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Effect of Wafer Dimension on the Dispersion and other Polarizing Properties of PCF

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Abstract

In this paper we propose some index guided Photonic Crystal Fiber (PCF) with elliptical holes. The design has been proposed such that it shows a decrease in the value of ratio of the area of elliptical air holes to that of the wafer dimension. The effect of variation in wafer dimension of a constant lattice size is analyzed for observing the unique properties of PCF like dispersion, birefringence, confinement loss and other polarizing properties. The simulation of the proposed structures has been carried out using OptiFDTD simulator with Full vector mode solver using FDTD method. The dispersion reported is almost zero at a wavelength of $0.3\mu m$ for some of the structures proposed. It is observed that all the structures proposed has shown the most negative dispersion in between the wavelength range of $0.35\mu m - 0.4\mu m$. The birefringence reported is of the order of 10^{-3}. However the confinement loss reported is low and of the order of 10^{-5}. Besides zero confinement loss is observed at a wavelength of $0.25\mu m$ and at $0.9\mu m$ for the structure proposed in configuration V and configuration I.

Key Words—Photonic crystal fiber (PCF), Total international reflection (TIR), Birefringence, Finite Difference Time Domain (FDTD), Transparent Boundary Condition (TBC), Confinement Loss, V-number, Normalized Wavelength.

I. INTRODUCTION

In the recent era PCF has been a point of attraction for the researchers. The technology of optical fibers has improved a lot in recent years. While the basic principle of directing light, total-internal reflection, has been popular for a long time, the capability of manufacturing materials such as silica into very pure, very small, and very long strands has only recently came into knowledge [1]-[6]. With such advancements in the manufacturing, engineers have been concentrated on optimizing the standard fiber design and have made great progress in reducing unwanted results such as loss and dispersion, and ensuring wanted results such as single mode operation. Keeping this in mind, researchers has begin to search a new kind of optical guidance mechanism which occurs in photonic crystal fibers. Recently, an optical fiber was a solid thread surrounded by another material with a lower refractive index. Today, photonic crystal fibers (PCFs) are established as an alternative fiber technology.

It is possible to produce PCF having very high birefringence [7] to obtain dispersion flattened fiber [9], or dispersion compensating fiber in high speed transmission system. All of these properties can be obtained by modifying the fiber design and the number of rings around the core. Several methods are used for the analysis of PCFs each having its own advantages and disadvantages. In this paper we propose some index guided Photonic Crystal Fiber (PCF) with elliptical holes. The design has been proposed such that it shows a decrease in the value of ratio of the area of elliptical air holes to that of the wafer dimension. It has been observed that all the proposed structure exhibits the most negative dispersion about a wavelength of $0.35\mu m$. The dispersion shows an arbitrarily behavior due to the effect of the ratio of area of elliptical air holes to that of area of wafer. Besides the properties like birefringence, confinement loss and normalized frequency shows a linear relation with some variance. The ratio (R) of area of elliptical air hole to that area of wafer dimension has been shown in Table I below.

Table I

Configuration	Ratio (R)
First (I)	0.1569879804
Second (II)	0.1441781915
Third (III)	0.1328746213
Fourth (IV)	0.1228500566
Fifth (V)	0.113918571

From Table it can be easily concluded that there is an decrease in the ratio (R).

The rest of the paper is organized as follows. In the next section (II) we present the proposed structure for the index guided PCFs. In section III simulation result has been focused. Finally we conclude in section IV.

II. PROPOSED STRUCTURE

In this section we propose some new structure for the index guided PCFs with elliptical holes. The PCF is designed by a five rings triangular pattern of elliptical air holes. The structure proposed has been designed in five different configuration. The variation in wafer dimension results in the change of number of points in the mesh for analysis in both the direction. The wafer length is taken initially to be $11.5X\Lambda$, such that all the elliptical holes can be accommodated with in the wafer dimension obtained. For the configuration II, III, IV, and V the wafer dimension are taken $12X\Lambda, 12.5X\Lambda, 13X\Lambda$, and $13.5X\Lambda$ respectively. All the configuration have a decrease in the ratio of area of elliptical air hole to that of the area of wafer dimension. The parameter of each configuration has been discussed one by one in the simulation section. The motivation for such an analysis has been obtained to observe the unique properties of PCFs like dispersion, birefringence, and confinement loss and other polarizing properties . Further we have compare the result with the previous work [8]. It would be interesting therefore to study the dispersion behavior, birefringence and confinement loss of PCFs having different ratio of area of elliptical air hole to that of the area of wafer dimension.

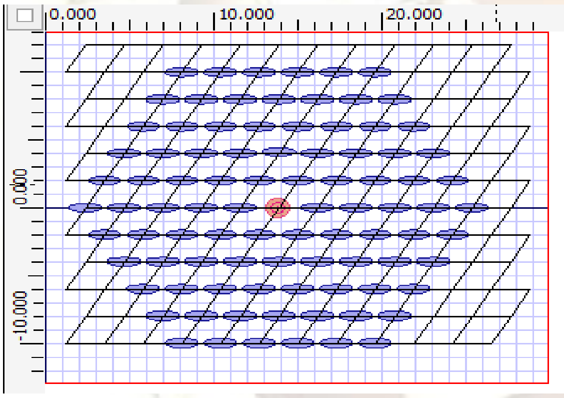

Fig. 1 Layout of a hexagonal PCF with triangular lattice of air holes using OptiFDTD simulator.

The waveguide dispersion at different wavelength for the structures is calculated using the formula [10]:

$$D = \frac{-\lambda}{c}\frac{d^2 n_{eff}}{d\lambda^2} \qquad (1)$$

Where D is the dispersion in ps/(nm-km), n_{eff} is the effective modal index number and λ is the wavelength in μm and c is the velocity of light in free space. The effective modal index is obtained from the simulations as a function of the wavelength and its second order derivative is computed using the three point difference formula for approximating the derivative.

The confinement loss of all the structures is calculated by using the formula [11]:

$$L_c = 8.686\,\mathrm{Im}[n_{eff} k_0] \qquad (2)$$

Where k_0 is the free space number and is equal to $\frac{2\pi}{\lambda}$, λ is the corresponding wavelength, n_{eff} is the imaginary part of effective modal index number.

Similarly the birefringence of all the five configuration are calculated using the formula [10]-[11]:

$$B = |n_x - n_y| \qquad (3)$$

where B is the birefringence, n_x and n_y are the effective refractive indices of two fundamental polarization modes and . (HE_{11}^x, HE_{11}^y).

The number of guided modes is obtained by the V-number or the normalized frequency and is calculated by using (4) [12].

$$V = \frac{2\pi\Lambda}{\lambda}(n_{core} - n_{effective}) \qquad (4)$$

Where Λ is the pitch factor, n_{core} is the refractive index of core , $n_{effective}$ is the effective refractive index number and λ is the corresponding wavelength in μm. The V number, if is less than 2.405 for a PCF, it is considered to be single mode. As the wafer size of the proposed configuration outside the PCF lattice is varying , it will effect the effective refractive index number and hence the other parameter will also get affected.

III. SIMULATION RESULT

In this section we present the simulation result of all the proposed structures carried out in OptiFDTD software. The wafer dimension of the structures proposed are chosen in such a manner to accommodate all the elliptical air holes so that the pitch factor should be uniform. The pitch factor (Λ) which is centre to centre spacing between two nearest holes, gives the characteristics of the lattice of the PCF. The value of the pitch factor (Λ) for the structures proposed is $2.3\mu m$. The refractive index of the chosen is 1.492 and that of the air hole is 1. The wafer chosen for the configuration I is $(11.5X2.3) = 26.45\mu m$ .and the width of the wafer is $\sin(60^0)$ times of the length. The boundary condition chosen is TBC. The mesh size for the finite difference time domain (FDTD) simulations is $\Delta x = \Delta y = 0.106\mu m$. The major radius of all the elliptical air hole is $1\mu m$ and the minor radius taken is $0.3364\mu m$. The reason for choosing these values of major and minor radius is to consider area of the elliptical air holes equal to that of the circular air hole of previous proposed structure [8].

TABLE 1

Configuration	Wafer Length (in μm)	Wafer Width (in μm)	No of points in mesh	
			Along X axis	Along Y axis
First (I)	26.45	22.90637	249	216
Second (II)	27.6	23.90230114	260	225
Third (III)	28.75	24.8923036	271	234
Fourth (IV)	29.9	25.89415957	282	244
Fifth (V)	31.05	26.89	292	253

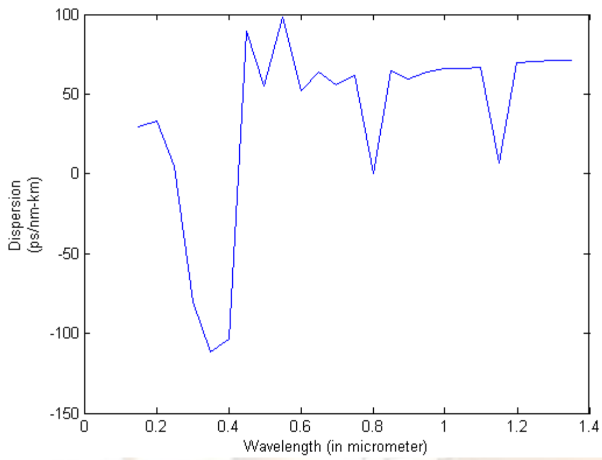

Fig. 2(a) The relation between dispersion and wavelength of the design proposed in configuration I

The curve shows almost positive dispersion value for the wide range of wavelength. It is observed that the most negative dispersion has been reported at a wavelength of $0.35\mu m$..

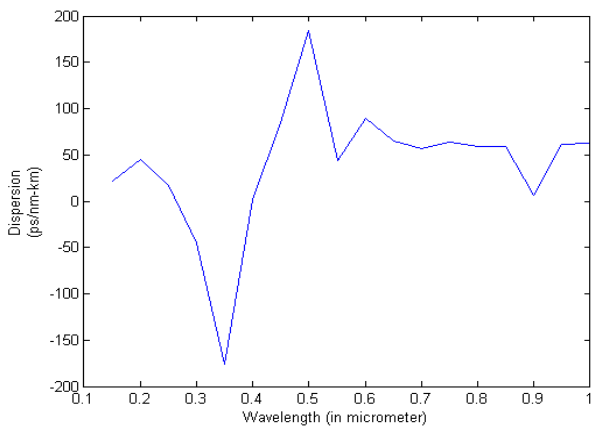

Fig. 2(b) The relation between dispersion and wavelength of the design proposed in configuration II.

The curve has shown same magnitude of dispersion with opposite polarity at wavelength $0.35\mu m$ and $0.45\mu m$. respectively as shown in the Fig. 2(b). Besides it shows more positive fluctuation for a wide range of wavelength.

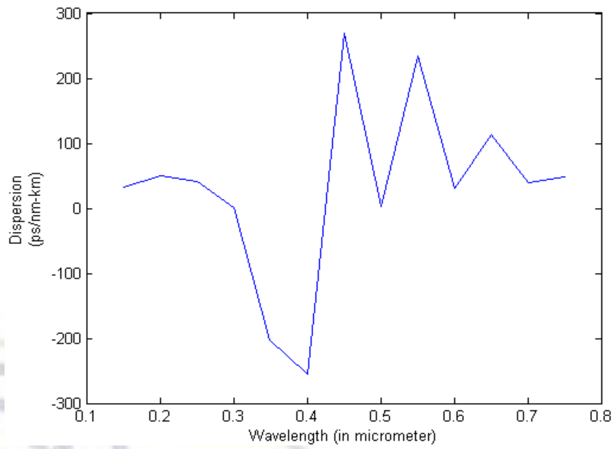

Fig. 2(c)The relation between dispersion and wavelength of the design proposed in configuration III.

The dispersion of the design proposed in configuration III was reported to be maximum among all the design proposed in this paper.

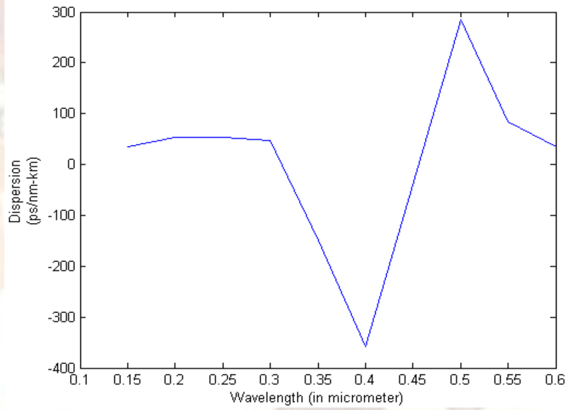

Fig. 2(c) The relation between dispersion and wavelength of the design proposed in configuration IV.

The result shows the most negative dispersion among all the design proposed in this paper. The most negative dispersion reported at a wavelength $0.4\mu m$.

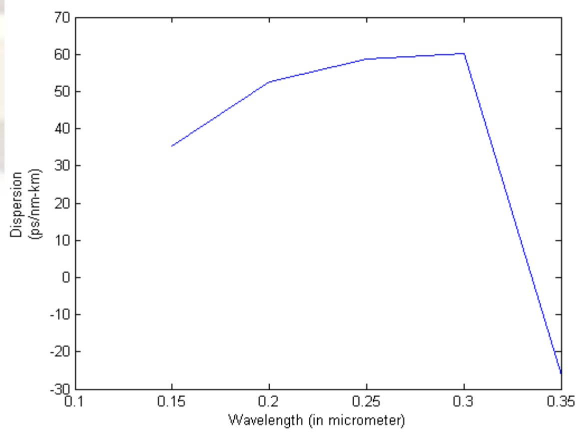

Fig. 2(d) The relation between dispersion and wavelength of the design proposed in configuration V.

The dispersion of the design proposed in configuration V is reported to be the smallest among all the configuration proposed. The dispersion observed is $60\,ps/nm-km$. Besides it must be noted that each of the design proposed has shown the most negative value of dispersion nearly at wavelength $0.35\mu m$.

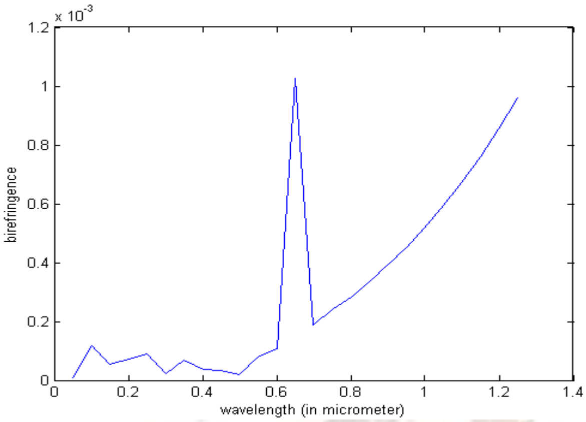

Fig. 3(a)The relation between birefringence and wavelength of the design proposed in configuration I

The birefringence reported for the design proposed in configuration I is the highest among all the design proposed.

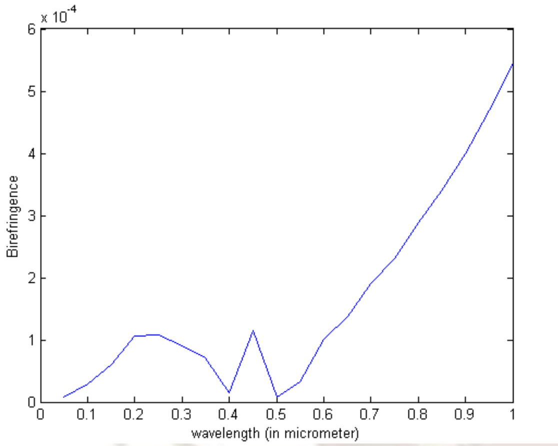

Fig. 3(b)The relation between birefringence and wavelength of the design proposed in configuration II.

The curve shows the low birefringence as shown in the Fig. 3(b). The birefringence reported to be of the order of 10^{-4}.

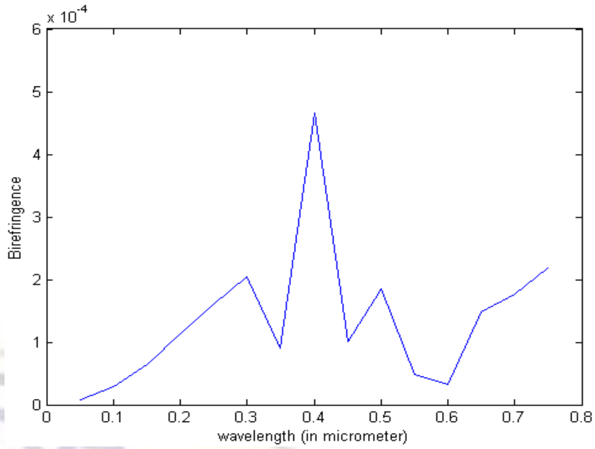

Fig. 3(c) The relation between birefringence and wavelength of the design proposed in configuration III.

The Fig. 3(c) shows birefringence of the design proposed in configuration III. It is observed maximum birefringence reported at wavelength $0.4\mu m$.

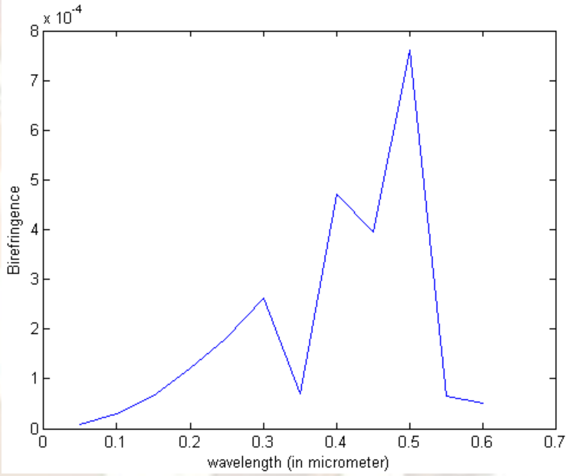

Fig. 3(c)The relation between birefringence and wavelength of the design proposed in configuration IV.

The maximum birefringence reported for the design proposed in configuration IV is at $0.4\mu m$.

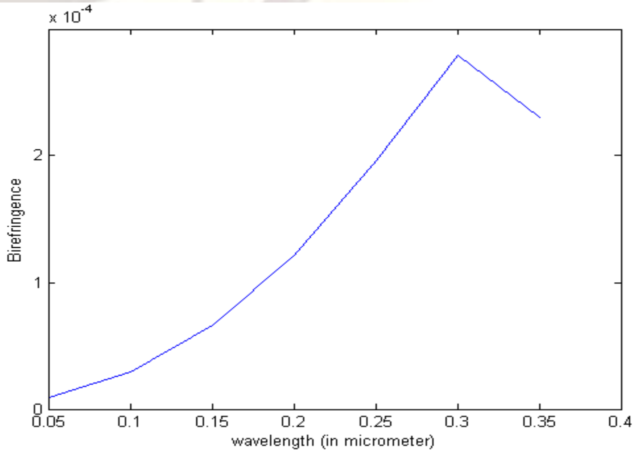

Fig. 3(e)The relation between birefringence and wavelength of the design proposed in configuration V.

The birefringence reported for the design proposed in configuration V is of the order 10^{-4}.as shown in Fig. 3(e).

The confinement loss of the design proposed for all the configuration was observed to be the order of 10^{-5}. The confinement loss of all the structure has been calculated by Using [11].

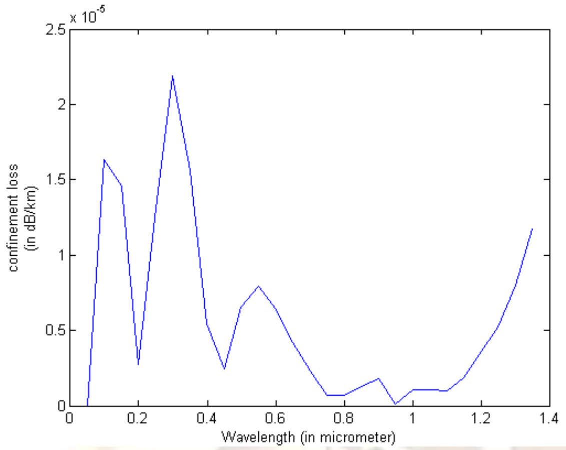

Fig. 4(a) The relation between confinement loss and corresponding wavelength.

The relation between the confinement loss at the corresponding wavelength has been shown in the figure Fig. 4(a) to Fig. 4(e).

The confinement loss for design proposed in configuration IV observed to be the order of 10^{-4}. Besides this zero confinement loss is observed at a wavelength of $0.25\mu m$ and at $0.9\mu m$ for the design proposed in configuration V and configuration I.

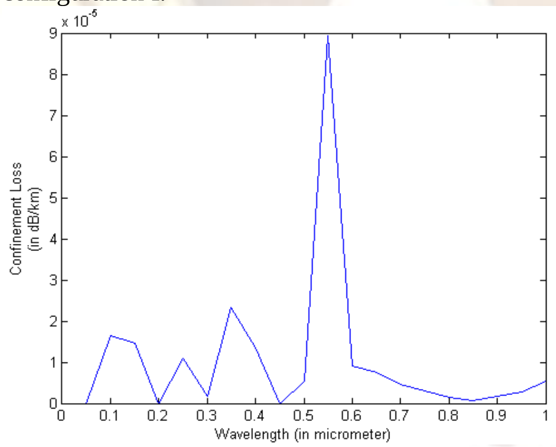

Fig. 4(b) The relation between confinement loss and corresponding wavelength.

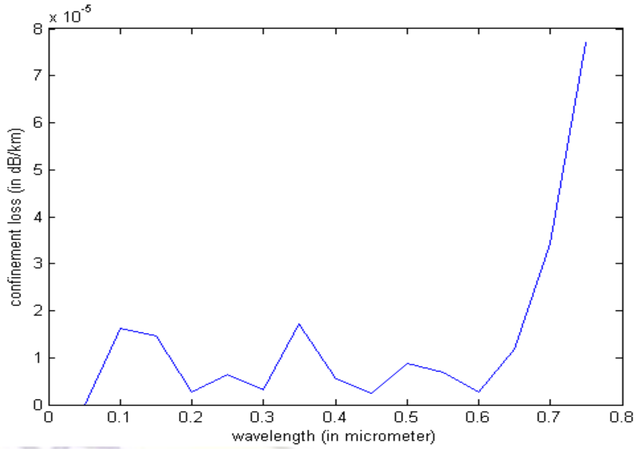

Fig. 4(c) The relation between confinement loss and corresponding wavelength.

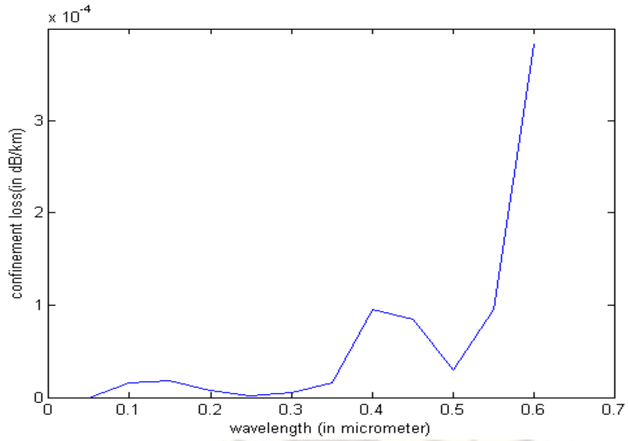

Fig. 4(d) The relation between confinement loss and corresponding wavelength.

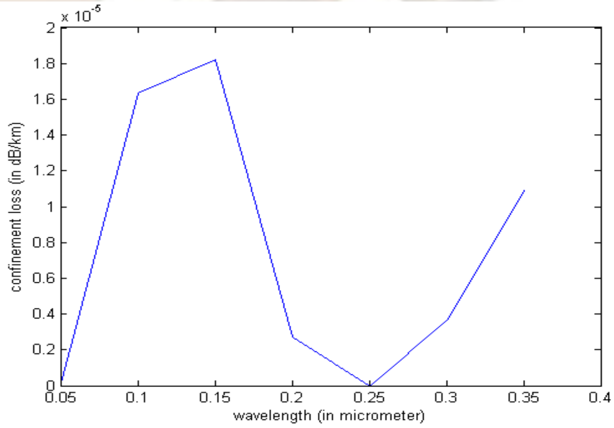

Fig. 4(e) The relation between confinement loss and corresponding wavelength.

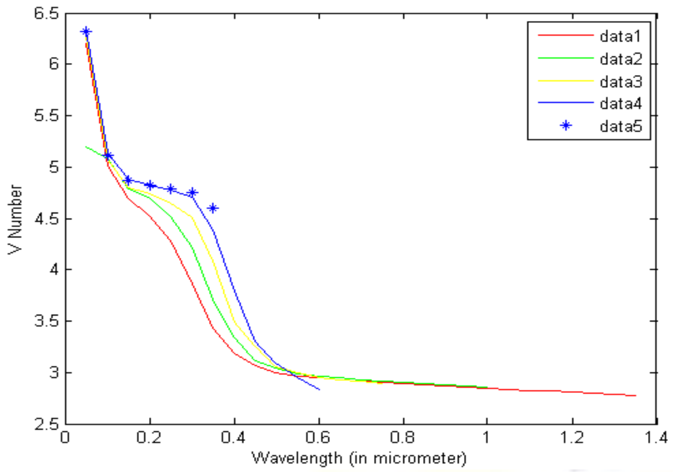

Fig. 5 The relation between V number and corresponding wavelength .

The relation between V number at different wavelength has been shown in the Fig. 5. The data1, data2, data3, data4 and data5 represents the V-number at the corresponding wavelength of the design propsed in configuration I, II, III, IV and V respectively.

As seen from Fig. 5. the value of modal index number decreases with the increasing value of normalised wavelength showing good agreement from theory [12].

IV. CONCLUSION

In this paper we have presented some new design of PCF having elliptical air holes with different configurations. It has been observed that the unique properties of PCF like dispersion birefringence, confinement loss and other polarizing properties got affected with the variation in the wafer dimension. We have design the PCF in five different configurations by maintaining the ratio of area of elliptical holes to that of wafer area in a decreasing order. It is observed that all the structures proposed has shown the most negative dispersion in between the wavelength range of $0.35\mu m - 0.4\mu m$. The birefringence reported is of the order of 10^{-3}. However the confinement loss reported is low and of the order of 10^{-5}. Besides zero confinement loss is observed at a wavelength of $0.25\mu m$ and at $0.9\mu m$ for the structure proposed in configuration V and configuration I.

REFERENCES.

[1] J. C. Knight, J. Broeng, T. A. Birks, and P. S. J. Russell, "Photonic bandgap guidance in optical fibers," *Science*, vol. 282, pp. 1476-1478, Nov. 1998.

[2] J. C. Knight, P. S. J. Russell, "Photonic crystal fibers: new ways to guidelight," *Science*, vol. 296, pp. 276-277, Apr. 2002.

[3] K Suzuki, H. Kubota, S. kawanishi, M. Tanaka and M. Fujita, "Opticalproperties of a low-loss polarization-maintaining photonic crystal fiber", *Opt. Express*, vol. 9, pp. 670-676, July 2001.

[4] T. A. Birks, J. C. Knight, and P. S. J. Russell, "Endless single-mode photonic crystal fiber," *Opt. Lettl.*, vol. 22 , pp. 961-963, July1997.

[5] K.K.Sharma, Pranaw Kumar, "Some novel photonic crystal fiber structures based on Pascal's triangle and their dispersion behaviour" *ICECT 2012, Kanyakumari, India*, april6-8,2012.

[6] T. Matsui, J. Zhou, K. Nakajima, and I. Sankawa, ''Dispersion flattened photoniccrystal fiber with large effective area and low confinement loss," *J. Lightw. Technol.*, vol. 23, pp. 4178–4183, Dec. 2005.

[7] M Pourmahyabadi and Sh. Mohammad Nejad, ― Numerical analysis of Index-Guiding photonic crystal fibers with low confinement loss and ultra-flattened dispersion by FDFD method,‖ *Journal of Electrical and Electronic Engineering Department of Electrical Engineering Iran University of Science & Technology*, vol. 5, no. 3, pp.170-179 , Sep. 2009.

[8] Ritu Sharma ,Vijay jaynyani , Rahul gupta "Effect of wafer dimension on the mode profile in PCF," *International Journal of Recent Trends in Engineering*, vol2,no. 6,November 2009.

[9] S.K. Varshney, N.J. Florous, K. Saitoh, M. Koshiba, T. Fujisawa, Numerical investigation and optimization of a photonic crystal fiber for simultaneous dispersion compensation over S+C+L wavelength bands,‖ *Optics Communications*, vol 274, pp.74-79, 2007.

[10] H.Ademgil, S.Haxha,"Highly birefringent PCF with ultralow chromatic dispersion and low confinement loss", Journal of light wave technology, Vol. 26, No. 4, 15, 2008.

[11] Razzak, S.M Abdur,Namihira, Yoshinori,"Simultaneous control of dispersion and confinement loss with octogonal PCF for communication system", The international conference on electrical engineering 2008, No. 064.

[12] John D. Joannopoulos, Steven G. ohnson, Josgua N. Winn, Robert D. Mede, *Photonic crystal fiber: Molding the flow of light*, 2nd edition, Priceton University Press, 2008.