International Journal of Scientific & Engineering Research Volume 4, Issue 1, January-2013
ISSN 2229-5518

Optimum Design of a Nearly Zero Ultra-flattened Dispersion with lower Confinement loss Photonic Crystal Fibers for Communication Systems

*Rifat Ahmmed Aoni[1], Rajib Ahmed[2], Md. Mahbub Alam[3], S. M. Abdur Razzak[4]

Abstract— This paper presents a triangular-lattice photonic crystal fiber for analysis of nearly zero ultra-flattened dispersion like 0.96 - -0.86 ps/nm/km with very low confinement loss less than 10^{-5} db/km, moderate effective area, lower splice loss & nonlinear coefficient property of photonic crystal fibers. A five-ringed photonic crystal fiber have be designed using Comsol 4.2 with the finite element method and perfectly matched absorbing layers boundary condition is used to investigate the guiding properties.

Index Terms— photonic crystal fiber, effective index, dispersion, confinement loss, effective area, splices loss, nonlinear coefficient.

1 INTRODUCTION

PCF is a artificiall photonic crystal structure. It is a single material optical fiber consisting of a silica-air microstructure. It contains microscopic air-holes in a silica background running down length of the fiber that form the silica-air microstructure as well as the lower refractive index cladding [1]. Air-holes can be arranged in the cladding in a periodic (hexagonal arrangement being the common) or an aperiodic fashion. The core may either be a solid (made of silica) or a hollow (made of air). The former core type PCF guides light based on the modified TIR mechanism likewise conventional fibers. The later guides light based on a new mechanism which is known as the photonic band gap (PBG) [2]. Hence, for PCFs, it is not necessary that the core must be made of a higher refractive index material than the cladding. Similarly, it is also not necessary that only the TIR mechanism confines light into the core of all optical fibers [3].

Day by day photonic crystal fibers have increasing its attention because of their attractive properties for examples, very high or very low nonlinearities [4], wideband dispersionultra-flattened or ultra low chromatic dispersion [5], lower confinement loss [6], very high or low birefringence [7], endlessly single mode guiding [8], and many others. Photonic crystal fibers (PCFs) [9] consisting of a central defect region surrounded by air holes running parallel to the fiber length have been one of the most interesting development in recent fiber optics. PCFs are usually made from pure silica and so the guided modes are inherently leaky because the core index is the same as the index of the outer cladding region without air holes. Control of chromatic dispersion in PCFs is very important problem for realistic applications of optical fiber communications [10], dispersion compensation [11] and so on.

In this paper we have proposed hexagonal PCF in order to nearly zero ultra-flatted dispersion, lower confinement loss, effective area, lower splice loss and nonlinear coeffecient in the range of telecommunication wavelength.

- Author Rifat Ahmmed Aoni, is with the Electronics and Telecommunication Engineering department, Institute of Rajshahi University of engineering and Technology, Rajshahi-6204, Bangladesh, Phone: +880-1914961164; e-mail: rifat.ete07@gmail.com).
- Co-Auther Rajib Ahmed, is with the Lecturer (study leave) of University of Information Technology & Sciences (UITS), Baridhara, Dhaka, Bangladesh and now doing MASters on Photonic NETworks Engineering, Institute of Scuola Superiore Sant' Anna, Pisa, Italy and Phone: +393892320071 e-mail: rajib.ahmmed.apece@gmail.com).
- Co-Author Md. Mahbub Alam, is with the Electronics and Telecommunication Engineering department, Institute of Rajshahi University of engineering and Technology, Rajshahi-6204, Bangladesh, Phone: +880-1715508498; e-mail: mahbub.ruet@gmail.com).
- Co-Author S. M. A. Razzak, is with the Associate professor of Electronics and Telecommunication Engineering department, Institute of Rajshahi University of engineering and Technology, Rajshahi-6204, Bangladesh, Phone: +880-1191014971; e-mail: razzak91@yahoo.com).

2 DESIGN METHODOLOGY

Figure 1 shows the five ring photonic crystal fiber. Where, first ring air hole diameter is d_1, second ring air hole diameter is d_2 and third to fifth ring air hole diameter is d. Through diameter is varied ring to ring but middle point of one air hole to another middle point of another air hole distance i.e. pitch constant or lattice constant Λ, is same for all rings. Here, pure silica is used for background material which refractive index is 1.46 and air holes act as a cladding in hexagonal PCF symmetry. The first ring i.e., the inner most ring contains six air-hole and the other rings contains integer multiple of six air-holes.

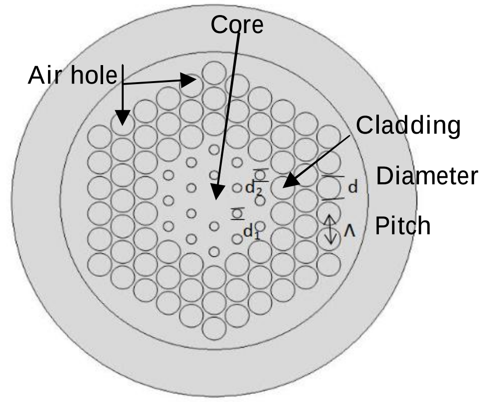

Figure 1: Geometry of proposed Hexagonal PCF with 1st ring's air-hole diameter d1, 2nd ring's air-hole diameters d2, and diameter of air-holes on 3rd to 5th rings' is d.

3 Simulation Methodology

The Comsol software version 4.1 is used as a simulation tool with anisotropic perfectly matched layers (PMLs) boundary condition. It is consider the most efficient boundary conditions for the PCF simulation. The modal effective refractive index, n_{eff} is obtained by solving an eigen value problem drawn from Maxwell equations using the Comsol 4.1 by using this effective refractive index chromatic dispersion D, is calculated from the following equation[12],

$$D = -\frac{\lambda}{c}\frac{d^2\,\mathrm{Re}[n_{eff}]}{d\lambda^2} \qquad (1)$$

Where, $\mathrm{Re}[n_{eff}]$ is the real part of n_{eff}, λ is the wavelength, and c is the velocity of light in vacuum. The material dispersion given by Sellmeier formula is directly included in the calculation. Therefore, D in (1) corresponds to the total dispersion of the PCF.

Using the imaginary value of refractive index confinement losses of PCFs are often calculated from the following relation [12],

$$L_c = 8.686 \times \mathrm{Im}[k_0 n_{eff}] \times 10^3 \,\mathrm{db/km} \qquad (2)$$

Where, $\mathrm{Im}[n_{eff}]$ is the imaginary part of n_{eff}, and k_0 is the free space wave number equal to $2\pi/\lambda$.

The effective area of the PCFs are obtained from the following formula [13],

$$Aeff = \frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}|E|^2\,dxdy}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}|E|^4\,dxdy} \qquad (3)$$

Here, E is the electric field derived by solving the Maxwell equations.

Finally the nonlinear coefficient and splice loss of the PCFs are calculated from the following equations (4) and (5) [14], [15],

$$Nonlinearity, \gamma = \left(\frac{2\pi n2}{\lambda Aeff}\right) \times 10^3 w^{-1} km^{-1} \qquad (4)$$

$$Ls = -20\log_{10}\frac{2w_{SMF}w_{PCF}}{w^2_{SMF} + w^2_{PCF}} \qquad (5)$$

Where, γ is the nonlinear coefficient, n2 is the nonlinear refractive index; W_{SMF} and W_{PCF} are the MFDs of the SMF and the PCF respectively.

4 Simulation Results

Nearly zero ultra-flatted dispersion curves are proposed shown in fig. 2 here, we varied first ring diameter d1, second ring diameter, d2 = 0.3 μm is constant and same of other rings diameter, d=1.47 μm and pitch, Λ= 1.63 μm also same for all rings. Optimizing the parameters we got the nearly zero ultra-flatted dispersion curves in the range 1.2 – 1.6 μm wavelength.

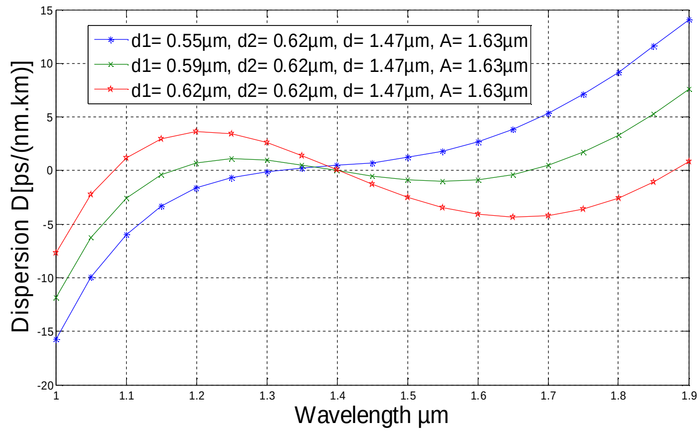

Figure 2: Dispersion is a function of wavelength for optimum parameters in five rings.

Figure 3 shows that, confinement loss is a function of wavelength. Here, confinement loss is found 10^{-1}, 10^{-3} and 10^{-5} db/km in air fill fraction d/Λ, 0.6, 0.7 and 0.8 at 1550 nm wavelength. So, we can say that with the increasing of air fill fraction confinement loss is decreased. Here, confinement loss is less achieved by keping first and second rings are scaled down to shape with the other rings are kept larger. It is also visible in figure 3 with the increasing of wavelength confinement loss also increased.

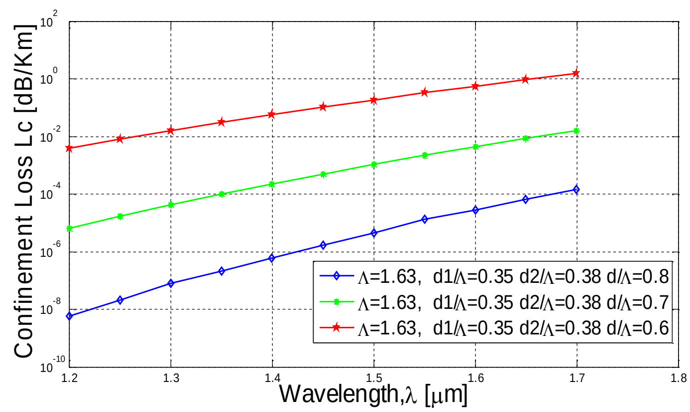

Figure 3: Confinement loss is a function of wavelength for optimum parameters in five rings.

In figure 4 it is shown that our propose design fiber effective area is 7.7 μm² at 1550 nm and the nonlinear co-efficient corresponding to the effective area 6.8 μm² is about 18 $W^{-1}Km^{-1}$ as is shown in Figure 5.

ISSN 2229-5518

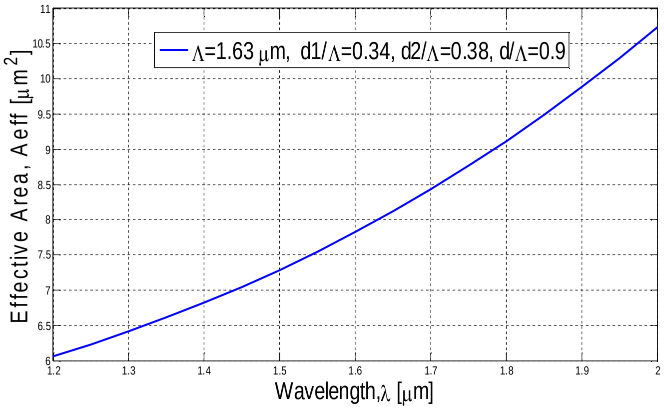

Figure 4: Confinement loss is a function of wavelength for optimum parameters in five rings.

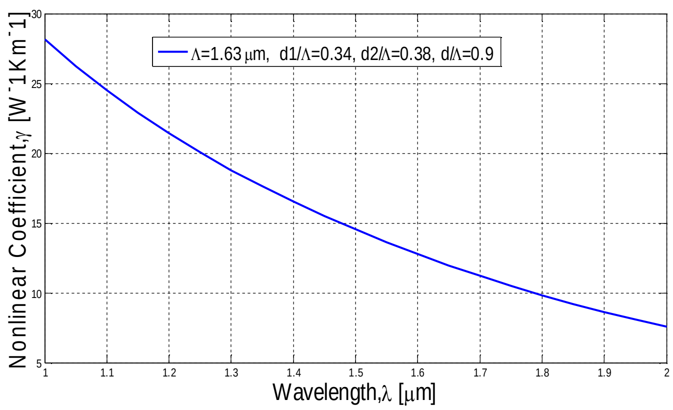

Figure 5: Nonlinear coffecient is a function of wavelength for optimum parameters in five rings.

From Figure 6 shows wavelength dependence of mode field diameter (MFD) and splice loss between this fiber and conventional single mode fibers (SMFs). The MFD of the SMF is considered 10 µm. Because of smaller MFD of proposed fiber, splice losses are generally higher. This is also true for all highly nonlinear fibers. This high splicing loss can be eliminated by the use of recent splice free interconnection technique between SMFs and PCFs [16].

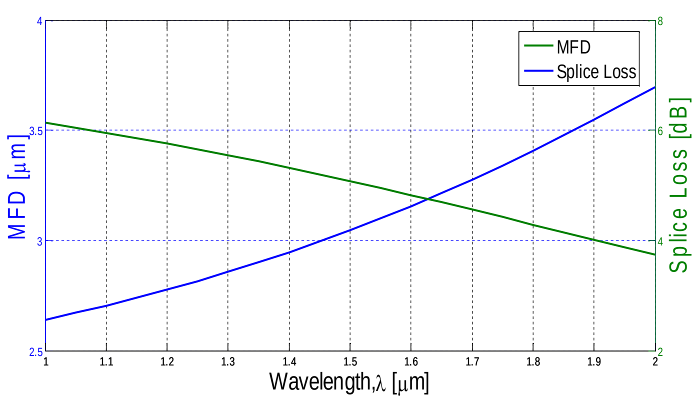

Figure 6: Splice loss and MFD of the hexagonal PCF for the optimum design parameters: d1/Λ = 0.34, d2/Λ = 0.38, d/Λ= 0.90, Λ = 1.63 μm and Nr = 5.

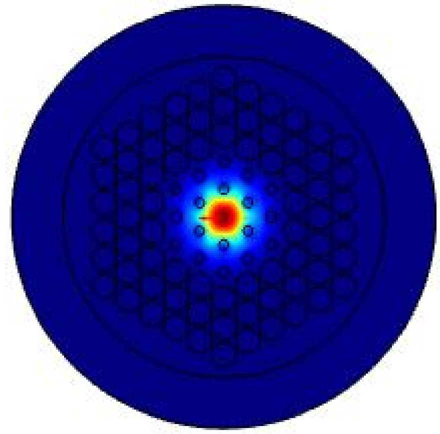

Figure 7: Mode field pattern of the fundamental mode at 1550 nmin 2D distribution. Red color represents the highest intensity and blue the lowest.

From figure 7 shows that, mode field intensity distribution of the fiber at 1550 nm wavelength corresponding to the optimum design. Here, 2-D plots justify that the field has confined well in the core as there are no evidences of light leakage into the cladding region beyond the first ring.

5 Conclusion

We have proposed hexagonal PCF with the variation of 1st rings diameter for nearly zero ultra-flatted dispersion with very low confinement loss. The results have been shown through numerical simulation results that a five-ring PCF can assume nearly zero ultraflattened dispersion 0.96--0.86 ps/nm/km in 1300-1600 nm wavelength. In telecommunication wavelength we were got the confinement losses is less than 10^{-5} db/km at 1550 nm for the air fill fraction d/A, is 0.80. Here, we got the effective area 7.7 µm^2 at 1550 nm wavelength and nonlinear coefficient is 18 $W^{-1}Km^{-1}$. This fiber has a modest number of design parameters, five rings, three air-hole diameters and an air-hole pitch.

Acknowledgement

We would like to thank all reviewer for their valuable comments, All gratitude is due to "ALLAH" who guides me to bring forth to light this paper. All thanks due especially to my parents for their prayer and inspiration, which has helped me in becoming what I am today.

References

[1]. P. St. J. Russell, "Photonic Crystal Fibers," Science, vol. 299, no. 5605, pp. 358-362, Jan. 2003.

[2]. J. C. Knight, "Photonic crystal fibers," Nature, vol. 424, pp. 847-851, Aug. 2003.

[3]. S. M. A. Razzak, Y Namihira (2010) Photonic Crystal Fibers Design and Applications LAP Lambert , Germany isbn:978-3-8383-6935-8.

[4]. 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.

[5]. A. Ferrando, E. Silvestre, P. Andres, J. Miret, and M. Andres, "Nearly zero ultraflattened dispersion in photonic crystal fibers," Optics Letters, vol. 25, pp. 790-792, 2000.

[6]. T. P. White, R. C. McPhedran, C. M. de Sterke, L. C. Botten, and M. J. Steel, "Confinement losses in microstructured optical fibers," Opt. Lett., vol. 26, no. 21, pp. 1660–1662, Nov. 2001.

[7]. M. Y. Chen, "Polarization and leakage properties of large-mode-area microstructured-core optical fibers," Optics Express, vol. 15, no. 19, pp. 12498-12507, 2007.

[8]. T. A. Birks, J. C. Knight, and P. St. J. Russell, "Endlessly single-mode photonic crystal fiber," Optics Letters, vol. 22, no. 13, pp. 961-963, July 1997.

[9]. T.A.Birks, J.C.Knight, B.J. Mangan, P.St.J. Russell, "Photonic crystal fibers: An endless variety", IEICE Trans. Electron. E84-C, 2001, 585-592.

[10]. F. Begum, Y. Namihira, S.M.A. Razzak, N. Zou. Novel, "Square Photonic Crystal Fibers with Ultra-Flattened Chromatic Dispersion and Low Confinement Losses", IEICE Trans. Electron. E90-C, 2007, 607-612.

[11]. L.P. Shen, W.P. Huang, S.S. Jian. "Design and optimization of photonic crystal fibers for broadband dispersion compensation", IEEE Photon. Technol. Lett. 15, 2003, 540-542.

[12]. K. Saitoh, M. Koshiba, T. Hasegawa, E. Sasaoka, "Chromatic dispersion control in photonic crystal fibers: application to ultra-flattened dispersion," Opt. Express, vol. 11, no. 8, pp.843-852, April 2003.

[13]. S. M. A. Razzak, Y. Namihira, F. Begum, S. Kaijage, N. H. Hai, and N. Zou, "Design of a decagonal photonic crystal fiber with ultra-flattened chromatic dispersion," IEICE Trans. Electron., vol. E90-C, no. 11, pp. 2141-2145, Nov. 2007.

[14]. S. M. A. Razzak and Y. Namihira, "Proposal for highly nonlinear dispersion-flattened octagonal photonic crystal fibers," IEEE Photonics Technol.Lett., vol. 20, no. 4, pp. 249-251, Feb. 2008.

[15]. S. M. A Razzak and Y. Namihira, "Tailoring dispersion and confinement losses of photonic crystal fibers using hybrid cladding," to be published in the IEEE/OSA J. of Lightwave Technol., 2008.

[16]. S. G. Leon-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," Optics Letters, Vol. 30, No. 13, pp. 1629-1631, 2005.

Authors:

Rifat Ahmmed Aoni was born in Kishoregonj, Bangladesh on 05 May, 1989. He received the B. Sc. Engineering degree in Electronics and Telecommunication Engineering from Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh, in 2012. His research interest concerns the photonics related works.

Rajib Ahmmed was born in Kishoregonj, Bangladesh on 05 May, 1986. He received the B. Sc. Honours and M.Sc degree in Applied Phsics, Electronics and Communication Engineering from Dhaka University, Dhaka, Bangladesh, in 2008. He is a Lecturer (study leave) of University of Information Technology & Sciences (UITS), Baridhara, Dhaka, Bangladesh. Now, he doing Erasmus Mundus MASters on Photonic NETworks Engineering (MAPNET), Institute of Scuola Superiore Sant' Anna, Pisa, Italy and Phone: +393892320071. His research interest concerns the photonic related works.

Mohammad Mahabub Alam was born in Dinajpur, Bangladesh in 1990. He received the B.Sc. degree on Electronics and Telecommunication Engineering from Rajshahi University of Engineering and Technology, Rajshahi-6204, Bangladesh. His research interests concerns the improvement of the bandwidth of the Microstrip Patch antenna.

S. M. Abdur Razzak was born in Natore Bangladesh, on December 31, 1974. He received the B.Sc. degree from Rajshahi University of Engineering and Technology (B.I.T. Rajshahi), Rajshahi, Bangladesh, in 1998 and the M.Eng. Degree in elec-trical and electronic engineering from the University of the Ryukyus, Okinawa, Japan, in 2007.