, M. Koshiba, T. Hasegawa, E. Sasaoka.. Chromatic dispersion control in photonic crystal fibers: application to ultraflattened dispersion. Opt. Exp. 11, pp. 843-852, 2003.
[4]G.P. Agarwal,“ *Nonlinear fiber optics*”, third ed., Academic press, New York, 1995.
[5]TAN Xiao-ling, GENG You-fu, TIAN Zhen, WANG Peng and YAO “Study of ultra flattened dispersion square-lattice photonic crystal fiber with low confinement loss” in OPTOELECTRONICS LETTERS, Vol.5 No.2, 1st March 2009.

[6]S.Tiwari. S.Jalwania and A.K. Bairwa,( Design Of Borosilicate Crown Glass Photonic Crystal Fiber With Flattened Dispersion And Low Confinement Loss.” 2012.

[7] Isabel C.S. Carvalho , Michael Fokine , Cristiano M.B. Cordeiro , Helio Carvalho , Raman Kashyap “Borosilicate glass for photonics applications”, Optical Materials 30 (1816–1821., 2008.

[8] Wei, B., S.-Q. Zhang, Y.-H. Dong, and F. Wang, A general FDTD algorithm handling thin dispersive layer," Progress In Electromagnetics Research B, Vol. 18, 243-257, 2009.

[9] 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, ISBN978147992299, 2013.

[10] Nihal Areed “Ultra-Flattened Dispersion Honeycomb Lattice Photonic Crystal Fiber” 5th International Conference: Sciences of Electronic, Technologies of Information and Telecommunications, March 22-26, 2009.

[11] Agrawal A, N. Kejalakshmy, J. Chen, B.M.A. Rahman and K.T.V. Grattan, “Golden spiral photonic crystal fiber: Polarization and dispersion properties”, Opt. Lett, Vol. 33, pp 2716- 2718, 2008.

[12] Shen L.P, W.P. Huang and S.S. Jain, “Design of photonic crystal fiber for dispersion related applications”, J. Lightwave Technol, vol. 21,2003.

[13] Ferrando A, E. Silvestre, J.J. Miret and P. Andres,“Nearly zero ultraflattened dispersion in photonic crystal fibers”, Opt. Lett, Vol. 25, pp 790- 792, 2000.

[14] Huttunen A and P. Torma, “Optimization of dual core and microstructure fiber geometries for dispersion compensation and large mode area”, Opt. Express, Vol. 13, 2005.

[15] Saitoh K and M. Koshiba, “Single polarization single mode photonic crystal fibers”, IEEE Photon Technol. Lett, Vol. 15, 2003.

[16] Kubota H, S. Kawanishi, S. Koyanagi, M. Tanaka and S. Yamaguchi, “Absolutely single polarization photonic crystal fiber”, IEEE Photon. Technol. Lett, Vol. 16, 2004, pp 182- 184.

[17] Dong X and H.Y. Tam, “ Temperature insensitive strain sensor with polarization maintaining photonic crystal fiber based on sagnac interferometer”, Appl. Phys. Lett, Vol. 90, 2007.

[18] Liu X, X. Zhou, X. Tang, J. Ng, J. Hao, T. Chai, E. Leong and C. Lu, “ Swithable and tunable multiwavelength erbium doped fiber laser with fiber bragg grating and photonic crystal fiber”, IEEE Photon. Technol. Lett, pp 1626- 1628, Vol. 17, 2005.

[19] Chen D and L. Shen, “ Highly birefringent elliptical hole photonic crystal fibers with double defect”, J. Light. Technol, vol. 25, pp 2700- 2705. 2007.

[20] Tripathy , Achary, Muduli and Palai, Tripathy “Nonlinear Rectangular Photonic Crystal Fiber (PCF) for Optical Communication Exclusively Super Continuum Generation”,et al., J Laser Opt Photonics 2015.

[21] Saeed Olyaee, Mahmood Seifouri and Ali Nikoosohbat ,“Improvement of Optical Properties in Hexagonal Index-Guiding Photonic Crystal Fiber for Optical Communications”, Mathematics Interdisciplinary Research 2, 2017.

[22] Bipul Biswasa, Kawsar Ahmed, Bikash Kumar Paul, Md. Abdul Khalek, Muhammad Shahin Uddin,”Numerical evaluation of the performance of different materials in nonlinear optical applications, Results in Physics 13, 2019.