Simulation of Borosilicate Crown glass Photonic Crystal Fibers with Flattened Chromatic Dispersion

Naveen Kumar Jain, Ravindra Kumar Sharma and Anurag Paliwal

Abstract— **In the conventional Photonic Crystal Fibers (PCFs), the cladding is formed by regular lattice of air holes with same diameter and silica glass is used as core material. In this paper, we have study a new structure of PCF filled Borosilicate Crown glass as core material. It is possible to control chromatic dispersion in wide wavelength range by varying the inner 3 layers hole diameter compare to outer 3 rings hole diameter. There are so many difficulties occur during the design process because when parameters are being changed the designing varies accordingly. Using this design principle, ultra flattened dispersion is also designed through a Scalar effective index method (SEIM) with Transparent Boundary Condition (TBC). Here we have also compare Borosilicate Crown glass PCF with Conventional silica glass PCF. A PCF with flat dispersion property may be very useful for next generation optical and communication data**

***Index Terms*— Photonic Crystal Fiber (PCF), Chromatic Dispersion, Scalar effective index method (SEIM), Transparent Boundary Xondition (TBC)**

I. Introduction

Photonic crystal fibers (PCFs) [1,2] have made from single material with a regular array of empty holes running along the length of the cladding. This structure enables light to be controlled within the fiber. Modern optical fibers, which transmit information in the form of short optical pulses over long distances at high speeds, have become integral part of life in the information age. In these years PCF [1,2] is very attracted in the research group because of many of their attractive properties [3] as high birefringence, very high and low nonlinearity, wideband dispersion [4-10] flattened characteristics, endlessly single mode guiding [11,12], fiber sensors [13, 14] and fiber lasers [15,16]. Many research papers have published some optical properties of PCFs such as unique chromatic dispersion, which are almost impossible for the conventional optical fibers. Most PCFs are used silica as core material and core is surrounded by air holes called photonic crystal structure [17-20].

Table 1. Comparisons of core material. [26]

Properties	**Silica Glass**	**BK7 Glass**
Density (g/cm^3)	2.2	2.51
Refractive Index (micrometer)	1.458	1.516
Light Transmission wavelength (micrometer)	0.18 to 2.5	0.35 to 2.5
Max Temperature (Degree C)	1120	560
Poission's Ratio	0.17	0.206
Specific heat capacity (J/Kg-K)	720	860
Speed of sound (m/s)	180*103	170*103

The PCF is made by a single material. Here we use Borosilicate crown glass as core material. Borosilicate glass was first developed by German glassmaker otto Schott in the late 19th century. Most borosilicate glass is colourless 70% silica, 10% boron oxide, 8% sodium oxide, 8% potassium oxide and 1% calcium oxide are used in the manufacture of borosilicate glass. Borosilicate crown glass (BK7) is an optical material used in a large fraction OPTICS products. It is relatively hard glass, doesn't scratch easily. Another important feature of BK7 is very good transmission down to 350 nm. Due to these properties, BK7 are widely used in the optics industry.

In this paper , we proposed two layer cladding PCF characterized by a common air hole space (pitch) and two different air hole diameters. The structure can ensure flat dispersion in a wide wavelength range and simple than the existing designs.

II. Equations

In this paper, two main properties of PCF are discussed. First Effective refractive index and second dispersion.
Effective mode index (n_{eff}) can be obtained as –

$$n_{eff} = \beta/k_0 \qquad (1)$$

here, β is the propagation constant and $k_0 = 2\pi/\lambda$. Where λ is the operating wavelength.
Total dispersion $D_T = D_W + D_M$
Here, D_W is waveguide dispersion and D_M is material dispersion. The waveguide dispersion is defined as-

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

C is the velocity of light [25] .
The material dispersion given by sellemier formula

$$n - 1 = \sum\left(\frac{}{\lambda-\lambda_i}\right) \qquad (3)$$

A. *Review Stage*

Submit your manuscript electronically for review.

Manuscript received December 19, 2013.

Naveen Kumar Jain, EC E Department, Rajathan Technical University/ Geetanjali Institute of Technical Studies, Udaipur, India, 9414549216
Ravindra Kumar Sharm,a, EC E Department, Rajathan Technical University,Kota ,India.
Anurag Paliwal, ECE Department, Geetanjali Institute of Technical Studies, Udaipur, India, 9799036175

B. *Final Stage*

When you submit your final version, after your paper has been accepted, prepare it in two-column format, including figures and tables.

C. *Figures*

As said, to insert images in *Word,* position the cursor at the insertion point and either use Insert | Picture | From File or copy the image to the Windows clipboard and then Edit | Paste Special | Picture (with "Float over text" unchecked).

The authors of the accepted manuscripts will be given a copyright form and the form should accompany your final submission.

III. Design Principle and Simulation Results

Figure 1. shows the proposed PCF. The inner three layer of cladding is composed of a common air hole pitch ∧ and diameter d_1 and outer three layer of cladding is composed diameter d_2, where d_1 is less than d_2. To achieve larger mode area we design the air holes of inner rings are chosen smaller. We have investigated the dispersion for different air hole diameter of inner and outer ring.

The wafer chosen is of Borosilicate crown glass with 1.5168 refractive index and the air hole refractive index is 1.0. In figure 1 we have change the inner and outer ring air hole diameter.

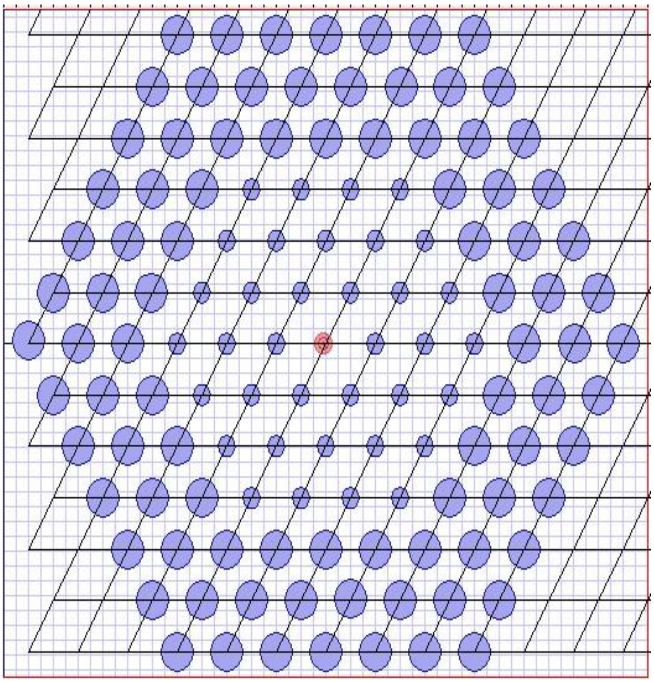


Figure 1. Proposed PCF.

Structure Parameter (when pitch and layer constant):

1. $d_1 = 0.5$ µm, $\wedge = 2.0$ µm and $d_2 = 1.5$ µm
2. $d_1 = 0.6$ µm, $\wedge = 2.0$ µm and $d_2 = 1.4$ µm
3. $d_1 = 0.7$ µm, $\wedge = 2.0$ µm and $d_2 = 1.3$ µm
4. $d_1 = 0.8$ µm, $\wedge = 2.0$ µm and $d_2 = 1.2$ µm

In this paper, we proposed two layer cladding PCF characterized by a common air hole space (pitch) and two different air hole diameters. The structure can ensure flat dispersion in a wide wavelength range and simple than the existing designs.

The effective refractive index difference is increased between proposed PCF and conventional PCF.

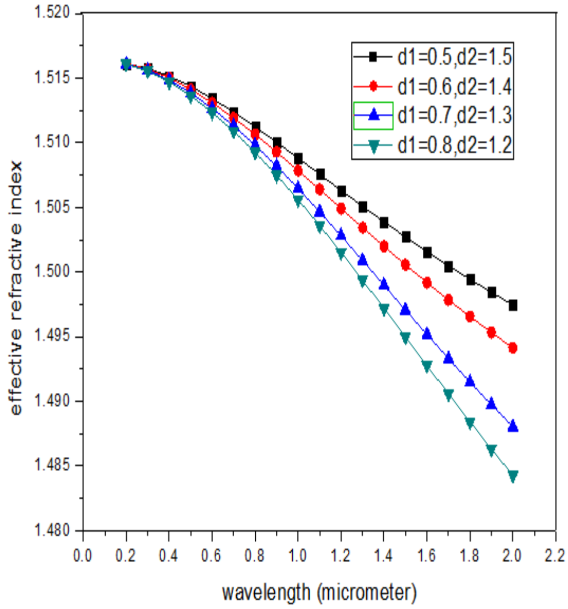


Figure 2. Shows the difference between effective refractive index of conventional PCF and Proposed PCF.

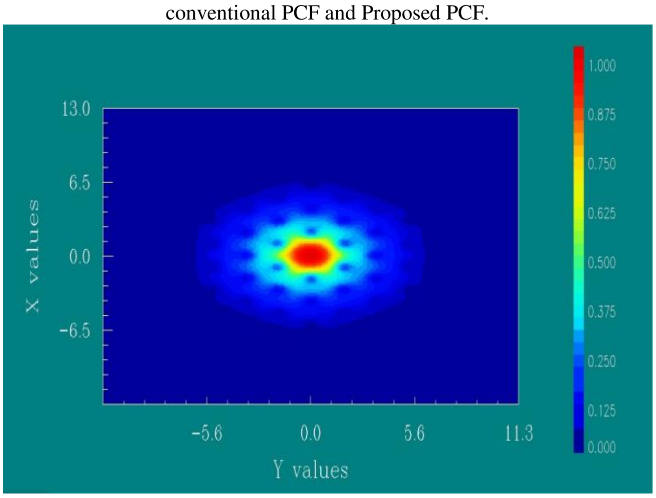


Figure 3. Shows mode field pattern of proposed PCF.

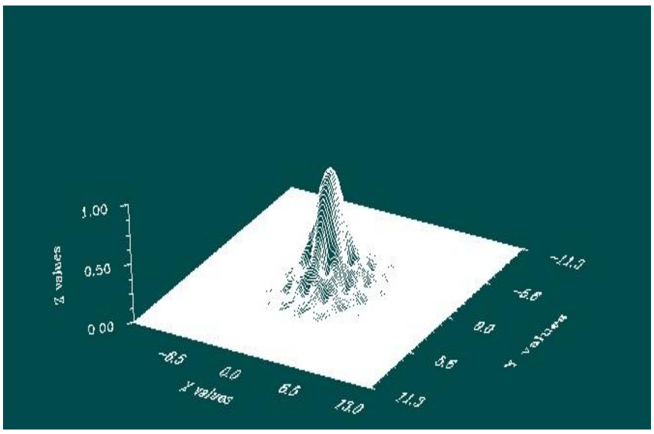


Figure 4. 3-D mode field pattern of proposed PCF.

The wafer is designed for width 26 µm and thickness 22.5166 micrometer.

Material dispersion is always unchanged for any structure (hexagonal or square). It is also independent of structure parameter as air hole diameter ‘d’ and pitch ‘ʌ’.

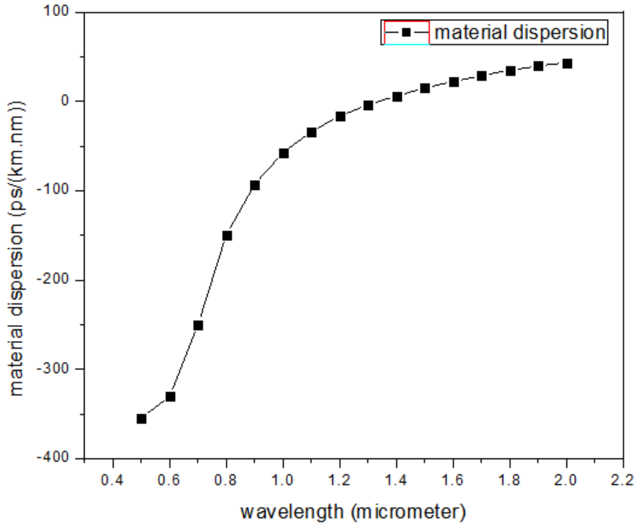


Figure 5. Material dispersion of Borosilicate crown glass PCF.

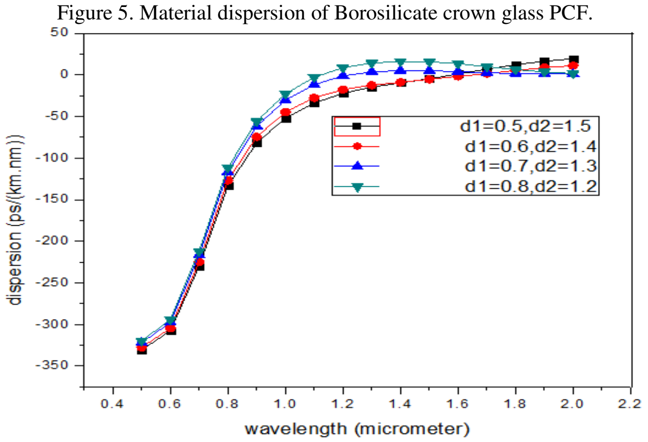


Figure 6. Chromatic dispersion of the proposed PCF for different values of the air hole diameters d_1 and d_2 when air hole spacing ‘ʌ’ = 2.0 µm.

Structure Parameter (when air hole diameter and layer constant):

d_1 = 0.7 µm, d_2 = 1.3 µm and 6 layer PCF

1. Pitch = 1.5µm
2. Pitch = 2.0µm
3. Pitch = 2.5µm

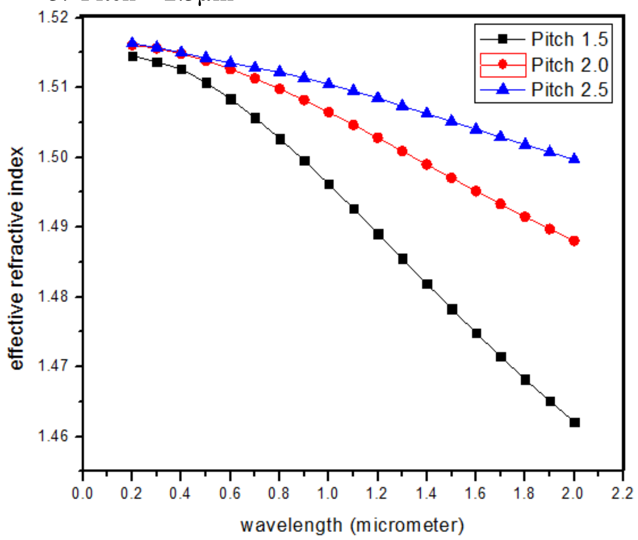


Figure 7. Shows the difference between effective refractive index of conventional PCF and Proposed PCF.

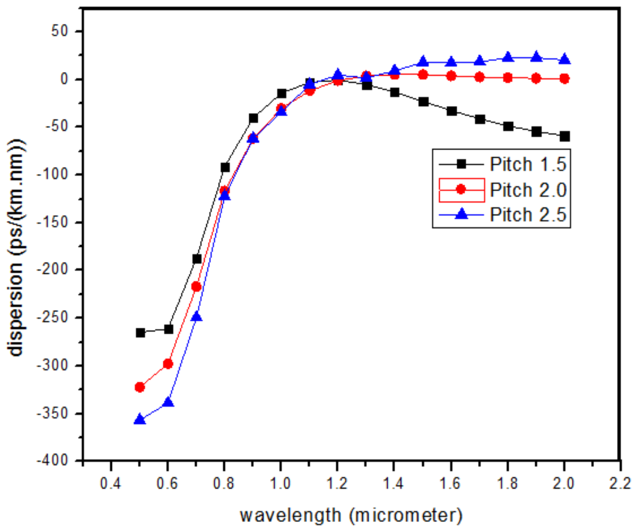
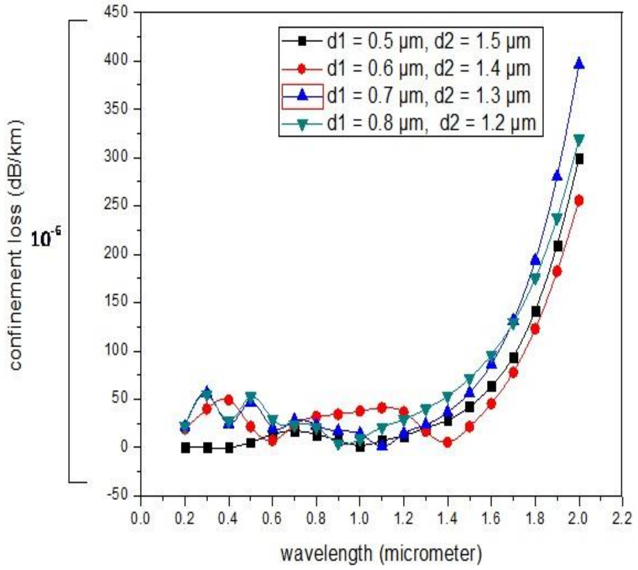


Figure 8. Chromatic dispersion of the proposed PCF for different values of Pitch when air hole diameter and layer of PCF is constant



The proposed Borosilicate crown glass PCF makes almost flat dispersion.

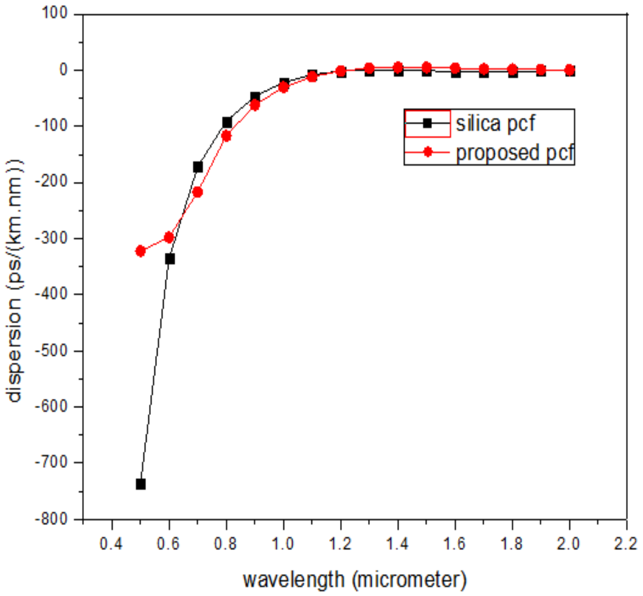


Figure 9. Shows the chromatic dispersion of proposed Borosilicate crown glass PCF and silica glass PCF when pitch ‘ʌ’ = 2.0 µm, d_1 = 0.7 µm and d_2 = 1.3 µm.

IV. Conclusion

The above results indicate that the proposed Borosilicate crown glass PCF has almost zero and flat dispersion in low wavelength range as silica glass PCF. But Borosilicate crown glass has good properties (like cheaper, good transmission, easy availability) compare to silica glass. So we can use Borosilicate crown glass as a core material on the place of silica glass. Borosilicate crown glass can substitute of silica glass.

References

[1] E. Yablonovitch, Phys. Rev. Lett. 58, 1987, pp 2059.
[2] J.C. Knight, T.A. Birks, P.St. J. Russell, D.M. Atkin, Opt. Lett. 21, 1996, pp 1547.
[3] Razzak S.M.A, Namihira Y, Begum F., " Ultra flattened dispersion photonic crystal fiber", Electronics Letters 43(11), 2007, pp 615- 617.
[4] 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, 2008, pp 2716- 2718.
[5] 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, pp 1644- 1651.
[6] Ferrando A, E. Silvestre, J.J. Miret and P. Andres, " Nearly zero ultraflattened dispersion in photonic crystal fibers", Opt. Lett, Vol. 25, 2000, pp 790- 792.
[7] Ferrando A, E. Silvestre, P. Andres, J. Miret and M. Andres, " Designing the properties of dispersion flattened photonic crystal fibers", Opt. Express, Vol. 9, 2001, pp 687- 697.
[8] Saitoh K, M. Koshiba, T. Hasegawa and E. Sasaoka, " Chromatic dispersion control in photonic crystal fibers : Application to ultra flattened dispersion", Opt. Express, vol. 11, 2003, pp 843- 852.
[9] Poletti F, V. Finazzi , T.M. Monro , N.G.R. Broderick, V. Tsc and D.J. Richardson, " Inverse design and fabrication tolerences of ultra flattened dispersion holey fibers", Opt. Express, vol. 13, 2005, pp 3728- 3736.
[10] 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, pp 627- 635.
[11] Saitoh K and M. Koshiba, " Single polarization single mode photonic crystal fibers", IEEE Photon Technol. Lett, Vol. 15, 2003, pp 1384- 1391.
[12] 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.
[13] Dobb. H, K. Kalli and D.J. Webb, " Temperature insensitive long period gratting sensors in photonics crystal fiber", Electron. Lett, Vol. 40, 2004, pp 657- 658.
[14] 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.
[15] Wadsworth. W.J, J.C. Knight, H.H. Reewes, P.S.J. Russell and J. Arriaga, " Yb^{3+} doped photonic crystal fiber laser", Electron Lett, Vol. 36, 2000, pp 1452- 1453.
[16] 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, Vol. 17, 2005, pp 1626- 1628.
[17] Hansen T.P, J. Broeng, S.E.B. Libori, E. Knudsen, A. Bjarklev, J.R. Jonson and H. Simonson, " Highly birefringent index guiding photonic crystal fibers", IEEE Photon. Technol. Lett, Vol. 13, 2001, pp 588- 590.
[18] Sapulak M, G. Statkiewicz, J. Olszewski, T. Martynkine, W. Urbanczyk, J. Wojcik, M. Makara, J. Klimek, T. Nasilowski, F. Berghmans and H. Thienpont, " Experimental and theoretical investigations of birefringent holey fibers with a triple defect", Appl. Opt., Vol. 44, 2005, pp 2652- 2658.
[19] Anthkowia K.M, R. Kotynski, T. Nasilowski, P. Lesiak, J. Wojcik, W. Urbanczyk, F. Berghmans, and H. Thienpont, " Phase and group modal birefringence of triple defect photonic crystal fibers", J. Opt. A. Pure Appl. Opt, vol. 7, 2005, pp 763- 766.
[20] Chen D and L. Shen, " Highly birefringent elliptical hole photonic crystal fibers with double defect", J. Light. Technol, vol. 25, 2007, pp 2700- 2705.
[21] G.P. Agarwal, " Nonlinear fiber optics", third ed., Academic press, New York, 1995.
[22] Bhawana Dabas, R.K. Sinha, " Dispersion characteristics of hexagonal and square lattic chalcogenide As2Se3 glass PCF", Opt. Comm, 2010, pp 1331- 1337.
[23] G. Boudebs, S. Cherokulappurath, M. Guignard, J. Troler, F. Smektola and F. Sanchez, " Linear optical characterization of chalcogenide glasses", Opt. Comm, 2004, pp 331- 336.
[24] G. Boudebsetal, Opt. Commun. 230(2004), pp 331.
[25] Ferrando A, Silvestre E, Andere's P, Miret J.J, Ander's MV, " Designing the properties of dispersion flattened photonic crystal fibers", Opt. Exp., 2001, pp 687.
[26] www.makeitfrom.com/material-data