Performance Analysis of Flattened dispersion on silica based PCF of Hybrid Hexagonal lattice

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Abstract— The technology of optical fibers has improved dramatically in recent decades. While the basic principle of guiding light, total-internal reflection, has been known for a long time, the ability to manufacture materials such as silica into very pure, very small, and very long strands has only recently emerged. Researcher across the world is starting to investigate a new kind of optical guidance. In this work, I focused on understanding and analyzing the model behavior of micro-structured fiber. Micro-structured fibers are fibers with a complex dielectric topology, and offer a number of novel possibilities, compared to standard optical fiber. It has been reported that PCF can realize endlessly single-mode guiding, controllable nonlinearity, flexible chromatic dispersion over a wide wavelength range, large effective area and highly birefringence. Generally, PCFs can be classified into two different types by their light-guiding mechanism.

Keywords— *photonic crystal fiber(PCF), Finite difference time domain(FDTD), dispersion characteristics, Effective refractive index (η_{eff}), Transparent boundary condition (TBC).*

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I. INTRODUCTION

During the last decade the scientific and technological interest of fiber optics research area has been focused on a special type of optical fiber, which is microstructured optical fiber or photonic crystal fiber (PCF)[1], with very interesting guiding properties. Photonic crystal fibers (PCFs) plays a vital role in optical communication system because of their various properties including endlessly single-mode[4], high nonlinearity , broadband negative chromatic dispersion and high birefringence [10] , which clearly surpass those of conventional optical fiber[3].

In conventional optical fiber When light is directed into an optical fiber the effectiveness of the wire depends on its ability to transmit the light ray in long distance applications, with little scattering or little absorption of the light as possible. These scattering or absorption losses can be reduced when the light ray must exhibit total internal reflection within the wire. Thus when considering the propagation of light for an optical fiber, one must know the refractive index of the dielectric medium. The typical fibers today are made out of glass or plastic since it is possible to make them thin and long. The fiber is constructed with a core of a high index surrounded by a layer of cladding of lower index.

Many PCF designs have been proposed to achieve ultra-flattened chromatic dispersion. Such as hexagonal PCFs (H-PCF), square PCFs(S-PCF), circular PCFs(C-PCF), triangular PCFs. H-PCFs are the most conventional type of PCF structures and are the most widely used [2]. Controllability of chromatic dispersion in PCFs is very important for realistic applications. In particular, ultra flattened dispersion PCFs are indispensable for optical data transmission systems over a broadband wavelength range because of the reduction of the accumulated dispersion difference in telecommunication bands without any zero-dispersion wavelength. Conversely, research is still going on to make it more enhanced by limiting dispersion and all other losses. The finite difference time domain method [4] and the TBC boundary condition is used for the simulation boundaries [2]. Internal structure and basic view of PCF structure is shown in fig 1 and fig 2.

PCF has number of properties which makes it very useful in optical communication system. The very important feature is to achieve zero dispersion and flattened dispersion over a wide wavelength range. This zero dispersion is achieved by varying the design parameters of PCF structure. These design parameters of PCF are hole pitch (^), hole diameter, number of rings, radius of major and minor axis of elliptical air holes. By varying these design parameters, and carefully designing the hybrid cladding micro structured PCF, the desired PCF features (i.e. low dispersion) can be achieved.

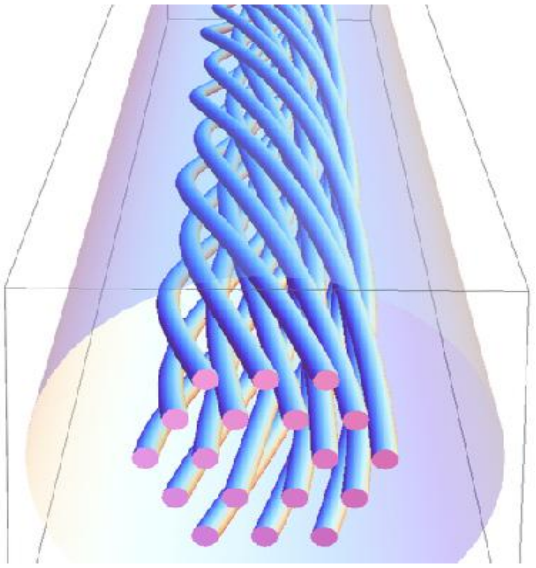

FIG 1. INTERNAL STRUCTURE OF PHOTONIC CRYSTAL FIBER

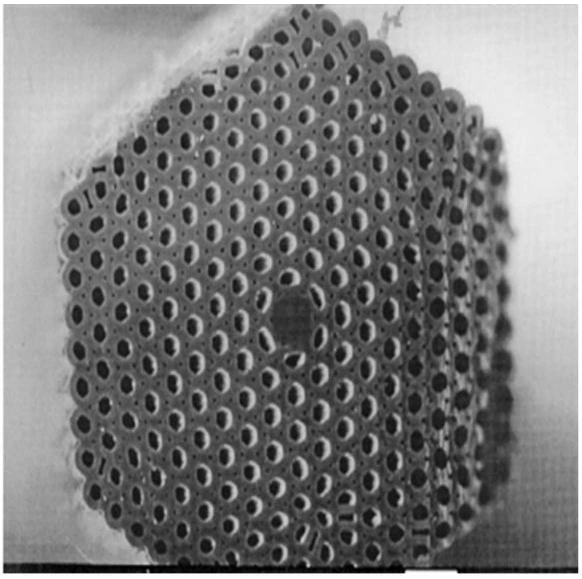

FIG 2. BASIC VIEW OF PCF

II. DISPERSION

Dispersion leads to broadening of transmitted pulses as they travel along the fiber. Pulses become indistinguishable at the receiver input due to the pulse broadening & overlapping with its neighbour. And this effect of overlapping between two pulses is known as inter symbol interference (ISI).The value of refractive index of silica glass is calculated by sellemier formula-

$$\varepsilon = n^2(\lambda) = 1 + \frac{A_1\lambda^2}{\lambda^2 - \lambda 1^2} + \frac{A_2\lambda^2}{\lambda^2 - \lambda 2^2} + \frac{A_3\lambda^2}{\lambda^2 - \lambda 3^2} \tag{1}$$

Where λ is the wavelength (µm).

For fused silica (fluorine-doped silica 1 mole %) sellmeier constants are

A_1=0.69616630 λ_1= 0.068404300µm

A_2=0.40794260 λ_2=0.11624140µm

A_3=0.89747940 λ_3=9.8961610 µm

Refractive index of the air hole is one. Material dispersion remains unchanged for different lattice structure of designed PCFs.

Refractive index of the Fused Silica Glass is 1.456. Refractive index of the air holes is 1.0 in vacuum.

The dispersion (D)[2] [6] of a PCF can be easily find out from the second order derivative of the mode index, $n_{eff} = \beta / k0$, with respect to wavelength. Once the mode index is solved, the chromatic dispersion parameter can be obtained.

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

Where D is Dispersion (ps/km/nm), λ is the wavelength (in µm); c is the velocity of light; n_{eff} is the effective index of core. The Chromatic dispersion [6]-[7] can be calculated as the sum of material dispersion and waveguide dispersion (also known as geometrical dispersion) as [26]

$$D(\lambda) \approx D_g(\lambda) + \Gamma(\lambda) D_m(\lambda) \tag{3}$$

Where $\Gamma(\lambda)$ is known as the confinement factor in silica and its value is close to 1.

Table 1 shows the material dispersion $D_m(\lambda)$ of fused silica glass its corresponding waveform is as shown in Fig. 3

TABLE 1
MATERIAL DISPERSION FOR FUSED SILICA GLASS

wavelength	Material dispersion
0.2	-3590.70
0.3	-3627.38
0.4	-2278.64
0.5	-768.57
0.6	-368.10
0.7	-204.07
0.8	-121.48
0.9	-74.15
1	-44.45
1.1	-24.22
1.2	-9.61
1.3	1.52
1.4	10.39
1.5	18.01
1.6	24.68
1.7	30.76
1.8	36.63
1.9	41.51
2	45.70

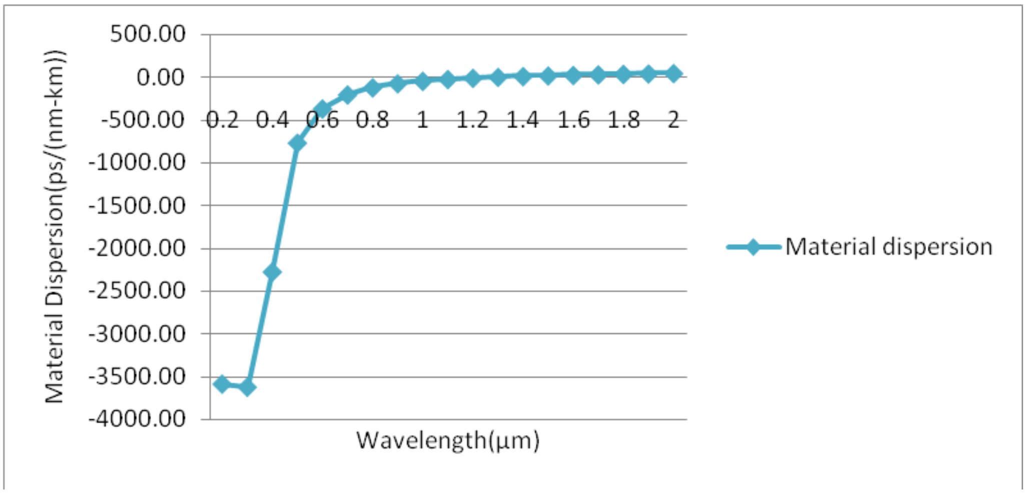

FIG. 3 MATERIAL DISPERSION OF FUSED SILICA GLASS

III. DESIGN & SIMULATION

In this paper 4 types of design are being proposed on the basis of effect of varying the dimension of air holes in the circular rings. All proposed PCF structures have different diameter of circular air holes while keeping the hole pitch(^) same as 2µm and have same number of rings which is equal to 6. According to the requirement of air holes size, the size of major axis radius and minor axis radius are changed [12]. Different diameters of circular air holes are created using elliptical waveguide. Elliptical waveguide is used to create circular and elliptical air holes by changing the dimensions of major and minor radius. Dispersion is calculated using FDTD numerical approach with transparent boundary condition (TBC) [15].

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3.1 Design-1

- This design is 6 ring structure in which first two rings have circular air holes with radius of 0.2µm and 0.3µm respectively
- 3rd & 4th rings are elliptical with major radius of 0.6µm and minor radius of 0.4µm
- 5th & 6th rings are circular with radius of 0.4µm & 0.5µm respectively.
- Cross section of design-1 is shown in fig.4. Figure shows the proposed PCF in which we find one missing air hole which makes solid core of PCF. Silica glass is used as a core material.

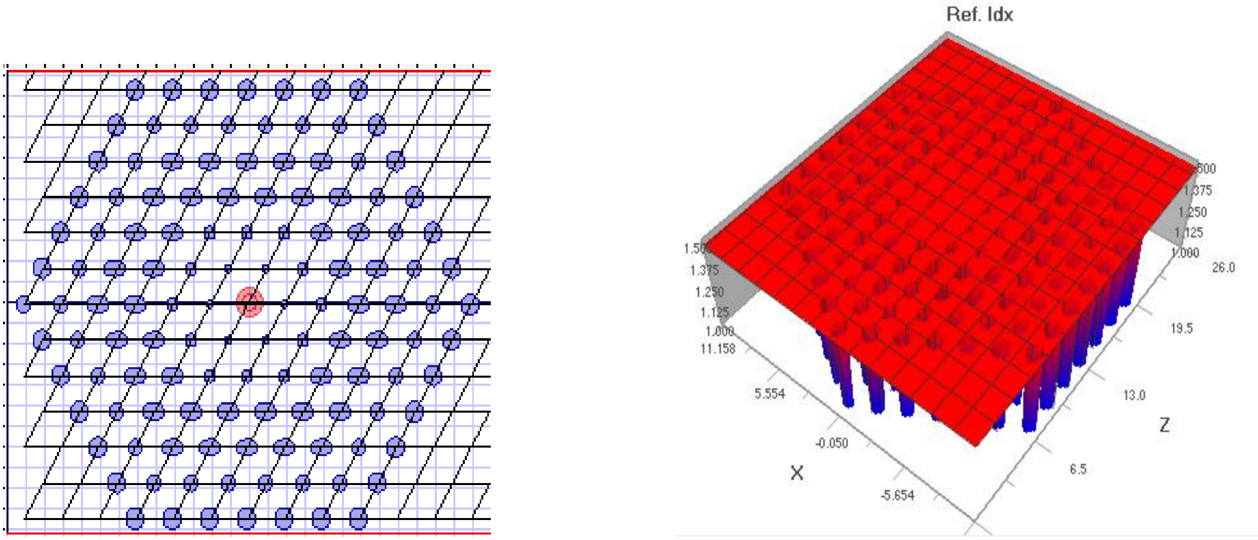

FIG. 4 CROSS SECTION OF PROPOSED PCF OF DESIGN-1

3.2 Design-2

- Design 2 is also a 6 ring structure in which 1st ring is elliptical with major radius of 0.4µm and minor radius of 0.3µm.
- 2nd ring is circular with radius of 0.4µm.
- 3rd ring is elliptical with major radius of 0.5µm and minor radius of 0.3µm
- 4th ring is elliptical with major radius of 0.6µm and minor radius of 0.4µm.
- 5th and 6th ring is circular with radius of 0.5µm. Cross section of design-2 is shown in fig.5

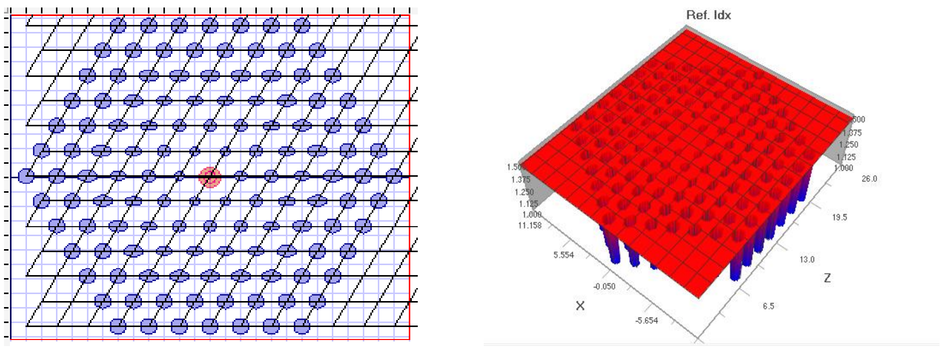

FIG. 5 CROSS SECTION OF PROPOSED PCF OF DESIGN-2

3.3 Design-3

- 1st &2nd ring is circular with radius of 0.3µm each.

- 3rd ring is elliptical with major radius of 0.5µm and minor radius of 0.3µm.
- 4th ring is elliptical with major radius of 0.6µm and minor radius of 0.4µm
- 5th & 6th rings are circular with radius of 0.5µm each.
- Cross section of design-3 is shown in fig.6

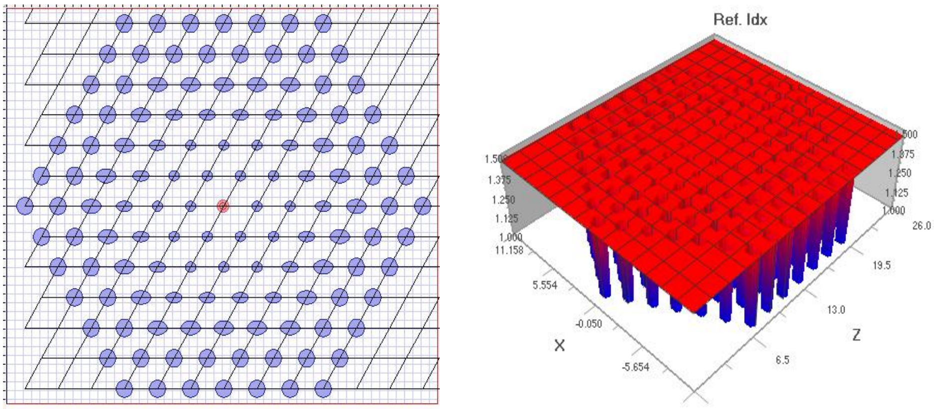

FIG. 6 CROSS SECTION OF PROPOSED PCF OF DESIGN-3

3.4 Design-4:

- 1st ring is circular with radius of 0.3µm.
- 2nd ring is elliptical with Major radius of 0.4µm and minor radius of 0.3µm.
- 3rd ring is elliptical with major radius of 0.5µm and minor radius of 0.3µm.
- 4th ring is elliptical with major radius of 0.6µm and minor radius of 0.4µm.
- 5th & 6th rings are circular with radius of 0.5µm each.

Figure shows the proposed PCF. In this PCF we find one missing air hole which make solid core of PCF. Silica glass is used as a core material. Cross section of design-4 is shown in fig.7

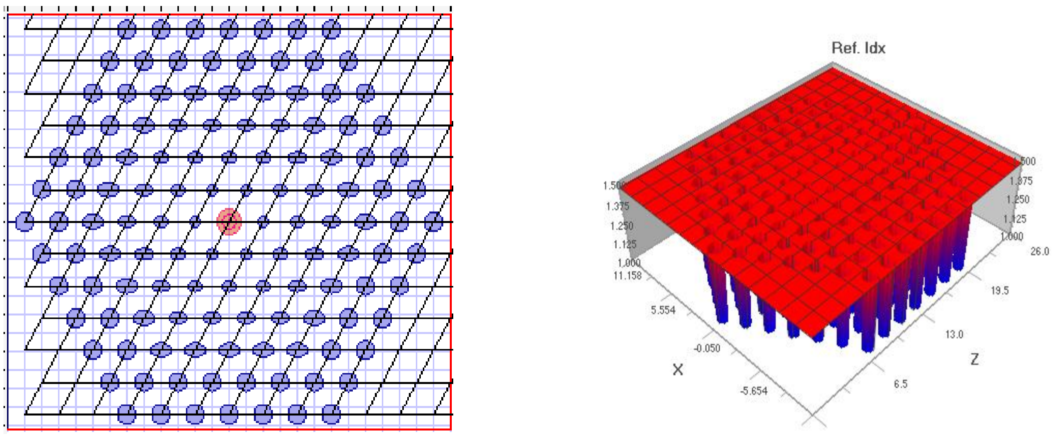

FIG.7 CROSS SECTION OF PROPOSED PCF OF DESIGN-4

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IV. SIMULATION RESULTS

I have already designed 4 PCF structures. Comparison of effective refractive index, waveguide dispersion, and chromatic dispersion of all of the designs are represented in table 2, table 3, table 4, and corresponding waveform also shown in fig 8, fig 9, fig10.

TABLE 2: EFFECTIVE REFRACTIVE INDEX OF DESIGN 1- DESIGN-4

wavelength	design-1	design-2	design-3	design-4
0.2	1.45711283	1.45698072	1.45716066	1.45707884
0.3	1.45632678	1.45598535	1.45626434	1.4561128
0.4	1.45563163	1.45528727	1.45527935	1.45521793
0.5	1.45510999	1.45471219	1.45447019	1.45462284
0.6	1.45445656	1.45381637	1.45377963	1.45385178
0.7	1.45369194	1.45273694	1.45271593	1.45278264
0.8	1.45274193	1.45140276	1.45158272	1.45156432
0.9	1.45171747	1.44996695	1.45025829	1.45019871
1	1.45063635	1.44843656	1.44887954	1.44875481
1.1	1.44952859	1.44684873	1.44745371	1.4472557
1.2	1.44841494	1.44521834	1.44600061	1.44573939
1.3	1.44729255	1.44357508	1.44457295	1.44420885
1.4	1.44618045	1.44192645	1.44316185	1.4426898
1.5	1.44507629	1.44028327	1.44178407	1.44119894
1.6	1.44398013	1.43865905	1.44044542	1.43973391
1.7	1.44289619	1.43706148	1.43914856	1.4383046
1.8	1.44182454	1.43549803	1.4379009	1.43691787
1.9	1.44076242	1.43397254	1.43670031	1.43557285
2	1.43971141	1.43248871	1.43554316	1.43427437

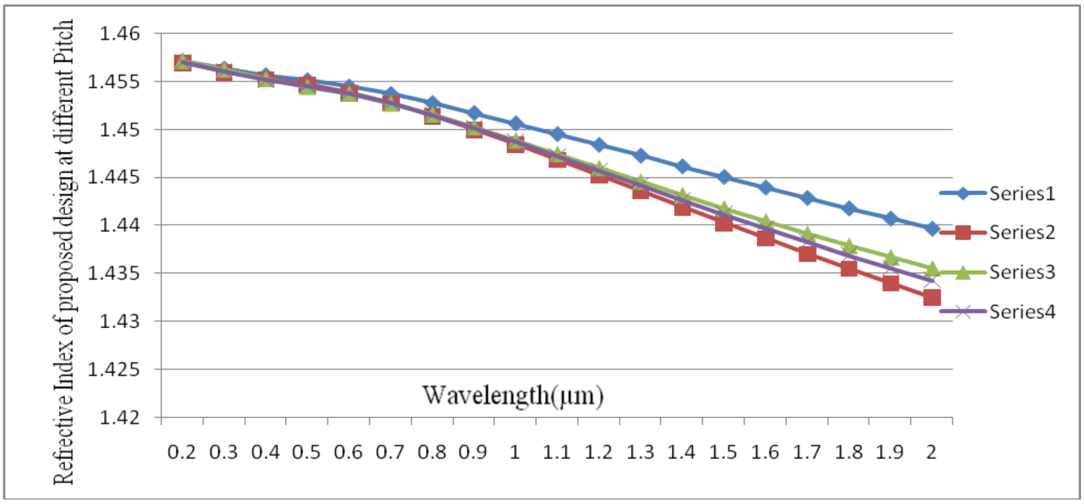

FIG. 8 EFFECTIVE REFRACTIVE INDEX (DESIGN-1 TO DESIGN-4)

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TABLE 3: WAVEGUIDE DISPERSION OF DESIGN 1- DESIGN-4

Wavelength	Design-1	Design-2	Design-3	Design-4
0.2	-4.69	-22.70	10.30	-0.94
0.3	-11.20	-25.40	2.26	-12.80
0.4	-10.20	-7.42	-12.70	-16.50
0.5	8.39	29.30	-1.66	14.60
0.6	27.00	47.20	34.90	46.10
0.7	32.50	46.40	41.10	43.40
0.8	26.10	36.90	33.80	34.80
0.9	16.10	26.10	26.00	26.90
1	9.66	21.00	14.70	17.20
1.1	4.33	14.30	6.99	9.53
1.2	1.31	7.37	-4.02	3.42
1.3	-2.14	1.97	-9.96	-4.00
1.4	-3.99	-2.86	-14.30	-10.90
1.5	-4.52	-8.76	-19.20	-14.50
1.6	-5.97	-14.20	-22.90	-18.70
1.7	-6.57	-18.80	-26.50	-23.00
1.8	-6.37	-22.80	-28.00	-25.90
1.9	-6.79	-25.80	-28.10	-28.70
2	-7.68	-28.40	-28.40	-31.90

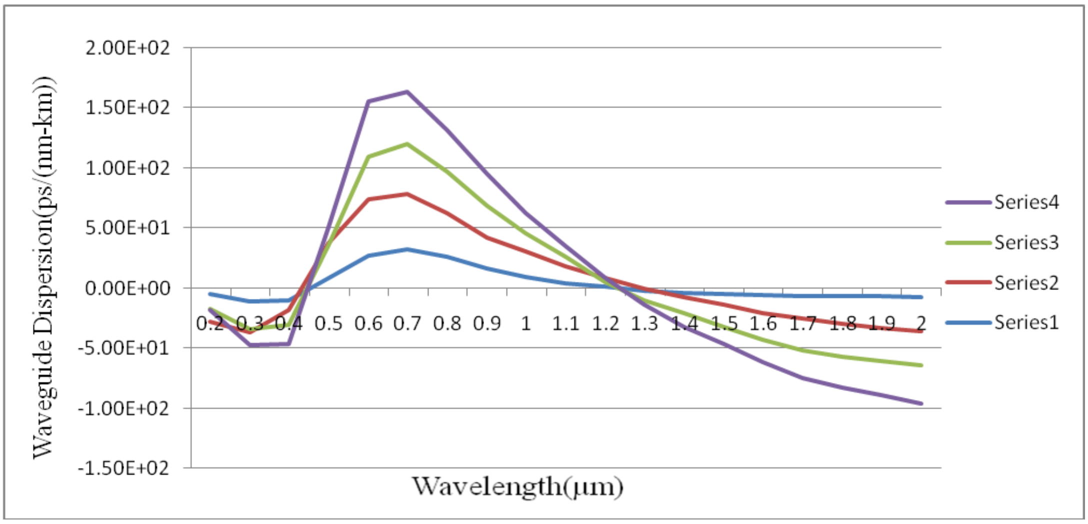

FIG. 9 WAVEGUIDE DISPERSION WITH WAVELENGTH (DESIGN-1 TO DESIGN-4)

TABLE 4: CHROMATIC DISPERSION OF DESIGN 1- DESIGN-4

	Chromatic Dispersion(Ps/(Nm-Km))			
Wavelength	Design-1	Design-2	Design-3	Design-4
0.2	-3595.39	-3613.44	-3580.37	-3591.64
0.3	-3638.55	-3652.77	-3625.13	-3640.23
0.4	-2288.85	-2286.07	-2291.37	-2295.15
0.5	-760.18	-739.30	-770.24	-753.97
0.6	-341.11	-320.94	-333.22	-322.01
0.7	-171.59	-157.68	-163.02	-160.66
0.8	-95.40	-84.62	-87.71	-86.66
0.9	-58.06	-48.02	-48.11	-47.20
1	-34.79	-23.43	-29.79	-27.28
1.1	-19.89	-9.96	-17.23	-14.69
1.2	-8.30	-2.23	-13.63	-6.19
1.3	-0.63	3.49	-8.44	-2.49
1.4	6.40	7.53	-3.89	-0.55
1.5	13.49	9.25	-1.17	3.56
1.6	18.72	10.49	1.75	6.02
1.7	24.19	11.93	4.22	7.71
1.8	30.25	13.85	8.59	10.73
1.9	34.72	15.70	13.41	12.78
2	38.02	17.29	17.32	13.84

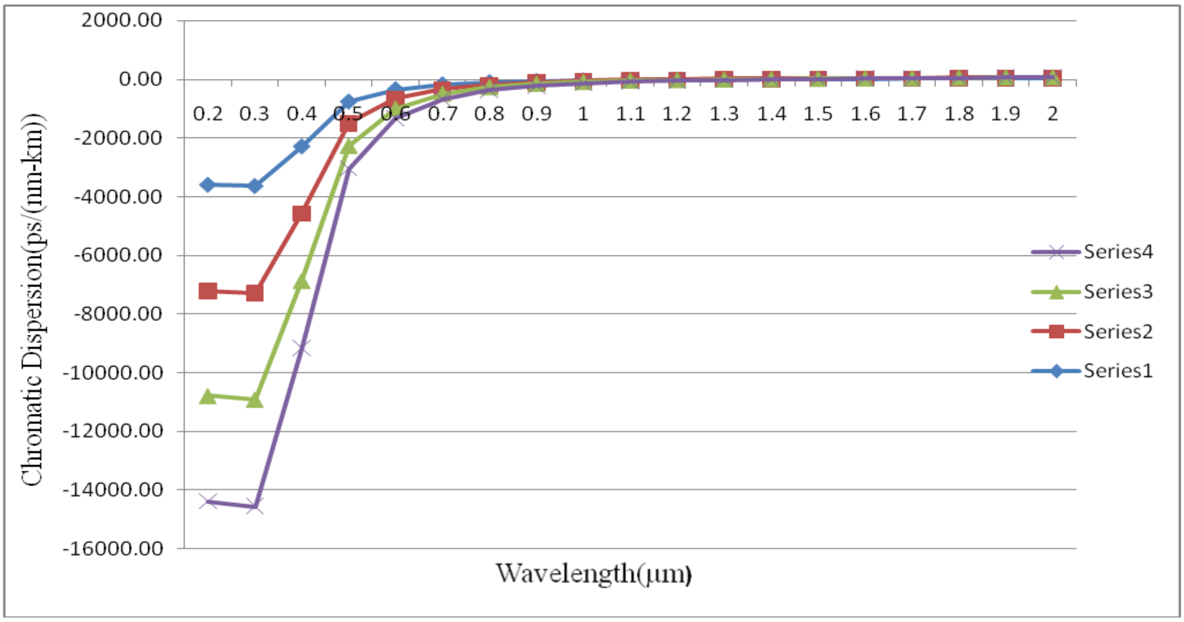

FIG. 10 CHROMATIC DISPERSION (DESIGN-1 TO DESIGN-4)

V. CONCLUSION

In this paper I investigated the four different designs of PCF by altering the dimensions of air holes. It is observed dispersion is affected by changing the dimensions of inner rings, not by changing the dimensions of outer rings. I observed that Flattened dispersion in design-3 is achieved at the wavelength range of 1µm to 2µm. Design 3 provides the very low dispersion which is equal to -1.17 ps/(nm-km) at 1.5µm, 1.75 ps/(nm-km) at 1.6µm and is zero in 1.55µm wavelength when the pitch is 2.0 µm of the circular and elliptical air holes. With this flat dispersion characteristics design-3 can be used in optical wideband transmission system, and can resolve the issue of inter symbol interference (ISI) at the receiver side.

VI. FUTURE SCOPE

The future scope of PCF is that it should be utilized to offer zero dispersion and minimize other losses (such as confinement loss, radiation loss etc.) at wide wavelength range. So in order to increase the usefulness of PCF in future telecommunications, innovations and future work is necessary by reducing the transmission losses.

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