Design of Hybrid Photonic Crystal Fiber for Low Confinement Loss and Dispersion Shifted Fiber

Rahul Kumar Meena, Himanshu Joshi, Ramesh Bharti, Khushbu Sharma

***Abstract*— A new kind of zero order dispersion with Hexagonal structure and triangular lattice photonic crystal fiber of different air-hole diameters in cladding region is projected and the dispersion is investigated employing a compact 3-D finite distinction frequency domain method with the anisotropic perfectly matched layers (PML) absorbing boundary conditions. The proposed result is through numerical simulation and optimizing the geometrical parameters like by changing the diameter of holes (d) for photonic crystal fibers in triangular lattice structure. After analyzing all the result, it has been demonstrated that it is possible to obtain zero dispersion at 1.55µm wavelength which lies in the wavelength range of 1.53 to 1.65 µm with low confinement losses from a six ring into which ring are designed as elliptic and circular. The best choice of material for the designing purpose is silica material, which has refractive index 1.458.**

***Index Terms*——Effective Refractive Index (n*eff*), Photonic Crystal Fiber (PCF), Transparent Boundary Condition (TBC), Perfectly matched layers (PML).**

I. INTRODUCTION

As the superb propagation properties, photonic crystal fibers (PCFs) have engrossed right smart consideration since the first fabrication of PCF in the year of 1996 [1]. Now days several analysis teams are creating constant effort all over the world to determine prevalence of PCFs over conventional fibers due to its novel optical characteristics. It has been reported that PCF will notice as endlessly single-mode guiding [1] [2], manageable nonlinearity [3], the chromatic dispersion over large wavelength vary, giant effective space and highly double refraction. Generally, PCFs are often classified into two types by their light-guiding mechanism. First types of the index guiding photonic crystal fibers in during which lightweight is guided by total internal reflection, and the photonic band gap fibers during which lightweight is guided by the impact of band gap [1].

The lattice configuration holes could be of different diameter or different shape [4]. In PCFs is incredibly vital for, over a broadband wavelength aim specific, immoderate planar dispersion PCFs are essential for optical information transmission systems. On the other hand, designs are based on triangular [1-4] and square lattice [5] PCFs. Subsequently it is very essential to investigate zero order dispersion in triangular lattice PCFs. In recent time the elliptic waveguide [6-7] property is used to fabricate the crystal structure as shown in Fig 1 and Fig 2 below. We can also use linear waveguide [8] to design the squared shape holes. In this paper we used circular as well as elliptic air holes. The Silica as a core material is extensively used for most of the PCF structure and the cladding is surrounded by the air holes and the shape of the air holes can be designed by the elliptic waveguide [1-5], linear waveguide [8] and arc waveguide.

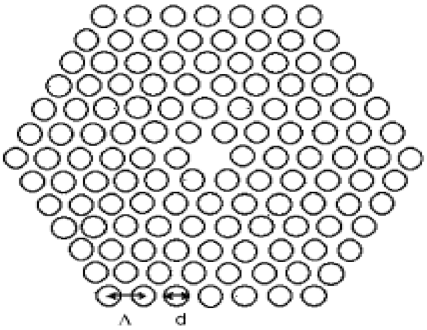

Fig. 1 Traditional high index core PCF [6]

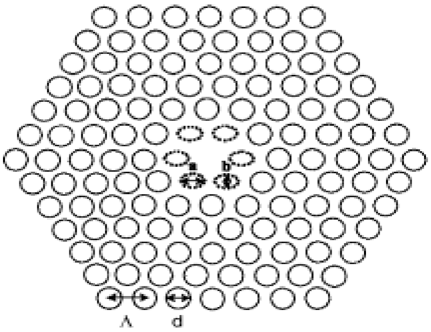

Fig. 2 Modified PCF with elliptical air-holes in the first central ring [6]

In this work fused silica crown glass as material is used. Here instead of pure silica fused silica material is used. A compact two-dimensional (2-D) finite difference frequency domain approach described in with anisotropic perfectly matched layers (PML) absorbing boundary conditions is used [1-5]. The calculated results show that our proposed PCF can simultaneously realize zero order dispersion and low confinement losses at a wavelength 1.55µm. In this paper, we propose a new kind of Hexagonal structure PCF with six rings air-holes.

II. ADVANTAGES OF PCFS

The PCF is having so many unique properties such as high birefringence [3], high nonlinearity [1], wideband dispersion flattened characteristics [1-2] [4-5], zero order dispersion, endlessly single mode guiding [1-2], fiber sensors and fiber lasers which are not realizable by conventional optical fiber. Such as super prisms and three-dimensional (3-D) mirrors are perfect crystals and valuable for fabricating dispersive elements. The frequencies and directions of propagating

Rahul Kumar Meena, M.Tech. Scholar, Jagannath University, Jaipur, India, Mobile No. 7615037271.

Himanshu Joshi, Assistant Professor, Jagannath University, Jaipur, India, Mobile No. 9414618668.

Ramesh Bharti, Assistant Professor, Jagannath University, Jaipur, India, Mobile No. 9460144512.

Khushbu Sharma, Assistant Professor, Department of ECE, VGIET, Jaipur.

magnetic force waves make them especially useful in optical telecommunications and as laser applications.

III. TYPES OF LOSSES AND THEIR CALCULATION

Material dispersion: Due to the different group velocities of various spectral components launched into the fiber from the optical source so that pulse broadening will occurs and produce material dispersion [1][4-6][8]. It happens once the part rate of the plane wave propagating within the insulator medium varies nonlinearly with wavelength and a fabric is about to exhibit material dispersion.

Waveguide dispersion: Determination of the distortion in signals at the output of end is done by dispersion, which is an essential categorization factor of optical fiber. The actual information carrying capacity or bit rate of the optical fiber is accountable of affection. When we examine the Dispersion gives an suggestion that the distortion to optical signals occurs when signal propagate down in the optical fibers while communication process is going on. An additional factor which affect is delay distortion. For example, creates the broadening in transmitted light pulses so that so that it will cause restriction of the information carrying capacity of the fiber[1][4][6][8].

The dispersion (D) is proportional to the subsequent derivative of the η_{eff}, with esteem to the wavelength (λ) obtained as [1] [4-6] [8-10]:

$$D = -\left(\frac{\lambda}{c}\right)\frac{d^2}{d\lambda^2}\left[Re\left(\eta_{eff}\right)\right] \qquad \text{(Eq. 1)}$$

Where Re $[\eta_{eff}]$ is the real part of η_{eff}, λ is wavelength, and c is the velocity of light in vacuum.

The total dispersion is depends upon the calculation of the sum of the geometrical dispersion (or waveguide dispersion) and the material dispersion obtained as [1] [4-6] [10]:

$$D(\lambda) = D_g(\lambda) + \Gamma D_m(\lambda) \qquad \text{(Eq. 2)}$$

Where Γ is the confinement factor in material (if we use Borosilicate crown glass), which is close to unity for the most practical PCFs as the modal power is almost confined in the material with high refractive index.

Confinement Loss: An additional imperative loss is confinement or leakage loss [1-5] [9-11] originates from the finite width of the cladding structure. By selecting the parameters *d* and Λ properly in PCFs we can formulate confinement loss minor. On the other hand, for miniature core fibers wherever the core size is analogous or slighter in dimension than the conceded light-weight wavelength, a foremost involvement in full loss of the fibers is accessible by the confinement loss [9]. Confinement loss is predominantly dominating within the wavelength region attention grabbing for telecommunication applications, as typically imperative negative conductor dispersion is absolute because of dispersion. The bulky negative conductor dispersion around 1550 nm may be achieved by lease the sphere go through into the shield region, which consecutively provides rise to augmented confinement loss. Low confinement loss may be achieved for small core PCFs by coming up with the fibers with a minimum of 6 rings of air holes for a closely packed structure. Raising the amount of air hole rings ends up in a supplementary reduced confinement loss [1][3][4-5] [9-10] (Eq.3)

$$\text{Confinement Loss (dB/m)} = 8.686\ \mathrm{Im}[k_0 * \eta_{eff}] \qquad \text{(Eq. 3)}$$

Where $k_0 = \frac{2\pi}{\lambda}$, λ is wavelength of light and η_{eff} is the effective refractive index of the proposed.

IV. PROPOSED DESIGN AND SIMULATION

The proposed elliptical hybrid cladding PCF is made up of silica crown glass and has an array of air holes running along its length. Now here we will analyze the dispersion properties of photonic crystal fiber. The designed PCF consists of a solid core with a regular array of air holes running along the length of the fiber acting as the cladding. For the entire configurations analyzed the mean cladding refractive index is lower than the core index. The core material is silica glass which refractive index is 1.458 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 1.95μm for the entire configuration. The lattice structure is in triangular lattice and it form Hexagonal shape. Here various configurations of PCF are considered. The dispersion property is numerically simulated by scalar effective index method. 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.

Design-1

The PCF structure is made up of six layer hexagonal lattice structure with inner two layer is circular holes which has diameter d=0.6μm, third layer has tilde elliptical holes with diameter a (major axis)= 1.08μm, b (minor axis)=0.66μm, forth layer is tilde elliptical holes where a (major axis) =1.3μm, b (minor axis)=1.0μm, fifth layer is elliptical where a (major axis) =1.4μm, b (minor axis)=1.2μm and sixth layer is d=1.4μm as shown in Fig 3.

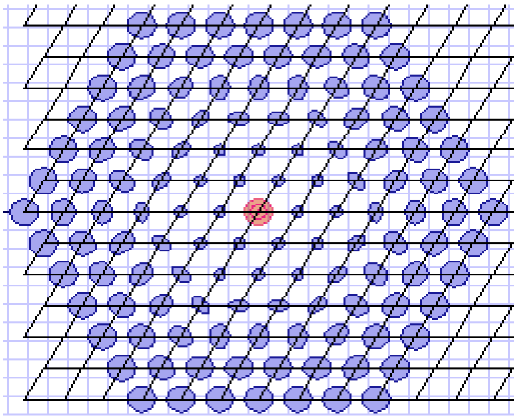

Fig. 3 Air-hole distribution of the Proposed Hybrid Structure for Design-1

Design-2

The PCF structure is made up of six layer hexagonal lattice structure with inner two layer is circular holes which has diameter d=0.6μm, third layer has tilde elliptical holes with diameter a (major axis)= 1.08μm, b (minor axis)=0.66μm, forth layer is tilde elliptical holes where a (major axis) =1.4µm, b (minor axis)=1.0µm, fifth layer is tilde elliptical where a (major axis) =1.4µm, b (minor axis)=1.2µm and sixth layer is d=1.4µm as shown in Fig 4.

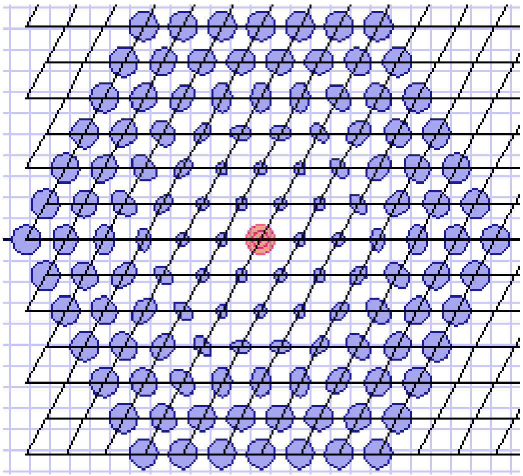

Fig. 4 Air-hole distribution of the Proposed Hybrid Structure for Design-2

Design-3

The PCF structure is made up of six layer hexagonal lattice structure with inner two layer is circular holes which has diameter d=0.6µm, third layer has tilde elliptical holes with diameter a (major axis)= 1.08µm, b (minor axis)=0.66µm, forth layer is tilde elliptical holes where a (major axis) =1.6µm, b (minor axis)=.9µm, fifth layer is tilde elliptical where a (major axis) =1.4µm, b (minor axis)=1.2µm and sixth layer is d=1.4µm as shown in Fig 5

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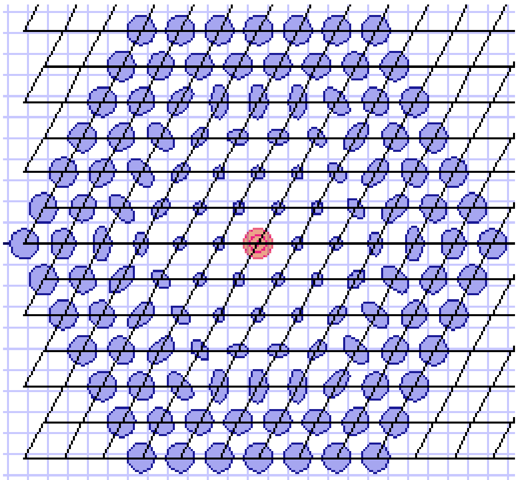

Fig. 5 Air-hole distribution of the Proposed Hybrid Structure for Design-3

In the proposed work there is a comparison between all the three designs is based on Total dispersion (chromatic dispersion) as shown in Fig 6 and Confinement loss as shown in Fig 7. The total dispersion or chromatic dispersion is the sum of waveguide dispersion and material dispersion. For above all the Design-1 to Design-3, we can conclude that design-3 gives zero order dispersion near 1.55 µm wavelength as compare to other two designs so that Design-3 is proposed design for the zero order dispersion as shown in Fig 6.

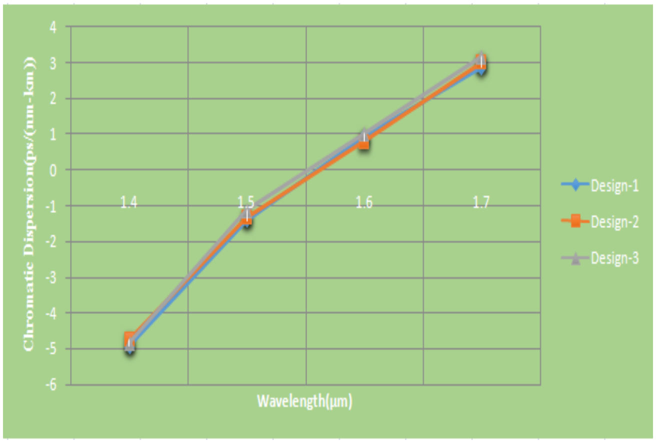

Fig. 6 Comparison of Chromatic dispersion for Design-1 to Design-3

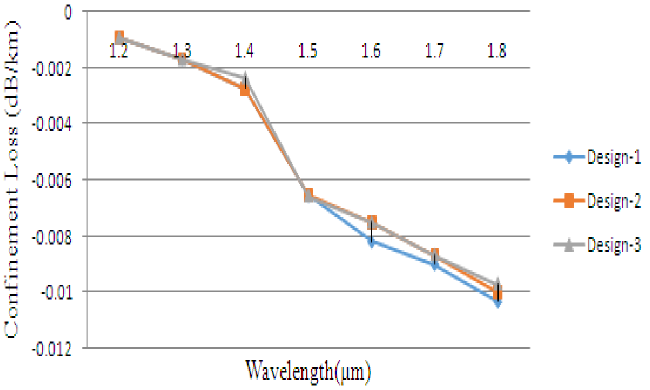

Fig. 7 Comparison of Confinement Loss for Design-1 to Design-3

For above all the Design-1 to Design-3, we can conclude that Design-3 gives low confinement loss near 1.55 µm wavelength as compare to other two designs so that design-3 is proposed design for the low confinement loss as shown in Fig 7.

V. RESULT

All the three PCF structure provides zero order dispersion values near the wavelength range 1.5µm to 1.6µm. Among three structures, Design-3 has nearly zero dispersion at 1.55µm wavelength as well as low confinement loss near about -0.007dB/km at 1.55µm wavelength. Design-3 with zero order dispersion lies in the C-band range (1.53µm-1.65µm). In this paper, the proposed PCF with six rings of array of air holes is designed for investigation of almost zero dispersion and minimum confinement loss with the elliptic air holes but holes have different diameter.

VI. CONCLUSION

According to above conclude result, so we obtained that the dispersion calculated for proposed photonic crystal fiber using the Scalar index method gives best result in comparison of other structures. So that here we have calculated the dispersion for various structure but it shows that when we increase the diameter of holes both Chromatic dispersion and Confinement loss are decrease with comparison to other structure with less diameter but Pitch 1.95µm is same for all and select total 6 layers, gives best result. The fiber parameters are optimized to yield best agreement with available data. It also should be known that the properties of practical PCF still depends on the manufacture technique and the level of accuracy will improve as the manufacture technique developed This kind of fiber can be used in optical communication and various polarization sensitive devices.

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Rahul Kumar Meena M.Tech. Scholar, Department of ECE, Jagannath University, Jaipur. He is the student of M.Tech. + B.Tech. integrated course in Jagannath University. His current research includes photonic crystal fiber.

Himanshu Joshi, Assistant Professor Department of ECE in Jagannath University, Jaipur, India. He has completed his M.Tech (VLSI and Embedded system) in 2011 from Gyan Vihar University, Jaipur, and B.E degree in 2007 from Rajasthan University. He is currently working in the VLSI and Communication Field.

Ramesh Bharti, Associate Professor Department of ECE in Jagannath University, Jaipur. He is currently pursuing PhD from Jagan Nath University. He has completed his M.Tech (ECE) in 2010 from MNIT Jaipur, and B.E degree in 2004 from Rajasthan University. He is currently working in the wireless communication.

Khushbu Sharma received the M.Tech. degree in Digital Communication in 2015 from RTU, kota and B.E. degree in Electronics & Communication Engineering in 2011 from Rajasthan Technical University, Kota Rajasthan. She is currently working as Assistant Professor in the department of E&C, Vedic Gurukul Institute of Engg. and Tech., Jaipur. Her current research includes photonic crystal fiber.