A

DISSERTATION REPORT

ON

ZERO ULTRA-FLATTENED DISPERSION BOROSILICATE HONEYCOMB PHOTONIC CRYSTAL FIBER

IS SUBMITTED AS A PARTIAL FULFILLMENT OF THE

MASTER OF TECHNOLOGY IN COMMUNICATION ENGINEERING

BY

NEETIKA MEENA

(2012PEC5245)

UNDER THE GUIDANCE OF

Dr. M. RAVI KUMAR

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

AUGUST 2015

A

DISSERTATION REPORT

ON

ZERO ULTRA-FLATTENED DISPERSION BOROSILICATE HONEYCOMB PHOTONIC CRYSTAL FIBER

IS SUBMITTED AS A PARTIAL FULFILLMENT OF THE

MASTER OF TECHNOLOGY IN COMMUNICATION ENGINEERING

BY

NEETIKA MEENA

(2012PEC5245)

UNDER THE GUIDANCE OF

Dr. M. RAVI KUMAR

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY JAIPUR

AUGUST 2015

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY
JAIPUR (RAJASTHAN)-302017

CERTIFICATE

This is certified that the dissertation report entitled **"ZERO ULTRA-FLATTENED DISPERSION BOROSILICATE HONEYCOMB PHOTONIC CRYSTAL FIBER"** prepared by **NEETIKA MEENA**(2012PEC5245), in the partial fulfilment of the Degree **Master of Technology** in **Electronics and Communication Engineering** of **Malaviya National Institute Of Technology Jaipur** is a record of bonafide research work carried out by him under my supervision and is hereby approved for submission. The contents of this dissertation work, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

Date:

Place:

Dr. M. Ravi Kumar
Assistant Professor
Dept. of E.C.E.
MNIT, Jaipur

DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

MALAVIYA NATIONAL INSTITUTE OF TECHNOLOGY

JAIPUR (RAJASTHAN)-302017

DECLARATION

I **NEETIKA MEENA** hereby declare that the dissertation entitled **"ZERO ULTRA-FLATTENED DISPERSION BOROSILICATE HONEYCOMB PHOTONIC CRYSTAL FIBER"** being submitted by me in partial fulfillment of the degree of **M.Tech(Communication Engineering)** is a research work carried out by me under the supervision of **Dr. M. Ravi Kumar,** and contents of this dissertation work, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma. I also certify that no part of this dissertation work has been copied or borrowed from anywhere else. In case any type of plagiarism is found out, I will be solely and completely responsible for it.

Date: **NEETIKA MEENA**

M.Tech.(Communication Engg.)

Place: 2012PEC5245 (Part Time)

ACKNOWLEDGMENT

I would like to express my sincere thanks to **Dr. M. Ravi Kumar,** Assistant Professor, Department of Electronics and Communication Engineering for his keen interest in guiding me on such a progressive topic with great dedication, expertise and knowledge thought the process of this research.

I am also thankful to **Prof. K. K. Sharma,** Head, Department of Electronics and Communication Engineering MNIT, Jaipur, for allowing me to work on the topic of my choice and providing me all possible support.

I thank all Technical, Non-Technical Staff of the Laboratory as well as office of Electronics and Communication Engineering Department MNIT, Jaipur for supporting and encouraging me throughout the research work.

Finally, I extend my sincere thanks to my **Family and Friends** for constant support and encouragement throughout the study.

ABSTRACT

In the present scenario, optical fibers are used as transmission media in Data and Telecommunications. Installed optical fibers are mature, and display physical characteristics which at times limit their capability to transmit high speed signals in the wavelength range from 1360 nm to 1530 nm. These are a cause of concern when using conventional single mode fibers, in which, high dispersion leads to partial loss of data in long distance data transmission. A great deal of work has been focused on photonic crystals due to their optical properties. A very useful attribute of a Photonic crystal fiber (PCF) is its change of dispersion with modifications in structure, or material. This attribute is the guide to many improvements proposed by various authors over the years. Hence, the focus of the present work will be on optical transmission media with zero dispersion and uniform response over a large wavelength range.

As compared to conventional optical fiber, PCFs are suppler, captivating and long lasting. In the present dissertation report, the focus is on a new design of Honeycomb PCF using borosilicate material to get Zero dispersion characteristics over a wide range. This is achieved by varying the dimension of air-holes in the honeycomb structure. There are different methods which are used to explore the dispersion in a PCF having high refractive index core. Among the different methods, most commonly used are Finite Difference Time Domain, or transparent boundary condition. The finest results of these techniques are from 1600 nm to 1900 nm wavelength range, and establish the diffusion is Zero-ultra flattened and in addition establish crouch dispersion attributes over l300 nm to 2000 nm wavelength range which has shown good result than usual PCF. The work will also prove that dispersion is better in borosilicate glass PCF in comparison to silica which sounds similar to that of silica and it ultimately leads to such PCF which have high potential values as compared to dispersion compensating fiber in optical window.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS USED

CTAE	College of Technology And Engineering
PCF	Photonic crystal fiber
PBG	Photonic band gap
HC	Hollow core
IG	Index guiding
BK7	Borosilicate crown glass
CD	Chromatic dispersion
PMD	Polarization mode dispersion
C	Speed of light in vacuum
D	Hole diameter
Λ	Wavelength
Λ	Pitch of the lattice
TBC	Transparent Boundary Condition

FDTD	Finite Difference Time Domain
WDM	wavelength division multiplexing
PML	The Perfectly Matched Layer (PML(
UPML	Un-split The Perfectly Matched Layer
PMC	Perfect Magnetic Conductor
PEC	Perfect Electric Conductor

CHAPTER 1

INTRODUCTION

To uphold a continuous approach in wavelength division multiplexed (WDM) communication systems with various wavelength channels and as per this system it is necessary that the optical fiber should conceptualize towards an ideal state which centers on ultra-flattened dispersion and very low loss. For optical data transmission, optical fiber is mostly used in WDM networks. The foremost problem is flexible dispersion or losses in optical fiber in high bit rate WDM systems. The demand for bandwidth is growing every year, and researchers are working on reducing the bit duration to accommodate higher data rates, which require controlled dispersion in the optical transmission line. Optical fibers and integrated optical waveguides are also used in spectroscopy, sensor technology and medication. Photonic Crystal Fibers (PCF), which are now leading in new generation of optical fibers are consequently a result of new expertise of industrialized photonic crystals. First PCF was launched in 1966. As they possess novel optical characteristics, it leads to a common area of interest for various research groups worldwide, not only that these researches are doing their level best in establishing their superiority of PCFs over conventional fibers. There are certain other factors too, which have made PCF a common focus point for researches, and they are: controllable dispersion, very low confinement loss and flexible design. PCF holds its importance in applications which are sensible and helps in controlling the chromatic dispersion as well. In optical data transmission systems ultra flattened dispersion PCFs are necessary over a broadband wavelength range, because no dispersion asserts that the possibility of accumulated dispersion difference in telecommunication bands reduces. At the same time, researchers are still continuously striving to prove it better and finer by limiting dispersion and all other losses.

CHAPTER 2
PHOTONIC CRYSTAL FIBER

2.1 Photonic Crystal:

In the present time, there are different fields where integrated optical waveguides and optical fibers are used and these fields are telecommunications, spectroscopy, sensor technology and medicine. TIR or total internal reflection index guiding is the light which is guided by the physical mechanism and it creates the base for the execution of optical fibers and integrated optical waveguides. It is mandatory that advanced refractive index of the core compared to the surrounding media should be present to attain TIR in these waveguides and they are generated from insulators or semiconductors. On the level of the optical wavelength, the consequence of PBG may be accomplished in at asymmetrical hiatus configured materials. Such periodic structures are regularly referred to as photonic crystals or photonic band gap structures. (8)

Earlier Photonic crystals fall among optical nano structured electromagnetic media that consciously effect the movement of photons in such a way that periodicity of a semiconductor crystal influences the suggestion of electrons, the quantity of the cyclic network, and the chattels of the constituent substances. In such a case the proliferation of electromagnetic waves in definite frequency bands (the photonic bandgaps) may be not allowed inside the crystal. The quality of photonic elements to diminish the extension of gauge boson with particular oftenest has a device likeness by means of the electronic assets of semiconductors. This effect in ample significance not only among photonic crystals but also in their deployment which results as the most important force on a large series of photonics appliances. In addition, the quantifiability of the magnetism property of photonic components instruments them to be controlled over the integral magnetism array, housing visual to microwave oftenness. These Photonic crystals can be made for one, two, or three dimensions. The different variations among dimensions are as follows: when the layers deposited are stuck together, it can form One-dimensional photonic crystals; two-dimensional ones can be prepared by making the holes in an appropriate substrate, and three-dimensional same by, for example, piling areas in a surrounding substance and suspending the spheres. Prohibited bands of wavelengths are called photonic band gaps. It also shows the ways to separate optical phenomena amid additional such as relevance of impulsive emission, omni-directional mirrors, high-reflecting and low-loss-wave guiding.

Photonic crystals principally have frequently repeating internal locations of advanced and reduced dielectric invariable. Whether Photons (acting similar as moving ridge) will propagate throughout this configuration, it utterly depends on the wavelength use in it. The lights of Wavelengths which are acceptable to pass through are recognized as modes, and collection of permitted modes outlined a bands. As the fundamental physical reality is based on diffraction, the periodicity of the photonic crystal configuration has to be of the identical distance-scale as half the wavelength of the EM waves i.e. ~200 nm (blue) to 350 nm (red) for photonic crystals working in the evident part of the spectrum (the replicating areas of elevated and low dielectric invariables have to be of this facet). The complete system of fabricating the optical photonic crystals formulates them additionally awkward and multifaceted. The arrangements of Photonic crystals are usually made according to the number of their dimensions.

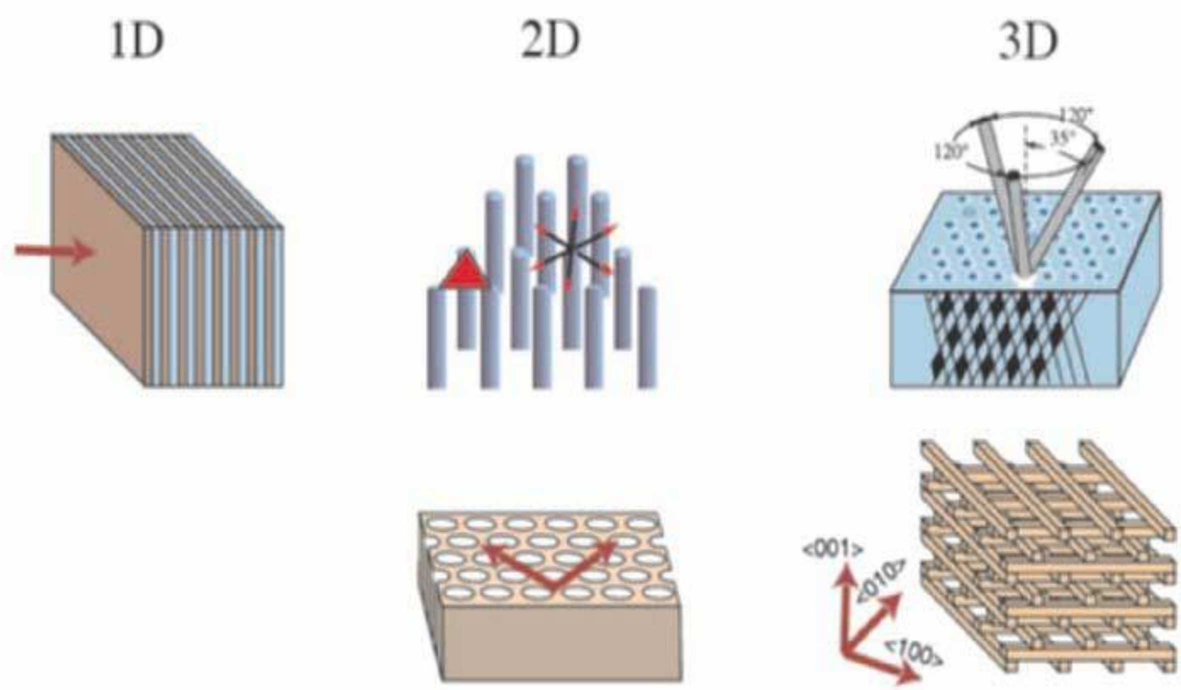

Fig 2.1: Basic Photonic Crystal Structure.

2.1.1 One-dimensional photonic constituents:

One-magnitude photonic crystals can also be isotropous or eolotropic. Earlier, before 1987 in the outward appearance of cyclic multi-layer dielectric stacks (such as the Bragg mirror) regular may be deposited collectively in one-dimensional photonic crystal. There was extensive control to outline a band gap in a single course, where ultimate prospective was on optical switch. After that, a graphene-based Bragg grating or one-dimensional photonic crystal was engendered and found its effectiveness for excitation of surface electromagnetic waves in the episodic composition by using 633 nm He-Ne laser as the light source. This arrangement also works as a far-IR filter for waveguide and sensing applications and is moreover competent of sustaining low-loss surface plasmons. Moreover, a original type of one-dimensional graphene-dielectric photonic crystal has also been undertaken.

2.1.2 Two-magnitude photonic constituents:

In the production of shorter wavelengths, two dimensional structures are much easier. In 1996, the first exposure of two-dimensional photonic sparkler at ocular wavelengths was prepared by Thomas Krauss. The elements including photonic crystals belong to exceptional class of ocular characters or waveguides by means of a two-dimensional (2D) intervallic distinction in the plane perpendicular to the fiber alliance and an invariant composition along it. In this arrangement, holes may be pierced in a substrate that is visible to the wavelength of radiation that the bandgap is conceived to artifact. The Holey material or photonic constituent material can be equipped by provocative rounded perches of container in polygon lattice, and then heating and stretching them, the airgaps (like triangle) connecting the glass rods turn out to be the holes that confine the modes. Triangular and quadrangle networks of gaps have been beneficially in use.

2.1.3 Three-dimensional photonic crystals:

Since three (3D) - dimensional photonic crystals are bigger which results in difficulty in fabrication, as a result they are found to be more slower as well. Moreover, a 3D photonic band gap crystal is not only cyclic in all directions but also shows a photonic band gap in all directions. Different structures are also constructed such as Spheres in a diamond lattice, Inverse opals or Inverse Colloidal Crystals, The Woodpile Structure, A pile of two-dimensional crystals, Circular polarization.

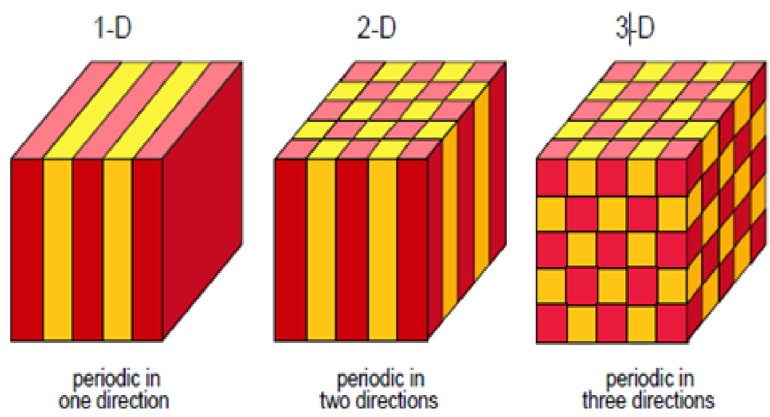

Fig2.2: Schematic diagram of Photonic crystals periodic one, two and three directions.

- One-dimensional configuration: Bragg mirror.
- Two-dimensional arrangements: hexagonal lattices created by rods or pores.
- Three dimensional configurations: 'Yablonovite' and 'woodpile' structures.

2.2 Photonic Crystal Fiber:

Photonic crystal fibers [PCF] are exceptional class of device which includes photonic crystals of optical fibers or waveguides. They comprises of two-dimensional (2D) episodic disparity in the level erect to the material alliance and an invariant composition beside it. The research group of Philip St. J. Russell first explored the PCF in the second half of 1990's. Russell and co-workers compromise superior silicon oxide fibers with an assortment of aerial gaps successively behind their dimension and pioneered this field by the insight of PCFs. In recent times as compared to conventional optical fibers this micro structured fiber or PCF has existed used to outline waveguides with new promulgation properties. Photonic Crystal Fiber (PCF) is a partition of Photonic Crystals. The new waveguides demonstrates significant properties; they have central part, with a refractive index ahead of the efficient indicator of the adjacent substance, and the wave guidance is caused by TIR. They had the liking of a material that is operated by the photonic circle space consequence.

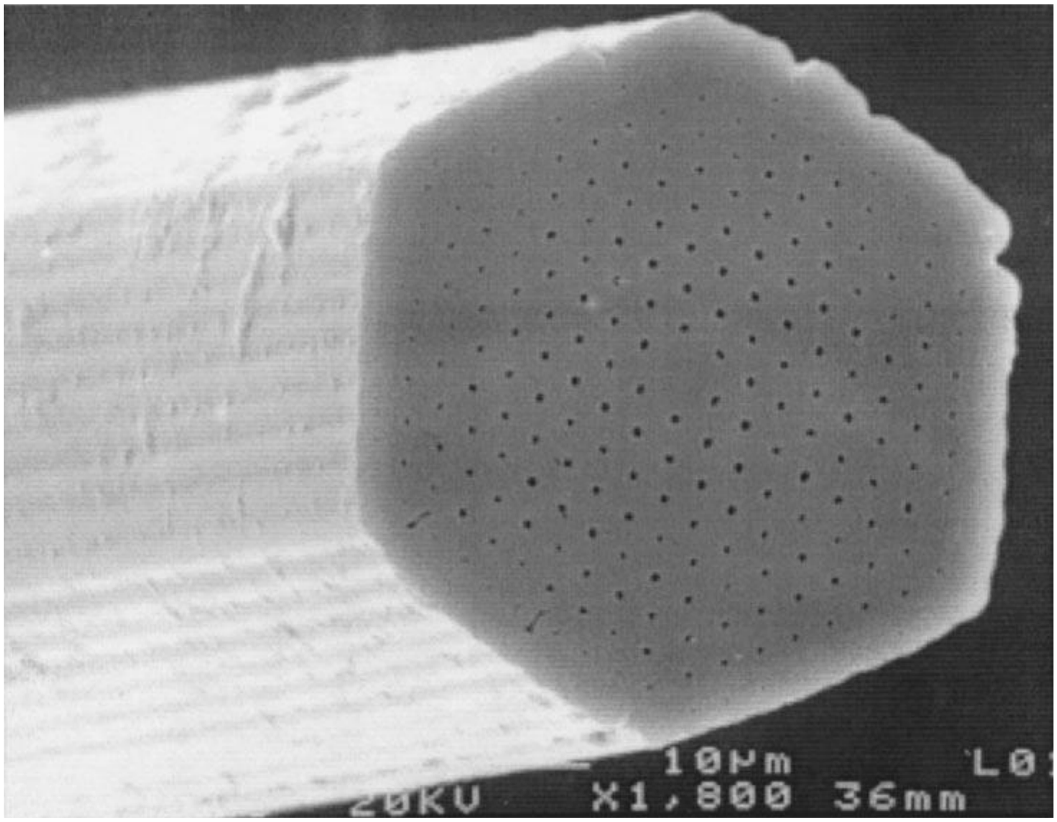

Fig. 2.3: Photonic crystal fiber, currently fabricated at the University of Bath (5)

PCFs are usually alienated into two main types: Photonic Bandgap Fibers and Index guiding Index. Photonic Bandgap Fibers are those fibers that have episodic micro composited ingredients and a center of little indicator substance (e.g. hollow core). Index Guiding Fibers are those fibers amid a solid core. Photonic crystal fiber is identified as optical fibers as they have built-in microstructure, and in the majority cases they also restrain small air holes in glass. This well-known distinctiveness do not subsist in normal optical fibers. Some of them are: single-mode procedure as of the UV to IR by means of huge mode-field diameters, extraordinarily high nonlinearity, numerical aperture (NA) ranging from very low to about 0.9, and optimized dispersion properties etc but PCF can straightforwardly offer them regularly and properly. PCFs are also used in a extensive variety of research fields like spectroscopy, metrology, biomedicine, imaging, telecommunication, industrial machining, military, fiber-optic communications, fiber lasers, nonlinear devices, high-power transmission, highly inclined gas sensors, and other areas. The reason for their applicability is that they recommend a wide collection of level of freedom in their design to achieve a multiplicity of asymmetrical properties, which result in making them fascinating for a wide assortment of applications.

A photonic crystal fiber or we can also state holey fiber, are acquired from waveguide belongings not commencing a spatially changeable flute work other than as of a assortment of extremely small and intimately spaced air holes which go through the whole length of fiber. The simplest (and nearly everyone frequently utilized) kind of photonic crystal fiber has a triangular model of air holes, with one hole omitted , i.e. with a solid core bounded by an collection of air holes. Such air holes can be acquired by means of performing with (larger) holes, which is prepared by stacking vessel and/or solid tubes (stacked tube technique) and adding them into a larger tube. Usually, this preform is first exhausted to a cane with a diameter of e.g. 1 mm, and subsequently into a fiber with the final diameter of e.g. 125 μm. Generally soft glasses and polymers (plastics) are also allocated the manufacture of preforms for photonic crystal fibers by extrusion. All these PCFs can be deliberate as specialty fibers.

The guiding properties of this type of PCF can be approximately undetermined through an efficient index representation: the region with the omitted hole has a superior effectual refractive index, comparable to the core in a usual fiber.

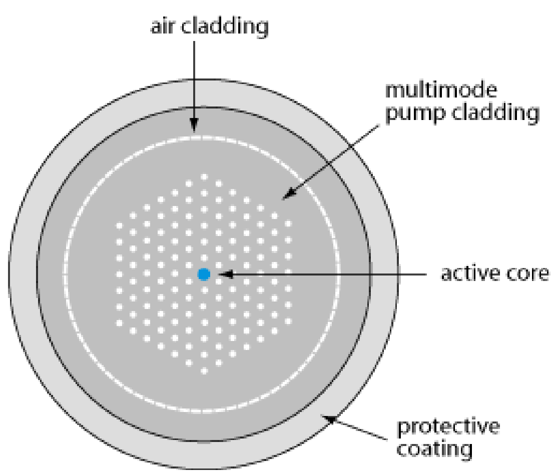

***Fig2.4: Structure of a photonic crystal fiber with an air cladding*.**

2.3 Fabrication of Photonic crystal Fiber:

While fabricating photonic crystal fibers, a glass is also being fabricated. A borosilicate glass is used here, which is produced by accumulation of boric oxide to the glassmaker's frit of silica sand, soda and ground lime. Some different techniques were required for industrial production as borosilicate glass melts at a higher temperature as compared to normal silicate glass. Such burners are required which can combine oxygen with natural gas and it can be borrowed from welding trade. Such fibers can be constructed by selecting some methods other than optical fibers: first, "preform" is constructed on the scale of centimeters in size, perform is then heated and is then reduced to a large amount lesser diameter (frequently as little as a human hair), here it is necessary to reduce the perform cross section while maintaining all the features. By stacking tubes and rods of silica glass, Photonic crystal fibers are created into a huge formation of the model of holes needed in the final fiber. The preform is bound with tantalum wire and then is taken to a furnace of fiber sketch overlook.

The tubes and glass rod gets soften when the boiler is full with argon and the temperature reaches nearby 2000ºC. After that perform is condensed by fusing it together to 1mm size with hole around 0.05 mm diameter. Hence, the air hole size can be reduced by increasing the furnace temperature. It is then reduced to its 20 times, which results in getting the smaller perform structure, then the entire process is repeated which ultimately helps in obtaining the spaces between the holes of 25 millionth of meter. In the case of highly nonlinear PCF defects can be formed by replacing tubes for solid rods. It can also be obtained by removing a group of tubes from the preform (hollow core photonic PCF). Strong geometrics can be achieved as the fabrication process is quite strong. For example, the geometry of the center flaw can be customized by the introduction of the thicker of thinner tubes at different position around the defect. In this method, kilometers of fiber can be constructed from a single perform. For the most part familiar technique engages stacking, even though drilling/milling was make use of to produce the primary intervallic devises, by stacking capillary and/or solid tubes (stacked tube technique) and placing them into a larger tube. This figured the resultant source for creating the first soft glass and polymer structured fibers. (10)

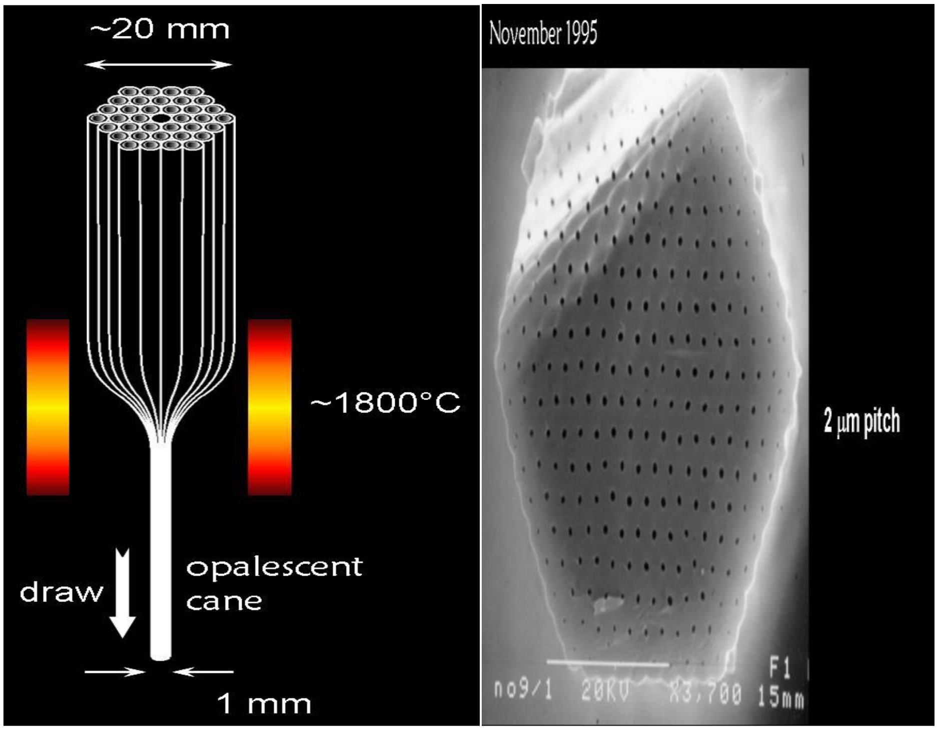

Fig2.5: Typical fabrication process in a photonic crystal fiber. (10)

2.4 Types of Photonic crystal fiber:

Photonic crystal fiber exists in many types. A specific category of PCFs and a value of refractive index inside are shown in Fig.1.4. (19)

- **Index Guiding Photonic Crystal Fiber (IG-PCF)(2-D Photonic Crystal Fiber):**

  While applying Holey reason, the effective index appears to be smaller than refractive index of solid core (silica) that is filled by material with smaller refractive index (air). The impressive index of material is formed by the holey cladding of the fiber. In this type of fiber the theory of the total reflection is used as same as a conventional fibers.

- **Bragg Fiber (1-D Photonic Crystal Fiber) :**

  In the recent times air-core Bragg fibers are used which are based on a combination of polymer and soft glass. A concentric ring of multilayer film is created to form Photonic-bandgap fiber. It uses Bragg PBG (Photonic Band Gap) method to get the omni directional-mirror. The core may have a much lower refractive index than the cladding.

- **Hollow Core Photonic Crystal Fibers (HC-PCF):**

  In the cross-sections, PCFs uses air holes, which is also known as holey fiber. The center can also be filled by air or gas in HC-PCF. It enables the supervision of the light in the hollow core with lesser attenuation than in the solid silica core. IG PCFs are commercially available in market.

- **Large Mode Area PCF (LMA-PCF):**

  A very huge area of mode enables high power levels without damaging material and a nonlinear effect.

- **Polarization Maintaining PCF (PM-PCF):**

  This type of fiber allows the polarization maintaining.

- **Highly Nonlinear Photonic Crystal Fiber (HN-PCF)**:

  Less than 1 μm or very small core size and the great fissure of index core-cladding facilitate to construct fibers with remarkably small efficient areas and high nonlinear coefficients.

- **Single-Mode Double Clad Fibers With Large Mode Area**:

  This type of fiber is also known as Air-clad fibers, which is similar to LMA-PCF. It uses dual clad and has active doped core.

- **Endlessly Single Mode Photonic crystal fiber**:

  The principle which forms the base for this method is simply standing on the verity that most important mode of the core area of solid core PCF will not escape because it does not fit into the spaces between the air holes. On the other hand higher order modes may escape the core. (19)

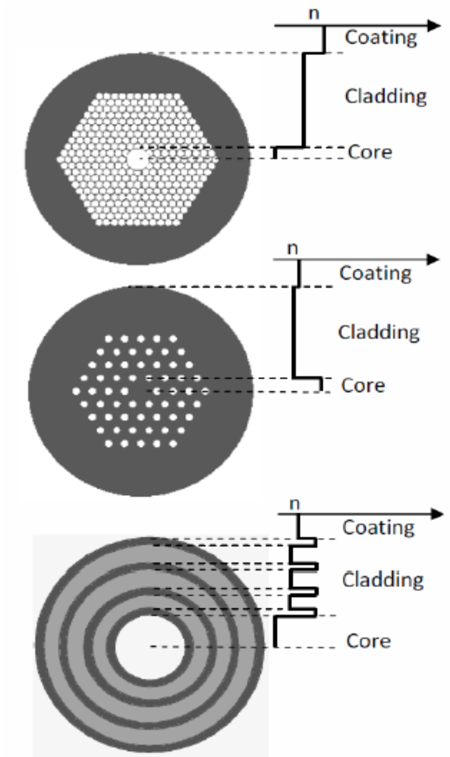

Fig2.6:Refractive index for HC-PCF (up), IG-PCF (middle),and Brag fiber(down). (19)

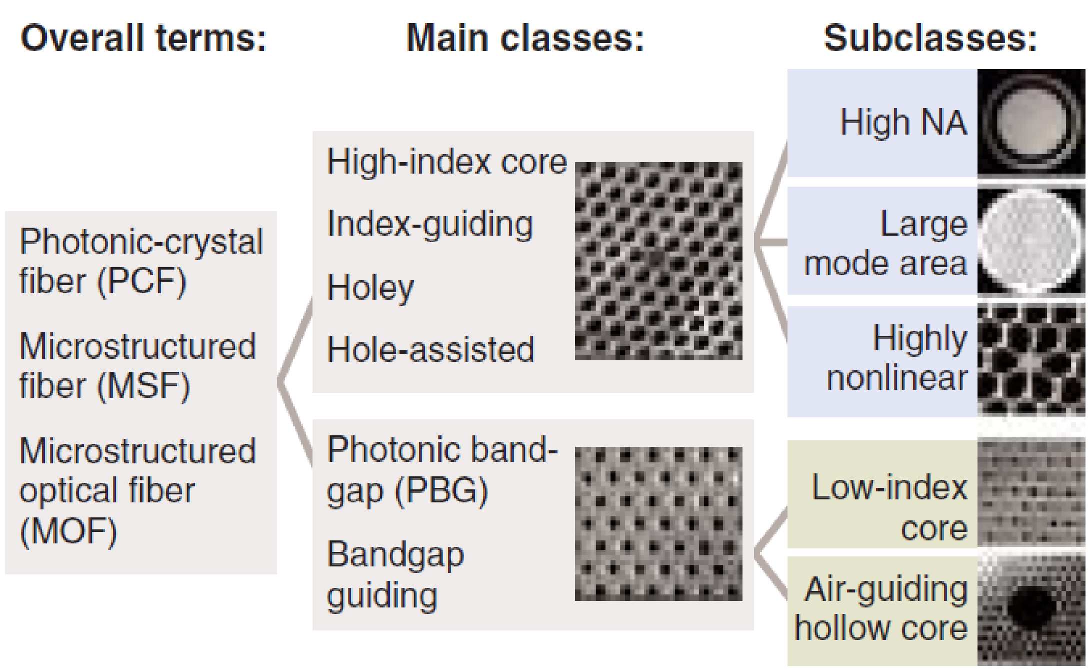

Fig.2.7. Classification of Photonic Crystal Fibers. (20)

2.5 Formulation of the Method:

The discussion on the formulation of the mode solver has been reviewed here.

2.5.1 Scalar Effective Index Method:

In the scalar effectual manifestation method, it first commences commence the scalar wave equation, where ∇_t transverse is laplacian operator in cylindrical coordinates, k = 2π/λ, here λ is used for free space wavelength, n is employed for substance index and β is used for the promulgation constant. By relating boundary situation equation for inner and outer areas of the air hole is

$$\left[\nabla_t + \left(k^2 n^2 - \beta^2\right)\right]\psi = 0 \qquad \text{.. (1)}$$

$$\psi_1 = AI_0(WR) \qquad \textbf{\textit{Air Hole}} \qquad \text{..(2)}$$

$$\psi_2 = BJ_0(UR) + CY_0(UR) \qquad \textbf{Core Material Region} \qquad \text{..(3)}$$

An eight value equation for evaluating the effective index n_{FSM} is obtained

$$BJ_1(u) + CY_1(u) = 0 \qquad \text{..(4)}$$

Where B and C are the constants given by

$$B = \frac{A}{J_0(U)}\left[I_0(W) - \frac{WI_1(W)J_0(U) - UJ_1(U)I_0(W)}{U\left(J_1(U)Y_0(U) - J_0(U)Y_1(U)\right)}\right] \qquad \text{..(5)}$$

$$C = \frac{A\left[WI_1(W)J_0(U) + UJ_1(U)I_0(W)\right]}{U\left[J_1(U)Y_0(U) - J_0(U)Y_1(U)\right]} \qquad \text{..(6)}$$

With parameters U, W, and U as follows

$$U = k_0 a\sqrt{n_s^2 - n_{cl}^2},\ W = k_0 a\sqrt{n_{cl}^2 - n_a^2},\ u = k_0 b\sqrt{n_s^2 - n_{cl}^2} \qquad \text{......................................(7)}$$

N_s and n_a are the refractive indices of As_2Se_3 glass and air correspondingly. The modal indices of fundamental space filling mode is acquired and therefore n_{c1} is determined.

2.6 Advantages of using PCF:

PCF holds many advantages against a conventional optical fiber. They are listed as follows:

- Bigger cores PCFs may carry more power than conventional fibers.
- Guiding optical light through air.
- Decreases of Absorption losses.
- Reduction of non linearity effects.
- High power transmission.
- Permitted for regulation through hollow fibers (air holes).
- Better distinction obtainable for effectual-index guidance
- Reduction does not effects mediocre than for usual fibers. Control on above diffusion and range of air holes may be tuned to shift point of zero dispersion into recognizable range of the light.
- To manage light, optical fiber uses total internal reflection.
- The disadvantage of normal optical fiber is that the border must be flat with respect to the wavelength of light; photonic crystal is totally a different mechanism, which is entirely based on band gap.

2.7 Applications of PCF:

The exacting properties of PCF make them striking for a broad assortment of functions. Various examples are:

- Fiber lasers and amplifiers, mode-locked fiber lasers as well as high-power devices.
- Nonlinear devices, like supercontinuum generation, Raman exchange parametric amplification, or pulse compression.
- Telecom elements, such as dispersion control, filtering or switching.
- A variety of fiber-optic sensors.
- Quantum optics, for e.g. creation of correlated photon pairs, electromagnetically stimulated lucidity, or control of cold atoms.

CHAPTER 3

DISPERSION

3.1 Dispersion:

The significant property of the transmission medium leads to and causes dispersion. Dispersion is an important factor in limiting the quality of signal transmission, which is formed with the spreading or broadening of light pulses, when they travel through the fiber. In optical fiber, dispersion is the result of stage rapidity of a signal and its occurrence. When the assemblage rapidity depends on the regularity, then such property is termed as dispersive media. The sources of diffusion can be classified in two categories: waveguide distribution and Material diffusion. Material scattering is the result of the response which comes from a frequency-dependent reaction of stuff to energy. Single-mode fibers, which are used in high-speed optical networks, are centralized which results in Chromatic Dispersion (CD). It also causes pulse expansion which is depended on its wavelength. The Polarization Mode Dispersion (PMD) causes pulse broadening which is also dependent on its polarization. To site the example of dispersion, a rainbow forms the best example. In a rainbow, dispersion origins the spatial severance of a white light into mechanism of altered wavelengths (different colours). Diffusion in optical fiber can be off the record into two classes. First group is intramodal dispersion and the second is intermodal dispersion. Intramodel dispersion occurs in optical fiber due to the delay in propagation differentiation amid diverse spectral parts of transmitted signal. Intermodal dispersion happens in optical fiber due to proliferation interruption divergence amid modes inside a multimode fiber. There are around three major category of dispersion: modal dispersion, chromatic dispersion and polarization dispersion. In the present work the focus will be on one of the chromatic dispersion. (1)

3.1.1 Chromatic (Intra modal) dispersion:

The primary reason of the chromatic dispersion (CD) is the reality that different spectral components of light impulse or different wavelengths travel in the optical fiber at different speeds. Wavelengths follow diverse time of upcoming to the conclusion of fiber which fallout in unusual wave lengths. It also results in the increase of impulse width and narrowing inter-bit spaces. The receiver cannot correctly recognize whether a transmitter in a precise bit interval sent a value of logical one or zero. The distortion of the transmitted information will then increase the bit error rate.(1)

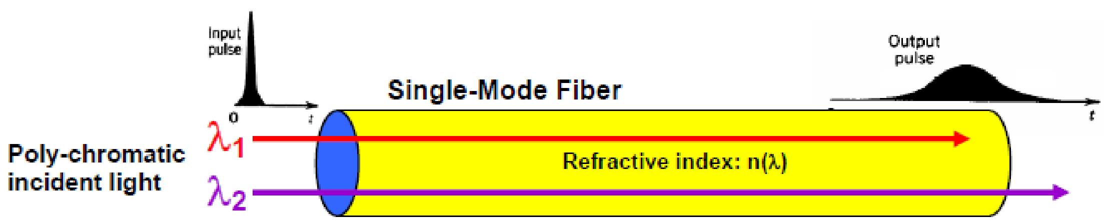

Fig.3.1: CD in single mode fiber. (1)

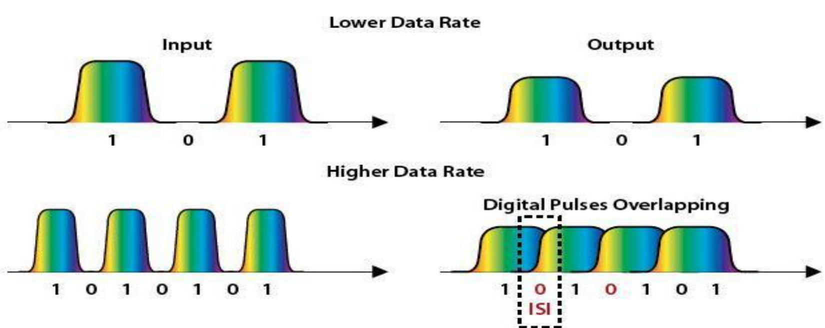

Fig.3.2: The dependence of pulses overlap on transmission rate (17)

The Parameters of Chromatic Dispersion

The chromatic dispersion coefficient is a primary parameter of a fiber which is articulated in ps/(nm-km). It size of the CD is determined by it and is then described by the equation. (17)

$$D= -\frac{\lambda}{c}\frac{d^2}{d}\frac{Re[neff]}{\lambda^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where, Re[*neff*] is the real part of *neff,* λ is the wavelength, and c is the velocity of light in vacuum. Therefore, D is the total dispersion of the PCF. The value of the chromatic diffusion coefficient D is numerically equal to the Gaussian pulse (in ps) of an initial spectral half-width of 1nm width extension after passing the fibre of a 1 km length. Pulse width increases with:

- an increasing coefficient of chromatic dispersion D
- a phantom width of the light source
- a length of the optical fiber

It is necessary to use narrower light pulses with shorter spaces at the upper transmission speeds. In this transmission the strongest limiting aspect is the chromatic scattering. The chromatic diffusion influences the use of suitable sources of optical signal on transmission system. (17)

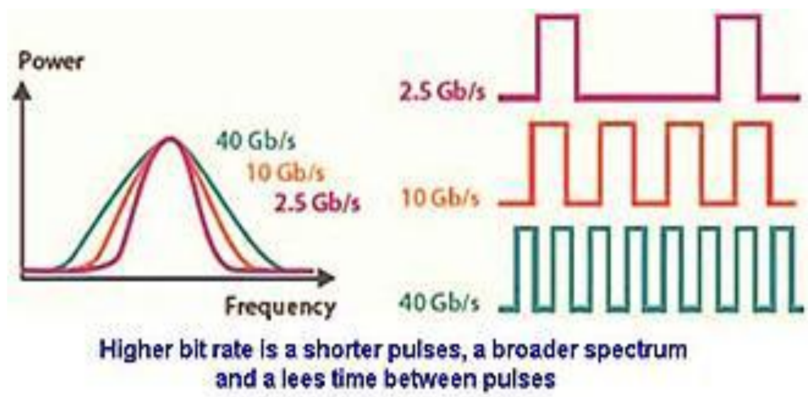

Fig.3.3:- Effect of increasing the transmission speed on pulse width and the width of the bit space. (17)

The chromatic dispersion consists of two components: the substance diffusion and the waveguide diffusion.

3.1.2 Material Dispersion:

Material dispersion depends on the resources which are built on Refractive index and it is difficult to change this material, especially if the dissimilarity exist in the refractive index with nonlinear wavelength and it ultimately results in dispersion. The speed of proliferation varies through wavelength and refractive guide and in a dielectric means the refractive index varies with wavelength. The consequences are as of the diverse assemblage velocities of the different ethereal mechanism launched into the fiber by the resource.

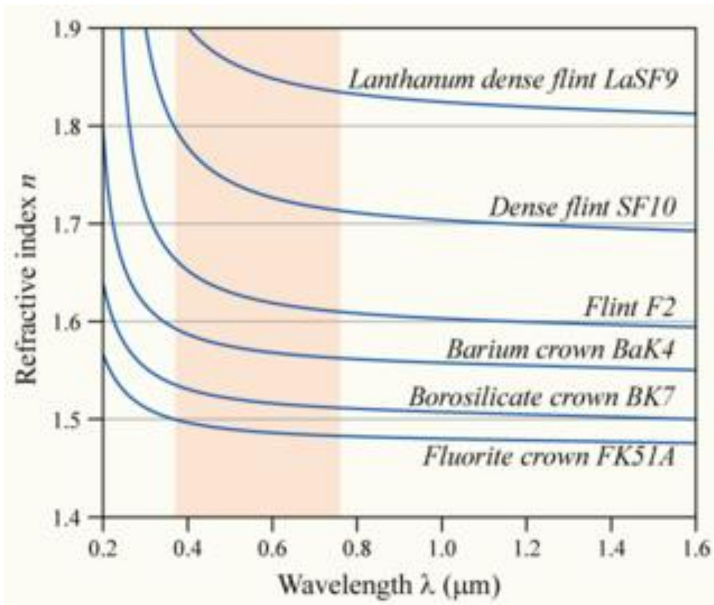

Fig.3.4: The distinction of refractive index vs. vacuum wavelength for different glasses.

The effect of the substance diffusion can be an enviable or detrimental in optical applications. The refractive indicator in some purpose of the frequency *f* of the light, thus *n* = *n*(*f*), or on the other hand, with reverence to the wave length *n* = *n*(λ). The wavelength believes of a material's refractive index is generally quantified by its Abbe amount or its coefficients in a practical formula such as the Cauchy or Sellmeier equations.

$$n^2 - 1 = \sum_i \left(\frac{A_I \lambda^2}{\lambda^2 - \lambda_i^2}\right) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where λ is operating wavelength in µm.

3.1.3 Waveguide Dispersion:

Generally diffusion can arise for waves proliferating throughout any inhomogeneous configuration (e.g., a photonic crystal), exclusive of assembling a great deal of dissimilarity whether these waves are restricted to a few constituency. Waveguide dispersion occurs when the pace of a wave in an ocular fiber depends on its regularity for numerical reasons, self-sufficient of any occurrence dependence of the materials from which it is constructed. Waveguide dispersion depends on the fiber's refractive indicator report and it is this part that can be engineered to allow put on of specialty fibers with exact dispersion profile. A comparable result owing to a rather unusual incident is modal dispersion, caused by a waveguide having various modes at a certain rate, each with an unusual pace.

Most important problem for single mode, in multimode mode dispersion into the cladding is very small in a comparative sense.

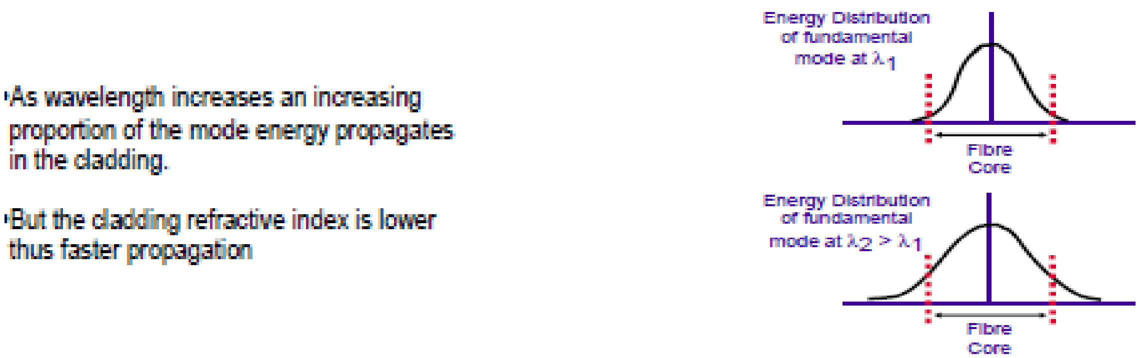

Fig3.5: Effect of waveguide dispersion.

Waveguide and substance diffusion are outlawed to provide necessary on the whole chromatic distribution varying the refractive index report will modify the waveguide dispersion. Amount of waveguide dispersion is comparatively supreme of wavelength. The waveguide and material dispersion results with the same effect on signal transmission in optical fiber and consequently common word the chromatic dispersion is used.

3.2 Birefringence:

The birefringence is to demolish the balance of the fiber configuration, which can also be achieved by varying the air gap sizes close to the center region or by destroying the figure of the air gaps (such as elliptical air holes).

The Birefringence of a PCF is firm by the distinction amid the actual element of the efficient indexes. Polarized along x and y axis.(19)

$$B=[Re(neff^{x})-Re(neff^{y})] \quad \ldots\ldots\ldots\ldots\ldots..(3)$$

3.3 Confinement Loss:

As the result of the confinement loss, the cladding occurs. As the amount of layers of air holes is restricted the ocular method propagates in the center province. It is also necessary that the mode escape from the center area into the external air gap section. Confinement losses of photonic crystal fiber are often computed using the formula:

$$L_c = 8.686 * Im[k_0 n_{eff}]*10^3 \text{ dB/km} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where, $Im[n_{eff}]$ is the imaginary part of n_{eff} , and k_0 is the free space wave length number equal to $2\pi/\lambda$.(19)

CHAPTER 4
METHODOLOGY (OPTI-FDTD)

4.1 Basics of FDTD:

Software that permits designs which are computer aided and components too posses simulation of higher passive photonic components, is reliable, trustworthy, user-friendly is Opti-FDTD software. This software works on the technique of restricted-difference time-domain (FDTD). The FDTD technique has shown to be an influential manufacturing instrument for incorporated and diffractive optics device simulations. The major reason for the popularity of this method is its salient features, which includes capability to form light promulgation, diffusion and diffraction, and likeness and schism belongings. The method can also work as a model material anisotropy and diffusion devoid of any pre-assumption of ground behavior such as the gradually varying amplitude rough calculation. The scheme is effective where powerful simulations and study of sub-micron strategy by means of very superior structural details are necessary. In a typical device design, this scale is required which implies a high quantity of illumination detention and regularly the huge refractive index divergence of the resources (mostly semiconductors).

4.2 Work Flow and Simulation Process of OPTI-FDTD:

The flow chart for the FDTD simulation in Opti-FDTD is as follows:

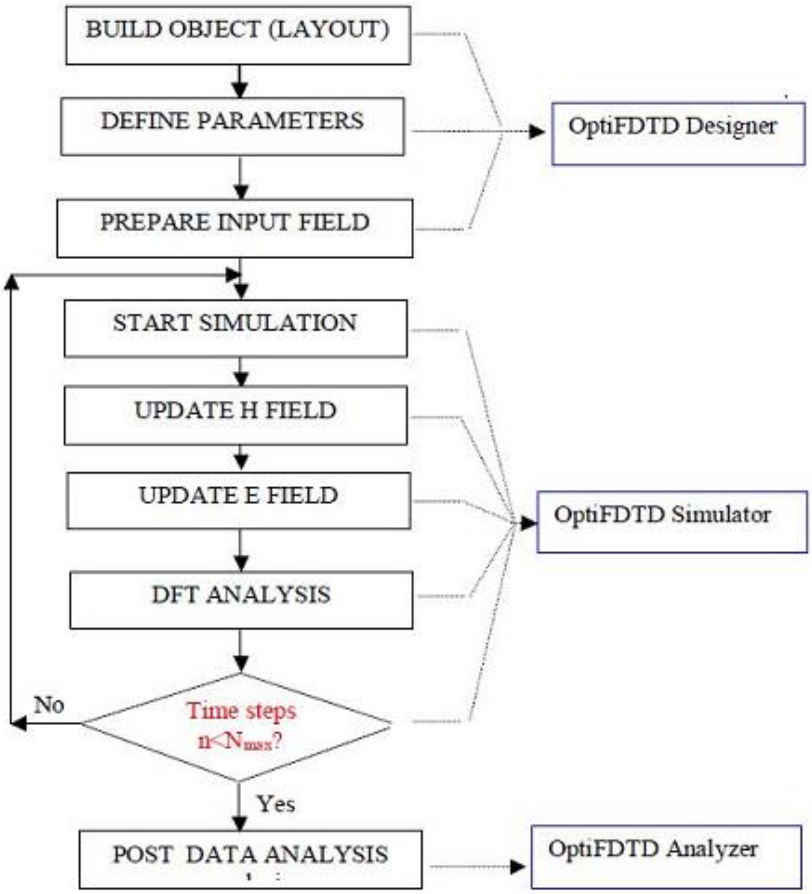

Fig. 4.1: FDTD Simulation Flow Chart in Opti-FDTD

Opti-FDTD tool is the method which is used to design photonic devices, simulations and further is helpful in analyzing the results. Fig4.1 shows the flow chart of FDTD design and simulations.

1. The first step is to create a new project, it is helpful in following ways:

    a. To Open Opti-FDTD Designer Window

    b. To Initialize the project Window

    c. To Open the Waveguide Profile Designer window

    d. To Define the material which we used in project

    e. To define the 2D and 3D channel profile.

2. Initial property Window is then set up.
3. A new design of waveguide is then created. It helps in:
    a. Depiction of a Linear Waveguide
    b. Locale up the contribution Plane
    c. Introducing the Input Plane
4. The Refractive Index Distribution table is then observed:
    a. Observing the Refractive Index Distribution table on window.
    b. Surroundings of an Observation Point
    c. Set up observation points, areas, and lines of project
5. Simulation can be run after that:
    a. Running the 32bit simulation
    b. Setting up the simulation parameters which we required in our project.
6. The simulation results can be analyzed
    a. To Calculate the Mode Overlap Integral (MOI).
    b. To Calculate the Input Overlap Integral (IOI).
    c. To Calculate the Input Overlap Integral Scanner (IOIS).
    d. To Analyze the results of project.
    e. To Open Opti-FDTD Analyzer window.
    f. To Calculate the Far Field Transform
    g. To Perform the Observation Object Analysis
7. Export results

4.3 OPTIFDTD Coordinates System:

4.3.1: 3-D FDTD Equations:

The simulation sphere is a cubic box in 3D simulations, where the space steps are in x, y, ans z guidelines correspondingly. Every field apparatus is available by a 3D array- **Ex(i,j,k), Ey(i,j,k), Ez(i,j,k),Hx(i,j,k), Hy(i,j,k), Hz(i,j,k)**. In Figure 3.2 the fields' mechanism location in Yee's Cell are shown. These placements and the data show that the E and H workings are interleaved at intervals of in space and for the function of implementing a leapfrog algorithm.

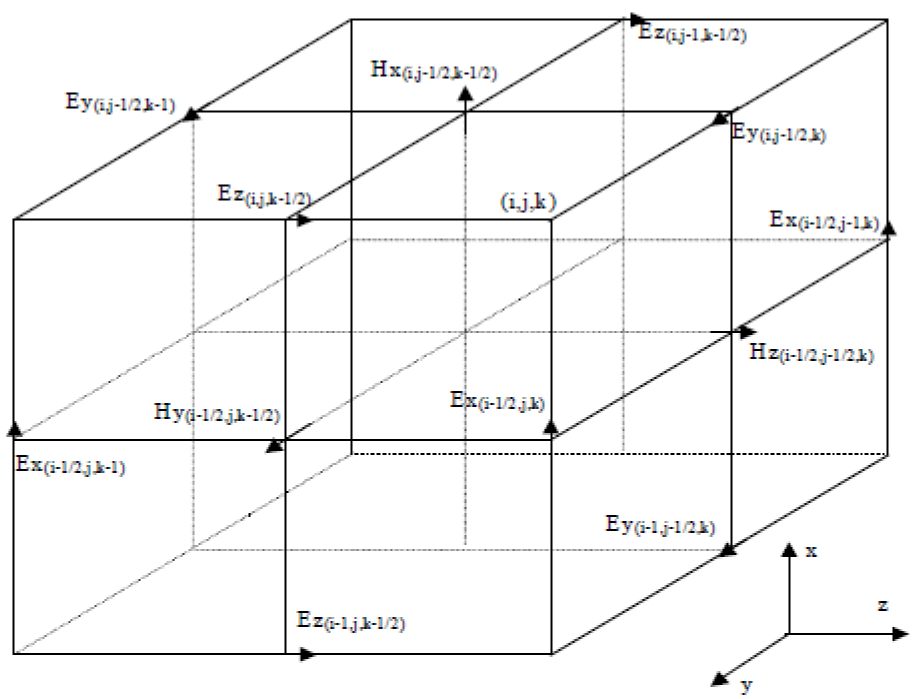

Figure 4.2. Dislocation of the electric and magnetic field vector mechanism about a cubic unit cell of theYee space lattice

1.11a

$$H^{n+1/2}_{x,i,j-1/2,k-1/2} = H^{n-1/2}_{x,i,j-1/2,k-1/2} + \frac{\Delta t}{\mu_0 \Delta z}(E^{n}_{y,i,j-1/2,k} - E^{n}_{y,i,j-1/2,k-1}) - \frac{\Delta t}{\mu_0 \Delta y}(E^{n}_{z,i,j,k-1/2} - E^{n}_{z,i,j-1,k-1/2})$$

1.11b

$$H^{n+1/2}_{y,i-1/2,j,k-1/2} = H^{n-1/2}_{y,i-1/2,j,k-1/2} + \frac{\Delta t}{\mu_0 \Delta x}(E^{n}_{z,i,j,k-1/2} - E^{n}_{z,i-1,j,k-1/2}) - \frac{\Delta t}{\mu_0 \Delta z}(E^{n}_{x,i-1/2,j,k} - E^{n}_{x,i-1/2,j,k-1})$$

1.11c

$$H^{n+1/2}_{z,i-1/2,j-1/2,k} = H^{n-1/2}_{z,i-1/2,j-1/2,k} + \frac{\Delta t}{\mu_0 \Delta y}(E^{n}_{x,i-1/2,j,k} - E^{n}_{x,i-1/2,j-1,k}) - \frac{\Delta t}{\mu_0 \Delta x}(E^{n}_{y,i,j-1/2,k} - E^{n}_{y,i-1,j-1/2,k})$$

1.12a

$$E^{n+1}_{x,i-1/2,j,k} = \frac{2\varepsilon - \sigma\Delta t}{2\varepsilon + \sigma\Delta t} E^{n}_{x-1/2,i,j,k} + \frac{2\Delta t}{(2\varepsilon + \sigma\Delta t)\Delta y}(H^{n+1/2}_{z,i-1/2,j+1/2,k} - H^{n+1/2}_{z,i-1/2,j-1/2,k}) - \frac{2\Delta t}{(2\varepsilon + \sigma\Delta t)\Delta z}(H^{n+1/2}_{y,i-1/2,j,k+1/2} - H^{n+1/2}_{y,i-1/2,j,k-1/2})$$

1.12b

$$E^{n+1}_{y,i,j-1/2,k} = \frac{2\varepsilon - \sigma\Delta t}{2\varepsilon + \sigma\Delta t} E^{n}_{y,i,j-1/2,k} + \frac{2\Delta t}{(2\varepsilon + \sigma\Delta t)\Delta z}(H^{n+1/2}_{x,i,j-1/2,k+1/2} - H^{n+1/2}_{x,i,j-1/2,k-1/2}) - \frac{2\Delta t}{(2\varepsilon + \sigma\Delta t)\Delta x}(H^{n+1/2}_{z,i+1/2,j-1/2,k} - H^{n+1/2}_{z,i-1/2,j-1/2,k})$$

1.12c

$$E^{n+1}_{z,i,j,k-1/2} = \frac{2\varepsilon - \sigma\Delta t}{2\varepsilon + \sigma\Delta t} E^{n}_{z,i,j,k-1/2} + \frac{2\Delta t}{(2\varepsilon + \sigma\Delta t)\Delta x}(H^{n+1/2}_{y,i+1/2,j,k-1/2} - H^{n+1/2}_{y,i-1/2,j,k-1/2}) - \frac{2\Delta t}{(2\varepsilon + \sigma\Delta t)\Delta y}(H^{n+1/2}_{x,i,j+1/2,k-1/2} - H^{n+1/2}_{x,i,j+1/2,k-1/2})$$

4.3.2 :Space and Time Steps:

The step size for time and space restricts the FDTD method. The steps involving time and space is related to the correctness, arithmetic diffusion, and the immovability of the FDTD technique. In order to maintain the outcome exact, a low numerical dispersive method is required where the mesh size often quoted is "10 cells per wavelength", which reflects that the side of each cell should be 1/10 or less at the highest frequency (shortest wavelength).

The subsequent equation is for the recommended mesh size

$$\min imum(\Delta x, \Delta y, \Delta z) \leq \frac{\lambda_{\min}}{10 n_{\max}} \qquad \text{.. (1)}$$

Where n_{max} is the utmost refractive manifestation value in the computational domain. Δt follows the Courant-Friedrichs-Levy (CFL) condition.

For 3D FDTD simulation, the CFL condition is:

$$\Delta t \leq \frac{1}{v\sqrt{\frac{1}{(\Delta x)^2} + \frac{1}{(\Delta y)^2} + \frac{1}{(\Delta z)^2}}} \qquad \text{.. (2)}$$

Where v is the speed of the light in medium.

For 2D simulations, the above CFL condition can be simplified as:

$$\Delta t \leq \frac{1}{v\sqrt{\frac{1}{(\Delta x)^2} + \frac{1}{(\Delta z)^2}}} \qquad \text{.. (3)}$$

4.4 Boundary Conditions:

4.4.1 PML Boundary condition:

The most difficult part of the FDTD simulations is the PML Boundary condition. By the side of the limitations of the computational windows, the essential FDTD algorithm ought to be adopted where suitable numerical absorbing boundary situation are also functional. The boundary condition follows the number of choices. Among them the best performance is reflected in The Perfectly Matched Layer (PML) boundary condition. The FDTD simulator uses the Anisotropic PML, which is also known as Un-split PML (UPML) version. The grounds of the UPML are clearly defined in some of the references given here. The UPML limit situation is substantial circumstances than statistical since their demonstration is based on a Maxwell and formulation quicker than on a mathematical form.

4.4.2 PMC/PEC Boundary Condition:

Perfect Electric Conductor (PEC) and Perfect Magnetic Conductor (PMC) boundary circumstances can be worn by Opti-FDTD as an alternative. It depends on the user as whatever boundaries he/she wanted to opt for. In this status the new stipulations of undertaking and Anisotropic PML can be exercised for the left extremities. With the PEC/PMC/Anisotropic PML aggregation, the favorable can be acquired

- Flat wave simulation.
- Province compressed replication for symmetric, intermittent, or photonic band gap configuration

4.4.3 PBC Boundary Conditions:

The use of Opti-FDTD gives an opportunity of using simplifies Periodic Boundary Condition (PBC). PBC can also work with other boundary conditions such as Anisotropic PML, PEC, and PMC. With PBC, it is easier to generate simple plane wave simulation or periodic layout simulations.

4.5 Benefits of Using Software:

- It influences the diminution of speculation risk and time-to-market.
- Quick, low cost prototyping.
- Assessment of parameters, sensitivities and tolerances.
- Performance assessment of various types of fibers before actual developed.
- Repeated constraint scanning and optimization.
- Illustration appearance of how the changes of proposed parameters influence fiber distinctiveness.

4.6 Main Features:

- Fiber contour.
- Birefringence and PMD Calculator.
- Material, Waveguide and Total Dispersion Calculator.
- LP and vectorial mode Cutoff Wavelength Calculator.

4.7 Application:

- The design is of MM fiber design.
- Fiber sensor design.
- Telecomm grade SM fiber design is also there.
- The devise of an unacquainted multilayer fiber with an illogical 2D refractive index sketch is used.
- It can analyze subsequent distinctiveness of any supported approach, elementary or superior order.
- Style field example, which can be exhibited in diverse ways.
- Capable refractile level, propagation expected.
- Entity scale, radical break.
- Three types of unit-rate scattering (material, waveguide and total)

- Technique tract diameters reported to contrasting definitions and competent mode area.
- Estimations of the cutoff wavelengths.
- Macrobending, microbending and splicing losses.
- Enhancement of the addiction of these distinctive on many scientific invariables of the fiber, considering geometry, chart form and constitution.
- Computation of birefringence possessions induced by intrinsic or extrinsic perturbations.
- PMD calculations based on different models.

4.8 Material Used:

Different types of glass material like silica, chalcogenide, and borosilicate are used in making PCF. In the present work Borosilicate crown glass (BK7) is used as objects.

Borosilicate crown glass (BK7) Material:

In the late 19th century German glassmaker Schott initiated Borosilicate. This particular glass shows unequaled homogeneous glass for construction of plant and piping in the chemical, dyestuff, food pharmaceutical, petrochemical industries. It had many advantages over conventional material which make them famous and popular:

- The corrosion resistance is excellent in it.
- It is more transparent.
- Catalytic tediousness.
- The surface is also smooth and aperture free.
- It does not affect taste and odour.
- Physiological inertness.

  Since Borosilicate glass has certain unique chemical and physical properties, which is also responsible for its preference. It is also calm of oxides. The principle modifiers/fluxes are Silica (SiO_2), Magnesia (MgO) and lead oxide (PbO).

(i) SUBSTANCE OPUS

The Borosilicate glass which is used for chemical plants has consequently projected composition.

$B_2 O_2$ - 12.5%	SiO_2 - 80.6%
Al_2O_3 - 2.2%	Na_2O - 4.2%

In the fabrication of borosilicate glass 10% boron oxide, 8% sodium oxide, 8% , colorless 70 % silica, 8% potassium oxide and 1% calcium oxide are used. Except hydroflouric acid (HF) phosphoric acid ((H_3Po_4) and hot strong caustic solutions, this glass is static to almost all materials.

(ii) OPTICAL PROPERTIES OF BOROSILICATE GLASS

Borosilicate glass appears clear and colourless as it shows important absorption in the visible region of spectrum. The transparency of ultra violet holds systemic importance in the process of photo chemical method. It prosecutes from the transmittance of matter in uv section that photo chemical responses such as chlorination & sulpho chlorination can be executed in it.

Borosilicate symbol container (BK7) is a visual substance exercised in a huge part OPTICS product. It is rather hard glass, which doesn't scrape easily. An additional significant feature of BK7 is very superior diffusion down to 350 nm. Owing to these properties, BK7 are extensively used in the optics business. Borosilicate glass is less dense (at about 2.23g/cm3) than usual soda-lime glass due to the low atomic weight of boron. N-BK7 is a Schott depiction for the majority in common. (glass.htm)

Transmission Range :	350nm to 2.5 μm
Refractive Index :	1.51680 @ 587.5618 nm (Yellow Helium Line)
Reflection Loss :	8.1% at 587.5618 nm (2 surfaces)
Density :	2.51(g/cm^3)
Melting Point :	557°C (Transformation Temperature)
Thermal Conductivity :	1.114 W m^{-1} K^{-1}
Thermal Expansion :	7.1 x 10^{-6} K^{-1}
Hardness :	Knoop 610
Specific Heat Capacity :	858 J Kg^{-1} K^{-1}

Youngs Modulus (E) :	82 GPa
Bulk Modulus (K):	34 GPa
Apparent Elastic Limit :	63.5MPa (9206psi)
Poisson Ratio :	0.206
Solubility :	Insoluble in water
Class/Structure :	Amorphous glass

CHAPTER 5

RESULTS AND DISCUSSION

In the procedure of designing new Honeycomb borosilicate photonic crystal fiber, the first initiative will be to design different parameters configurations. The results will be then evaluated and in turn the best result can be sorted out. The configuration and its results are as follows.

Configuration 1:

There will be circular air holes of d=0.6µm in a PCF structure which is prepared up of seven layer honeycomb structure. Network constant or pitch (Λ) = 2.0µm. with refractive index 1.5186 of wafer and refractive index of air holes is 1.The results of this type structure shows that at wavelength λ= 1.6µm dispersion will be zero but after that the result will be found positive dispersion.

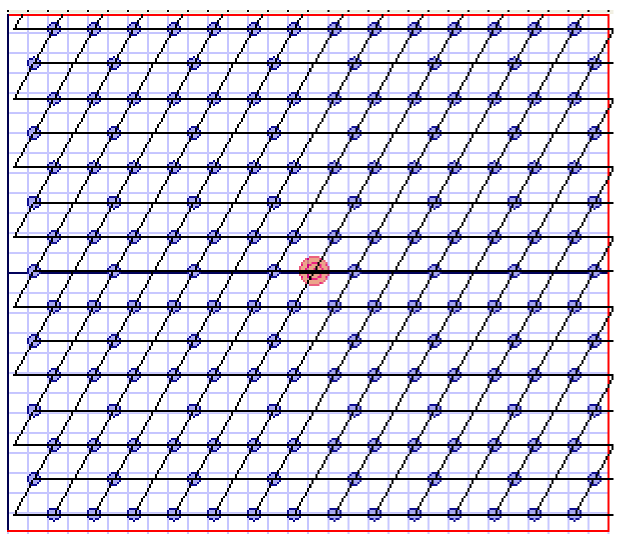

Fig5.1: The PCF seven layer honeycomb structure with circular holes where d=0.6µm.

Configuration 2:

The PCF configuration is prepared up of seven layer honeycomb constitution with circular air holes of d=0.8µm. Lattice constant or pitch (Λ) = 2.0µm. with refractive index 1.5186 of wafer and refractive index of air holes is 1.The results of this type structure shows that at wavelength λ= 1.7μm dispersion will be zero but after that the result will be found positive dispersion.

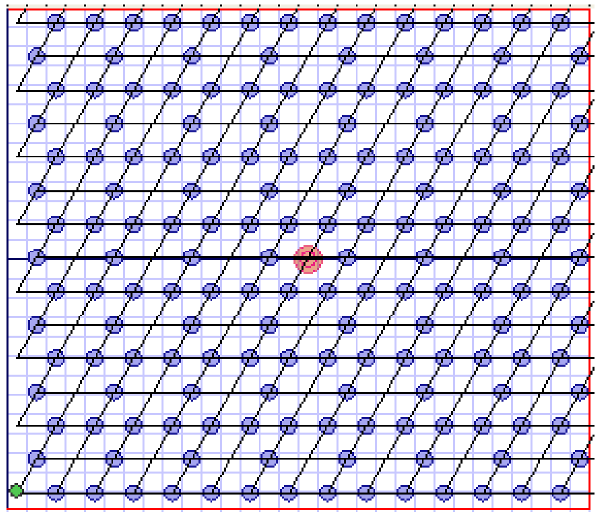

Fig5.2. The PCF seven layer honeycomb lattice structure with circular holes where d=0.8μm

Configuration 3:

There will be a seven layer honeycomb structure comprising of PCF structure with circular air holes of d=0.9μm. Lattice constant or pitch (Λ) = 2.0μm. with refractive index 1.5186 of wafer and refractive index of air holes is 1.The results of this type structure shows that at wavelength λ= 1.6 μm to 1.7μm and 2.0 μm dispersion will be zero but after that the result will be found positive 1 dispersion.

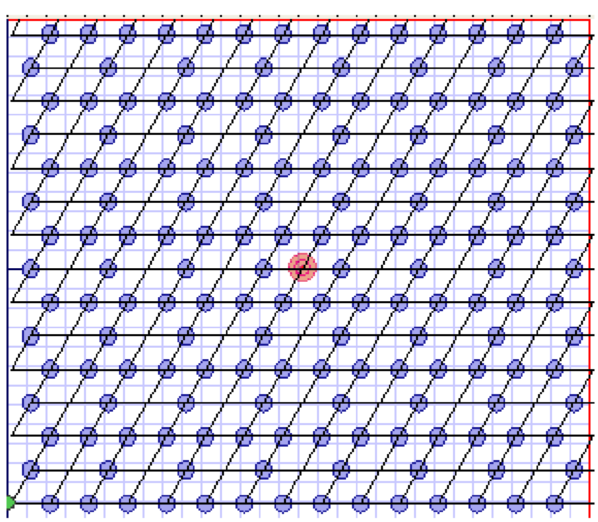

Fig.5.3.The PCF seven layer honeycomb lattice structure with circular holes where d=0.9μm.

Configuration 4:

In the honeycomb structure of seven layer, which comprises of PCF structure, the circular air holes are of d=1.0µm. Lattice constant or pitch (Λ) = 2.0µm. with refractive index 1.5186 of wafer and refractive index of air holes is 1.The results of this type structure shows that at wavelength λ= 1.6 µm to 1.9µm dispersion will be zero and zero ultra flattened dispersion at1.36µm to 2.0µm.

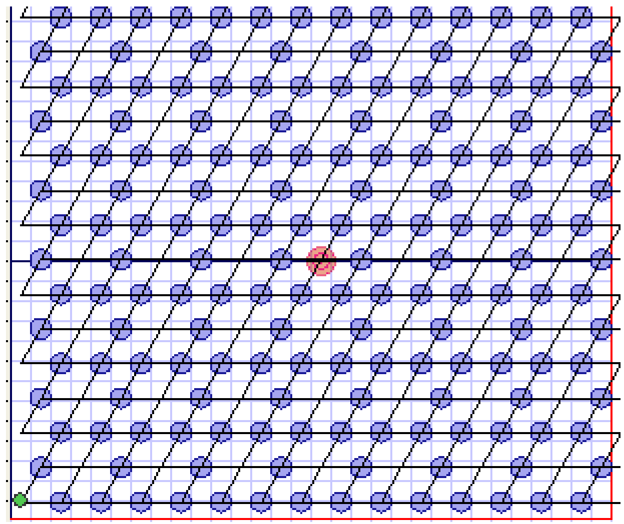

Fig.5.4: The PCF seven layer honeycomb lattice structure with circular holes where d=1.0µm.

Configuration 5:

In the PCF structure where there are seven layer of honeycomb structure, circular air holes are of d=1.1µm. Lattice constant or pitch (Λ) = 2.0µm. with refractive index 1.5186 of wafer and refractive index of air holes is 1.The results of this type structure shows that at wavelength λ= 2.0µm dispersion will be zero and but after that the result will be found positive minimum dispersion.

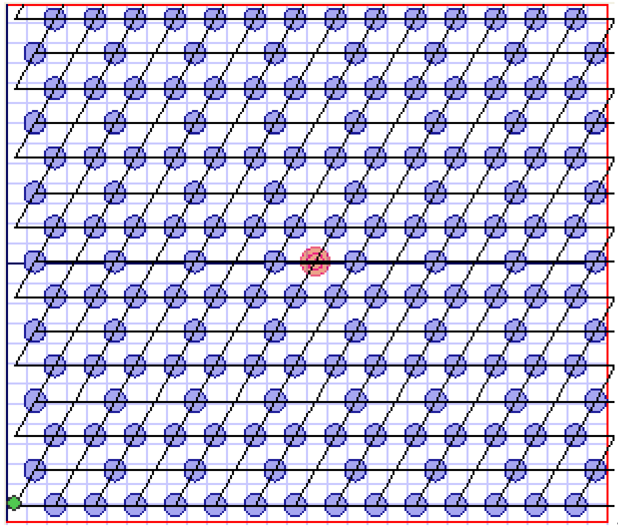

Fig5.5: The PCF seven layer honeycomb lattice structure with circular holes where d=1.1µm.

- **Pattern 4 proves to be the best among all the deign patterns**.

Table 5.1: Simulation results values of configurations wavelength vs dispersion (ps/km.nm)

wavelength	Confi.1	Confi.2	Confi.3	Confi.4	Confi.5
0.5	-346.098	-322.695	-319.569	-317.398	-311.06697
0.6	-320.805	-301.704	-294.644	-289.492	-282.38237
0.7	-245.666	-225.216	-215.962	-207.678	-198.95919
0.8	-155.841	-135.102	-120.364	-113.171	-101.19223
0.9	-96.9789	-87.9509	-72.5878	-60.5585	-49.50405
1	-62.4776	-52.9093	-49.0533	-32.5636	-19.2377
1.1	-44.7113	-32.9019	-25.924	-21.8081	-6.17636
1.2	-29.0277	-24.3305	-14.2925	-9.36914	-2.2402
1.3	-18.8685	-14.9604	-12.6274	-1.19471	9.63637
1.4	-11.8402	-8.41018	-7.08042	-2.73275	11.724086
1.5	-6.05707	-4.12948	-2.64721	-2.35826	4.76667
1.6	-0.87343	-1.82076	-0.08756	-0.39043	3.81247
1.7	4.25704	-0.4127	0.81782	0.65479	3.14276
1.8	9.7105	1.22513	1.05852	0.63823	2.61359
1.9	14.0039	2.63087	1.00524	-0.10861	1.79588
2	17.04336	3.54402	0.75876	-1.07083	0.80713

5.2. Simulation results of configurations:

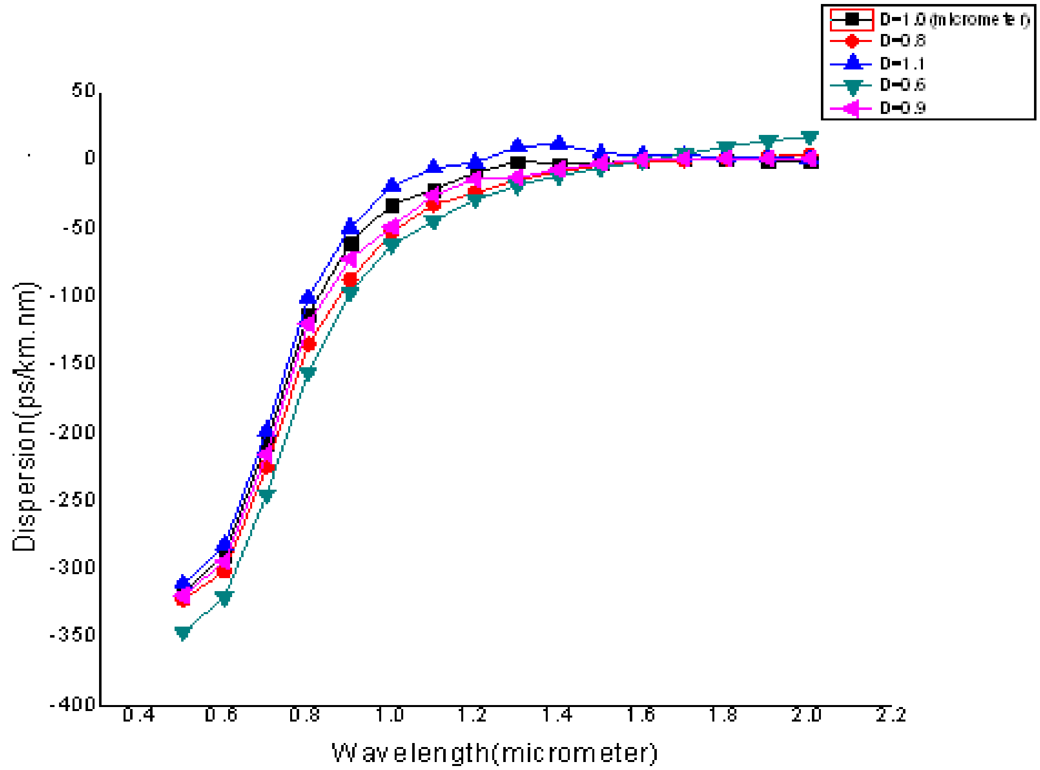

Fig.5.6 Chromatic diffusion of the projected PCF for unusual standards of the air hole diameters d when air hole spacing "Λ" = 2.0 μm.

5.3 Material dispersion:

Figure 5.7 shows the graph between silica and BK7. As compared BK7 with silica, BK7 gives almost flat dispersion at high wavelength. Material dispersion all the times remain unaffected for each configuration (hexagonal or square). It is furthermore free of composition limit as air hole diameter "d" and pitch difference "Λ".

Table: 5.2. Material dispersion between Silica and Borosilicate

Wavelength	Silica dispersion (ps/km.nm)	Borosilicate dispersion (ps/km.nm)
0.5	-769.00	-354.29
0.6	-368.00	-330.58
0.7	-204.00	-250.01
0.8	-121.00	-149.77
0.9	-74.20	-92.84
1	-44.40	-57.46
1.1	-18.25	-33.57
1.2	-9.61	-16.41
1.3	1.52	-3.79
1.4	10.39	6.30
1.5	18.01	15.01
1.6	24.68	22.42
1.7	30.76	28.92
1.8	36.63	34.97
1.9	41.51	39.77
2	45.70	43.53

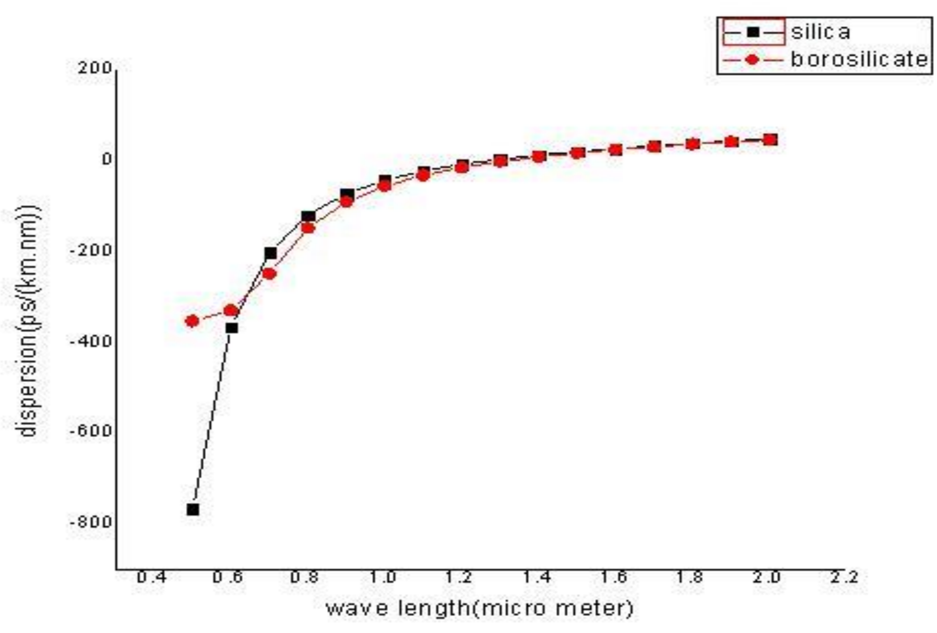

Fig5.7: objects dispersal amid silica and borosilicate glass.

Table 5.3: Comparison of Silica with BK7 (Borosilicate)

Properties	**Silica glass**	**BK7 (borosilicateglass)**
Light transmission wavelength (micrometer)	0.18to2.5	0.35to2.5
Density(g/cm^3)	2.2	2.51
Refractive Index (micrometer)	1.458	1.516
Material dispersion at 1.55µm	18.01246ps/km .nm	15.01038
Max. Temperature (degree C)	1120	560

5.4 Relationship amid projected models with silica model:

Figure 5.8 demonstrates the chromatic diffusion of anticipated Borosilicate crown glass HPCF and silica glass HPCF when pitch "Λ" = 2.0 µm, d=1.0 µm. The planned Borosilicate crown glass HPCF creates almost Zero ultra flat dispersion.

Simulation results of silica model and proposed model wavelength vs dispersion (ps/km.nm)

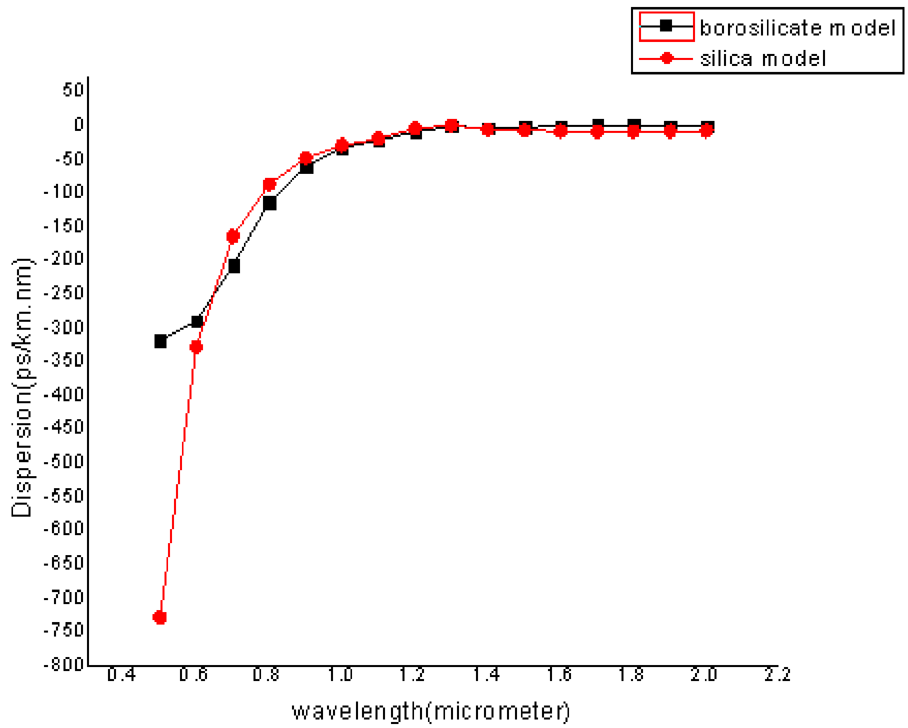

Fig5.8: chromatic dispersion of proposed Borosilicate crown glass HPCF and silica glass HPCF when pitch "Λ". = 2.0 µm, d = 1.0 µm

In the work shown above different designs of models of honeycomb borosilicate PCFs are shown but the configuration is configuration 4 which gives best results among all these models which are shown in Table 5.1 and Fig. 5.6. The comparison of borosilicate material and silica material is also shown. In Fig. 5.8 the comparison between silica models with proposed model is shown and the reason for using borosilicate material has also been made clear. Hence, all these reasons prove PCF as the best method best to solve dispersion problem.

CHPATER 6

CONCULUSION

6.1 Conclusion:

Among the propagated designs, the best result is shown in D=1.0µm in which simulations results get zero dispersion at 1.6µm to 1.9µm. It has been proved that an ultra flattened dispersion characteristic over wide wavelength series has superior presentation than usual photonic crystal fiber. In addition it is also revealed that borosilicate glass PCF offers a large amount of diffusion as contrasted to silica of the similar composition. Honeycomb structure is used for zero ultra flattened dispersion. Borosilicate crown glass contains better properties such as good transmission, cheaper, easy availability and therefore they can be used as a core material by replacing silica glass. BK7 is tremendously superior descending diffusion to 350 nm in comparison to silica glass and low dispersion at 1.55µm

6.2 Future Scope:

The results of this work show the minimum and zero dispersion of photonic crystal fiber. The study can be further be extended for better dispersion through new borosilicate honeycomb photonic crystal fiber at very low cost. There also lies a wide scope in further development of the PCF for various purposes like size estimation of PCF with different glass materials, etc for minimum and zero dispersion which leads to calculate other quality parameters such as confinement loss and birefringence etc.

CHAPTER 7

REFERENCES

1. Chauvel, G. (white paper), Dispersion in Optical Fibers. *Anritsu Corporation*

2. F.Poli, "Tailoring of Flattened Dispersion in High Nonlinear Photonic Crystal Fibers", IEEE Photon. Tech. Lett.vol. 16, no 4, pp. 1065–1067, Apr. 2004.

3. G. Xu, W. Zhang, Y. Huang, J. Peng (2006)." Optical Properties of solid core honeycomb photonic crystal fiberwith different doping levels."

4. Huizhen Xu, Jian Wu, Yitang Dai, Cong Xu , and Jintong Lin ; Design procedure for photonic crystal fibers with ultra flattened chromatic dispersion .December 2010

5. Homepage of the Optoelectronics Group, Department of Physics, University of Bath.

6. J. R.Folkenberg, C.Jakobsen, and H.R.Simonsen(2004). "Photonic crystal fiber with a hybrid honeycomb cladding.

7. Juan Juan Hu et al. "Full-Vectorial Analysis of Photonic Crystal Fibers" IEEE photonics technology letters, vol. 19, no. 24, december 15, 2007

8. J. Broeng, D. Mogilevstev, S. E. Barkou and A. Bjarklev." Photonic Crystal Fibers: A New Class of Optical Waveguides *Department of Electromagnetic Systems, Technical University of Denmark, Building 348, DK-2800 Lyngby, Denmark* September 9, 1998

9. M.chen, Q.yang, T.li, M.chen and N.he. "New high negative dispersion photonic crystal fiber" ScienceDirect,Optik 121 (2010) 867–871..

10. Mahfoud, A.project, (white paper), Photonic Crystal Fiber.

11. N.AREED, "Ultra-Flattened Dispersion Honeycomb Lattice Photonic Crystal Fiber", 5th International Conference: Sciences of Electronic, Technologies of Information and Telecommunications, March 22-26, 2009 – TUNISIA

12. S.S. Mishra and Vinod Kumar Singh, "Comparative Study of Fundamental Properties of Honey Comb Photonic Crystal Fiber at 1.55μm Wavelength", Journal of Microwaves, Optoelectronics and Electromagnetic Applications, Vol. 10, No. 2, 343-354, December 2011.

13. S.Tiwari. S.Jalwania and A.K. Bairwa,(2012). "Design Of Borosilicate Crown Glass Photonic Crystal Fiber With Flattened Dispersion And Low Confinement Loss."

14. S. Olyaee and F. Taghipour(2012). "Ultra-flattened dispersion hexagonal photonic crystal fibre with low confinement loss and large effective area".

15. S. Sharma,R.K.Sharma and K.Vyas,"Novel design a honeycomb photonic crystal fiber with nearly zero flattened chromatic dispersion", IEEE International Conference on Communication and Signal Processing, ICCSP'13 (3rd, 4th & 5th April 2013).

16. S. Akbar, N. Agarwal and S.Gupta, "Elliptical hybrid cladding Borosilicate photonic crystal fiber Design for minimum chromatic dispersion**",** IEEE,2014

17. Štěpánek,L.2012.(whitepaper), Chromatic Dispersion in optical communications.

18. Steven G. Johnson and J. D. Joannopoulos, MIT.2003. Introduction to Photonic Crystals. Bloch's Theorem, Band Diagrams, and Gaps (But No Defects)

19. Sporik, J. Filka, M.Tejkal,.V. and Reichert,P.2011. Principle of photonic crystal fibers. *Fakulta elektrotechniky a komunikačních technologií VUT v Brně*. ISSN:1213-1539.

20. Shen L.P, W.P.Huang and S.S. Jain, " Design of photonic crystal fibers for dispersion related applications", J. Lightwave Technol, Vol. 21, pp 1644- 1651, 2003.

21. Sunil Sharma, Ravindra Kumar Sharma, Suman Sankhla, "Comparative Study of Dispersion between Conventional PCF and Honeycomb PCF", International Journal of Engineering and Technical Research (IJETR) ISSN: 2321-0869, Volume-1, Issue-2, April 2013

22. T.A.Birks, J.C.Knight and P.St.J.Russel, "Endlessly single-mode photonic crystal fiber," *Optics Lett.* 22, 961, 1997.