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Highly Nonlinear Dispersion Compensating Square Photonic Crystal Fiber Using Only Circular Air Holes

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ABSTRACT: *Photonic crystal fiber in square lattice structure is numerically researched and proposed for broadband dispersion compensating in optical circulation system. Throughout the simulation, we found an ultra-high negative dispersion of about -1020 ps/(nm.km) at the wavelength of 1550 nm. Experimentally it is investigated that the design fiber obtain high birefringence is about* 1.2×10^{-2} *at the wavelength of 1550 nm. Finite element method (FEM) with accurate match layers is used in numerical investigation of leading geometrical properties of the proposed PCF. To obtain ultra-high negative dispersion for the high speed reliable transmission system the gained result of our proposed design is completely attractive.*

KEYWORDS *-Ultra high negative dispersion, Birefringence, Non-linear co-efficient*

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I. INTRODUCTION

For designing electromagnetic structure photonic crystal fiber (PCF) is the best alternative platform [1,2]. Now a days PCF proposed a novel design which is used in telecommunication, medicine, spectroscopy and sensor technology [1]. According to guiding mechanism PCFs can be represented by two different types. One is index guiding which conduct light by internal reflection and the other one is photonic band gap which regularly spread air holes in the cladding explore photonic band gap and a designed error in the center forms of the fiber core.In the PCFs it offers a remarkable diversity of possible geometries exploit the feature, volume and arrangement of air holes in micro-structured cladding. The nonlinear properties, transmission and the dispersion properties of the fiber are controlled by the air-hole diameter and hole-to-hole spacing [3-15].

Having a large number of negative dispersion in this dispersion compensating fibers (DCFs), the coupling between two space separated unbalanced concentric modes which support two permeable modes one is inner mode and another one is outer mode. By appropriate design mode matching can create between these two modes at the necessary wavelength. After a lot of analyses have been accomplished that higher negative dispersion can be found in triangular lattice PCFs. Here we have worked strictly for achieving higher negative dispersion value with square lattice. For certain properties square lattice PCF is beneficial compare with triangular lattice PCF. Square-lattice displays board range of individual mode operation with the same d/Λ value compared to triangular-lattice [16]. The triangular-lattice effective area is lower than square-lattice, construct the former best high-power management [17]. Birks et. al who first introduced the dispersion compensation fiber which guide the lower compensation bandwidth [17]. Moreover, advantages of higher birefringence fibers is one of the most hopeful applications for rise of PCFs. It is proved that, a large wide spectrum of PCFs non-linear properties only allows a new light resources. Though the design realization a light effective area and improve nonlinearity has accommodated a comprehensive range of source parameters than operable fibers. High negative dispersion provides a better performance for long distance transmission system [18].

According to different geometry proposed in Ref [19] which gained plentiful negative dispersion of –204.4 ps/(nm.km) requiring enhance fiber to compensation the accumulated dispersion at 1550nm of wavelength. Now a day a large number of PCF designs have been proposed for accosting the issue of broadband dispersion compensation dynamic non- linearity simultaneously. Broadband circular reparation for single mode circular PCF (C-PCF) is proposed in Ref [20] which gained a huge dispersion peak of about −386.57 to −971.44 ps/(nm.km) is probable to achieve the wavelength range from 1340 to 1640 nm. Furthermore, doping the intimate core create the fabrication process too much complicated. A hybrid PCF is proposed in Ref [21] which achieved a negative dispersion of −356 to −1189 ps/(nm.km) and gave a high birefringence and nonlinearity of 3.45×10^{-2} and 39 $W^{-1}km^{-1}$ gradually wavelength from 1350 nm to 1630 nm simultaneously.

According to requirements, we proposed a broadband dispersion compensating PCF based on square-lattice formation. This geometry has been exhibit for transmitting optical light from inner core to outer core at the continuation point. Our numerical exploration displays a high negative dispersion coefficient of −610 to −1080 ps/(nm.km) over a mass wavelength ranging 1340 nm to 1640 nm. Moreover, the proposed PCF formation has a birefringence 1.2×10^{-3} at the same wavelength which is compatible in great speed optical communication process for efficient dispersion reparation.

II. GEOMETRIC STRUCTURE

Figure 1 shows cross sectional geometry of the proposed fiber with air hole distributions. The proposed PCF generally form only of a single material silica which has a potential impact on the PCF dispersion. The central air-hole is missing, forming it the inner core. On the contrary all the other circular air holes are act as cladding. The proposed S-PCF contains circular air holes only. The symphony of the core of the proposed S-PCF is maintained strictly by keeping all the air holes circular. To increase the local refracting index for making the ring as the outer core circular air-hole diameter is reduced. So, by constructing the structural parameters of PCFs, it can be gained a PCF with great features; high nonlinear coefficient and high negative varicolored dispersion, along with ultra-high birefringence in individual frequency regimes.

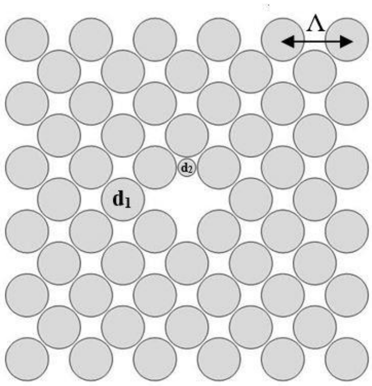


Figure 1: Cross-sectional view of proposed square PCF.

III. MATERIAL AND METHOD ANALYSIS

The circular FEM accurately matched boundary condition is used to verify the result of the following properties of proposed PCF. We use Commercial full vector finite element software (COMSOL 4.2) to verify the modal properties of the proposed PCF. The background of the proposed PCF generally is taken to be silica whose refractive index has been considered through Sellmier's equation. Here some major part of designing PCFs like dispersion D, Birefringence B, nonlinear coefficient γ and effective area A_{eff} will be described. The dispersion feature can be spontaneously controlled by modifying the shape, size and pitch of the air holes. The chromaticdispersion D(λ) is calculated from effective index of the elementary mode n_{eff}versus the wavelength using

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

Here λ is denoted as wavelength, c is the velocity of light in the vacuum, Re[n_{eff}] is considered as real part of effective indices . The birefringence B is calculated by the equation given it below:

$$B = |n_x - n_y|$$

Here n_x and n_y is the effective refracting index of two perpendicular polarization modes. The nonlinear coefficient γ is calculated by using:

$$\gamma = (\frac{2\pi}{\lambda})(\frac{n_2}{A_{eff}})$$

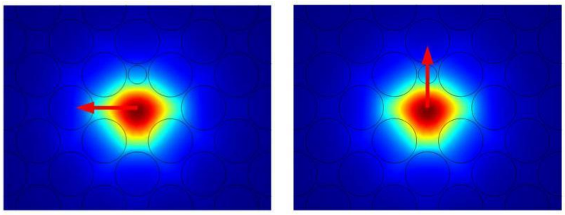
Here A_{eff} is denoted as the effective area which can be calculated by the following equation

$$A_{eff} = (\iint |E|^2 dxdy)^2 / \iint |E|^4 dxdy$$

Where E is denoted as the electric field.

IV. RESULTS AND DISCUSSION

Figure 2 shows the optical field distribution of fundamental modes x and y polarization at the operating wavelength of 1550nm. For broadband dispersion, it is researched that the negative dispersion curve gains a negative dispersion slope of operable single mode fiber. According to research result, the optical light sharply confined into core part. The chromatic dispersion coefficient is obtained about −1020 ps/(nm.km) at the operating wavelength of 1550 nm which is quite higher than Ref. [21].



(a) (b)

Figure 2: Optical Field distributions of fundamental modes at 1550 nm for (a) x polarization and (b) y-polarization

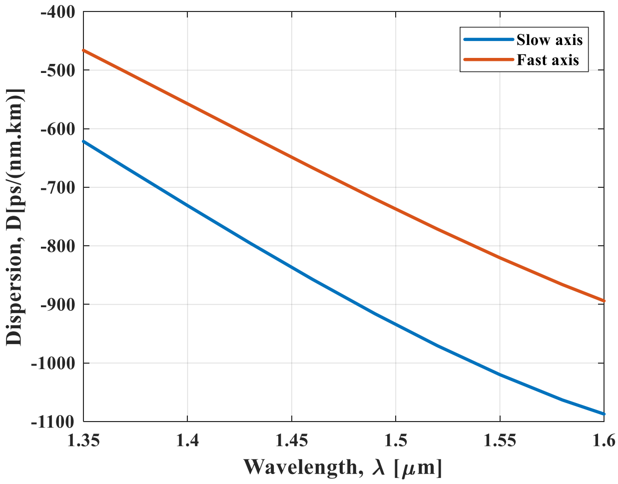


Fig. 3. Dispersion as a function of wavelength for fast axis and slow axis using optimum design parameters: Λ = 0.76µm and d_1 = 0.52µm and d_2 =0.3µm.

A simple method is used to optimize the parameters and considered y-polarized mode to get optimum results. For broadband dispersion, the optimized parameters Λ=0.76 µm, d_1 =0.72µm and, d_2 =0.30 µm are considered. Figure 3 displays the dispersion coefficient versus wavelength for the proposed S-PCF for the optimized parameters. The dispersion value diverges from -470 to -897.5 ps/(nm.km) for fast axis -610 to -1080 ps/(nm.km) for slow axis respectively atwavelength range of 1350nm to 1600 nm.

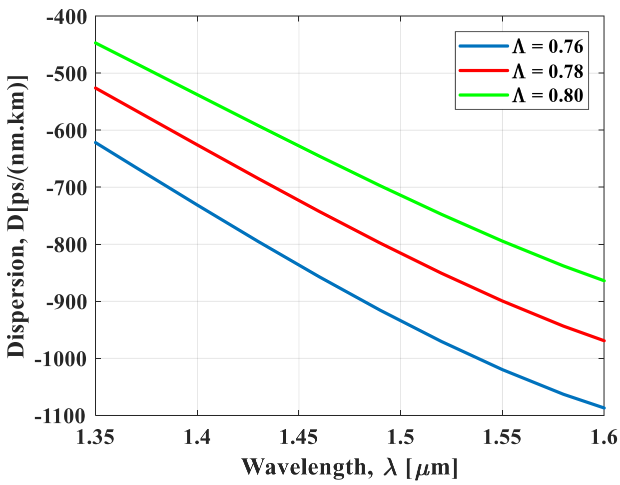


Fig. 4. Effect of dispersion by varying the pitch Λ = 0.76 µm; Λ = 0.78 and Λ = 0.80 µm.

Figure 4 illustrated the pitch variation calculation where, d_1 =0.72µm and, d_2 =0.30µm is considered as constant value. According to the pitch variation (Λ) values are Λ=0.76,0.78 and 0.80 at operating wavelength of 1550nm, the results are -1020, -899.6 and -794.6 ps/(nm.km), respectively. By reducing pitch, the higher negative dispersion can be obtained. Hasan et.al showed that PCF can recompense for the dispersion co-efficient of 100 times.

Now, in figure 5 demonstrate the pitch variation d_1 where Λ and d_2 are considered as constant. Here d_1 values are 0.72,0.68 and 0.70 at the operating wavelength of 1550 nm and the results are -1020, -993.5 and -966.5 ps/(nm.km) respectively.

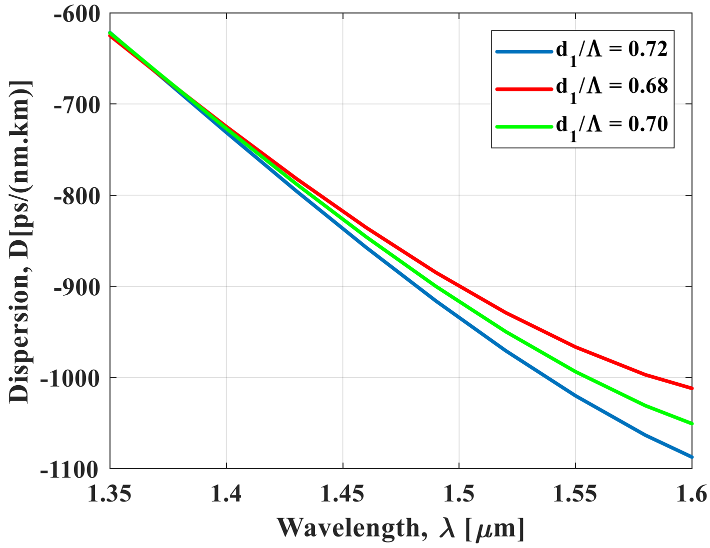


Figure 5: - Dispersion vs wavelength where d_1/Λ = 0.72, 0.68 and 0.70.

Figure 6 exhibits the pitch variation d_2 and keeping Λ and d_1 are constant. At the operating point 1550 nm the values of d_2 are 0.30,0.28 and 0.32 and the gained results are -1020, -988.6 and -1052 ps/(nm.km), respectively.

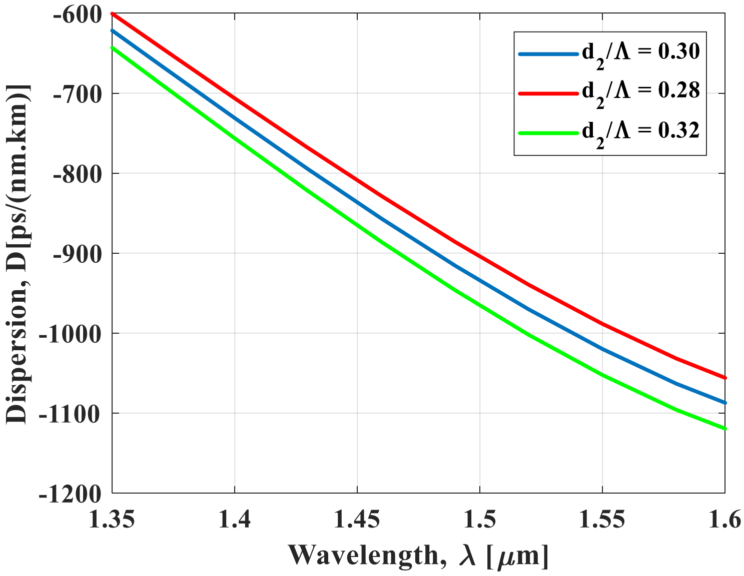


Figure 6: - Dispersion vs wavelength where d_2/Λ= 0.30, 0.28 and 0.32.

Figure 7 represents an illustration of the effect on varying pitch of the dispersion characteristics from ±1% to ± 2 %. At operating wavelength of 1550nm, the gained result for ± 1% of pitch is -972.3 ps/(nm.km) and -1068 ps/(nm.km) respectively and for ± 2% of pitch the result is -924.7 ps/(nm.km) and -1115 ps/(nm.km) respectively. The average optimum value for pitch is -1010 ps/(nm.km) at 1550 nm wavelength.

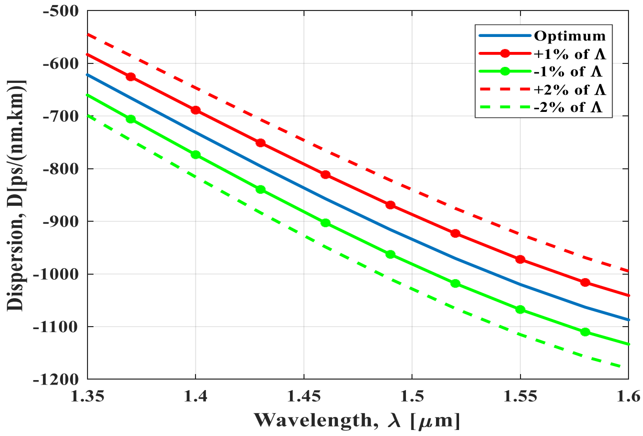


Fig. 7. Effect of dispersion while varying the pitch (Λ) value from ± 1% to ± 2 %.

Figure 8 shows the result of birefringence. From Fig. 8 it is clearly observed that birefringence is increase according to wavelength. In our proposed design the birefringence has been obtained about 1.2×10^{-2} at operating wavelength of 1550 nm with the optimum design parameters. In our proposed S-PCF has ultra-high birefringence which gives a great impression in telecommunication system.

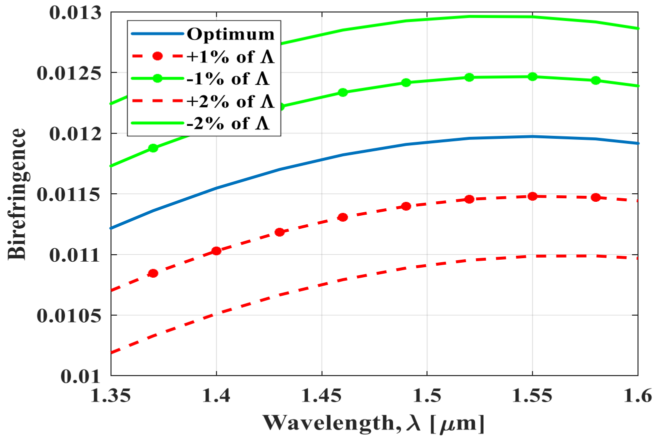


Figure 8: - Birefringence properties of S-PCF.

In Fig. 9, the nonlinear coefficient is plotted against wavelength by keeping the diameters of the air holes d_1 and$d_2$constant while the pitch Λ is varied. This is to account for the accuracy of the manufacturing process in getting the correct pitch. The nonlinear co-efficient is about 88 $w^{-1}km^{-1}$ at operating wavelength of 1550nm with the optimum design parameters.

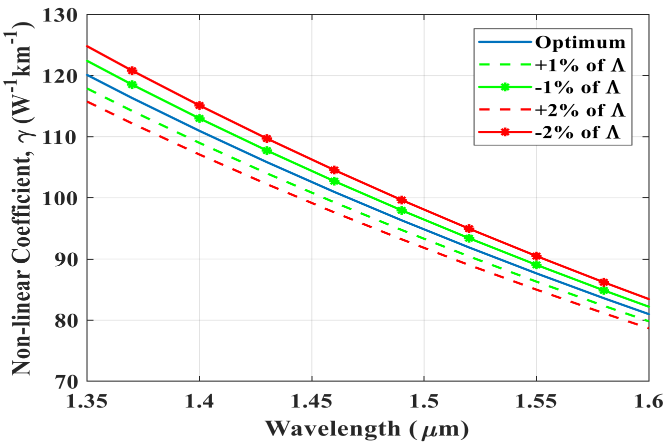


Fig. 9. Effect of changing pitch on nonlinear coefficient.

Table 1 is about comparison between proposed PCFs design and recent related design of PCFs. Through this comparison it displays the dispersion(D), birefringence (B), non-linear co-efficient (γ) and effective area(A_{eff}) at operating wavelength of 1550 nm. From table 1 it is clearly noticed that our proposed PCFs results is better than in case of dispersion and non-linear co-efficient term. Our proposed PCFs negative dispersion is 1.78,1,58 and 1.68 times higher in compare to [22, 23,24] respectively except [21]. Moreover, in proposed PCFs the non-linear co-efficient (γ) is 2.25, 1.66 and 1.93 times higher in compare to [21, 22,23], respectively. Highly nonlinear property is widely used in optical microcavity for the application in sensing [25-30]. So, the application of the proposed fiber is fiber optic transmission system as well as sensing.

Table 1: Comparison between properties of the proposed S-PCF and other PCFs at 1550 nm wavelength.

PCFs	D(λ)$ps/(nm.km)$	B=$\|n_x$-$n_y\|$	γ($w^{-1}km^{-1}$)	$A_{eff}(um^2)$
[21]	-1054.4	3.45×10^{-2}	39	----------
[22]	-578.5	2.64 ×10^{-2}	53.10	1.92
[23]	-650.0	2.10 ×10^{-2}	45.50	---------
[24]	-613.0	2.10 ×10^{-2}	------------	2.80
Proposed PCF	-1020	1.2 ×10^{-2}	88	1.46

Fabrication process of proposed PCFs is comparatively easy than others. To fabricate any shape of PCFS, there are lots of method have been proposed but those methods have some limitations also. Because of proposed PCFs may face some difficulties. Due to large air hole uniformity, the difficulty of fabrication will be reduced in the Proposed PCFs structure, Issa et al. [31] given a method called sol-gel to fabricate the S-PCF with all structures and they give the freedom to balance shape, air-hole size, and spacing. Now in case, for the proposed PCFs the sol-gel casting technique provides design flexibility that will be important.

V. CONCLUSION

In this work, we have theoretically researched chromatic dispersion compensation property displayed by square-lattice geometry of the PCFs based on pure silica. Throughout the researched result, proposed PCFs gained high negative dispersion value of -1020 ps/(nm.km), birefringence of 1.2×10^{-2}, non-linear co-efficient of 88$W^{-1}km^{-1}$ at 1550nm wavelength. The modal properties of S-PCF like birefringence, nonlinearity, effective are investigate by using FE (finite element) techniques. To most beneficial sensation, these results give more promising percolation into structural PCFs with important leading properties compare to earlier fibers. For future applications like high-bit-rate transmission networks and sensing systems it is hoped that proposed S-PCF will be very suitable.

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