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Low-Flattened Dispersion Hexagonal Photonic Crystal Fiber With Low Confinement Loss

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***Abstract*-- In this paper, a new photonic crystal fiber (PCF) with low and flattened dispersion and low confinement loss at wide wavelength range is presented. Significant improvement of PCFs it term of chromatic dispersion and confinement loss are presented by careful selection of dimension of air holes and spacing between adjacent air holes. To analyse this PCF, finite-difference time domain (FDTD) with perfectly matched boundary condition is used. After optimizing these parameters finally we observe that we reduce the chromatic dispersion to 16.71536ps/nm-km and confinement loss to 0.001059dB/km at 1.5µm wavelength which can be utilised for broadband optical communication applications.**

***Keywords*-- Chromatic dispersion, confinement loss, finite-difference time domain (FDTD), Photonic crystal fibers (PCFs), total internal reflection.**

I. INTRODUCTION

Dispersion control in optical fiber at a wide spectral range is a major issue in high bit rate wavelength division multiplexing (WDM) optical communication systems [1-2]. At present, several hundreds of Gbps based WDM transmission systems are being successfully presented in the fields of optical transmission [2]. The intersymbol interference (ISI) between adjacent bits in transmission channel can occur by the linearly accumulated dispersion along the transmission fiber, which can affect the communication system quality [2]. Waveguide and Chromatic dispersion management in optical fibers design are largely divided into three categories: dispersion flattened fiber (DFF), non-zero dispersion shifted fiber (NZDSF), and dispersion compensating fiber (DCF), which require specific waveguide designs different from standard single mode fiber (SSMF) [3–5].

In recent years, the photonic crystal fibers (PCFs) are investigated to explore their potential in the dispersion control as an alternative to conventional solid core/cladding optical fibers [6–11]. The PCFs are new type of fibers are also called as holey or micro-structured fibers. The cladding of PCF is two dimensional photonic crystal consisting of air holes that run along the length of fiber, thus their unique holey cladding structures, these are attractive for the dispersion control by varying structural parameters such as the air hole diameter d, the hole-to-hole spacing or pitch Λ, and arrangements of air holes. In pure silica PCFs, the effective refractive index can be controlled by varying the air hole diameter such that a layer of air holes with a smaller or larger diameter or by selecting elliptical shape.

Flattened near-zero dispersion over a broad spectral range was recently reported in a PCF using a similar technique with five air-hole rings with different diameters in the hexagonal arrangement [6]. Despite notable dispersion characteristics in prior theoretical predictions, such PCFs have not been successfully fabricated due to their strict requirements meticulous control and maintenance of the whole geometry with a very low tolerance. Recently the researchers have proposed a new method to control the guiding properties of hexagonal PCF by introducing hollow ring defects [12–14]. These were adopted from the hollow optical fiber structure that consists of a central air hole, a high index ring core, and a silica cladding [15- 16]. In this paper, we further explore the potential in a triangular lattice photonic crystal fiber to provide a new method to flexibly control the chromatic dispersion characteristics and confinement loss characteristics of PCFs.

II. ANALYSIS METHOD

Effective mode index of a guided mode for a given wavelength is obtained by solving an Eigen value problem drawn from Maxwell's equations using the FDTD. Effective mode index is a complex value has both real and imaginary parts. The effective mode index, n_{eff}, can be obtained as [14]

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

Here, β is the propagation constant and k_o is the free space wave number.

Dispersion is a general term which is use to describe the phenomenon that causes pulses to spread while propagating. It severely limits the transmission capacity of the system. Total dispersion or chromatic dispersion D consists of two components [6-9]: material dispersion D_m and waveguide dispersion D_w.

$$D = D_m + D_w \qquad (2)$$

Control of the chromatic dispersion in PCFs is essential for practical applications in optical communication systems, dispersion compensation and linear/nonlinear optics. The Waveguide dispersion Dm of the PCF is obtained from the n_{eff} values against the wavelength [6-9] using

$$D = -\frac{\lambda}{c}\frac{\partial^2 Re(n_{eff})}{\partial \lambda^2} \qquad (3)$$

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Where c is the velocity of light and 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. The material dispersion given by Sellmeier's formula [17] is directly included in the calculation.

Confinement loss or leakage loss is due to the finite air holes in cladding. The confinement loss is calculated from the imaginary part (Im) of the complex effective mode indexn_{eff}, using the following equation [11-13]:

$$Conf.Loss = \frac{40\pi}{\ln(10)\,\lambda} Im(n_{eff}) =$$

$$8.686k_0 Im(n_{eff}) \left[\frac{dB}{m}\right] \quad (4)$$

Through the use of best design parameters, the proposed PCFs offer low flattened dispersion and very low confinement loss in a wide wavelength range. Finite-difference time-domain (FDTD) method has been employed for simulation work.

III. Design Parameter

The proposed PCF have five air holes rings in cladding with solid core. Where the each air holes of first two rings are in elliptical shape with major axis (a) equal to 0.4µm and minor axis (b) equal to 0.3µm. The outer three rings in proposed design are identical having the diameter (d2) of 1.4µm.The spacing between the adjacent air holes or pitch, Λ is equals to 2.3µm. The lattice structure for the proposed PCF is triangular or hexagonal. The transverse cross section for proposed PCF is shown in figure-1

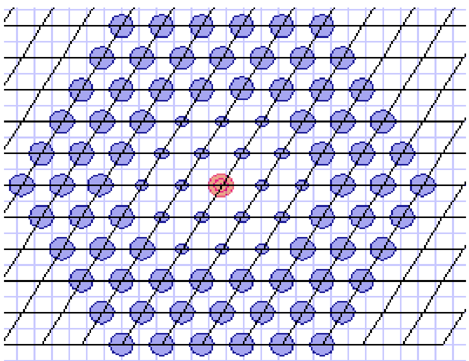

Figure1- Cross section of proposed PCF with inner two rings are elliptical with major axis a=0.4µm, minor axis b=0.3µm, diameter of outer three rings are d2=1.4µm and pitch, Λ=2.3µm.

Now, the dimension of air holes rings and the spacing between air holes are varied to study the dispersion and confinement loss properties of PCF.

IV. Simulation Result

Case 1- In this case we study the effect of altering the dimension of inner two air hole rings on dispersion and confinement loss. Thus the initial value of this case is considered as diameter of air holes in outer three rings d2= 1.4µm, pitch Λ=2.3µm and dimension of air holes in inner two rings with elliptical shapes is considered as a=0.4 b=0.3, a=0.4 b=0.2, and a=0.4 b=0.1 i.e. we are increasing the ellpticity of air holes. Figure-2 shows the dependence of real part of effective mode index solving by the Eigen value drawn from the Maxwell's equation using the FDTD simulation tool on wavelength.

Thus from figure-2 below it can be observed that real part of effective mode index decrease with the increase in wavelength and increase with increasing the ellpticity of air holes.

Figure-3 shows the variation in chromatic dispersion with wavelength in range from 0.7µm to 2.0µm. From this it is observed that increasing the ellpticity shifts the dispersion toward the lower value i.e. below the zero dispersion for lower wavelength but it shifts upward i.e. above zero dispersion for the higher wavelength. From our observation it is observed that the value of chromatic dispersion for these three variation a=0.4 b=0.3, a=0.4 b=0.2 and a=0.4 b=0.1 are 27.54233ps/nm-km, 16.10554ps/nm-km and 20.3355ps/nm-km respectively at 1.5µm wavelength.

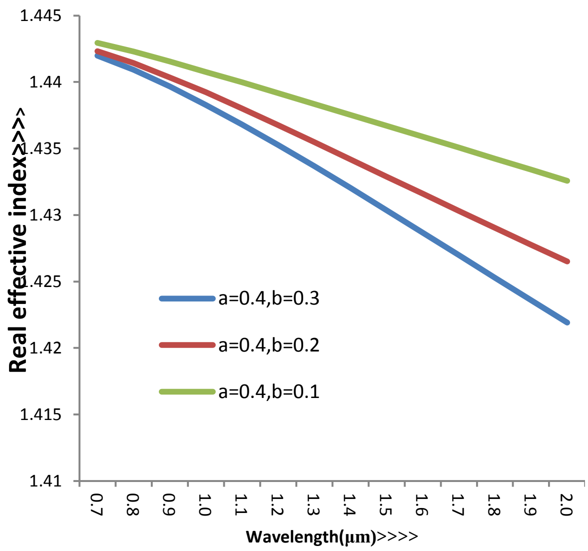

Figure2- Real part of effective mode index dependence on wavelength

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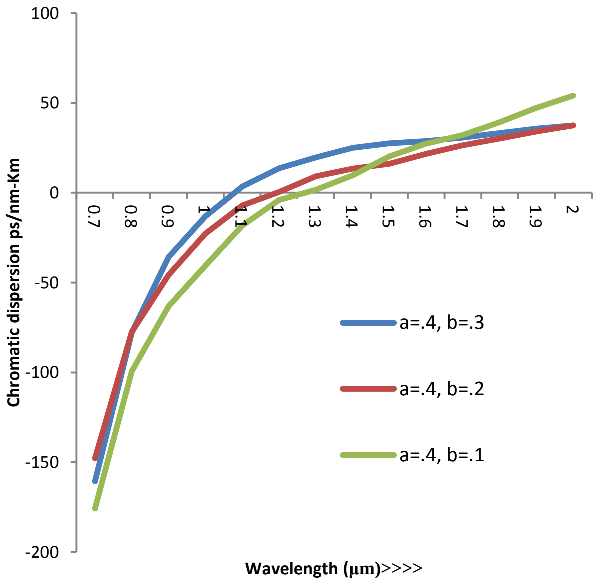

Figure3- Chromatic dispersion variations with wavelength for d2=1.4µm and Λ=2.3µm.

Figure-4 below shows the confinement loss variation with respect to wavelength with altering the dimension of inner two air hole rings .From this it can be observed that confinement loss decrease with increasing the ellpticity of air holes. The confinement loss for these three variations is 0.010185dB/Km, 0.008002dB/Km and 0.004365dB/Km respectively at 1.5µm wavelength. Thus from this study of case-1 it can be observed that ellpticity with a=0.4 and b=0.2 gives the lowest chromatic dispersion and lowest confinement loss among these three variation, and the variation of dimension of inner rings have more effect on dispersion and have less impact on confinement loss.

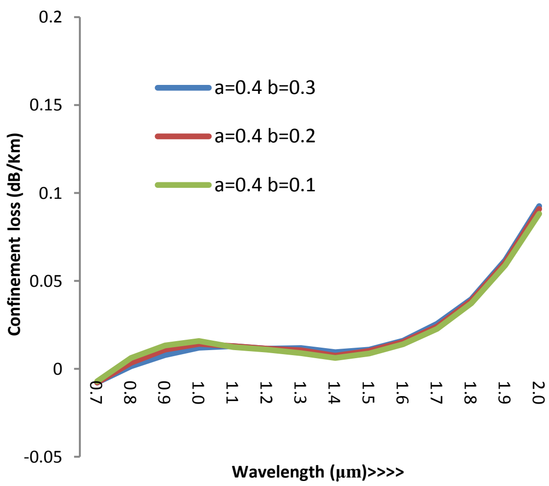

Figure4- Confinement loss variations with wavelength for d2=1.4µm and Λ=2.3µm.

But, since we have the application of WDM to enhance the capacity of communication channel we want low and flattened dispersion profile, so among these three variation most flattened chromatic dispersion is given with the parameter a=0.4µm and b=0.3µm. Thus from figure-3 it is observe that value of chromatic dispersion is almost flattened from wavelength range 1.2µm to 1.8µm with a=0.4 and b=0.3. Value of confinement loss is very low with this parameter.

Case-2, In this case we will study the effect of altering the value diameter of outer three air holes ring on dispersion and confinement loss. So in this case we will consider value of d2 as 1.2µm, 1.4µm and 1.6µm while taking the value of pitch Λ=2.3µm and ellpticity of inner two rings with major axis a=0.4µm and minor axis b=0.3µm.

Figure-5 below shows the chromatic dispersion variation with the wavelength range from 0.7µm to 2.0µm. Thus from this it is observed that value of chromatic dispersion for d2=1.2µm, 1.4µm and 1.6µm is 26.62424ps/nm-km, 27.54233ps/nm-km and 28.33045ps/nm-km respectively at 1.5µm wavelength. Thus it shows that dispersion increase significantly with increasing the diameter of outer air hole rings.

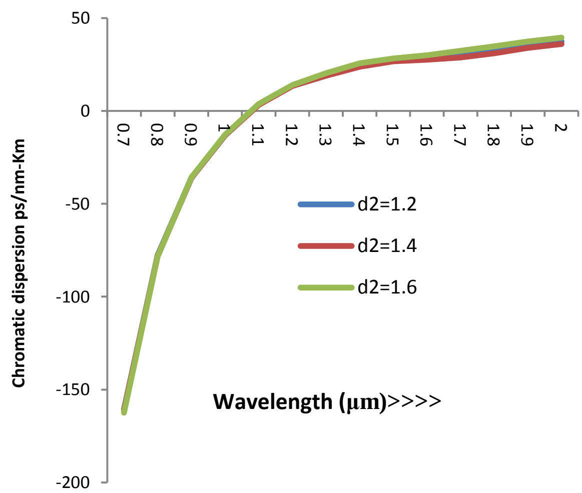

Figure5- Chromatic dispersion variations with wavelength for a=0.4µm, b=0.3µm and Λ=2.3µm.

Figure-6 below shows the variation of confinement loss with wavelength on altering the diameter d2. Thus from this it is observed that confinement loss for d2=1.2µm, 1.4µm and 1.6µm are 0.012012db/km, 0.01018db/km and 0.00873db/km respectively. Which show that confinement loss decrease with increasing the diameter of outer air holes d2. Thus from the study of second case of altering the dimension of outer air holes, it is observed that here is less variations in the value of chromatic dispersion but have large effect on confinement loss compare to first case of varying inner rings dimension.

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Thus considering both dispersion and confinement loss we will take the value of d2=1.4µm.

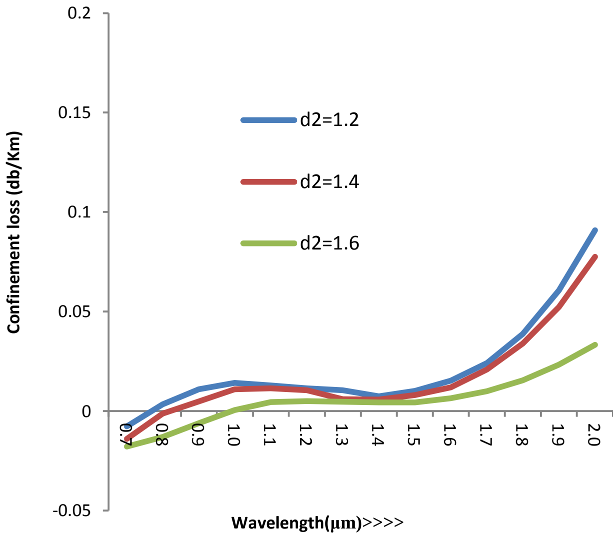

Figure6- Confinement loss variations with wavelength for a=0.4µm, b=0.3µm and Λ=2.3µm.

Case-3- in this case we will study the effect of changing the spacing of air holes or pitch. Here we will take the value of pitch 2.1µm, 2.2µm, 2,3µm and 2.4µm to see the effect on dispersion and confinement loss. Figure-7and Figure-8 shows the variation in chromatic dispersion and confinement loss respectively. . From this it can be observed that the chromatic dispersion shifts upward with increasing the spacing between air holes. It gives the dispersion are 25.85435ps/nm-km, 26.04542ps/nm-km, 27.54233ps/nm-km and 28.45545ps/nm-km with increasing value of pitch as in figure at 1.5µm wavelength.

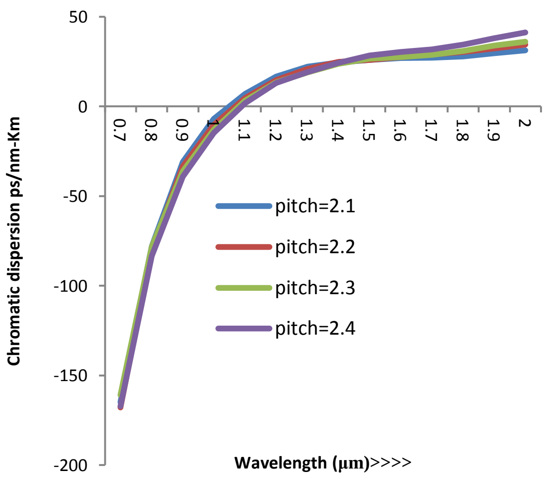

Figure7- Chromatic dispersion variations with wavelength for inner two rings dimension a=0.4µm, b=0.3µm and d2=1.4µm.

Figure-8, below shows that confinement loss increases with decreasing the spacing between air holes or pitch.

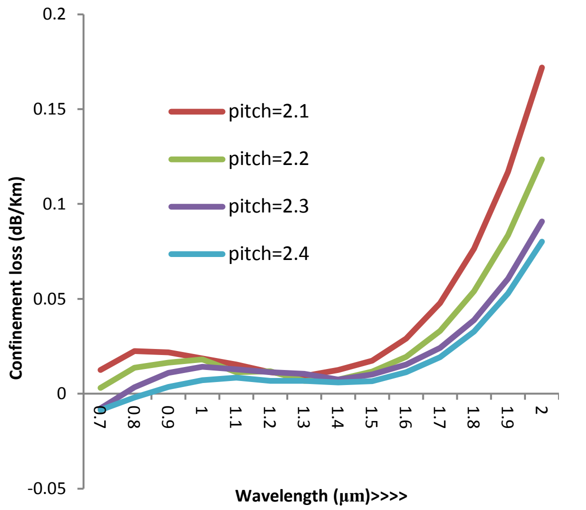

Figure8- Chromatic dispersion variations with wavelength for inner two rings dimension a=0.4µm, b=0.3µm and Λ=2.3µm.

Thus from figure-7 and Figure-8 it is seen that there is trade-off between the dispersion and confinement loss. Thus considering both dispersion and confinement in mind we will go with the parameter are d2=1.4µm, pitch=2.1µm and dimension of inner two rings are elliptical with major axis a=0.4µm and minor axis b=0.3µm. Thus from these parameter result we observed a low flattened dispersion in the wavelength range of 1.2µm to 1.7µm.and very low confinement loss. It gives a chromatic dispersion 25.85435ps/nm-km and confinement loss 0.01163dB/km at 1.5µm wavelength, which is mostly use telecom wavelength for optical communication.

Case-4- In this case we optimize our result with a new design with above parameter. The cross section of this proposed design is shown in figure-9 below.

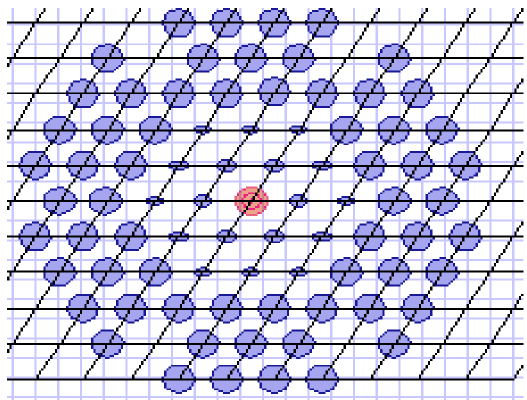

Figure9- Cross section of a new proposed design with first inner ring dimension a=0.4µm, b=0.3µm and for second inner ring is a=0.4µm, b=0.2µm, and diameter of outer three rings d2=1.4µm and pitch, Λ=2.1µm.

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In this design the ellpticity of inner first ring is same as above with a=0.4µm and b=0.3µm but here we change the ellpticity of inner second ring with a=0.4µm and b=0.2µm i.e. we increase the ellpticity of second air holes ring to minimize the dispersion considering the study of above case. The diameter of outer three rings is same d2=1.4µm, pitch is 2.3µm and other change as shown in figure-9 below.

Figure-10, Figure-11 and Figure-12 show the waveguide dispersion, chromatic dispersion and confinement loss dependence on wavelength. Thus from figure-10 it can be observed that waveguide dispersion decrease with increase in wavelength. It shows that waveguide dispersion is -1.28463ps/nm-km at 1.5µm wavelength. Figure-11 shows a low and flattened dispersion in the wavelength range of 1.3µm to 1.8µm range and the value of chromatic dispersion is 16.71536ps/nm-km at 1.5µm wavelength, which is very low and more flattened compare to design proposed first.

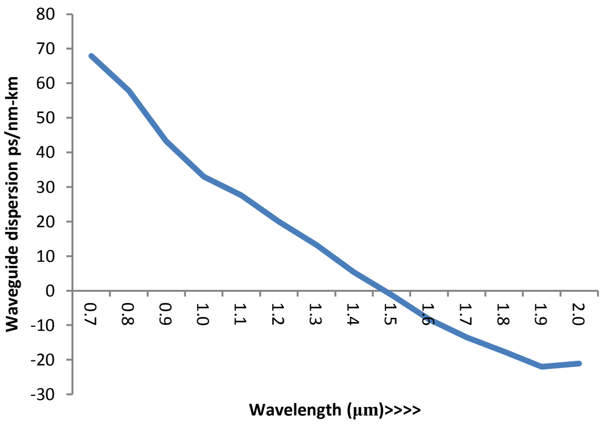

Figure10- Waveguide dispersion variation with wavelength.

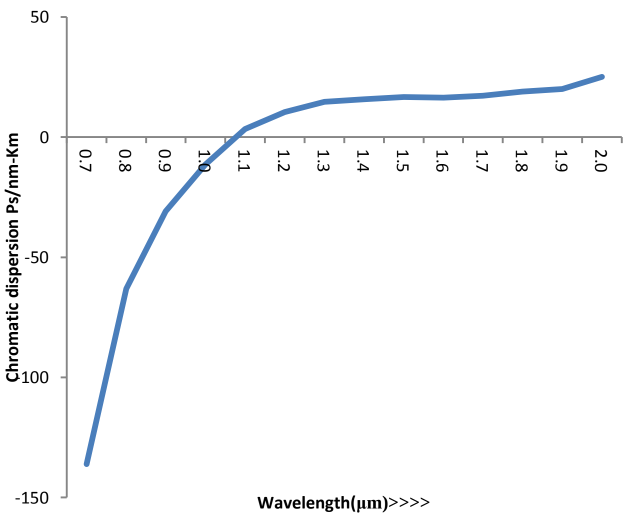

FIgure11- Chromatic dispersion variation with wavelength

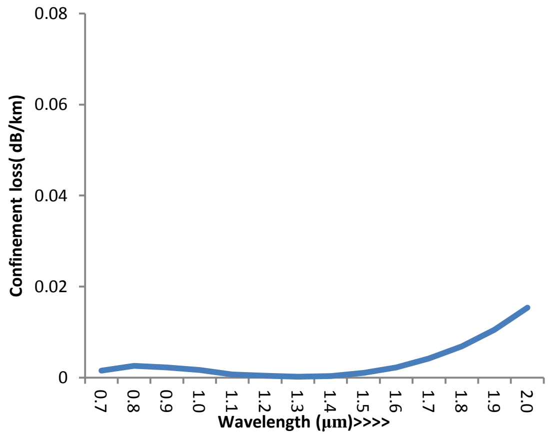

Figure12- Confinement variation with wavelength

Figure-12 shows the confinement loss variation with wavelength. This shows a very low confinement or leakage loss compare to design proposed first. It shows a very low confinement loss of 0.001059db/Km at 1.5µm wavelength.

Thus from our result we can use proposed design in case-4 for optical communication because it show a low and flattened dispersion and low confinement loss for a wide wavelength range.

V. CONCLUSION

The proposed PCF gives a good performance in term of chromatic dispersion and confinement loss. The motivation behind this paper is to optimize the design parameter of PCF to gain low-flattened chromatic dispersion and low confinement loss at wide wavelength range. Thus in this paper, a new design of PCF having low-flattened chromatic dispersion and low confinement loss in wide wavelength range is demonstrated by carefully adjusting the air holes in each rings, air holes dimensions and spacing between air holes or pitch. The proposed design is exceptionally practical for use in optical communication domain.

REFERENCES

[1] F. M. Madani and K. Kikuchi, "Design theory of long-distance WDM dispersion-managed transmission system," J. Lightwave Technol. **17**(8), 1326–1335 (1999).

[2] M. Bass and E. W. V. Stryland, Fiber Optics Handbook: Fiber, Devices, and Systems for Optical Communications (McGraw-Hill, 2002), Chap. 13.

[3] S. Yin, K. Chung, H. Liu, P. Kurtz, and K. Reichard, "A new design for non-zero dispersion-shifted fiber (NZDSF) with a large effective area over 100µm2 and low bending and splice loss," Opt. Commun. **177**(1-6), 225–232 (2000).

[4] R. Lundin, "Dispersion flattening in a W fiber," Appl. Opt. **33**(6), 1011–1014 (1994).5. L. Gruner-Nielsen, S. N. Knudsen, B. Edvold, T. Veng, D. Magnussen, C. C. Larsen, and H. Damsgaard, "Dispersion compensating fibers," Opt. Fiber Technol. (2), 164–180 (2000).

[5] Uddin, M.J., Alam,'Dispersion and confinement of photonic crystal fibers', Asian J .inf. Technol. 2008. 7. P-344

[6] K. Saitoh, M. Koshiba, T. Hasegawa, and E. Sasaoka, "Chromatic dispersion control in photonic crystal fibers: application to ultra-flattened dispersion," Opt. Express **11**(8), 843–852 (2003).

[7] F. Poli, A. Cucinotta, M. Fuochi, S. Selleri, and L. Vincetti, "Characterization of microstructured optical fibers for wideband dispersion compensation," J. Opt. Soc. Am. A **20**(10), 1958–1962 (2003).

[8] F. Begum, Y. Namihira, T. Kinjo, and S. Kaijage, "Supercontinuum generation in square photonic crystal fiber with nearly zero ultra-flattened chromatic dispersion and fabrication tolerance analysis," Opt. Commun. **284**(4), 965–970 (2011).

[9] F. Begum, Y. Namihira, S. M. A. Razzak, S. F. Kaijage, N. H. Hai, K. Miyagi, H. Higa, and N. Zou, "Flattened chromatic dispersion in square photonic crystal fibers with low confinement losses," Opt. Rev. **16**(2), 54–58 (2009).

[10] G. Renversez, B. Kuhlmey, and R. McPhedran, "Dispersion management with microstructured optical fibers: ultraflattened chromatic dispersion with low losses," Opt. Lett. **28**(12), 989–991 (2003).

[11] F. Gérôme, J.-L.Auguste, and J.-M. Blondy,"Design of dispersion-compensating fibers based on a dualconcentric- core photonic crystal fiber," Opt. Lett. **29**(23), 2725–2727.

[12] S. Kim, Y. Jung, K. Oh, J. Kobelke, K. Schuster, and J. Kirchhof, "Defect and lattice structure for air-silica index-guiding holey fibers," Opt. Lett. **31**(2), 164–166 (2006).

[13] J. Park, S. Lee, S. Kim, and K. Oh, "Enhancement of chemical sensing capability in a photonic crystal fiber with a hollow high index ring defect at the center," Opt. Express **19**(3), 1921–1929 (2011).

[14] T. Grujic, B. T. Kuhlmey, A. Argyros, S. Coen, and C. M. de Sterke, "Solid-core fiber with ultra-wide bandwidth transmission window due to inhibited coupling," Opt. Express **18**(25), 25556–25566 (2010).

[15] K. Oh, S. Choi, Y. Jung, and J. W. Lee, "Novel hollow optical fibers and their applications in photonic devices for optical communications," J. Lightwave Technol. **23**(2), 524–532 (2005).

[16] S. Lee, J. Park, Y. Jeong, and K. Oh, "Guided wave analysis of hollow optical fiber for mode coupling device applications," J. Lightwave Technol. **27**(22), 4919–4926, 09

[17] Agrawal, G. P., Nonlinear Fiber Optics, 4th edition, Academic Press, Boston, 2007