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Design of Low Dispersion Photonic Crystal Fiber Using Smoothing Filter Coefficients

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ABSTRACT

In this paper, the designs for Photonic Crystal Fiber (PCF) with elliptical air holes having rectangular lattice are proposed. These designs are derived from the coefficients of smoothing Filter. These designs are very practical and easily applicable. The simulations of these Photonic Crystal Fiber (PCF) designs are carried out using OPTIFDTD simulator with Full Vector Mode Solver that uses Finite Difference Time Domain (FDTD) Method. The simulator shows that dispersion of the proposed design approaches almost zero at wavelength of 1.41µm. The dispersion of all the proposed designs is negative and almost negligible at range of wavelengths between 1.0µm to 1.5µm. The proposed designs suit the requirements of high data bandwidth applications.
KEYWORDS: Photonic Crystal Fiber, FDTD, Dispersion, Birefringence, Smoothing Filter

1. INTRODUCTION

In the field of communication the idea of Photonic Crystal Fiber (PCF) emerged in 1991, since then it attracted the research community and a variety of PCFs have been reported. It is a new class of optical fiber also known as microstructure fiber, holey fiber or photonic band-gap fibers. PCF is finding applications in fiber-optic communications, fiber lasers, nonlinear devices, high-power transmission, highly sensitive gas sensors, and other areas. Because of PCF's ability it helped to cope with the limitations of the conventional fiber optics. In PCF, the light travels enclosed in a solid core having periodic array of air holes running along the entire fiber length. Its unique design, has paved the way to achieve wide range of peculiar properties [1, 8]. With the passage of time, the technology has progressed and developed, reshaping itself as one of the most useful optical fibers [1, 3].

According to the characteristics PCF may be classified into two categories: a)Index-guiding PCF, it functions on the principle of total internal reflection phenomena, guides light in a solid core and a cladding with many air-holes; b) Ideally cyclic structure, it uses photonic band-gap (PBG) effect at the operating wavelength to guide light in a low index core-region. Using PCF very low dispersion properties that is approaching to zero can be achieved[3,4,9].What more describes index-guiding is its distinguished quality of controlling chromatic dispersion by its diverse hole diameter (d), spacing between the holes pitch (Λ) and lattice arrangement.[6, 14].

Hansen offered a hybrid-core PCF with three fold symmetry; well obtained dispersion slop is reported [2].Matsui et al. put forward a dual-core structure which numerically shows that proposed design attain an ultralow dispersion fluctuation [4]. Razzak et al. propose a PCF structure with octagonal lattice which gives finer control capability of dispersion and confinement loss, with this design large effective area has not been noticed [7].

For the amelioration of results variant modus operand adopted in recent, e.g. modifying lattice dimension, amend the shape of air hole into ellipse, hole to hole center spacing $\wedge$ pitch, progressively surge the hole diameter form inner hole to outer vice versa, particularly filling the PCF with fluid [10].

Some PCF with the extraordinary zero dispersion wavelength which is near to visible and infrared wavelengths, large positive dispersion with a negative slope, and ultra-flattened chromatic dispersion in the range of 1.55 µm wavelength [3, 5]. With such remarkable achievements in the manufacturing of PCF, now, the engineers are working on the standard fiber design to reduce the loss and dispersion as much as possible [13]. Lately many different PCFs structures have been proposed, one of them is Pascal Triangle (PT) which has almost negligible dispersion in the range of large wavelength [11, 12].

In this paper, Photonic band-gap PCF structures with elliptical air holes having rectangular lattice are proposed. These designs are derived from smoothing filter that are practical and easy apply. The simulation of these Photonic Crystal Fiber (PCF) designs is carried out using OPTIFDTD simulator with Full Vector Mode Solver that uses

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Finite Difference Time Domain (FDTD) Method. The proposed designs suit the requirements of high data bandwidth applications.

The rest of the paper is organized as follows. Section 2 describes the proposed technique having complete details of photonic band-gap PCFs. Experimental results are given in Section 3 to show the effectiveness of the proposed technique. Finally, Section 4 concludes this paper.

2. PROPOSED TECHNIQUE

In this section, new structures for PCF photonic band-gap (hollow core) are proposed. Photonic band-gap is made up of air holes enclosed by dielectric core. The working principles of photonic band gap are different from that of index guided PCF. The proposed structure of photonic band gap PCF is shown in Figure1 and Figure 2 having five rows of elliptical air holes along all sides of the core. The proportions of the air holes are taken from 5x5 smoothing filter design (Equation 1). Dividing the whole structure of PCF into four parts and applying the coefficients of 5x5 smoothing filter, the proportion of air hole at the upper part remains the same as the other three parts. The reason for choosing the proportions from the smoothing filter is the fact that coefficients in smoothing filter are decaying from center to edges suits the condition of PCF. The dispersion behavior and the birefringence of PCF with their geometries derived from smoothing filter makes an interesting study. The waveguide dispersion of the structure at different wavelengths is calculated using the formula (Equation 2):

$$\frac{1}{125}\begin{bmatrix} 2 & 4 & 4 & 4 & 2 \\ 4 & 6 & 8 & 6 & 4 \\ 4 & 8 & 13 & 8 & 4 \\ 4 & 6 & 8 & 6 & 4 \\ 2 & 4 & 4 & 4 & 2 \end{bmatrix} \tag{1}$$

$$D = -\frac{\lambda}{c}\frac{d^2 n_{eff}}{d\lambda^2} \tag{2}$$

Where “D” is the dispersion and is measured in ps/(nm-km),$n_{eff}$is effective modal index number, $\lambda$is wavelength in μm and c is the velocity of light in free space. The simulation gives the effective modal index as a function of the wavelength.

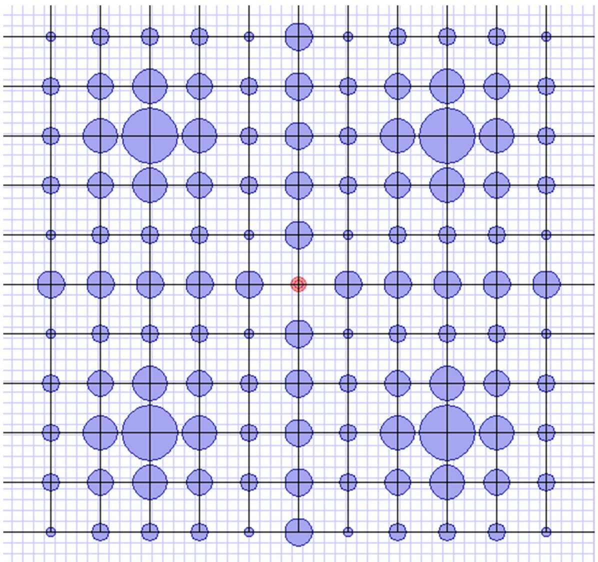

Figure 1. PCF Structure I

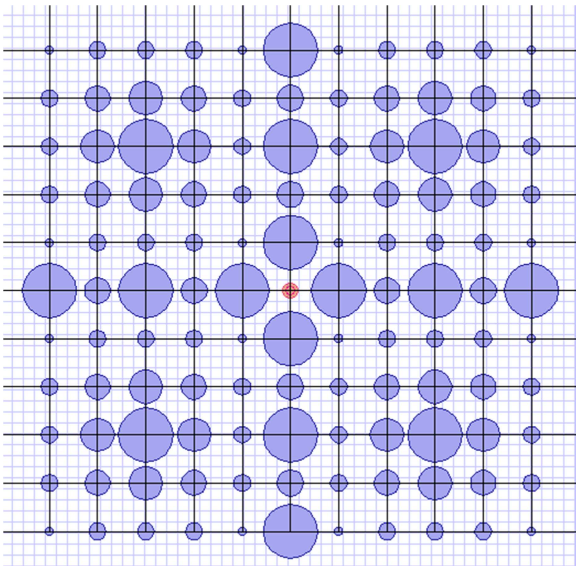

Figure 2. PCF Structure II

The birefringence of the structures is calculated using the formula:

$$B = |n_x - n_y| \tag{3}$$

Where “*B*” is the birefringence,n_x and $n_y$is the effective refractive index.

3. EXPERIMENTAL RESULTS

This section exhibits the simulation results performed on a well-known OPTIWAVE OPTIFDTD simulator. The wafer dimensions selected in such a way that accommodates all the holes of the proposed structure keeping a uniform pitch throughout the structure. The pitch is center to center distance between the two neighboring air holes. The refractive index of the holes is taken as 1.46, filled with 1.0 which is the refractive index of air. The boundary condition chosen for the structure is Transparent Boundary Condition (TBC).

For simulating the structure proposed in Figure 1 the selected parameters are: i) the wafer length is27.6µm,ii) width is 27.886µm,iii) The radius of holes is taken as smoothing filter from Equation 1, normalizing coefficients by dividing each by 10,iv) The holes which are above, below, left and right of the core is uniformly taken as 0.625µm and v)The pitch factor Λ is chosen as 2.3µm.

For simulating the structure proposed in Figure 2, same parameters are selected with minor changes. The holes which are above, below, left and right of the core are taken as 0.625µm for small and 1.25µm for large hole.

The dispersion calculation of the structure as shown in Figure 1 and Figure 2 is carried out using equation (2) and the results are given in Figure 4 and Figure 5 respectively. Simulation results showed that the structure based on smoothing filter having elliptical air hole contains negligible and negative dispersion. The dispersion comparison between both structures is shown in Figure 6. The normalized wavelength is defined as$^{\lambda}/_{\Lambda}$, showed the decreasing trend in the effective modal index number and increase in the wave length. The effective modal index and normalized wavelength curve is shown in Figure 7.

Equation 3 is used to calculate birefringence for the proposed structures. Birefringence is plotted against wavelength and is shown in Figure 8. From the simulation result given in Figure 7, structure presented in Figure 2(data 2) has more birefringence than the structure shown in Figure 1(data 1).

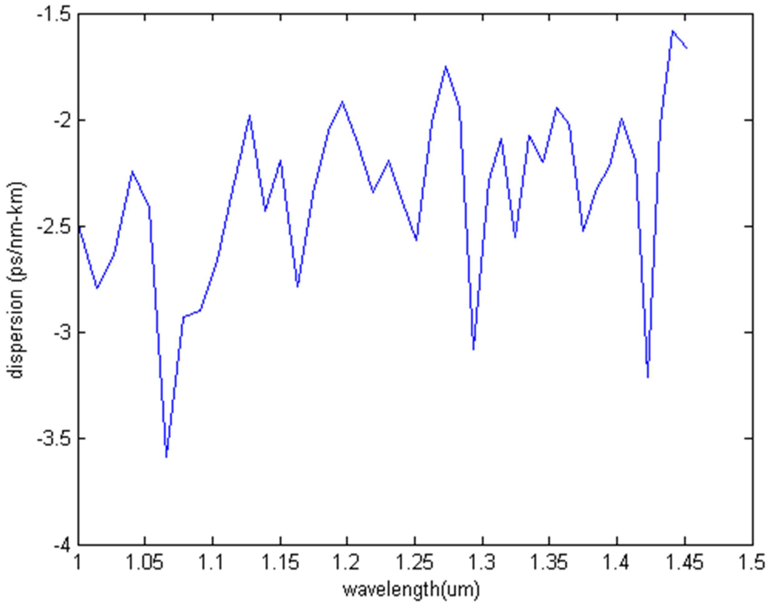

Figure 4. Dispersion curve of Figure 1(Structure I)

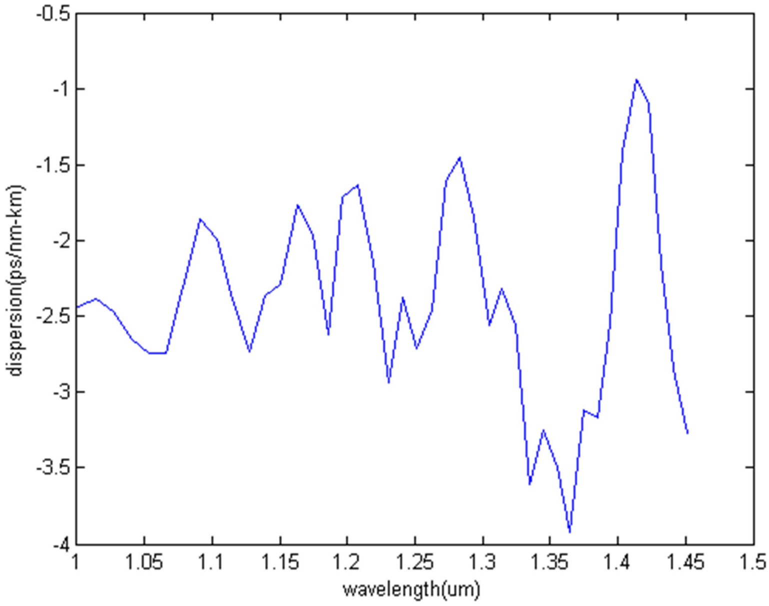

Figure 5. Dispersion curve of Figure 2(Structure II)

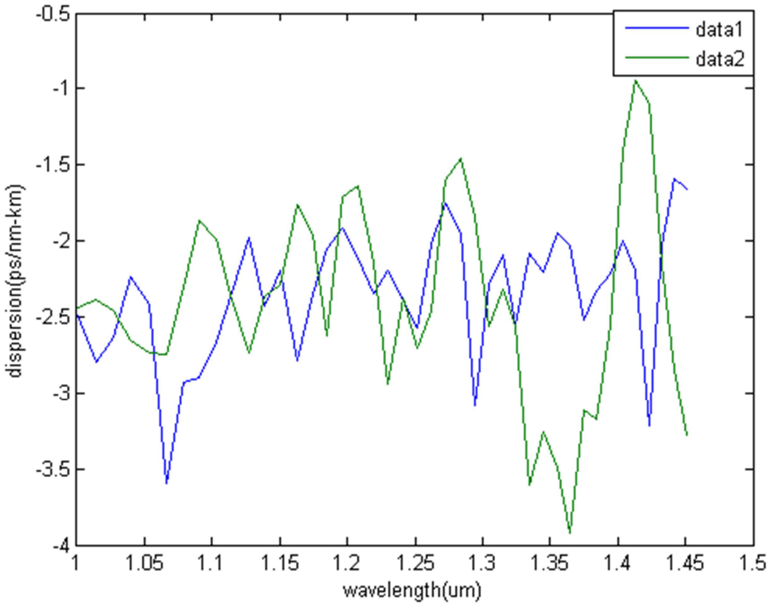

Figure 6.Dispersion comparison of Structure I (data 1) and Structure II (data 2)

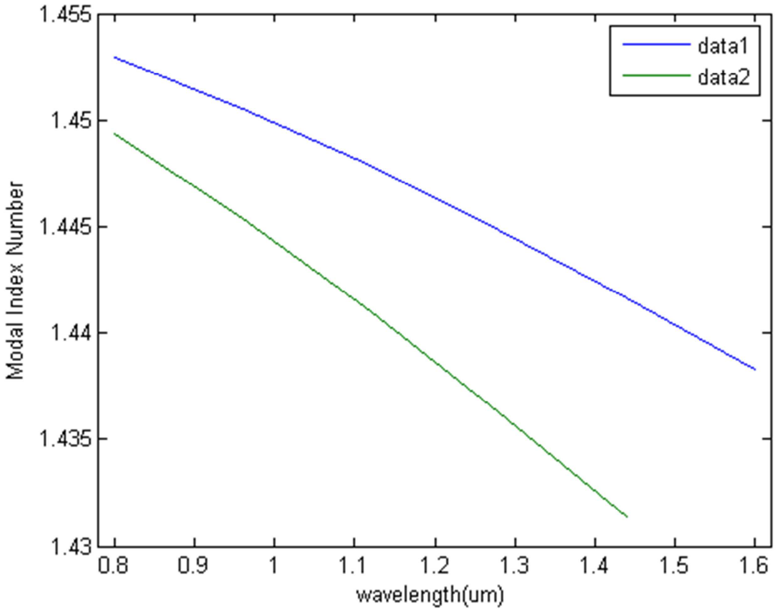

Figure 7. Curve between modal index number and wavelength of structure I (data 1) and structure II (data 2)

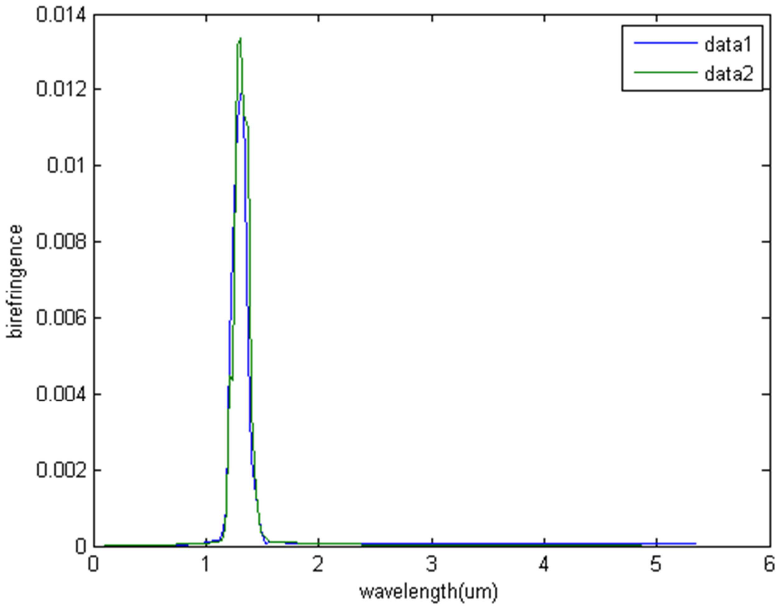

Figure 8. Curve between birefringence and wavelength of structure I (data 1) and structure II (data 2)

4. CONCLUSIONS

In this paper, the designs for PCF with elliptical air holes having rectangular lattice with coefficients derived from Smoothing Filter are proposed. The proposed structures of photonic band gap PCF have five rows of elliptical air holes along all sides of the core. The structure is divided into four parts and the dimensions of the air holes are taken from 5x5 smoothing filter design. The proportion of air hole at the upper part remains the same as the other three parts. The reason for choosing the proportions from the smoothing filter is the fact that coefficients in smoothing filter are decaying from center to edges suits the condition of PCF. The dispersion behavior and the birefringence of PCF with their geometries derived from smoothing filter makes an interesting study. The dispersion of the proposed design approach to zero at the wavelength of 1.41µm. The dispersion of all the proposed designs is negative and almost negligible within the range of wavelengths between 1.0µm to 1.5µm. Hence, the proposed technique suits the requirements of high data bandwidth applications.

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