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Dispersion analysis of a Hybrid Photonic Crystal Fiber

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***Abstract*—In this study, a new photonic crystal fibre (PCF) structure is proposed which is suitable for optical telecommunications. This PCF has some features including low- and ultra-flattened dispersion and low confinement loss as well as a large effective area in a wide range of wavelengths In this paper we compare and analyze the design of Hybrid Photonic Crystal Fiber Structure with circular air hole and elliptical air holes for the total dispersion property of both the configuration. By varying the size of the air holes it is possible to obtain the flattened dispersion for the wavelength range 1.1 µm to 1.5 µm range. A full vector FDTD method is used to simulate and analyze the dispersion property of PCF.**

***Keywords*- Photonic crystal fiber (PCF), chromatic dispersion, flattened dispersion, effective refrective index, finite difference time domain (FDTD).**

I. INTRODUCTION

The design of Photonic Crystal Fiber (PCF) [1] is very simple. It is a new class of optical fibre based on the properties of photonic crystals. Because of its ability to confine light in hollow cores or with confinement characteristics not possible in conventional optical fibre, PCF is now finding applications in fibre-optic communications, fibre, nonlinear devices, high-power transmission, highly sensitive gas sensors, and other areas. More specific categories of PCF include photonic band gap fibre (PCFs that confine light by band gap effects), holey fibre (PCFs using air holes in their cross-sections), hole-assisted fibre (PCFs guiding light by a conventional higher-index core modified by the presence of air holes), and Bragg fibre (photonic-band gap fibre formed by concentric rings of multilayer film). Photonic crystal fibres may be considered a subgroup of a more general class of micro structured optical fibres, where light is guided by structural modifications, and not only by refractive index differences.

In general, regular structured fibres such as photonic crystal fibres, have a cross-section (normally uniform along the fibre length) micro structured from one, two or more materials, most commonly arranged periodically over much of the cross section, usually as a "cladding" surrounding a core (or several cores) where light is confined [2]. For example, the fibres first demonstrated by Russell consisted of a hexagonal lattice of air holes in a silica fibre, with a solid (1996) or hollow (1998) core at the centre where light is guided. Other arrangements include concentric rings of two or more materials, first proposed as "Bragg fibres" by Yeh and Yariv (1978), a variant of which was recently fabricated by Temelkuran et al. (2002) and others. (Note: PCFs and, in particular, Bragg fibres, should not be confused with fibre Bragg gratings, which consist of a periodic refractive index or structural variation along the fibre axis, as opposed to variations in the transverse directions as in PCF. Both PCFs and fibre Bragg gratings [3] employ Bragg diffraction phenomena, albeit in different directions.) There are several parameters to control: air hole shape and diameter, refractive index of the glass, type of lattice and distance between hole to hole that is lattice pitch. Autonomy of design allows one to obtain endlessly single mode fibers, which are single mode in all optical range [4] and a cut-of wavelength does not exist. By manipulating the structure it is probable to design desired dispersion properties of the fiber. PCFs having zero, low, or anomalous dispersion at visible wavelengths can be designed and fabricated. In this paper, we have tried to get the effective modal index of hexagonal PCF [5] considering different lattice pitch using OPTI FDTD 8 Software.

II. DISPERSION

The most important factors in development of communication systems [6] are reduction of dimensions and increasing information transfer rate and capacity. So for information transmission, conventional optical fibres are used as proper transmission media. In order to decrease dispersion effect, dispersion-shifted fibres and zero-dispersion single-mode fibres are designed at a specified wavelength.

In high-speed optical transmission, flat dispersion [7] slope and low loss are needed in addition to zero-dispersion. Thus, in recent years, researches are focused on new fibres called photonic crystal fibres (PCFs) because of their unique features such as very low confinement loss even in small bending radius, flexible design and controllable dispersion [8].

In this paper, the main focus is on Dispersion is an important characterization factor of optical fiber as it determines the distortion at the output of signals launched into the fiber. This in effect modifies the actual information carrying capacity or bit rate of the optical fiber. Dispersion measurement [9] gives an indication of the distortion to optical signals as they propagate down optical fibers. The delay distortion which leads to the broadening of transmitted light pulses, limits the information carrying capacity of the fiber.

The dispersion in optical fiber may arise due to various reasons and in practice three main factors have been analyzed, namely

(i) Material dispersion

(ii) Waveguide dispersion

(iii) Differential group dealy or Intermodal dispersion

The dependence of profile on the wavelength, also called as profile dispersion, is an important factor in introducing dispersion in fiber. The material dispersion is due to the variation of the refractive index of the fiber with the wavelength of signal source. The bandwidth in a fiber is also defined as the baseband frequency at which the transfer function falls to the half of its maximum value.

PCFs possess the attractive property great controllability in chromatic dispersion [5]. The chromatic dispersion profile can be easily controlled by varying the air hole diameter and the air hole pitch. The chromatic dispersion of a fiber is expressed in ps/(km-nm) by the equation 1.

The dispersion (D) is proportional to the second derivative of , with respect to the wavelength (λ) obtained as;

(1)

Where Re( ) is the real part of , λ is wavelength, and c is velocity of light in vacuum.

Sellmeier Equation:

The material dispersion also can be obtained by equation 2. The effective refractive index is directly obtained from the three-term Sellmeier formula given as:

(2)

Where λ is operating wavelength in µm and the Sellmeier coefficients for silica are:

=0.69616630, =0.40794260, =0.89747940

=0.068404300µm, =0.11624140µm,

=9.8961610µm

Total Dispersion:

The total dispersion is calculated as the sum of the geometrical dispersion [7] (or waveguide dispersion) and the material dispersion obtained as:

D( ) = (3)

Where, is the confinement factor in silica that is close to unity. PCFs as the modal power is almost confined in the silica with high refractive index. Secondly, the total dispersion is obtained by equation 3.

III. SIMULATION

Now we will analyze the dispersion properties of photonic crystal fiber and compared the properties for both the circular air holes ring and elliptical air holes rings. 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 wafer chosen is pure silica with refractive index 1.4446 and the refractive index of air holes is 1. The pitch (A) which is center to center spacing between two nearest air holes is kept as 2.3µm for the entire configuration. The lattice structure is in triangular shape and it form Hexagonal shape [10]. Here various configurations of PCF are considered. The dispersion property is numerically simulated by semi vector finite difference method for TE mode (X-polarization) [11]. The full- vectorial finite difference method for TE mode (X-polarization) and the TBC boundary condition is used for the simulation boundaries [12]. The various layouts designed and investigated using OPTIWAVE SYSTEM-FDTD mode solver tool and graphs are plotted using OriginPro 8 (The data analyzing and work space).

A. Configuration – I

The PCF layout has hexagonal lattice [13] with circular air holes, number of ring =5 air hole diameter (d) = 0.5 µm, lattice constant (A) = 2.3 µm. The wafer dimension for three rings is length = 16.1µm and width = 13.943µm with refractive index 1.4446 of wafer and refractive index of air holes is 1.

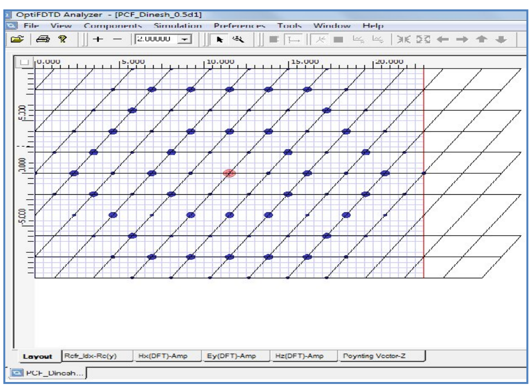

Fig.1 HPCF Hexagonal Lattice with Circular air hole ring structure with pitch A = 2.3 µm and different diameter

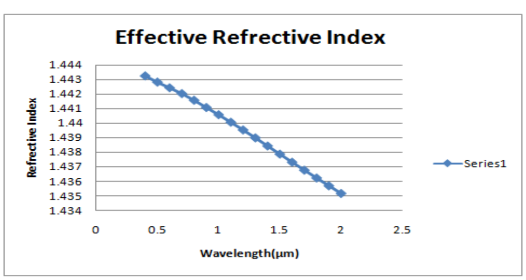

Fig.2 Graph showing Effective Refrective Index for HPCF hexagonal structure

B. Configuration – II

The PCF layout has hexagonal lattice with Circular air holes, number of ring =5, air hole diameter (d) = 0.1 µm to 0.5 µm (in increasing order from first ring to fifth ring) for layout, lattice constant (A) = 2.3 µm. The wafer dimension for five rings is Length = 23 um Width = 19.9186 um with refractive index 1.4446 of wafer and refractive index of air holes is 1. Fig. 5 to fig.8 show the layout for 5 ring Circular air holes with various diameters.

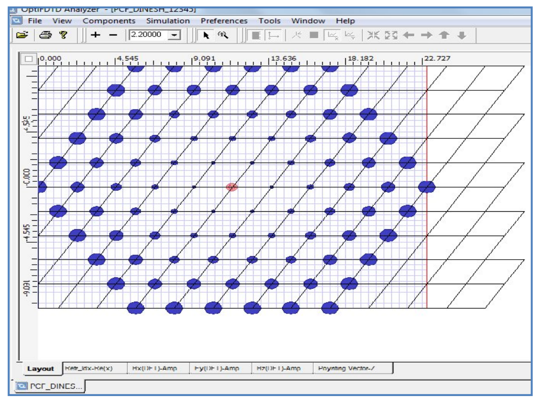

Fig.3 HPCF Hexagonal with Circular air hole structure

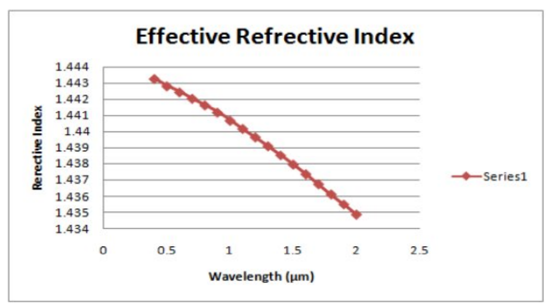

Fig.4 Graph for Effective Refrective index distribution profile For PCF Structure (Circular air holes)

C. Configuration - III

PCF layout has hexagonal lattice with Elliptical air holes, number of ring = 5, air hole diameter (d) with major axis = 0.2 µm, 0.4 µm, 0.6 µm, 0.8 µm, 1.0 µm and minor axis = 0.05 µm, 0.1 µm, 0.15 µm, 0.2 µm, 0.25 µm (in increasing order from first ring to fifth ring) for layout, lattice constant (A) = 2.3 µm.

The wafer dimension for five rings is Length = 23 um Width = 19.9186 um with refractive index 1.4446 of wafer and refractive index of air holes is 1. Fig.5 to fig.8 shows the layout for 5 ring elliptical air holes with various diameters

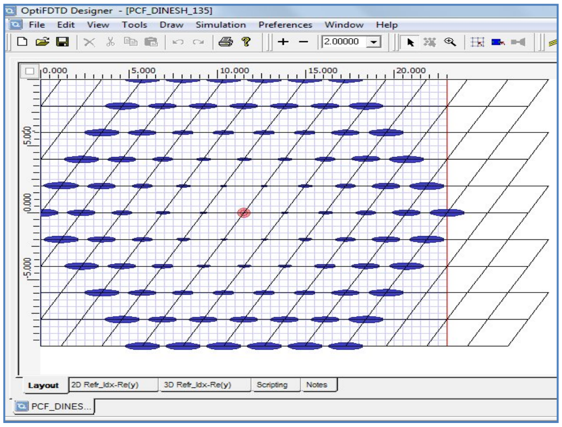

Fig.5 HPCF Structure with Elliptical air hole

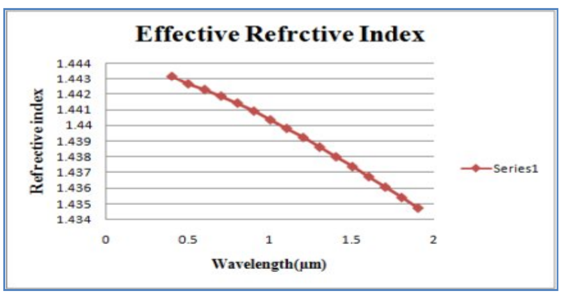

Fig.6 Refrective Index Distribution Profile of HPCF Structure (Elliptical air hole ring with pitch A = 2.3 µm and different diameter)

IV. RESULTS AND CONCLUSION

In this paper, we have presented some new design of PCF having Hybrid Structure with different air holes configurations. It has been observed that the unique properties of PCF like Zero order dispersion got affected with the variation in the wafer dimension.. It is observed that all the structures proposed has shown the most negative (zero order) dispersion in between the wavelength range of 1.0 µm to 1.5 µm.

But HPCF structure with Elliptical Air holes having the more flattened dispersion characteristics compare than other two structures (Circular Air holes).

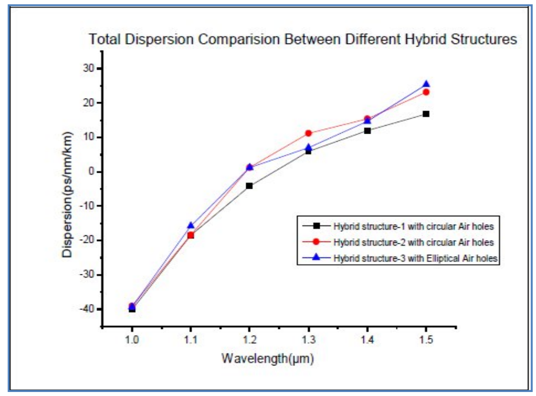

Fig.7 Graph Showing Total dispersion in Different Hybrid PCF hexagonal structures at different Diameters air holes with pitch (A) = 2.3µm

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