Modified Structure of Photonic Crystal Fiber with Dispersion and Confinement Loss Properties for Wideband Applications

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Abstract: In this article, an optimized structure of Photonic Crystal Fiber (PCF) has been planned that investigates the effect of dispersion and confinement loss of square shaped photonic crystal fiber, intended for wideband applications ranges from 1.35um to 1.70um. The objective of the suggested geometry is to attain such optical properties by fluctuating its parameters like pitch, number of outer circular rings and inner elliptical rings to make it flexible and simple for manufacturing. Finite Element Method and Perfectly Matched Boundary layer (PML) is set for this proposed geometry. Moreover, recommended PCF structure has unlimited application value in the fiber-optic communications such as fiber lasers, highly sensitive gas sensors, nonlinear devices, high-power transmission and much more.

***Keywords*—**Confinement Loss (CL); Finite Element Method (FEM); Perfectly Matched Boundary layer (PML).

I. INTRODUCTION

The knowledge of a photonic crystal fiber was first offered by Yeh et al. [1] in 1978.

Photonic Crystal fibers are observed a favorable fiber technology that yields some exceptional features like controllable non-linearity, dispersion [2,3,4] and endless single mode [2]. PCF structure can be designed more flexible way with desired optical characteristics when compared with conventional fibers [5,6]. As discussed in [7], a PCF requires transmission ability that confirms a low confinement loss (CL), low cross talk, large mode area and low dispersion.

According to one of the researches by to Broeng J and Knight J C, the impact of modeling parameters on optical characteristics of PCF has been discussed in [8,9]. Several other researches about Dispersion Compensating Fiber DCF which exhibits large negative dispersion. [10-15]. A. A Nair and S.K.Singh examined several impressive properties like dispersion, confinement loss, effective area, non-linearity etc. through suitable selection of holes diameter, pitch constant (Λ), number of rings (Nr), and arrangement of air holes mentioned in [16-17]. Another reported research on low dispersion and low confinement loss by changing PCF structure is observed by H. Ademgil and S. Haxha, in [18].

Dispersion is one of the pitfalls in PCF. To overcome this hazard many techniques have been used earlier to get flattened dispersion like by varying air holes shape, air holes diameter and filling of air holes with different liquids and gases as revealed in [19-22]. In previous researches, a hexagonal geometry using Silica with five number of rings by has been observed in [23] and A square lattice PCF structure is inspected in [24-25]. Furthermore, a single mode PCF using octagonal lattice is discussed in [26].
and other geometries with higher nonlinearity are mentioned in [27-31]. PCF adjustments in structural parameters with zero dispersion and dispersion shifted fibers are discussed in [32].

In previous work of 2019, we have analyzed a square lattice PCF structure by means of Silica and Borosilicate crown glass as their core materials and extracted optical properties like confinement loss and dispersion, also discussed the effect of diameter of air holes [33].
This research is the expansion based on the prior literature [13]. Now we further investigated the potential in same Square lattice geometry using only Silica as a core material, consists of inner elliptical and outer circular air hole rings and studied the impact of parameters like Number of rings N_r, Major axis (a) and Minor axis (b) of elliptical air holes focused on same geometry discussed [34].

II. NUMERICAL ANALYSIS

1. *Chromatic Dispersion*:

The chromatic dispersion D can be determined from the n_{eff} values versus the wavelength from the given formula mentioned in [35].

$$D = -\frac{\lambda}{c}\frac{d^2 Re[n_{eff}]}{d\lambda^2} \quad (1)$$

where c is the velocity of light in a vacuum, λ is wavelength of the light in fiber. and Re stands for the real part and (n_{eff}) is the effective refractive index of the mode can be obtained by calculating the Eigen value of Maxwell's equation in [23] and [34]. The material dispersion is calculated by given Sellmeier's formula in [36].

$$n(\lambda) = S_0 - S_1\lambda^2 - S_2\lambda^4 + \frac{S_3}{C} - \frac{S_4}{C^2} + \frac{S_5}{C^3} \qquad (4)$$

Where $S_{1,2,3,4,5}$ are the experimentally determined Sellmeier's coefficients given as.

S0 = 1.4508554, S1 = 0.0031268 , S2 = 0.0000381,

S3 = 0.0030270, S4 = 0.0000779, S5 = 0.0000018

C = $\lambda^2 - 0.035$

2. *Confinement Loss:*

The loss produced by the waveguide geometry is a confinement loss Lc. Its an additional loss arises in single-material fibers mainly in PCFs because they are usually made of pure silica given in [37].

$$CL = 8.686\ \frac{2\pi}{\lambda}\ Im[n_{eff}] \qquad \left[\frac{dB}{m}\right] \qquad (3)$$

III. PCF DESIGN

The proposed PCF structure consists of total five number of air holes rings (Nr) including the elliptical inner holes with major axis (a), and minor axis (b) and outer circular rings with diameter (d) solid core and hole–hole spacing (pitch).

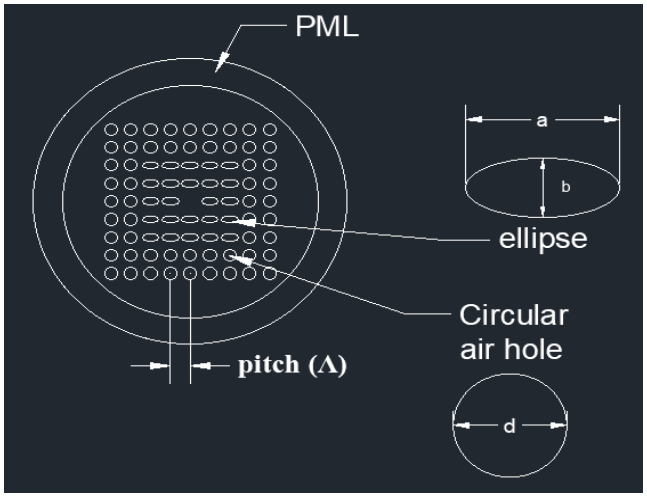

Fig. (1). Geometry of proposed square lattice PCF of with inner elliptical rings with major axis a (µm) and minor axis b (µm) and outer circular rings with diameter d in µm and pitch Λ in µm.

This design is modelled using the following steps given below.

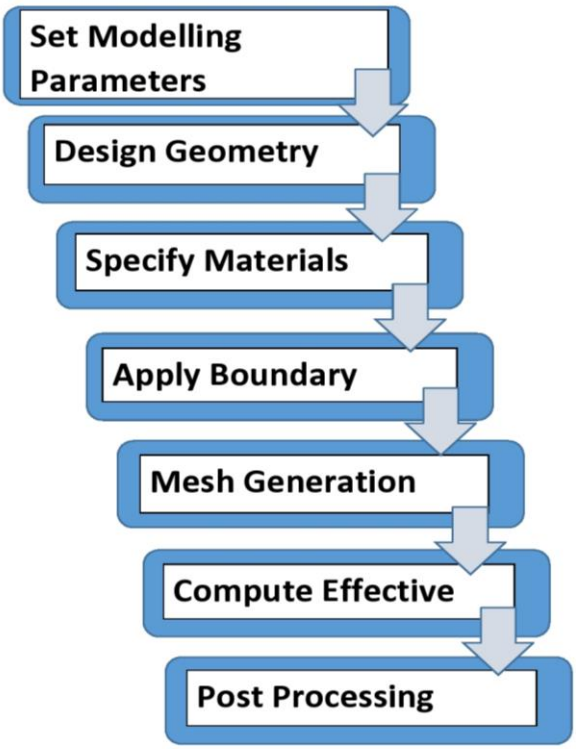

Fig. (2). Simulation steps of modelling PCF Structure.

IV. RESULTS & DISCUSSIONS

The effect of both dispersion and confinement loss is investigated in various cases by selected the main features mentioned below, carried out in the wavelength ranges from 1.1 to 1.8 µm.

Case I- In this case, minor axis is carefully chosen particularly at b=0.1µm, 0.2µm and 0.3µm and the initially considered values are: d=1.0µm diameter of the circular air hole, pitch is Λ=2.3µm and major axis a= 0.4µm.
Figure 3 demonstrate the dispersion effect for the above discussed case. It can be clearly observed that due to the increase in minor axis b the dispersion effect is nearly zero.

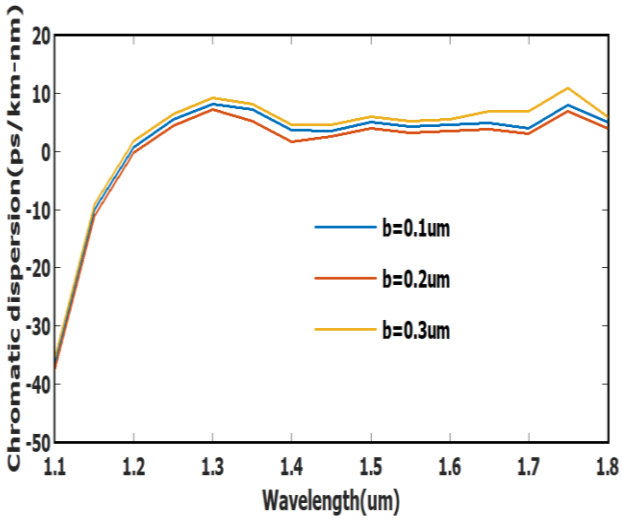

Fig. (3). Plot of chromatic dispersion variation due to change of minor axis b at d=1.0µm, Λ=2.3µm, a= 0.4µm.

Figure 4 shows the effect of confinement loss for the same case. It is obvious from this profile that the confinement loss is continuously moving upward with the increase in minor axis.

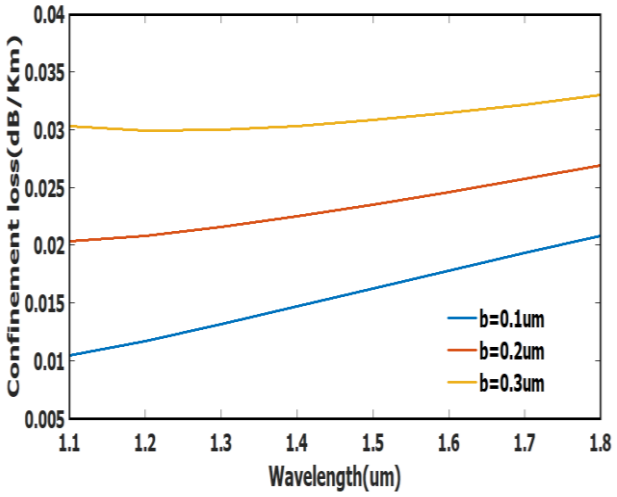

Fig. (4). Plot of confinement loss variation due to change of minor axis b at d=1.0µm, Λ=2.3µm, a= 0.4µm.

Case II- In this case, major axis is selected particularly at a=0.3µm, 0.4µm and 0.5µm and the primarily considered values are: d=1.0µm diameter of the circular air hole, pitch is Λ=2.3µm and minor axis a= 0.1µm.

In Figure 5 dispersion effect can be analyzed for the above discussed case. We observed that due to the slight increase in major axis, numerous effects can be investigated. It can be noticed that the solid red line represents the flat dispersion in the range from 1.4 µm to 1.7 µm and before that it has negative dispersion which is being used a Dispersion Compensating Fiber. [13] whereas at major axis 0.5 µm it goes all the way down towards negative dispersion.

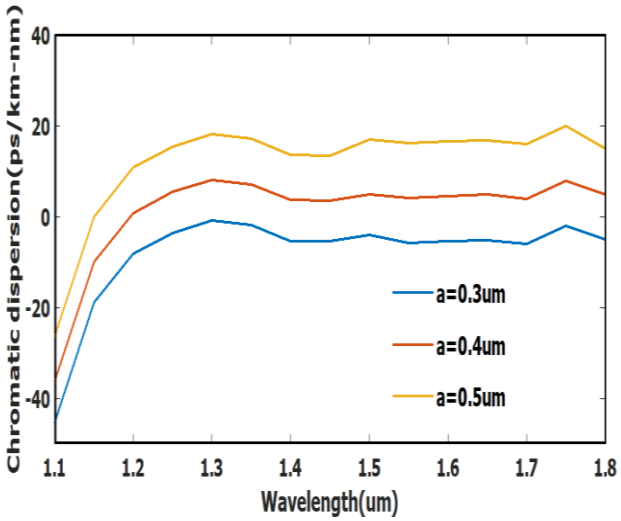

Fig. (5). Plot of chromatic dispersion variation due to change of major axis a at d=1.0µm, Λ=2.3µm, b= 0.1µm.

Figure 6 gives the information about confinement loss for the same case. This line graph is clearly identifying that the confinement loss varies due to the variation in major axis.

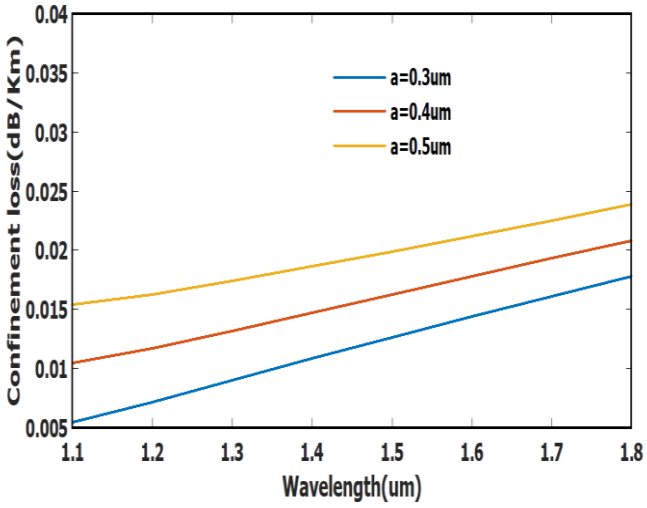

Fig. (6). Plot of confinement loss variation due to change of major axis a at d=1.0µm, Λ=2.3µm, b= 0.1µm.

Case III- In this case d=1.0µm diameter of the circular hole, major axis a= 0.4µm, minor axis b=0.1 µm are kept constant and pitch between air holes are efficiently selected at 2.1µm, 2.3µm and 2.5µm.

Figure 7 displays the dispersion profile as it is attracting more towards zero dispersion that is consistent between 1.4 µm to 1.7 µm wavelengths at pitch value 2.1 µm and 2.3 µm but as the value of pitch varies to 2.5 µm, the dispersion will excite rapidly.

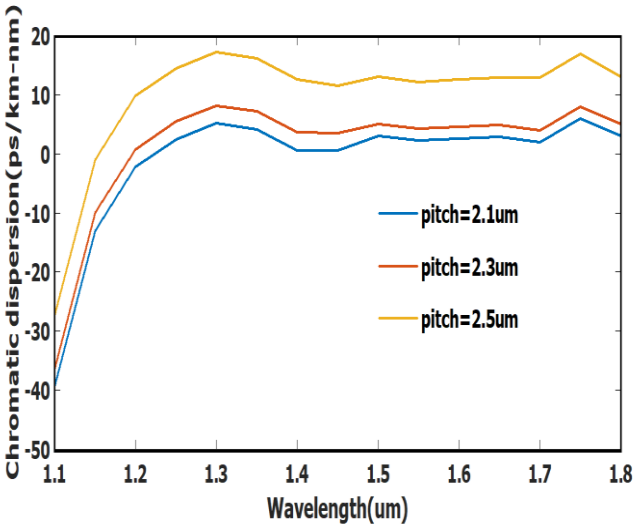

Fig. (7). Plot of chromatic dispersion variation due to change of pitch (Λ) at d=1.0µm, a= 0.4µm, b=0.1 µm.

Figure 8 is a clear demonstration of confinement loss as it providing the lowest loss with respect to the increase in pitch. Due to this attractive feature it becomes more striking as comparable to the losses we calculated earlier.

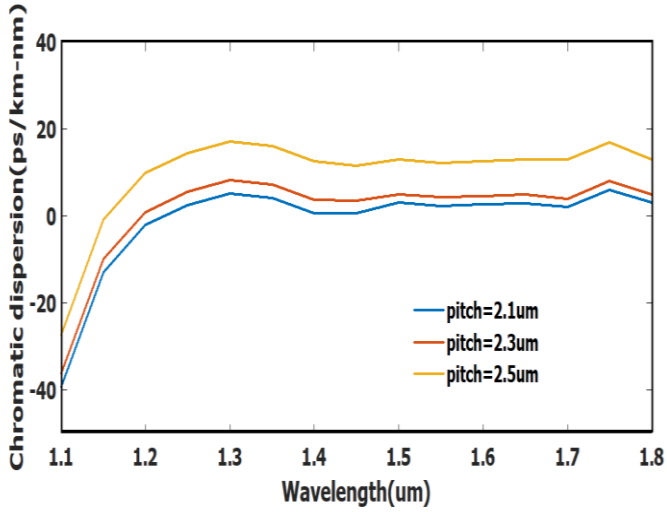

Fig. (8). Plot of confinement loss due to change of pitch (Λ) at d=1.0µm, a= 0.4µm, b=0.1 µm.

Case IV- This case shows the working on number of circular rings Nr randomly selected at 4, 5 and 6 whereas rest of parameters priory discussed i-e diameter of the circular hole d=1.0µm, major axis a=0.4µm, minor axis b=0.1 µm and pitch=2.3µm are kept constant.

The plot shown below in figure 9 demonstrates the dispersion effect achieved due to the increased number of circular rings. This case gives the information that when the number of rings is selected 4, dispersion is high, at Nr=5 dispersion tends to nearly zero (flat dispersion) and at Nr=6 it reaches towards negative dispersion.

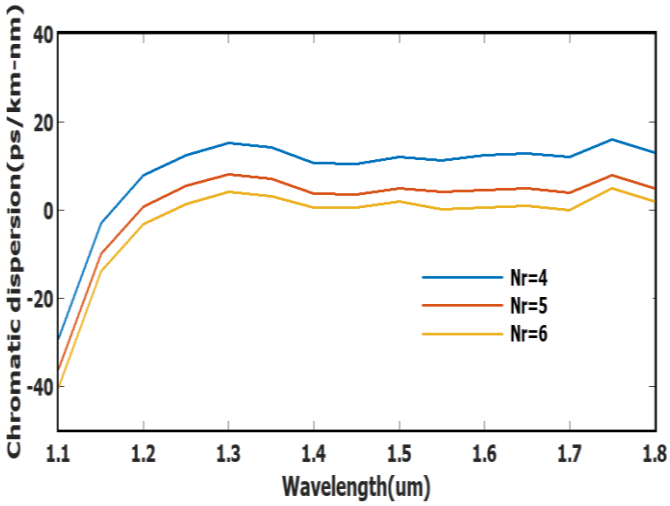

Fig. (9). Plot of chromatic dispersion variation due to change of number of circular rings Nr at d=1.0µm, Λ=2.3µm a= 0.4µm, b=0.1 µm.

Confinement loss also falling-off as we are increasing the number of circular rings shown in Figure 10.

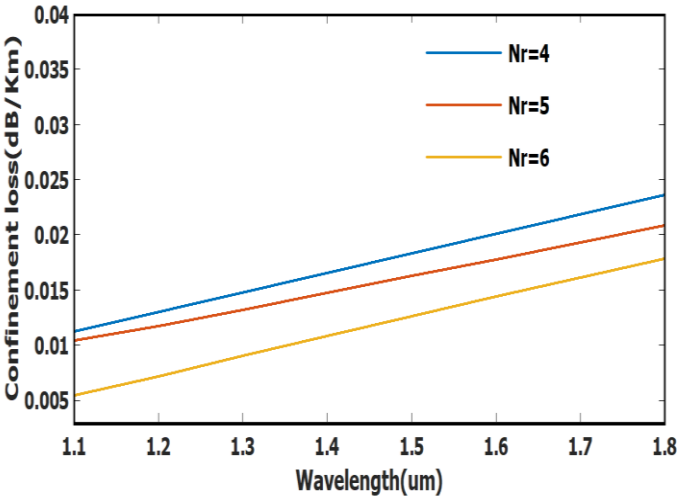

Fig. (10). Plot of confinement loss variation due to change of number of circular rings Nr at d=1.0µm, Λ=2.3µm a= 0.4µm, b=0.1 µm.

Case V- This case gives the information about chromatic dispersion and confinement loss, arises due to the variation in number of elliptical air rings Nr chosen at 4, 5 and 6 whereas all other parameters diameter of the circular hole d=1.0µm, major axis a=0.4µm, minor axis b=0.1µm and pitch=2.3µm are kept constant.

In Figure 11 it can be easily observed that increased number of elliptical rings providing us the positive response that are heading towards flat dispersion with respect to the smaller number of rings.

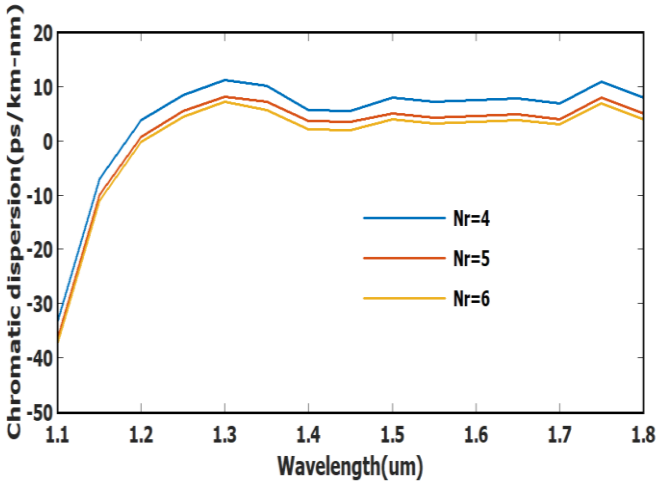

Fig. (11). Plot of chromatic dispersion variation due to change of number of elliptical rings Nr at d=1.0µm, Λ=2.3µm a= 0.4µm, b=0.1 µm.

In Figure 12 it can be noted that Confinement loss is inversely proportional to the number of elliptical rings. The loss is dropped rapidly as we increased the number of elliptical rings.

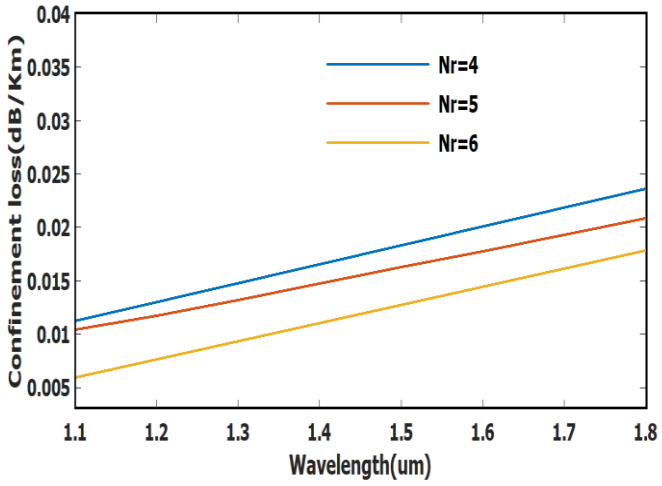

Fig. (12). Plot of confinement loss variation due to change of number of elliptical rings Nr at d=1.0µm, Λ=2.3µm a= 0.4µm, b=0.1 µm.

V. CONCLUSION

This article is the modified version of our previous work, in which effect of both chromatic dispersion and confinement loss has been investigated on square lattice PCF with wavelength ranges 1.1-1.8µm, under the influence of different parameters like pitch between two holes, number of circular and elliptical rings, variation in sizes of circular and elliptical holes. These results demonstrate that the optimized PCF performs very well and accomplishes great progress in terms of dispersion and confinement loss. Finally, we can say that these parameters can be adjustable based on the applications requirement. Besides, the proposed structure can be operated over the vastly usable communication applications such as fiber lasers, nonlinear devices, high-power transmission, highly sensitive gas sensors, and other areas.

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