

PCF Structure with Circular Air Hole and Square Lattice and its High Birefringence and Lower Zero Dispersion Behavior

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Abstract — In this paper a square lattice Photonic Crystal Fiber (PCF) with circular air hole has been designed and the numerical analysis reported a zero dispersion for one of the proposed structure. A very high Birefringence of the order of 10^{-2} have been observed. Among all the structures proposed, two structures have shown both increment and decline in the value of confinement loss at the same interval of wavelength. It has also been shown the shifting of zero of dispersion wavelength toward lower wavelength range with increase in the number of circular air holes of large area compared to the number of circular air holes of smaller area. A Full-vector TM, FDTD method has been used.

Keywords - Photonic Crystal Fiber (PCF), Total International Reflection (TIR), Birefringence, Finite Difference Time Domain (FDTD), Transparent Boundary Condition (TBC), Confinement Loss.

I. INTRODUCTION

PCF has been proved to be an emerging class of fiber that provide a very large flexibility in designing [1]-[4]. PCF has been a point of attraction for the researchers due to some unique features like dispersion, birefringence and other polarization properties [5]-[8]. The optical analogue is the photonic crystal, in which the atoms or molecules are replaced by macroscopic media with differing dielectric constants, and the periodic potential is replaced by a periodic dielectric function [9]. The parameters that affect the dispersion of the PCF include its profile shape, number of air holes, distance between two adjacent air holes and diameter of the air holes [10]. Several variations of the structure in terms of the above mentioned parameters of the PCFs have been investigated in the literature from the point of view of improvement in the dispersion and attenuation and other important properties of the PCF. For instance in [11]-[12], many propagation properties of index guided PCFs with various shape air holes have been discussed.

A comparison of the effect of changes in the hole structure from circular to elliptical in the hybrid square lattice PCF is done [12]. In this paper we propose some index guided PCF structure whose geometries are derived from [12]. The proposed structure is analyzed with the full vector mode solver using FDTD method. The simulations are carried out using OptiFDTD simulator. It is observed that the proposed structures exhibit almost negligible waveguide dispersion behavior over a very large wavelength range.

The rest of the paper is organized as follows. In section II, we present some new structures for the index guided PCFs. The simulation results of these structures are presented in section III. The conclusions are given in section IV

II. NUMERICAL ANALYSIS

The novel features of PCF is the flexibility in design of fiber with compared to conventional fiber. Moreover there are some unique properties like dispersion, birefringence and other polarization properties which make it different from that of conventional fiber. Various PCF design with noticeable dispersion have been investigated both experimentally and numerically. The waveguide dispersion of PCF at different wavelength for the structures proposed has been analyzed by using the formula [10].

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

Where D is the dispersion in ps/nm-km, n_{eff} is the effective modal index number, λ is the wavelength in μm and c is the velocity of light in free space. The effective modal index number has been obtained from the simulations as the function of wavelength and its second order derivative.

A novel high birefringence index guided PCF have been investigated using the Finite Element method. The birefringence of all the three structures is calculated by the formula [13].

$$B = |n_x - n_y| \quad (2)$$

Where n_x and n_y are the effective refractive index of two fundamental polarization mode (HE_{11}^x, HE_{11}^y).

Similarly the confinement loss of all the proposed structures are calculated using the formula [14].

$$L_c = 8.686 \text{Im}[n_{eff} k_0] \quad (3)$$

Where k_0 is the free space wave number and is equal to $\frac{2\pi}{\lambda}$, where λ is the corresponding wavelength and n_{eff} is the effective modal index number. The analysis of the proposed structure has been done using full vector mode solver using FDTD method. The simulation are carried out using optiFDTD simulator.

III. PROPOSED STRUCTURE

PCF as discussed earlier consists of array of microscopic air channels surrounded by dielectric core. In this section we propose some new PCF structures which has been derived from the structure proposed [12]. All the elliptical air holes [12] has been replaced by the circular air hole each having area one fourth of the previous area. A Full vector, TM, FDTD method is used instead of TE [12].

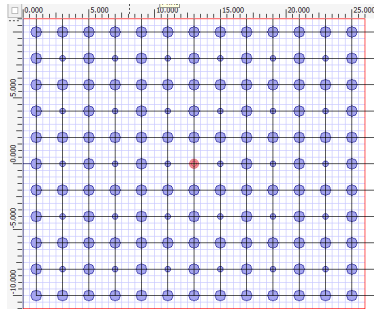


Fig.1. PCF structure with larger radius of larger circular air holes.

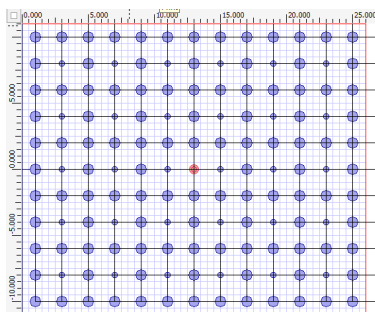


Fig. 2. PCF structure with lesser radius of larger circular air holes.

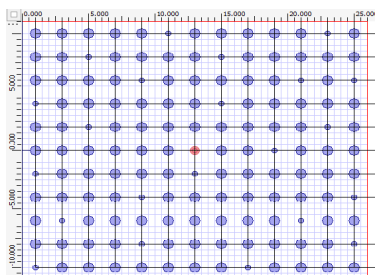


Fig. 3. PCF structure with random distribution of smaller circular air holes.

The structures proposed in Fig. 1 and Fig. 2 shows the periodic arrangement of circular air holes with smaller area along with the circular air hole of larger area. The radius of the larger circular air hole of the structure proposed in Fig.1 is more than the radius larger circular air hole of the structure proposed in Fig. 2. A random distribution of the circular air hole with smaller area is made in the structure proposed in Fig. 3. The distribution is made such that the ratio of the number of circular air hole with larger area to that of the number of circular air hole with smaller area will be high.

IV. SIMULATION RESULTS

In this section the results of the proposed structures carried out in OptiFDTD software has been shown. The refractive index of wafer is taken as 1.46 and that of air is 1. The wafer dimension in the simulation are chosen for each structure [12] have length = $26\mu m$ and width = $22\mu m$. The wafer dimension ensures high degree simulation accuracy. The pitch factor (Λ) i.e. centre to centre spacing between two air holes, gives the characteristics of hybrid square lattice. The pitch factor considered in proposed structure is equal to $2\mu m$. The boundary condition chose are TBC. The mesh size is $\Delta x = \Delta z = 0.106\mu m$ for both the directions. The radius of the smaller circular air hole for all the structures proposed is equal to $0.2\mu m$. The radius of the larger circular air hole for the structures proposed in Fig. 1 and Fig. 3 is equal to $0.4\mu m$ whereas the radius of larger circular air hole of the structure proposed in Fig. 2 is equal to $0.398\mu m$. A hybrid square lattice PCF is investigated with circular air holes in order to control both birefringence and waveguide dispersion.

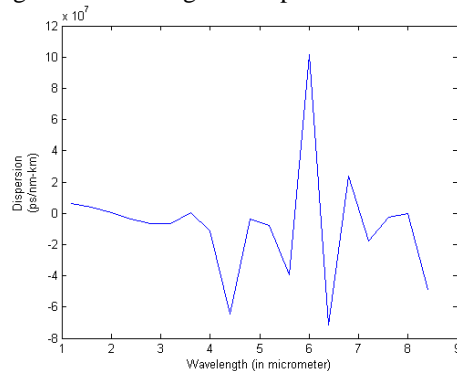


Fig.4. (a) The relation between Dispersion and wavelength of the structure proposed in Fig. 1

The proposed structure as shown in Fig. 1 produces a maximum dispersion of 10 ps/nm-km at a wavelength of $6\mu m$, as shown in Fig. 4(a).

The structure proposed in Fig. 2 has shown a high fluctuation in the dispersive behavior.

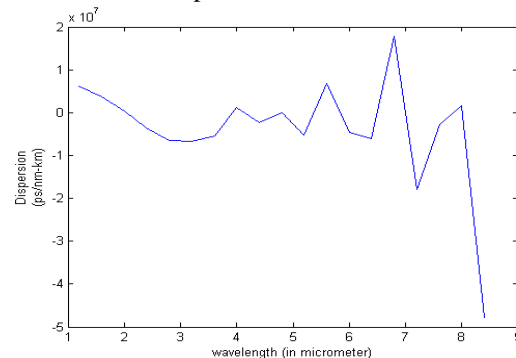


Fig.4. (b) The relation between Dispersion and wavelength of the structure proposed in Fig. 2.

The structure has given the most negative dispersion with a value of 4.7ps/nm-km at a wavelength of $8.4\mu\text{m}$. The curve shows a positive fluctuation in the rest values of wavelength.

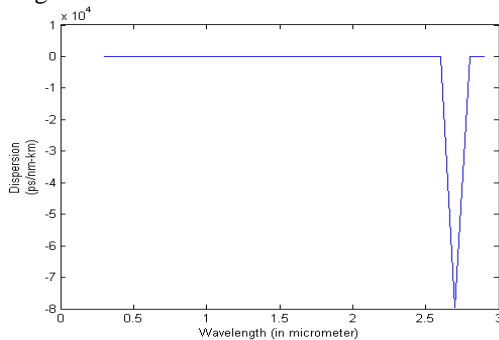


Fig.4. (c) The relation between Dispersion and wavelength of the structure proposed in Fig. 3.

The structure proposed in Fig.3 has shown the most attractive result. It has been found that almost zero dispersion was observed for a wider range of wavelength ($0.3\mu\text{m} - 2.4\mu\text{m}$) as shown in the Fig. 4(c). The Fig. 4(c) shows the most negative dispersion at $2.7\mu\text{m}$. The relation between the confinement loss with respect to the corresponding wavelength of structure of in Fig. 1 and Fig. 2 has been shown in Fig. 5(a).

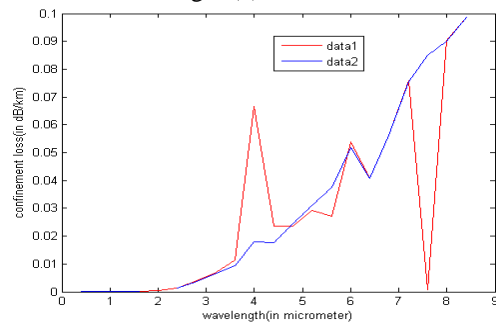


Fig.5. (a) The relation between confinement loss and the corresponding wavelength, data1 represents the confinement loss for structure shown in Fig. 1 whereas data2 represents the same for structure shown in Fig. 2.

The confinement loss curve of the data1 shows a decline in the confinement loss in between the wavelength of $6-7\mu\text{m}$ whereas the curve of data2 shows the increment in the value of confinement loss with in the same interval of wavelength. The curve of data1 shows almost zero confinement loss at higher wavelength i.e. $7.6\mu\text{m}$.

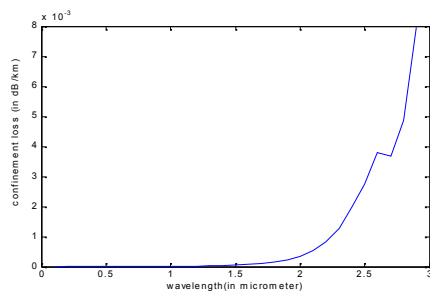


Fig.5. (b) The relation between confinement loss and the corresponding wavelength of the structure shown in Fig. 3.

The confinement loss observed for the structure shown in Fig. 3 is of the order of 10^{-3} . However the curve shows an increase in confinement loss with the increasing value of wavelength as shown in Fig. 5(b).

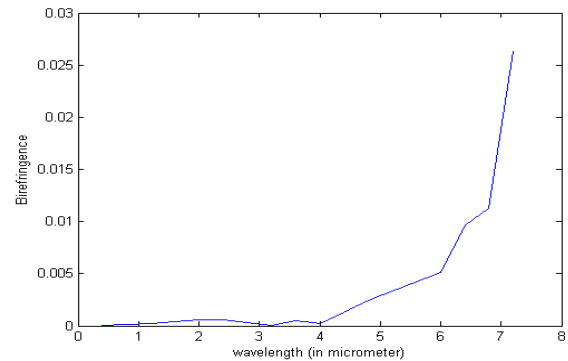


Fig.6. (a) The relation between birefringence and wavelength of structure shown in Fig. 1.

The birefringence of the structure of Fig. 1 shows an incremental relation with the wavelength. The birefringence reported is high with respect to the work done in [12].

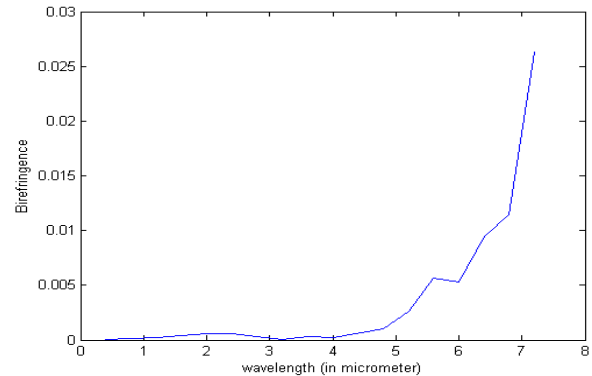
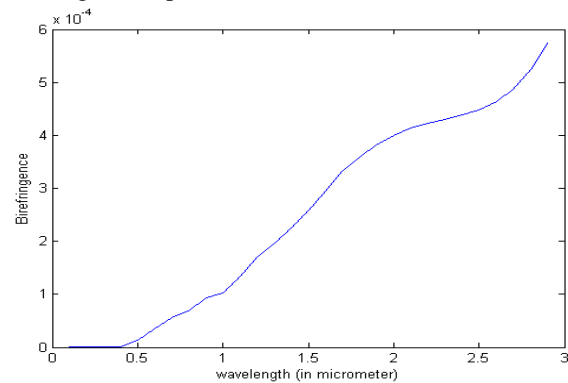


Fig.6. (b) The relation between birefringence and wavelength of structure shown in Fig. 2.

The birefringence reported in Fig. 6(b) has shown almost the same relation as shown in Fig. 6(a). The order of birefringence reported was 10^{-2} .



The birefringence reported for the structure of Fig. 3 was very less and of the order of 10^{-4} . The curve shows an increment in the value of birefringence with the increase of wavelength.

V. CONCLUSION

In this paper we have proposed some PCF structures which have been derived from the previous work [12]. It is observed that one of the proposed structures of Fig. 3 have reported almost zero dispersion over a wide range of wavelength. Birefringence reported for the structure proposed in Fig. 1 and Fig. 2 was very high and is of the order of 10^{-2} . The confinement loss reported for the structures of Fig. 1 and Fig. 2 shows a peculiar result as shown in Fig. 5(a). The curve of Fig. 5(b) is increasing with increase in wavelength. The structure of Fig. 3 is preferred over the structure proposed in Fig. 1 and Fig. 2, as its confinement loss reported are of the order 10^{-2} where as it is reported of the order of 10^{-3} for the structure proposed in Fig. 3. Finally we can say that a square lattice PCF with circular air holes are compared and analyzed for their unique properties like dispersion, confinement loss and birefringence. Hence proposed structure with unique features can be used as high birefringence and almost zero dispersion.

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