Journal of Multidisciplinary Engineering Science and Technology (JMEST)
ISSN: 2458-9403
Vol. 3 Issue 10, October - 2016

Large Negative Dispersion Ultraflattened Hybrid Photonic Crystal Fiber for Residual Dispersion Compensation Over 750 nm Bandwidth

[1]Md Asaduzzaman Shobug
Department of Electrical and Electronic Engineering
Pabna University of Science & Technology (PUST)
Pabna, Bangladesh-6600
sabs.ruet@gmail.com

[2]Emran Khandker
Department of Electrical and Electronic Engineering
Rajshahi University of Engineering & Technology (RUET)
Rajshahi, Bangladesh-6204
mitulkdr@gmail.com

***Abstract*— A hybrid photonic crystal fiber (HyPCF) is numerically investigated for the purpose of compensating residual chromatic dispersion, which may be used in a wavelength-division-multiplexing optical fiber transmission system, in the wavelength range of 1250-2000 nm. The designed fiber exhibits average negative dispersion of –110.21 ps/nm/km with an absolute dispersion variation of 1.49 ps/nm/km over 750 nm bandwidth. The guiding characteristics are investigated using an efficient finite element method with perfectly matched layers.**

***Keywords*— photonic crystal fiber; residual dispersion; ultraflattened large negative dispersion**

A. Introduction

Photonic Crystal Fibers (PCFs) [1] consist of microstructure air-holes around a solid un-doped core in which light is guided by total internal reflection. The properties like dispersion, birefringence, confinement loss, nonlinearity etc. of PCFs can be controlled by tailoring the geometrical structure of cladding & core. Among the properties of PCF, chromatic dispersion is the most important one for fiber optic communication application. Long-haul transmission systems require single mode optical fibers (SMFs) with nonzero chromatic dispersion to avoid nonlinear interactions like crosstalk and information loss [2]. The SMFs have anomalous dispersion from 10 to 20 ps/nm/km. So, this anomalous dispersion is needed to be suppressed and can be done by including a dispersion-compensating fiber (DCF) of short length with a large negative dispersion in the optical link [3]-[5]. This dispersion compensating technique has been studied by many research groups and several papers have been published on this topic. A flat negative dispersion coefficient of about −98.3 ps/nm/km with absolute dispersion variation (ΔD) of 1.1 ps/nm/km was proposed over S + C+ L wavelength band in [6]. A PCF which exhibits ultraflattened negative dispersion over S + C + L + U wavelength bands and average dispersion of about −179 ps/nm/km with an absolute dispersion variation of 2.1 ps/nm/km was proposed in [3]. The design shown in [4] describes flat negative dispersion of –212 ps/nm/km with a flat variation of 11 ps/nm/km over E + S + C + L + U wavelength bands in which the core is Ge-doped. Recently, a Negative dispersion coefficient of –227 ps/nm/km with absolute dispersion variation of about 8.6 ps/nm/km has been obtained over E + S + C + L + U bands using equiangular spiral photonic crystal fiber styles are shown in [5]. The improvement of this work was described in [7] with negative dispersion of –393 ps/nm/km with a variation of 10.4 ps/nm/km. More recently, a photonic crystal fiber in photonic crystal fiber has been proposed which ensure highest average negative dispersion to date having average dispersion of –457.4 ps/nm/km over E + S + C + L + U wavelength bands [8]. All the designs mentioned above have obtained dispersion profile within the wavelength range from 1360 nm to 1690 nm. Again, the minimum variation of dispersion of the reported designs is about 2.1 ps/nm/km. The designs of [4,5,7,8] have complex structures and are very difficult to fabricate using conventional stake-and-draw method.

In this paper, a hybrid photonic crystal fiber is proposed that exhibits average negative dispersion of –110.21 ps/nm/km with dispersion variation of only 1.49 ps/nm/km. The dispersion profile is achieved in the broad wavelength range of 1260-2000 nm which is much broader than the previous designs. The proposed geometry is much simpler and can be fabricated easily using conventional stake-and-draw method.

B. HyPCF design

The cross sectional view of the proposed residual dispersion compensating fiber (RDCF) with optimized air-hole diameters d_1, d_2, d_3 pitch Λ is shown in *Fig. 1*. The designed structure is a combination of four hexagonal inner rings and three octagonal outer rings. The proposed design is similar to [9] but modified cladding leads to a very distinct dispersion characteristics. The hexagonal structure is best for dispersion controlling and octagonal structure is well known for confinement loss controlling [10]. As the octagonal structure has isosceles triangular lattices, it has more air-hole rings in the cladding region in contrast to hexagonal PCF (H-PCF). This results in a higher air-filling ratio and a lower refractive index around the core, thus providing strong confinement ability and low confinement losses. The diameters of the hexagonal rings have been tailored very carefully to obtain large negative dispersion with a very small variation in the wavelength range of 750 nm.

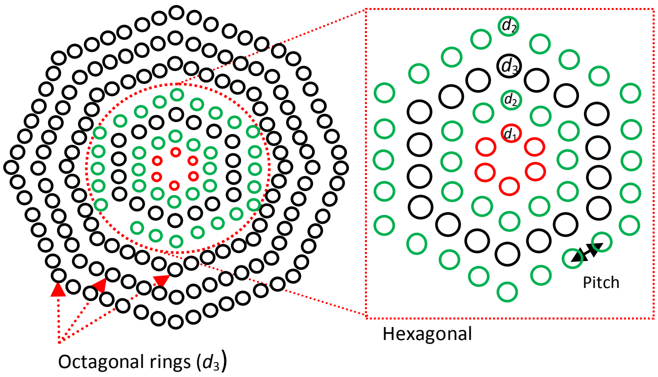

Fig. 1 (a) Cross-section of the proposed HyPCF, and (b) Illustration of the structure parameters.

C. Numerical results

A commercial full-vector finite element software (COMSOL) was used for both modal and loss analyses of the proposed design. Chromatic dispersion is the combination of material dispersion and waveguide dispersion. A sellmeier equation was introduced to evaluate the material dispersion of silica. The total dispersion caused by the combined effect of material and waveguide dispersion is calculated by the following formula

$$D = -\frac{\lambda}{c}\frac{d^2\left[\mathrm{Re}(\eta_{eff})\right]}{d\lambda^2}$$

(1)

Where λ is the wavelength, c is the velocity of light, Re(n_{eff}) is the real part of the effective mode index. The wavelength dependence of chromatic dispersion properties of the proposed structure is shown in *Fig. 2*. This Figure exhibits an average chromatic dispersion of –110.21 ps/nm/km with a dispersion variation of 1.49 ps/nm/km in the wavelength range of 1250-2000 nm for the optimum design parameters: Λ = 0.90 *μ*m, d_1/Λ = 0.38, d_2/Λ = 0.52, d_3/Λ = 0.60. The comparison among the dispersion properties of the proposed structure and previous works are shown in *Fig. 3*. The average negative dispersion of our structure is not so large but we have achieved flatness in a very long wavelength range of 750 nm. Again dispersion variation (*ΔD*) of our work is the smallest of all and it is only 1.49 ps/nm/km.
It is known that up to ±2% change in air-hole diameter can occur unintentionally during fabrication [11]. To ensure feasibility of the design, these variations in the air-hole diameter should not affect the average dispersion and dispersion variation much. The tolerance analysis has been performed carefully by changing one parameter at a time while other optimum parameters remained fixed.

We consider only first three air-hole rings to justify dispersion sensitivity because it has already been proved by some reports that the outer ring dimension has insignificant effect on fiber dispersion [12].

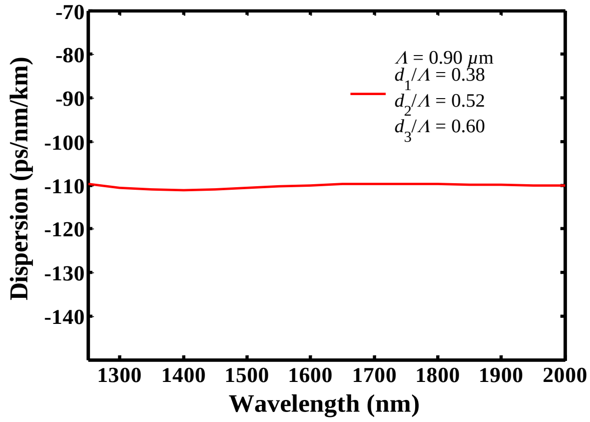

Fig. 2 Flattened negative dispersion at optimum design parameters.

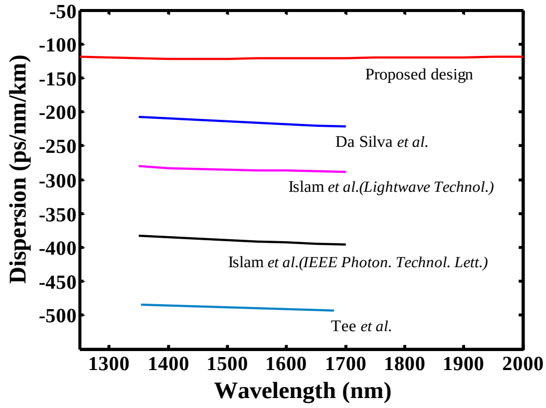

Fig. 3 Comparison of dispersion properties of the proposed fiber with some recent reported fibers.

Fig.4 shows the sensitivity analysis of dispersion due to the change in first air hole ring diameter (d_1) up to ±2%. It is seen that the negative average dispersion (D) changes only ± 18.6% and the flatness (ΔD) vary slightly.

The sensitivity analysis due to change in second air-hole diameter (d_2) is shown in *Fig. 5*. The figure shows that the average dispersion (*D*) varies ~±7.13%. Wavelength response of dispersion for the variation of third air-hole ring diameter (d_3) up to ±2% is shown in *Fig. 6*. The average dispersion variations for change in d_3 and pitch are ~±5.65% and ~±6.43% respectively. So there will be no major change in dispersion profile due to small change in first to third air-hole ring diameters and pitch during fabrication.

The cure of effective area for the optimum design parameters is shown in Fig.7. The value of average effective area of this fiber is found to be around 4.5μm^2. The effective area is relatively small and can be used for some nonlinear applications. It is evident from the figure that effective area of the fiber increases with the wavelength and there is no evidence of abrupt change in effective area. The effective area of the fiber at 1550 nm is 4.2 μm^2.

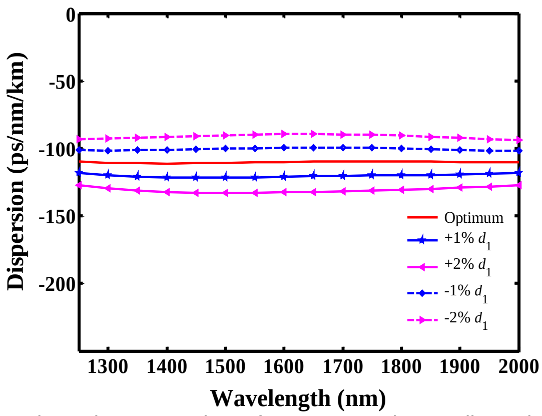

Fig. 4 Dispersion properties of HyPCF: optimum dispersion and effects of changing d_1.

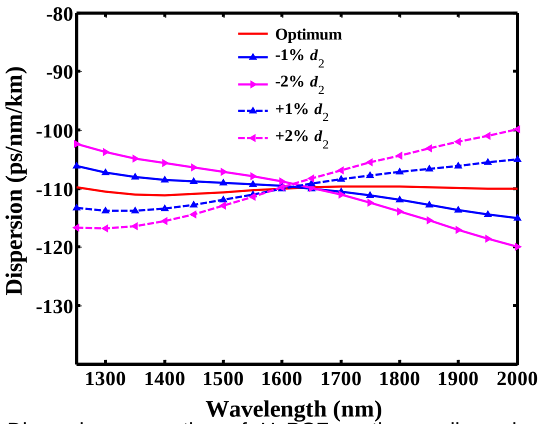

Fig. 5 Dispersion properties of HyPCF: optimum dispersion and effects of changing d_2.

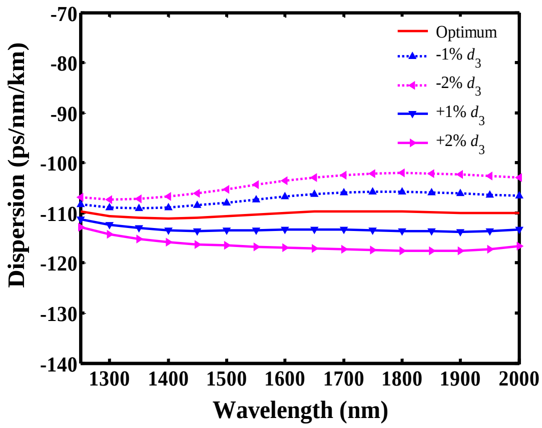

Fig. 6 Dispersion properties of HyPCF: optimum dispersion and effects of changing d_3.

Wavelength dependence of confinement loss of the HyPCF for optimum design parameters is shown in Fig. 8. The confinement loss is found to be high and this value is 0.01dB/m at 1550 nm. Confinement loss in HyPCF is much lower than normal hexagonal structured PCF due to more air-holes in the cladding region for same ring. The techniques about reducing confinement loss are discussed in the next chapter. It is evident from the figure that confinement loss of the fiber increases with the wavelength and there is no evidence of abrupt change

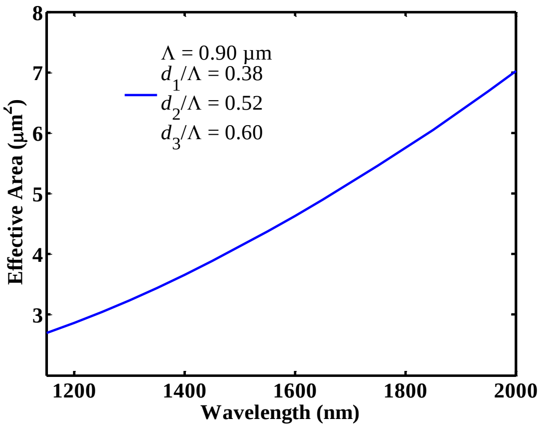

Fig. 7 Effective area Curve for optimum dispersion curve.

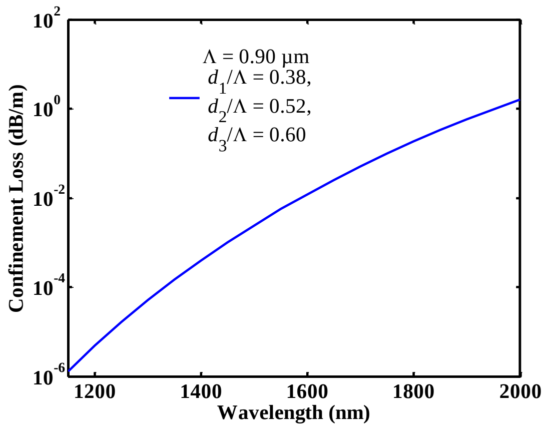

Fig. 8 Confinement loss curve for optimum dispersion parameter.

Splice loss is higher as the effective area of this fiber is quite small. Leon-Saval *et al.* [13] presented a splice loss free interconnection technique for connecting single mode fiber and dispersion compensating fiber.

D. CONSLUSION

In this paper, a hybrid PCF has been proposed for residual dispersion compensation over 750 nm bandwidth. It has been demonstrated that our structure shows ultraflattened large negative dispersion of –110.2 ps/nm/km with an absolute dispersion variation of 1.49 ps/nm/km in a broad wavelength ranging from 1250 nm to 2000 nm. The dispersion variation (*ΔD*) and the wavelength range of the obtained dispersion profile are most updated. This structure is much easier to fabricate and can be applied in the communication link for broadband dispersion compensation.

REFERENCES

[1] J. C. knight, “Photonic crystal fibers,” Nature, vol. 424, pp. 847–851, 2003.

[2] G. P. Agrawal, “Fiber-Optic Communication Systems”, 3rd ed. New York: Wiley, 2002, pp. 15–64.

[3] M. A. R. Franco, V. A. Serrão, and F. Sircilli, “ Microstructured optical fiber for residual dispersion

compensation over S+C+L+U wavelength bands", IEEE Photon. Technol. Let*t*., vol. 20, no. 9, pp. 751–753, May 1, 2008.

[4] J. P. Silva, D. S. Bezerra, V. F. R. Esquerre, I. E. Fonseca, and H. E. H. Figueroa, "Ge-doped defect-core microstructured fiber design by genetic algorithm for residual dispersion compensation", IEEE Photon. Technol. Lett., vol. 22, no. 18, pp. 1337–1339, Sep. 15, 2010.

[5] Md. Asiful Islam, and M. Shah Alam, "Design of a Polarization-Maintaining Equiangular Spiral Photonic Crystal Fiber for Residual Dispersion Compensation Over", IEEE Photon. Technol. Lett., vol. 24, no. 11, June. 1, 2012.

[6] S. K. Varshney, N. J. Florous, K. Saitoh, M. Koshiba, and T. Fujisawa, "Numerical investigation and optimization of a photonic crystal fiber for simultaneous dispersion compensation over *S* + *C* + *L* wavelength bands", Opt. Commun*.*, vol. 274, pp. 74–79, 2007.

[7] M. A. Islam, and M. S. Alam, "Design Optimization of Equiangular Spiral Photonic Crystal Fiber for Large Negative Flat Dispersion and High Birefringence", Journal of Lightwave Technol., vol. 30, no. 22, Nov. 2012.

[8] D. C. Tee, M. H. A. Bakar, N. Tamchek, and F. R. M. Adikan, "Photonic crystal fiber in photonic crystal fiber for residual dispersion compensation over *E* + *S* + *C* + *L* + *U* wavelength bands*",* IEEE Photon. Journal, vol. 5, no. 3, pp. 7200607, Jun. 2013.

[9] S. M. Abdur Razzak, and Yoshinori Namihira, "Tailoring Dispersion and Confinement Losses of Photonic Crystal Fibers Using Hybrid Cladding", Journal of Lightwave Technol*.*, vol. 26, NO. 13, July 1, 2008.

[10] W. H. Reeves, J. C. Knight, and P. St. J. Russell, "Demonstration of ultra-flattened dispersion in photonic crystal fibers", Opt. Express, vol. 10, no. 14, pp. 609–613, 20.

[11] K. Kaneshima, Y. Namihira, N. Zou, H. Higa, and Y. Nagata, "Numerical investigation of octagonal photonic crystal fibers with strong confinement field", IEICE Trans. Electron*.*, vol. E89-C, no. 6, pp. 830–837,2006.

[12] S. M. A. Razzak and Y. Namihira, "Highly birefringent photonic crystal fibers with near-zero dispersion at 1550 nm wavelength", J. Mod. Opt*.*, vol. 56, no. 10, pp. 1188–1193, Jun. 2009.

[13] S. G. L. Saval, T. A. Birks, N. Y. Joly, A. K. George,W. J.Wadsworth, G. Kakarantzas, and P. St. J. Russell, "Splice-free interfacing of photonic crystal fibers", Opt Lett., vol. 30, no. 13, pp. 1629–1631, 2005.

[14] J.C. Knight, T.A. Birks, P.St.J. Russell, and D.M. Atkin: "All-silica single-mode optical fiber with photonic crystal cladding," *Opt. Lett.* 21, 1547-1549 (1996).

[15] K. Saithoh, N. J. Florous, M. Koshiba, "Ultra-flattened chromatic dispersion controllability using a defect-core photonic crystal fiber with low confinement losses," *Opt. Express*., 13(21), 2005, pp. 8365–8371.

[16] P. St. J. Russell, "Photonic crystal fibers," *Science,* vol. 299, pp.358-362, 2003. (Review article).

[17] J. Ju, W. Jin, and M. S. Demokan, "Properties of a highly birefringent photonic crystal fiber," *IEEE Photon. Technol. Lett*., vol. 15, no. 10, pp. 1375–1377, Oct. 2003.

[18] A. Ortigosa-Blanch, J. C. Knight, W. J. Wadsworth, J. Arriaga, B. J. Mangan, T. A. Birks, and P. S. J. Russell, "Highly birefringent photonic crystal fibers," *Opt. Lett*., vol. 25, pp. 1325–1327, 2000.

[19] P. Petropoulus, T. Monro, W. Berlardi, K. Furusawa, J. Lee, and D. Richardson, "2R-regenerative all-optical switch based on a highly nonlinear holey fiber," *Optics Letters*, vol. 26, pp. 1233-1235, 2001.

[20] S. M. A. Razzak, Y. Namihira *et. al.,* "Properties of a decagonal photonic crystal fiber", *Journal of Microwave and Optoelectronics*, vol. 6, no. 1, pp. 44-49, 2007.

[21] Feroza Begum, Yoshinori Namihira, S.M. Abdur Razzak, Shubi Kaijage, Nguyen HoangHai, Tatsuya Kinjo, Kazuya Miyagi, Nianyu Zou, "Novel broadband dispersion compensating photonic crystal fibers: Applications in high-speed transmission systems," *Optics & Laser Technology*, vol.41, pp. 679-686, 2009.

[22] K. Petermann, "Constrains for fundamental-mode spot size for broadband dispersion-compensated single-mode fibers," *Electron. Lett.*, vol. 19, pp. 712-714, Sept. 1983

[23] Rifat Ahmmed Aoni1, Rajib Ahmed, Md. Mahbub Alam3, S. M. Abdur Razzak "Optimum Design of a Nearly Zero Ultra-flattened Dispersion with lower Confinement loss Photonic Crystal Fibers for Communication Systems" International Journal of Scientific & Engineering Research Volume 4, Issue 1, January-2013, ISSN 2229-5518