A new design of square lattice photonic crystal fiber is made by borosilicate material with circular and square air holes to minimize dispersion

Archana Mahur, Yogendra Kumar Katiyar

Abstract-**The photonic crystal fibers (PCF) are more flexible than conventional optical fiber. In this paper we proposed a new design of photonic crystal fiber using borosilicate material. Square lattice is used with linear and elliptical waveguide in cladding. The PCF are very useful for optical transmission. For better transmission, ultra flattened dispersion or near to zero dispersion is desirable. To minimize dispersion we designed different air holes of different diameter. Finite Difference Time Domain (FDTD) method and transparent boundary condition (TBC) is used to analyze the dispersion property in a high-index core PCF. Through simulation and optimizing the PCF, we find that the proposed photonic crystal fibers give flattened dispersion in wavelength range of 1.2µm to 1.8µm in scalar mode then TM and TE mode of photonic crystal fiber. It is also observe that borosilicate glass PCF gives much better dispersion as compared to silica of the same structure, so such PCF can be used as a dispersion compensating fiber in optical window with high potential.**

Keywords- **Chromatic dispersion, photonic crystal fibers (PCFs), square lattice, Effective Refractive Index (neff), Finite Difference Time Domain (FDTD) method, Transparent Boundary Condition (TBC)**

I. INTRODUCTION

Optical fiber is widely used in wavelength division multiplexing (WDM) network for optical data transmission. In WDM communication systems, it is essential to maintain a uniform response in the different wavelength channels, which requires that the transmission line approach the ideal state of ultra-flattened dispersion and ultra-low loss [1]. But flexible dispersion or losses in optical fiber have been become a major problem in high bit rate wavelength division multiplexing optical communication systems. The dispersion is a phenomenon that causes to broaden optical pulses, when they spread in the optical fibers [1]. So when a pulse come to receiver, it is not possible to differentiate whether it high or low. The intersymbol interference (ISI) can occur between the bits in communication channel, by linearly accumulated chromatic dispersion along the transmission channel, which can affects the communication process & communication quality.

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Because of this, zero and flat dispersion slope with low losses are needed in high speed optical communication.
Thus, a new technology of manufacturing photonic crystals has led to a new generation of optical fibers, namely Photonic Crystal Fibers. The PCF has some features such as controllable dispersion, very low confinement loss and flexible design. The photonic crystal fibers (PCFs) are also called microstructures fibers or holey fibers. The photonic crystal fiber structure is formed by a core and a cladding. The cladding is two dimensional photonic crystal types consisting of air holes that run along the fiber length show unique properties.

Light guidance in PCFs are depending on the core and cladding photonic crystal materials. The refractive index difference between the core and cladding is always positive in index-guiding PCF. It can be possible by choosing a core material with a higher refractive index than the cladding refractive index. The photonic crystal fiber is also known as solid core photonic crystal fiber. These fibers guide light through a form of total internal reflection (TIR).
The refractive index of the cladding is higher than refractive index of the core in the fibers with air core. However, in fibers with air core, TIR is not possible. So light guidance in these fibers attained by coherent Bragg scattering, where light at wavelengths within well-defined stop bands is prohibited from propagating in the photonic crystal cladding and is confined to a central defect [2].Only some wavelength bands are confined and guided down the fiber. Each band corresponds to the presence of a full two-dimensional PBG in the photonic crystal cladding. For this reason, these fibers are called photonic band gap fibers (PBGFs) or hollow core fibers in which light is guided in a low-index core by the PBG effect[1,2].

Reducing dispersion & confinement loss are main aim to designing PCF's. To designing PCF's, multiple parameters can change such as diameter & shape of the holes, the number of air hole ring and the spacing between these holes. Many designs of PCF's have been proposed for the nearly zero ultra-flattened chromatic dispersion and low confinement loss.

II THEORY OF DISPERSION

The dispersion (D) is proportional to the second derivative of the effective refractive index (η_{eff}) with respect to the wavelength (λ) obtained as:

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

Where Re[η_{eff}] is the real part of the effective refractive index, λ is wavelength, and c is the velocity of light in vacuum. The total dispersion is calculated as the sum of the waveguide dispersion and the material dispersion obtained as:

$$D(\lambda) = DM + DW$$

Where DM is the material dispersion and DW is the waveguide dispersion. The value of material dispersion is depending on value of effective refractive index of the material. The effective refractive index is directly obtained from the three-term Sellmeier formula [6].

$$n(\lambda) = \sqrt{1 + \sum_{i=1}^{M} A_i \cdot \frac{\lambda^2}{\lambda^2 - \lambda_i^2}}$$

III DESIGN AND SIMULATION

The proposed square lattice PCF is made up of borosilicate crown glass (BK7) and has an array of air holes running along its length. Now we will calculate the values of dispersion of proposed PCF in scalar, TE and TM mode. First compared the dispersion values of proposed PCF in Scalar, TE and TM mode and second compared the dispersion values for both materials silica and borosilicate. The proposed PCF consists of a solid core with a regular array of air holes running along the length of the fiber acting as the cladding. The core material is borosilicate glass, which refractive index is 1.5168 and the refractive index of cladding air holes is 1. The pitch difference (Λ) which is center to center spacing between two nearest air holes is kept as 2.0µm for the entire configuration. The lattice structure is in square lattice. In this, various configurations of PCF are considered. The finite difference time domain method and the TBC boundary condition are used for the simulation boundaries. The software is used for various layouts designed and investigated is OPTIWAVE SYSTEM-FDTD mode solver tool.

(a) Configuration 1:
The PCF structure is made up of seven layer square lattice structure with inner five rings has circular air holes and outer two rings has square air holes. First, second, third and fourth ring air hole d = 0.12 µm. Fifth ring air hole d = 0.6 µm. Sixth and seventh ring air hole W = 1.2µm and L = 1.2µm.

(b) Configuration 2:
The PCF structure is made up of seven layer square lattice structure with inner five rings has circular air holes and outer two rings has square air holes. First, second and third ring air hole d = 0.12 µm. Fourth and fifth ring air hole d = 0.6 µm. Sixth and seventh ring air hole W = 1.2µm and L = 1.2µm.

(c) Configuration 3 (proposed PCF model):
The PCF structure is made up of seven layer square lattice structure with inner five rings has circular air holes and outer two rings has square air holes. First and second ring air hole d = 0.12 µm. Third ring air hole d= 0.9 µm. Fourth and fifth ring air hole d = 0.6 µm. Sixth and seventh ring air hole W = 1.2µm and L = 1.2µm.

(d) Configuration 4:
The PCF structure is made up of seven layer square lattice structure with inner five rings has circular air holes and outer two rings has square air holes. First and second ring air hole d = 0.12 µm. Third, fourth and fifth ring air hole d = 0.6 µm. Sixth and seventh ring air hole W = 1.2µm and L = 1.2µm.

Note:
According to our four design configuration the best one is configuration 3.

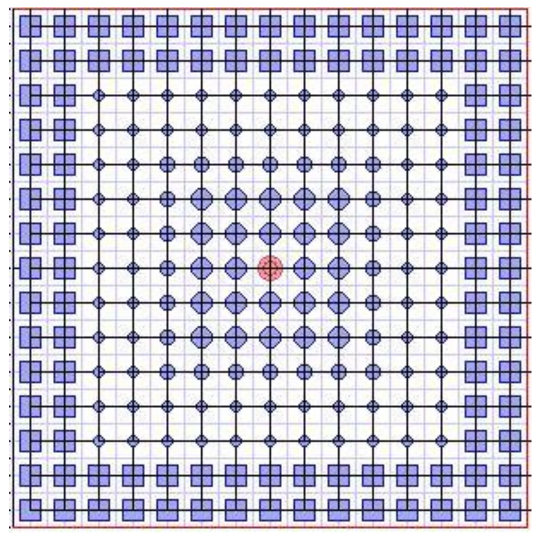

Fig.1 Inner two layer d=0.12µm, 3rd layer d=0.9µm, 4th and 5th layer d=0.6 µm.6th and 7th layer W=L=1.2 µm. pitch (Λ) = 2.0µm.

IV SIMULATION RESULT

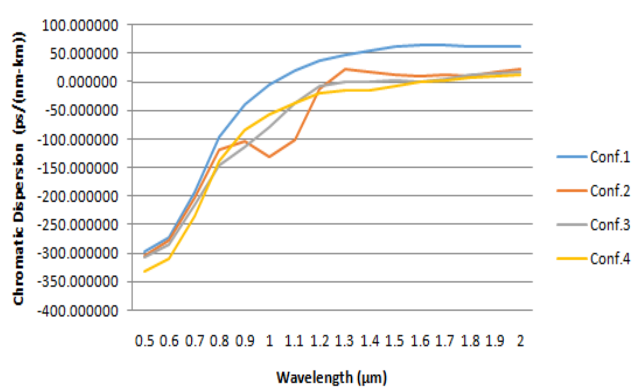

Fig.2 Simulation results graph of square lattice PCF of borosilicate crown glass (BK7).

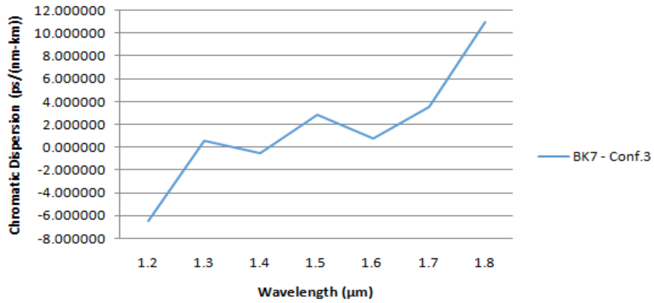

Fig.3 Near zero ultra flattened dispersion graph of proposed PCF of BK7 at 1.2 to1.8µm wavelength.

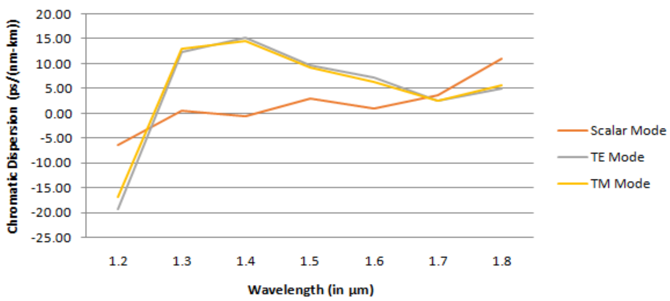

Fig.4 Dispersion graph of proposed PCF of BK7 in Scalar, TE and TM mode at 1.2 to1.8µm wavelength.

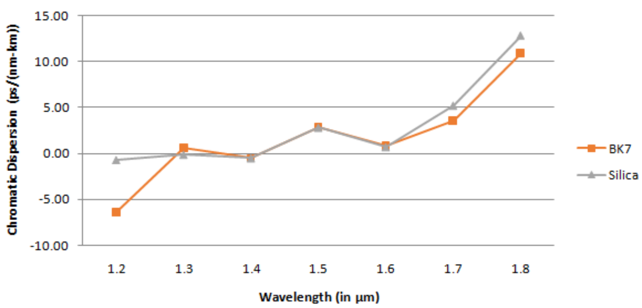

Fig.5 Dispersion graph of proposed PCF with Borosilicate and Silica at 1.2 to1.8µm wavelength.

V. CONCLUSION

According to our configurations the best one is configuration 3 that structure simulations results get ultra flattened and near zero dispersion characteristics over l.2µm to1.8µm wavelength range. This configuration shows the value of dispersion is zero between1.2µm – 1.3µm, 1.3µm - 1.4µm and 1.4µm – 1.5µm wavelengths.

Wavelength (µm)	Dispersion of proposed PCF Conf.3
1.2	-6.425442
1.3	0.583236
1.4	-0.524196
1.5	2.85447

Figure 4 shows that proposed PCF provide better performance in scalar mode compare to TE and TM mode. Figure 5 also shows that borosilicate glass PCF provides much better dispersion as compared to silica of the same structure. The Borosilicate crown glass has good properties (like cheaper, good transmission, easy availability) so we can use Borosilicate crown glass as a core material on the place of silica glass.

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