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# Structure parameter effects of PCF on dispersion for singlemode regime based on V-parameter

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## Abstract

In this paper, the dispersion of photonic crystal fiber (PCF) with five rings hexagonal geometry have investigated by varying different parameters. Many researchers had used small size of fiber ( small pitch distance) to ensure the single mode operation but decreasing the pitch distance leads to increasing the dispersion. It is important to get suitable pitch distance so that it is not large to avoid the multimode operation and not small to avoid high dispersion. In this work, this condition has obtained depended on V-parameter. We have estimated the V-parameter by using the step-index fiber approximation. The Pitch distance which has been obtained is 5 um with low dispersion and low V-parameter  $\leq$ 2.405 (single mode operation). In addition, to get more low dispersion and Vparameter, a doping with two different value of Ge ( 4.1% and 7%) has been applied in core.

#### Introduction

Transferring data using optical communication systems are very important role. Optical multiplexing systems have long been the technology of choice for transferring large amounts of data between sites. A lot of channels can be sent simultaneously in high bit rates on same optical fiber with Optical multiplexing systems. But the dispersion and dispersion slope of optical fibers produce a partial loss of data for long distances of data communication in modern optical systems. The dispersion may induce temporal optical pulse broadening, when they propagate in the optical fibers. To get the transmission line close in the best possible state of ultra-flattened dispersion and near zero dispersion, it is important to keep a uniform response in the different wavelength channels[1,2].

In order to get flattened chromatic dispersion, numerous designs have been presented. Among these designs, it can be mentioned to PCF with replacing the circular air holes with the elliptical air holes of two first rings[3], PCF with modify the size of the central air hole defect [4], PCF based on square lattice structure with two different air hole diameters in cladding region[5], PCF with varied air hole diameter, pitch distance, and air hole diameter to pitch distance ratio for three different materials[6], a PCF with additional air holes inserted between the essential air holes in the same ring [7], PCF with smaller air hole in the first ring of cladding [8], a PCF with different size of air holes in first ring and doped core [9].

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The most important goal of this work is to realize the effects of the structural parameters of PCF on the dispersion. The authors study the effects of air hole diameter, pitch distance and doping of the core on the characteristics of the dispersion for single-mode regime. If their effect can be analyzed, then optimum structure of PCF can be obtained to produce certain characteristics.

#### **Theoretical Background**

Using the FDTD, an Eigen value of an Effective mode index of a guided mode can be obtained by solving the Maxwell's equations for a certain wavelength. The effective mode index  $(n_{eff})$  can be obtained as[3,11]

$$n_{eff} = \beta/k_o \tag{1}$$

Where  $\beta$  and  $k_o$  are the propagation constant and the free space wave number respectively .

Effective mode index is a complex number with real and imaginary parts. The guided modes of the present PCF had been solved by the FEM that simulate PCFs. The chromatic dispersion is collect of the tow type of dispersion: material dispersion and waveguide dispersion. It is simply computed from the second derivative of the real part of the effective mode indices using Eqn. (2)[3,11]

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

With  $Re(n_{eff})$  is the real part of the effective index getted from simulations and c is the speed of light in vacuum.

In order to find the single-mode operation , it is important to find a solution to the fundamental mode over a wide range of wavelengths. The number of higher order modes is related to the V-parameter , which is inverse proportional to the wavelength without limit. It can be defined that it is reasonable whether a fiber is single-mode or higher order modes. The fiber is single mode only for the values of V (V<2.405) and the fiber support more modes if the value of V > 2.405. An effective V value for the PCF can be obtained according to Eq.(3)[10]

$$V_{eff} = \frac{2\pi}{\lambda} a \sqrt{n_0^2 - n_{eff}^2}$$
(3)

With  $\lambda$  is The wavelength, *a* is the core radius,  $n_0$  is the core index and  $n_{eff}$  is the effective index of fundamental guided mode. All the parameters are straightforward except for the effective cladding index  $n_{eff}$ . It can be obtained by numerical methods.

#### **Design Parameters and Simulation Result**

In this paper, PCF of five rings hexagonal structure have been designed using A finite element method (FEM) with the perfectly matched layers (PML) boundary conditions. The first design for presented PCF is shown in Fig.1.This PCF have five air hole rings with solid core. The diameter of the cladding region is 135  $\mu$ m. The perfectly matched layers is set as 7% of the cladding diameter. The air hole diameters is considered to be d=8  $\mu$ m. The lattice structure of the cladding is hexagonal and the distance between the centers of adjacent holes (is called pitch distance),  $\Lambda$ , is 10  $\mu$ m. The back ground of the PCF is taken to be pure silica whose refractive index has been considered by Sellmier's Eq. (4).[12]

$$n^{2}(\lambda) = 1 + \frac{B_{1}\lambda^{2}}{\lambda^{2} - \lambda_{1}^{2}} + \frac{B_{2}\lambda^{2}}{\lambda^{2} - \lambda_{2}^{2}} + \frac{B_{3}\lambda^{2}}{\lambda^{2} - \lambda_{3}^{2}}$$
(4)

With all constant are different for different material as shown in Table (1)

	$B_1$	B <sub>2</sub>	B <sub>3</sub>	$\lambda_1(\mu m)$	$\lambda_2(\mu m)$	$\lambda_3(\mu m)$
Pure silica	0.696166300	0.407942600	0.897479400	0.0684043	0.1162414	9.896161
100%SiO2						
4.1%GeO2	0.686717749	0.43481505	0.89656582	0.07267518	0.11514351	10.002398
+						
95.9%SiO2						
7% GeO2+	0.6869829	0.44479505	0.79073512	0.07807858	0.11551840	10.436628
93% SiO2						

#### Table (1) : Sellmeier Constants for different doped glass[12]



Fig. 1. The cross section of proposed PCF with Transversal field

At the beginning, Different sizes of Photonic crystal fiber are used to see the effect of structure size on the broadening of the chromatic dispersion compensation. The size of fiber can be depended on pitch distance,  $\Lambda$ . An effective refractive index of the mode, chromatic dispersion and V-parameter with respect to the wavelength  $\lambda$  (1.2 µm-1.6 µm) obtained for different pitch distances,  $\Lambda$ ,(from 10 um to 3 um in step of 1 um) with diameter to pitch distance ratio (d/  $\Lambda$ ) is 0.8 as shown in Fig.2.It is obvious from the Figures, the effective refractive index of the fundamental mode and V-parameter are decreasing with decreasing of pitch distances,  $\Lambda$ , while the chromatic dispersion is increasing.

From Fig.2,All pitch distances ,  $\Lambda$ , have V-parameter more than 2.405 except pitch distance which has 3  $\mu$ m. Therefore ,the starting point of fiber size is 3  $\mu$ m to get balance between pitch distance and V-parameter less than 2.405 to ensure maximum pitch distance with single mode operation. The second important parameter is diameter to pitch distance ratio (d/  $\Lambda$ ). Different diameter to pitch distance ratio (d/  $\Lambda$ ) are used to see the effect on the broadening of the chromatic dispersion compensation. An effective refractive index of the mode, chromatic dispersion and V-parameter with respect to the wavelength  $\lambda$  (1.2  $\mu$ m-1.6  $\mu$ m) obtained for different diameter to pitch distance ratio (d/  $\Lambda$ )(0.7 to 0.3 with step 0.05) as shown in Fig.3. It is obvious from the Figures, the effective refractive index of the fundamental mode is increasing with decreasing of diameter to pitch distance ratio (d/  $\Lambda$ ), while the chromatic dispersion and V-parameter are decreasing



Fig. 2. (a) Effective refractive index. (b) chromatic dispersion and (c) V-parameter with  $(d/\Lambda)$  is 0.8 and different pitch distances

In Fig 3. The chromatic dispersion is not enough low, therefore it is important to modify the structure of the fiber to enhance the chromatic dispersion. In this work the holes of the first inner ring of photonic crystal fiber are removed as shown in Fig. 4. The advantage of removing the holes are decreasing the chromatic dispersion and increasing the mode field diameter which is useful to increase the Affective area of fiber. The disadvantage is increasing the higher order modes.

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Fig. 3. (a) Effective refractive index. (b) chromatic dispersion and (c) V-parameter with pitch distance is 3  $\mu$ m and different (d/  $\Lambda$ )



Fig. 4. The cross section of PCF with Transversal field intensity distribution after removing the holes of the first inner ring

For the structure of the fiber in Fig 4, An effective refractive index of the mode, chromatic dispersion and V-parameter with respect to the wavelength  $\lambda$  (1.2 µm-1.6 µm) obtained for different pitch distance,  $\Lambda$ ,(from 10 um to 3 um in step of 1 um) with diameter to pitch distance ratio (d/  $\Lambda$ ) is 0.3 as shown in Fig. 5. From the figure , pitch distance with 5 um is critical structure to ensure single mode operation with maximum pitch distance depended on V-parameter.



**Fig. 5.** (a) Effective refractive index. (b) chromatic dispersion and (c) V-parameter with with  $(d/\Lambda)$  is 0.3 and different pitch distances

In addition to modify the structure ,the doping of core with certain material to up refractive index is effected on chromatic dispersion .In this work tow type of doping are used which is mentioned in table(1).Increasing the doping of core leads to decrease the chromatic dispersion and V-parameter while An effective refractive index is increasing. An effective refractive index of the mode, chromatic dispersion and V-parameter with respect to the wavelength  $\lambda$  (1.2 µm-1.6 µm) obtained for different doping with diameter to pitch distance ratio (d/  $\Lambda$ ) is 0.3 and pitch distance is 5 µm as shown in Fig 6.



**Fig. 6.** (a) Effective refractive index. (b) chromatic dispersion and (c) V-parameter with  $(d/\Lambda)$  is 0.3 , pitch distances is 5 µm and different doping of the core

#### Conclusion

This paper studies the influence of the structural parameters of PCF on chromatic dispersion by numerical simulation technique. Different layout of hexagonal PCF have created based on different air hole diameter and pitch distance. Chromatic dispersion is decreasing with decreasing the air hole diameter while it increasing with decreasing the pitch distance. V-parameter is proportional to pitch distance. In this work a suitable fiber size is obtained for single mode operation with maximum pitch distance. Pitch distance with 5  $\mu$ m and diameter to pitch distance ratio (d/  $\Lambda$ ) with 0.3 are considering for low chromatic dispersion and single mod operation. In addition, for safety factor to ensure the single mode operation, different type of doping are used. Up-doping of core of PCF leads to decreasing the Chromatic dispersion

#### References

[1] S.F. Kaijage, Y. Namihira, N.H. Hai, F. Begum, S.M.A. Razzak, T. Kinjo, H. Higa, and N. Zou, "Multiple defect-core hexagonal photonic crystal fiber with flattened dispersion and polarization maintaining properties," Opt. Rev. Vol. 15, pp. 31-37, 2008.

[2] S. Olyaee and F. Taghipour, "Design of Low-Dispersion Fractal Photonic Crystal Fiber S." International Journal of Optics and Photonics (IJOP)Vol. 6, No. 1, 2012.

[3] Sh. Mohammad nejad ,M.Pourmahyabadi, "Design of Single Mode Photonic Crystal Fibers with Low-Loss and Flattened Dispersion at 1.55µm Wavelength", Iran University of Science and Technology Tehran, Iran. Iranian Journal of Electrical & Electronic Engineering, Vol. 12, No. 1, March 2016

[4] K. Saitoh, N. Florous and M. Koshiba, "Ultraflattened chromatic dispersion controllability using a defected-core photonic crystal fiber with low confinement losses", *Opt. Express*, Vol. 13, No. 21, pp.8365-8371, 2005.

[5] Lisha Agrawal, Himanshu Joshi, Khushbu Sharma "Investigation of Single Mode Square Lattice Photonic Crystal Fiber with Ultraflattened Dispersion" International Journal of Engineering and Applied Sciences (IJEAS), Volume-3, Issue-7, July 2016.

[6] Biswas, S., Rafi, R.S., Al-Amin, Md.A. and Alam, S. "Analysis of the effect of Air Hole Diameter and Lattice Pitch in Optical Properties for Hexagonal Photonic Crystal Fiber". *Optics and Photonics Journal*, **5**, 227-233, (2015).

[7] S. Haxha and H. Ademgil, "Novel design of photonic crystal fibers with low confinement losses, nearly zero ultra-flatted chromatic dispersion, negative chromatic dispersion and improved effective mode area", Optics Communications, Vol. 281, No. 2, pp. 278–286, 2008.

[8]Shashi Kant Pandey, Akshay Kumar Singh, Neha Taneja, Parul Jindal "Characteristics of Terahertz Photonic crystal fiber using core mode coupling" International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 2 Issue X, October 2014

[9] M. Chen and S. Xie, "New nonlinear and dispersion flattened photonic crystal fiber with low confinement loss", Optics Communications, Vol. 281, No. 8, pp. 2073–2076, 2008.

[10] Debbal, Mohammed; Chikh-Bled, Mohamed "Designing the Mode solving of the photonic crystal fiber via BPM and Exploring the Single-Mode Properties" International Journal of Computer Science Issues (IJCSI);Mar2012, Vol. 9 Issue 2, p598

[11] Shahid Masood Ahmad Khan, Mohammad Shahid "Effects of Parameters of Photonic Crystal Fibre on Dispersion and Confinement" International Journal of Advanced Engineering, Management and Science (IJAEMS), Vol-3, Issue-3, Mar- 2017.

[12] Huda M. Mohammad, Nawfal Y. Jamil, Abdulghafoor I. Abdullah "Dispersion Properties of Updoping Photonic Crystal Fibers" Rafidain journal of science, Vol. 25, No.1 pp. 101-107, 2014