Analysis of Loss & Dispersion of Photonic Crystal Fiber

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Abstract: **We have theoretically investigated the dispersion and confinement loss characteristics of dual-core PCF, based on square-lattice and hexagonal-lattice geometry by varying different parameters. The fiber exhibits a very large negative dispersion because of rapid slope change of the refractive indices at the coupling wavelength between the inner core and outer core. The dependence of different geometrical parameters, namely, hole-to hole spacing (Λ) and different air-hole diameter (d), was investigated in detail. By proper adjustment of the available parameters, a high negative dispersion value of −47,500 ps/nm/km has been achieved in case of square-lattice and -106040ps/nm/km around the wavelength of 1550 nm. Our proposed fiber will be an excellent device for dispersion compensation in long-haul data transmission as being thousand times more than the available DCFs.**

Keywords: **dual-core PCF, hole-to hole spacing (Λ) and different air-hole diameter (d).**

1. INTRODUCTION

Photonic crystal fibers (PCFs) [1, 2] or Holey Optical Fibers offered a tremendous variety of possible geometries utilizing the *shape, size,* and *positioning* of air-holes in the microstructured cladding. The air-hole diameter (d) and hole-to-hole spacing (Λ) not only control the dispersion properties, but also the transmission and the nonlinear properties of the fiber as well. Achieving very high negative values of dispersion around the communication band has been the target for long time [3–15] .Chromatic dispersion in single mode optical fibres causes broadening of optical pulses and limits the data transmission rate in broadband wavelength division multiplexing (WDM) systems.

The principle behind having a very large negative dispersion in these Dispersion Compensating Fibers (DCFs) being the coupling between two spatially separated asymmetric concentric coreswhich support two leakymodes: inner mode and outer mode. By proper design, mode matching can take place between these two modes at the desired wavelength. A few analyses have been performed to realize high negative dispersion with triangular lattice PCF [8–15]. In this work we have studied rigorously towards achieving high negative dispersion value with regular square lattice and hexagonal lattice. Square-lattice based PCF is superior to triangular-lattice PCF for certain properties [16, 17]. Square-lattice PCF shows wider range of single mode operation with the same d/Λ value compared to the triangular one [16].The effective area of square lattice PCF is higher than triangular one, making the former better for high power management [17]. Square-lattice PCF can better compensate the inline dispersion around the 1550nm wavelength than the triangular-lattice PCF [17].

In recent times, a square-lattice PCF preform has been realized with a standard fabrication process, stack and draw, in order to study the localization and control of high frequency sound by introducing two solid defects in the periodic distribution of air-holes [18].Thus the technological feasibility of the square-lattice PCFs has been demonstrated, since the final PCFs can be obtained by drawing the intermediate prepared preforms [18]. In another example, experimental study of negative refraction has been studied with squarelattice photonic crystal [19]. So, square-lattice PCF can be experimentally realized like that of the usual triangular-lattice PCF.

2. GEOMETRY OF THE STRUCTURE AND ANALYSIS METHOD

Cross-sectional geometry of the proposed/studied fiber has been shown in Figure 1 and Figure2. It is well known that a triangular lattice PCF is usually described by air-hole diameter d and hole-to-hole distance (also called pitch) Λ. Now, we use Λ as the hole-to-hole spacing both in horizontal and vertical directions in the square-lattice PCF geometry with $d1$ as the diameter of the bigger air- holes. The central air-hole is missing, making it the inner core. The inner cladding is formed by the first two air-hole rings with air-hole diameter $d1$. The diameter of the air-holes for the 3rd air-hole ring is reduced, thereby increasing the local refractive index of the ring, making the ring as the outer core. The diameter of the air-holes in this outer ring is represented as $d2$. The rings of holes beyond the third rings form the outer cladding with air-hole diameter $d1$.The background of the fiber is taken to be silica whose refractive index has been considered through Sellmeier's equation:

$n(\lambda) = [1+\frac{0.6961663\,\lambda}{\lambda-(0.0684043)}+\frac{0.4079426\,\lambda}{\lambda-0.1162414}+\frac{0.8974794\,\lambda}{\lambda-9.896161}]^{1/2}$

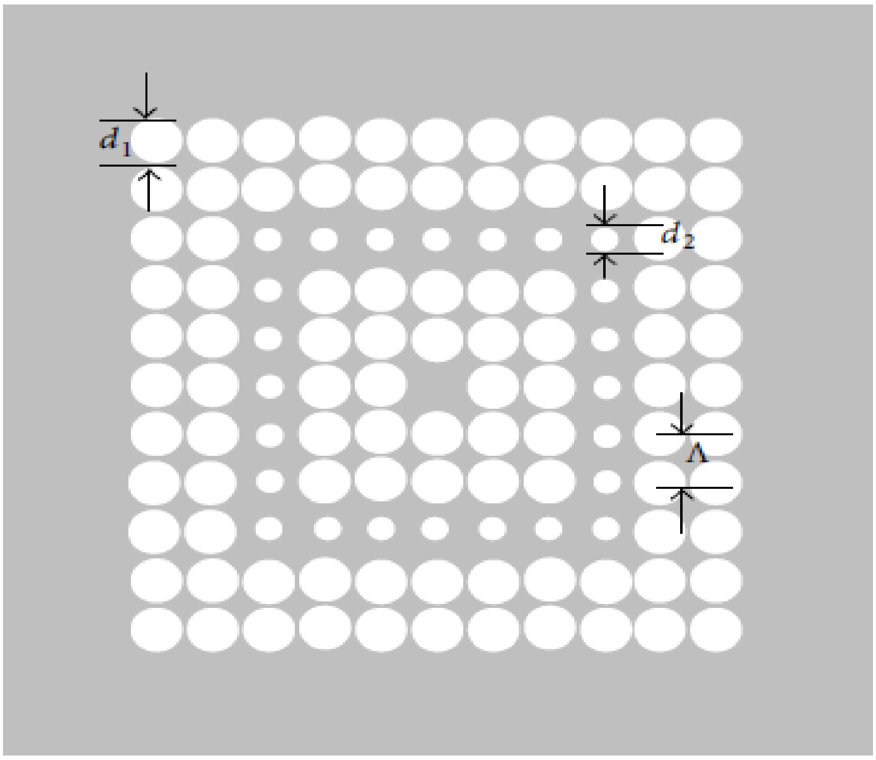

Figure1:- Cross-section of the proposed/studied fiber. The air-hole diameter of the third air-hole ring is reduced to create the outer core, thereby creating the dual-core structure.

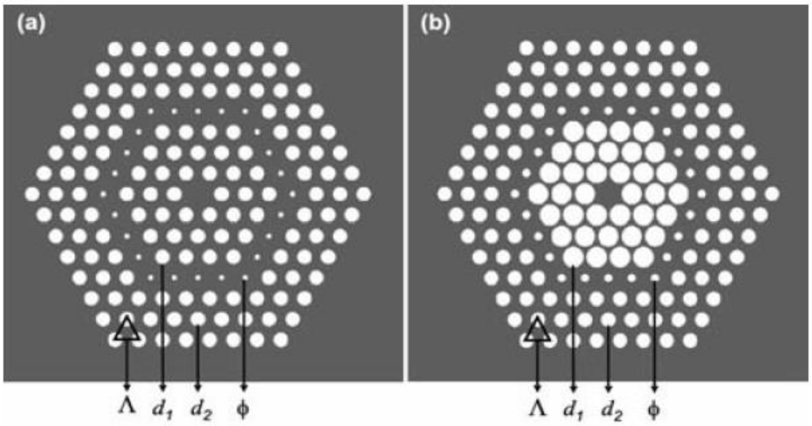

Figure2:- View of cross section of the dual-concentric-core dispersion compensation photonic fibers of crystal

We have calculated the dispersion parameter using

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

with Re($n$eff) being the real part of the effective indices obtained from simulations and c being the speed of light in vacuum.

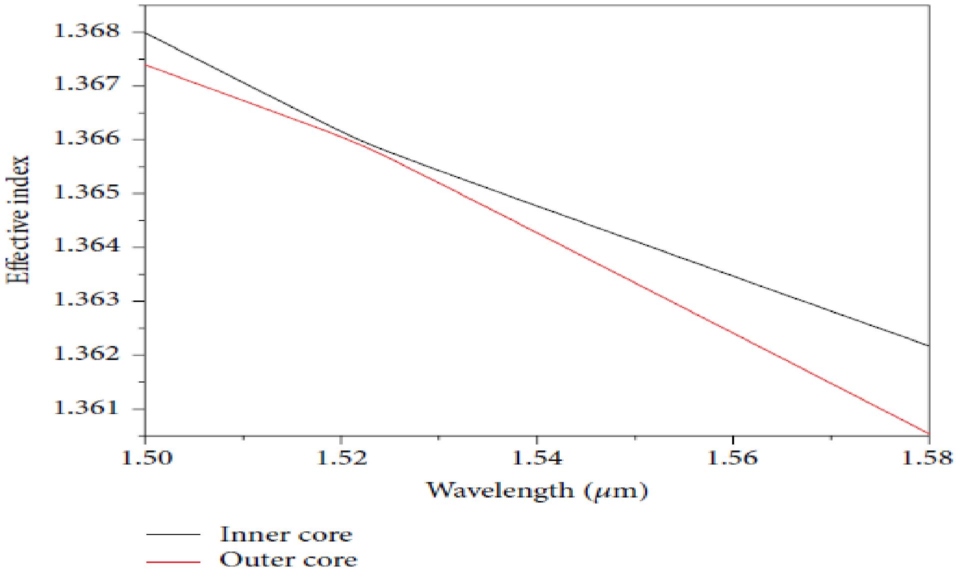

Figure 3:- Variation of real part of the effective indices for both the cores (inner core-black line and outer core red-line) of square lattice PCFs

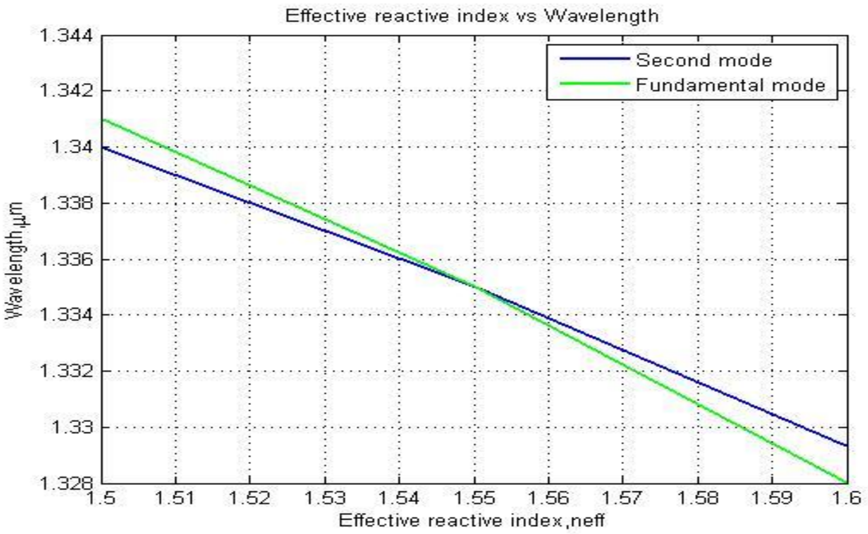

Figure 4:- Variation of real part of the effective indices for both the cores (inner core-black line and outer core red-line) of hexagonal lattice PCFs.

The confinement loss for the structures has been calculated through

$$L = \frac{2\pi}{\lambda}\frac{20}{\ln(10)}10^{6}Im(n_{eff})\frac{dB}{m}$$

where Im($n$eff) is the imaginary part of the effective indices (obtained from the simulations) with λ is in micrometer.

3. DISPERSION ANALYSIS OF THE STRUCTURE

We started our dispersion analysis with Λ = 1.40μm and $d1/\Lambda$ = 0.8 and $d2/d1$ = 0.5. A very high negative dispersion of −21,700 ps/nm/km around the wavelength of 1522 nm was observed as shown in Figure 4.The corresponding variations of effective index have been presented in Figure 3 & 4 which shows a distinctive change of slope at the coupling wavelength.The variation of the indices for both the inner and outer cores is presented in Figure 3 & 4. The cross-off between the two cores (inner core and outer core) can be better viewed from Figure 3 which represents the imaginary part of the refractive indices (Im($n$eff)) of the two cores. The two curves meet at the coupling wavelength of 1522 nm. After the coupling,most of the power in the inner core goes to the outer core.This principle can be used for suppressing spontaneous emission of certain wavelengths.

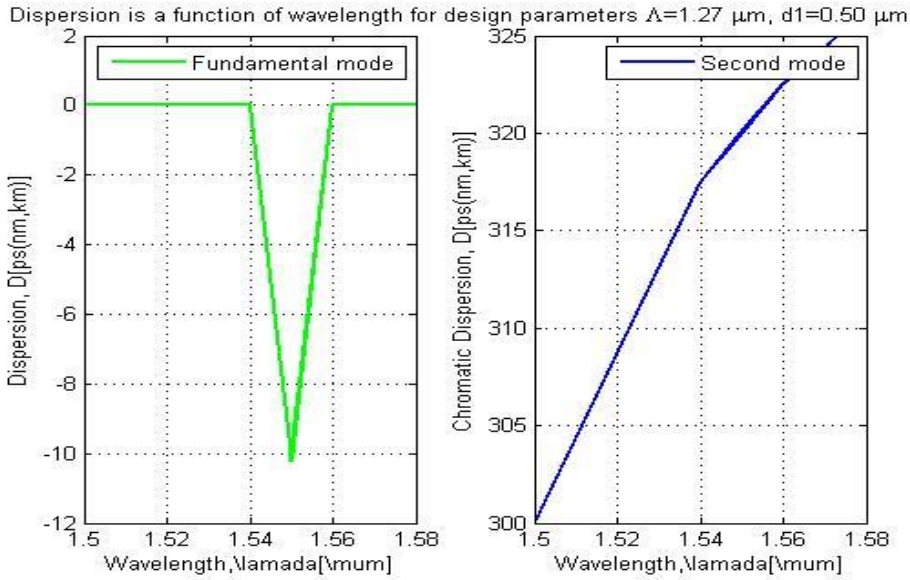

Figure 5:- Dispersion analysis of Hexagon lattice PCF.

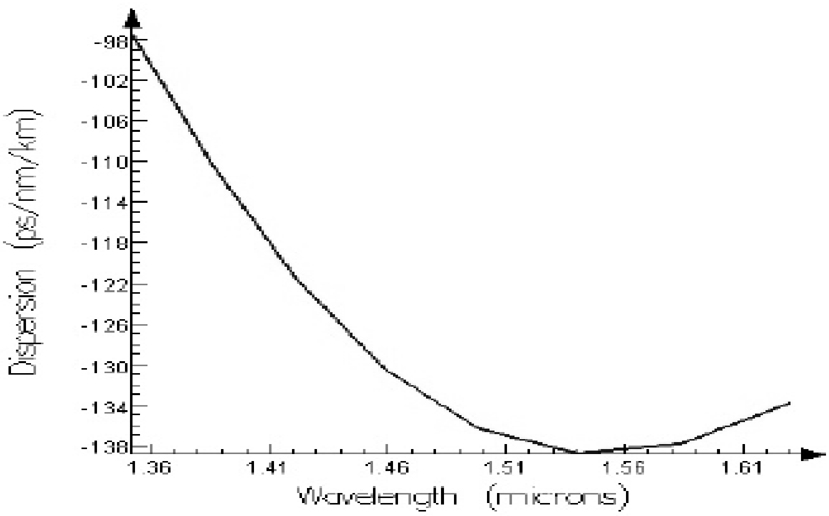

Figure 6:- Dispersion analysis of secondary core of Square lattice of PCF.

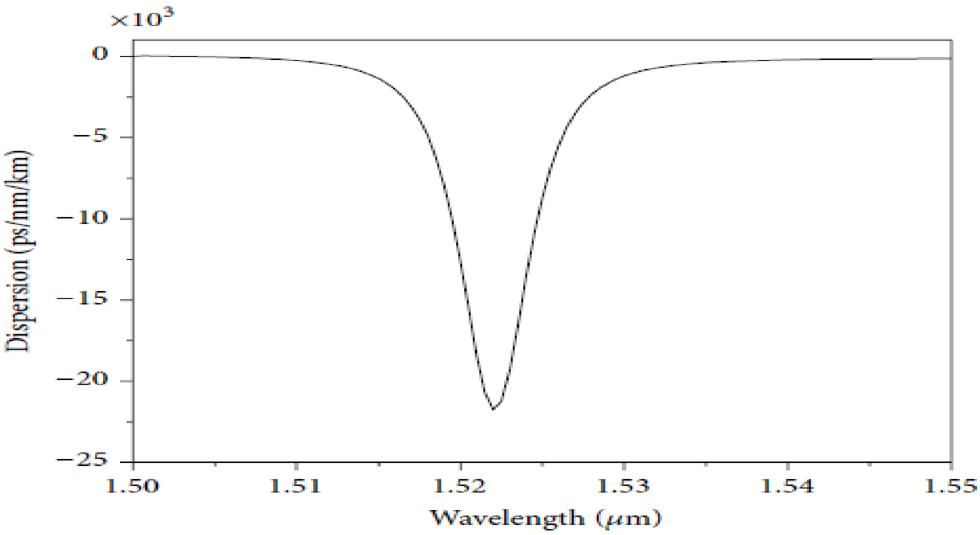

Figure 7:- Dispersion analysis of fundamental core of Square lattice of PCF.

The dependence of dispersion upon the geometrical parameters ($d1$, $d2$, and Λ) has been presented in Figures 5 & 6. The dependence of the variation of bigger air-holes ($d1$) upon dispersion has been presented in Figure 5 & 6. For this purpose we have kept Λ = 1.40μm, keeping $d2/d1$ = 0.5.From the figure it is clearly visible that the absolute values of the biggest negative dispersion increase as $d1$ increases (air filling rate increases), the corresponding coupling wavelength is red-shifted, and the absolute values of the dispersion slope increase, but the value of full width at half maximum (FWHM) decreases. From the figure it can be easily observed that with an increase of negative dispersion the corresponding FWHM decreases making the product of bandwidth and peak dispersion almost constant. The dispersion curves of PCFs for different d 2 have been presented in figure with Λ = 1.40μm and $d1$ = 1.12μm. The figure clearly represents that values of the biggest negative dispersion decrease as $d2$ increases (air filling rate of the outer core increases), the corresponding coupling wavelength is red-shifted, and the absolute values of the dispersion slope decrease. Here with the increases of outer air-hole diameter the peak dispersion decreases, but the corresponding FWHM increases keeping the product of bandwidth and peak dispersion almost constant.The dependence of hole-to-hole distance (Λ) upon dispersion has been presented in figure . For this purpose we have considered two different PCFs with $d1/\Lambda$ = 0.8 and $d2/d1$ =0.5. figure 7 clearly represents that the absolute values of the biggest negative dispersion reduces appreciably as Λ increases and the analogous wavelength is red-shifted and the absolute values of the dispersion slope decrease significantly.

4. CONCLUSIONS

In this paper we have theoretically investigated chromatic dispersion compensation property exhibited by square-lattice and hexagonal–lattice geometry of the PCFs based on pure silica. We have extensively studied the effect of different geometrical parameters upon dispersion towards achieving ultra-negative dispersion.We have shown that with an increase of bigger air-hole diameter, the peak dispersion is red-shifted with higher negative dispersion at the cost of narrower FWHM while an increase of smaller air-hole diameter in the outer core again red-shifted the coupling wavelength but with smaller values of negative dispersion.Changing hole-to-hole distance has the effect of red-shifting the coupling wavelength with smaller values of negative dispersion. Based upon the above findings we could achieve an ultra-negative dispersion of −47,000 ps/nm/km for square lattice and -106040 ps/nm/km for hexagonal lattice around 1550nm of wavelength by properly changing the parameters. Our designed fiber will be very useful for dispersion compensation in long-haul data transmission some thousand times more than the available DCFs. Thebasic principle of power transformfrominner core to the outer core after the coupling can be applied for suppressing spontaneous emission after a particular wavelength.

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