DESIGN A NEW BOROSILICATE HYBRID CLADDING PHOTONIC CRYSTAL FIBER TO MINIMIZE CHROMATIC DISPERSION.

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SHUMAILA AKBAR

THESIS
MASTER OF TECHNOLOGY
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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING
COLLEGE OF TECHNOLOGY AND ENGINEERING
MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
UDAIPUR

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Thesis

Submitted to the
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IN
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SHUMAILA AKBAR
2015

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY

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This is to certify that **Mrs. Shumaila Akbar** has successfully completed the comprehensive examination held on 31.01.2013 as required under the regulation for **Master of Technology** in **Electronics and Communication Engineering.**

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CERTIFICATE-II

This is to certify that this thesis entitled **"Design A New Borosilicate Hybrid Cladding Photonic Crystal Fiber To Minimize Chromatic Dispersion"** submitted for the degree of **Master of Technology** in the subject of **Electronics and Communication Engineering** embodies bonafide research work carried out by **Mrs. Shumaila Akbar** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on ………..

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This is to certify that this thesis entitled **“Design a new borosilicate hybrid cladding photonic crystal fiber to minimize chromatic dispersion”** submitted by **Mrs. Shumaila Akbar** to the Maharana Pratap University of Agriculture and Technology, Udaipur in partial fulfillment of the requirements for the degree of **Master of Technology** in the subject of Electronics and Communication Engineering, after recommendation by the external examiner was defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination was satisfactory; we therefore, recommend that the thesis be approved.

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This is to certify that **Mrs. Shumaila Akbar** student of **Master of Technology** in the subject of **Electronics and Communication Engineering,** Department of **Electronics and Communication Engineering**, has made all corrections/modifications in the thesis entitled **"Design a new borosilicate hybrid cladding photonic crystal fiber to minimize chromatic dispersion"** which were suggested by the external examiner and the advisory committee in the oral examination held on …..….. The final copies of the thesis duly bound and corrected were submitted on …… are enclosed for approval.

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ABSTARCT

Telecommunications and data communications using optical fibers as transmission media have become vast, evolving industries and service providers have to face continuously growing bandwidth demands in all networks areas, from long-haul to access A great deal of work has been focused in photonic crystals due mainly to their optical properties. However, most of the installed optical fibers are old and exhibit physical characteristics that may limit their ability to transmit high-speed signals in the second and third wavelength window have caused serious concerns using conventional single mode fibers. High dispersion in conventional single mode fibers leads to partial loss of data in long distances of data transmission. Thus our new proposed work in optical transmission media with zero dispersion and uniform response in different wavelength range.

Photonic crystal fibers (PCF) are more flexible absorbing and promising than conventional optical fiber. In this dissertation report we proposed a new design elliptical hybrid cladding borosilicate photonic crystal fiber with flattened dispersion characteristics by changing the diameter of circular air-holes of the third ring and forth ring into elliptical air hole. Finite Difference Time Domain (FDTD) method and transparent boundary condition (TBC) is used to analyze the dispersion property in a high-index core PCF. This method produced best result at third attenuation coordinate (1.55μm)and found the dispersion is minimum (±0.81ps/km.nm)and ultra flattened and also found low dispersion characteristics over l.4μm to 1.8μm wavelength range that has better performance than conventional photonic crystal fiber. It is also shown that borosilicate glass PCF provides much better dispersion as compared to silica of the same structure, so such PCF have high potential to be used as a dispersion compensating fiber in optical window.

सारांश

दूरसंचार और डाटा संचार, आप्टिकल फाइबर का उपयोग प्रसारण मिडिया के रूप में किया जाता है। सभी नेटवर्क क्षेत्रों में लगातार बेडविड्थ की मांग बढ़ रही है। जिसे बड़े उद्योगों और सेवा प्रदाताओं को सामना करना पड़ता है। फोटोनिक क्रिस्टल में काम का एक बड़ा सौदा मुख्य रूप से उसके आप्टिकल गुण की वजह से ध्यान केन्द्रित किया गया है। हालांकि अधिकतर स्थापित आप्टिकल फाइबर पुराने है और शारीरिक विशेषताओं के कारण वो दूसरे और तीसरे तरंगदैर्ध्य खिड़की में उच्च गति का संकेत संचारित करने के लिए अपनी क्षमता को सीमित कर सकते है और जो कि गंभीर चिंता का कारण है। पारंपरिक एकल मोड़ फाइबर के उपयोग के लिए पारंपरिक एकल मोड़ फाबर में उच्च फैलाव डेटा संचारण की लंबी दूरी में डेटा का आंशिक नुकसान होता है। इस प्रकार मेरा नया प्रस्तावित काम आप्टिकल ट्रांसमिशन मीडिया में शून्य फैलाव और विभिन्न तरंगदैर्ध्य रेंज में एक समान प्रतिक्रिया को प्रदान करता है।

फोटोनिक क्रिस्टल फाइबर (पीसीएफ) अधिक अवशोषित लचिला और आप्टिकल फाइबर से जयादा भरोसेमंद है। इस शोध प्रबंध रिपोर्ट में हमने एक नए डिजाइन अण्डाकार संकर कंलेडिंग के बोरोसिलिकेट फोटोनिक क्रिस्टल फाइबर का प्रस्ताव रखा है जिसमें हमने चपटी फैलाव विशेषताओं के साथ तीसरी रिंग के हवा छेद और चौथे रिंग के हवा छेद के व्यास को अण्डाकार हवा घेरे में बदला है।

परिमित अंतर समय डोमेन (एफडीटीडी) विधि और पारदर्शी सीमा हालत (टीबीसी) एक उच्च सूचकांक को पीसीएफ में फैलाव संपन्नित का विश्लेषण करने के लिए प्रयोग किया गया है। यह विधि में (1.55 माइक्रोमीटर) समन्वय तीसरे क्षीणन में सबसे अच्छा परिणाम का उत्पादन किया और फैलाव चपटा न्यूनतम (±0.81पिको सैकण्ड/किलोमीटर नेनोमिटर) और तरंगदैर्ध्य रेंज 1.4 माइक्रोमीटर से 1.8 माइक्रोमीटर तरंगदैर्ध्य में अल्ट्रा सपाट व कम फैलाव विशेषता पायी गई। जो पारिपरिक फोटोनिक क्रिस्टल फाइबर से बेहतर है। और यह भी दिखाया गया है कि एक ही संरचना के सिलिका की तुलना में बारोसिलिकेट ग्लास पीसीएफ ज्यादा बेहतर फैलाव प्रदान करता है। इसलिए इस तरह के पीसीएस उच्च क्षमता आप्टिकल विंडो में एक फैलाव कम्पन–सेंटिग फाइबर के रूप में इस्तेमाल किये जाते हैं।

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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

CHAPTER 1
INTRODUCTION

1.1Background:

Electromagnetic wave propagation in periodic media was first considered by Lord Rayleigh in 1887, showing they had a photonic band-gap in one dimension. In 1987 Research interest grew with work by Yablonovitch and John on periodic optical structures with more than one dimension, now called photonic crystals. Photonic crystals are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of electromagnetic waves (EM) in the same way as the periodic potential in a semiconductor crystal affects the electron motion by defining allowed and forbidden electronic energy bands. Photonic crystals are normally classified by the number of their dimensions optical fibers with a built-in microstructure, in most cases consisting of small air holes in glass is called photonic crystal fiber. This is partly because these fibers offer many degrees of freedom in their design to achieve a variety of irregular properties, which make them interesting for a wide range of applications

1.1.1. Photonic Crystal :

Photonic crystals are periodically optical nanostructured electromagnetic media that are designed to affect the motion of photons in a similar way that periodicity of a semiconductor crystal affects the motion of electrons. Photonic crystals occur in nature and in various forms to be useful in different forms in a range of applications . Photonic crystals are composed of periodic dielectric or metallo-dielectric nanostructures that affect the propagation of electromagnetic waves (EM) in the same way as the periodic potential in a semiconductor crystal affects the electron motion by defining allowed and forbidden electronic energy bands. Photonic crystals can be fabricated for one, two, or three dimensions. One-dimensional photonic crystals can be made of layers deposited or stuck together; two-dimensional ones can be made by drilling holes in a suitable substrate, and three-dimensional ones by, for example, stacking spheres in a matrix and dissolving the spheres. Essentially, photonic crystals contain regularly repeating internal regions of high and low dielectric constant. Photons (behaving as waves) propagate through this structure - or not - depending on their wavelength. Wavelengths of light that are allowed to travel are known as modes, and groups of allowed modes form bands. Disallowed bands of wavelengths are called photonic band gaps. This gives rise to distinct optical phenomena such as inhibition of spontaneous emission, high-reflecting omni-directional mirrors and low-loss-wave guiding, amongst others. Since the basic physical phenomenon is based on diffraction, the periodicity of the photonic crystal structure has to be of the same length-scale as half the wavelength of the EM waves i.e. ~200 nm (blue) to 350 nm (red) for photonic crystals operating in the visible part of the spectrum - the repeating regions of high and low dielectric constants have to be of this dimension. This makes the fabrication of optical photonic crystals cumbersome and complex. Photonic crystals are normally classified by the number of their dimensions.

1.1.2.One-dimensional photonic crystals:

Before 1987, In one-dimensional photonic crystals in the form of periodic multi-layer dielectric stacks (such as the Bragg mirror) constant may be deposited or adhered together to form a band gap in a single direction were studied extensively**.** One-dimensional photonic crystals can be either isotropic or anisotropic, with the final having potential use as an optical switch.

In recent times, a graphene-based Bragg grating (one-dimensional **photonic crystal**) has been fabricated and established its capability for excitation of surface electromagnetic waves in the periodic structure by using 633 nm He-Ne laser as the light source. This structure can act as a far-IR filter and also is capable of supporting low-loss surface plasmons for waveguide and sensing applications. Further, a novel type of one-dimensional graphene-dielectric photonic crystal has also been proposed.

1.1.3.Two-dimensional photonic crystals:

Thomas Krauss in 1996, made the first revelation of a two-dimensional photonic crystal at optical wavelengths. Two dimensional structures are easy to fabricate for shorter wavelengths using standard semiconductor processing techniques. In this structure, holes may be drilled in a substrate that is transparent to the wavelength of radiation that the bandgap is designed to block. Triangular and square lattices of holes have been successfully employed.

The Holey fiber or photonic crystal fiber can be made by taking cylindrical rods of glass in hexagonal lattice, and then heating and stretching them, the triangle-like airgaps between the glass rods become the holes that confine the modes.

1.1.4.Three-dimensional photonic crystals:

The study of three-dimensional photonic crystals has proceeded more slowly than their two-dimensional because of the increased difficulty in fabrication. A three dimensional photonic band gap crystal is periodic in all directions and so exhibits a photonic band gap in all directions. There are several structure types that have been constructed such as Spheres in a diamond lattice, Inverse opals or Inverse Colloidal Crystals, The Woodpile Structure, A stack of two-dimensional crystals, Circular polarization.

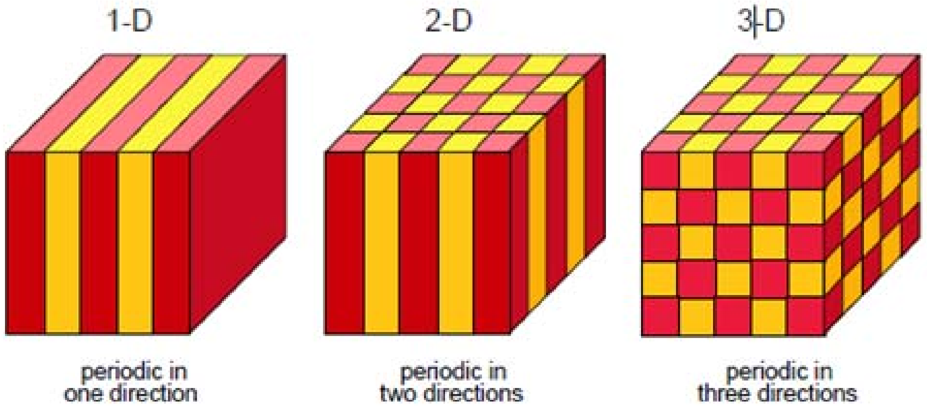


Fig1.1: Schematic diagram of Photonic crystals periodic one, two and three directions .

- One-dimensional structure: Bragg mirror.
- Two-dimensional structures: hexagonal lattices formed by rods or pores.
- Three dimensional structures: 'Yablonovite' and 'woodpile' structures.

1.2 Photonic Crystal Fiber:

Photonic Crystal Fiber (PCF) is a separation of Photonic Crystals. The field of PCF was first explored in the latter half of 1990's by the research group of Philip St. J. Russell and quickly evolved into a commercial technology. PCFs are generally divided into two main categories: Index Guiding Fibers that have a solid core, and Photonic Bandgap Fibers that have periodic micro structured elements and a core of low index material (e.g. hollow core). They can provide characteristics that ordinary optical fiber cannot, such as: single-mode operation from the UV to IR with large mode-field diameters, exceptionally high nonlinearity, numerical aperture (NA) ranging from very low to about 0.9, and optimized dispersion properties. Applications of PCFs are found in a wide range of research fields like spectroscopy, metrology, biomedicine, imaging, telecommunication, industrial machining, military, fiber-optic communications, fiber lasers, nonlinear devices, high-power transmission, highly sensitive gas sensors, and other areas. optical fibers with a built-in microstructure, in most cases consisting of small air holes in glass is called photonic crystal fiber. This is partly because these fibers offer many degrees of freedom in their design to achieve a variety of irregular properties, which make them interesting for a wide range of applications

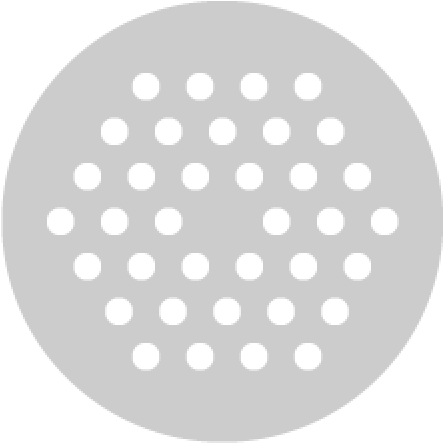


Fig 1.2: A frequently used solid-core photonic crystal fiber design.

A photonic crystal fiber or we can also say holey fiber, hole-assisted fiber, microstructure fiber, or microstructured fiber which obtains its waveguide properties not from a spatially varying glass composition but from an arrangement of very tiny and closely spaced air holes which go through the whole length of fiber. The simplest (and most often used) type of photonic crystal fiber has a triangular pattern of air holes, with one hole missing (see Figure 1), i.e. with a solid core surrounded by an array of air holes. Such air holes can be obtained by using a preform with (larger) holes, made e.g. by stacking capillary and/or solid tubes (stacked tube technique) and inserting them into a larger tube. Usually, this preform is then first drained to a cane with a diameter of e.g. 1 mm, and thereafter into a fiber with the final diameter of e.g. 125 µm. Particularly soft glasses and polymers (plastics) also allow the fabrication of preforms for photonic crystal fibers by extrusion. All these PCFs can be considered as specialty fibers.

The guiding properties of this type of PCF can be roughly understood with an effective index model: the region with the missing hole has a higher effective refractive index, similar to the core in a conventional fiber.

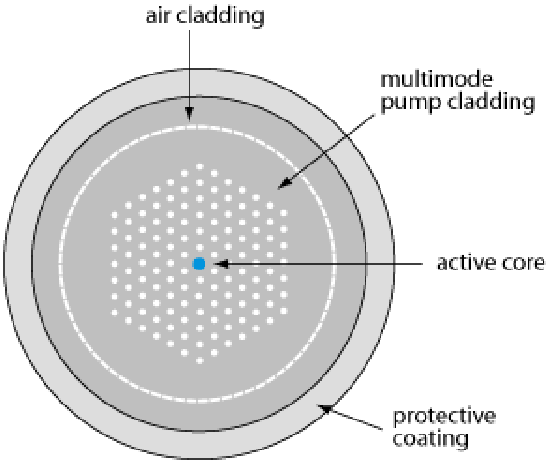


Fig1.3: Structure of a photonic crystal fiber with an air cladding.

1.3.Types of Photonic crystal fiber:

A More specific categories of PCFs and a value of refractive index inside are shown in Fig.1.4. .(J. Sporik *et al*,2011)

Bragg Fiber (1-D Photonic Crystal Fiber):

Photonic-bandgap fiber formed by concentric rings of multilayer film. It uses Bragg PBG (Photonic Band Gap)mechanism for reach the omnidirectional-mirror .The core may have a much lower refractive index than the cladding. Current air-core Bragg fibers are based on a combination of polymer and soft glass.

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

  The effective index is smaller than refractive index of solid core (silica) due to the holey are filed by material with smaller refractive index (air). The holey cladding of the fiber forms effective index of material. Like in conventional fibers, the principle of the total reflection is used.

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

  PCFs using air holes in their cross-sections. It is also called holey fiber. The core can be filled by air or gas. It enables the guidance of the light in the hollow core with lower attenuation than in the solid silica core. Commercially available IG PCFs.

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

  The very huge mode area enables high power levels without material damage and a nonlinear effect.

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

  Less than 1 μm or very small core size and the large gap of index core-cladding enable to create fibers with exceptionally small effective areas and high nonlinear coefficients.

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

  This type of fiber is similar to LMA-PCF. They are also called Air-clad fibers, but it uses double clad and it has active doped core.

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

  The principle is based on the fact than fundamental mode may not escape the core region of solid core PCF due to it does not fit into the gaps between the air holes. Higher order modes may escape the core

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

  This type of fiber allows the polarization maintaining.(J. Sporik *et al*,2011)

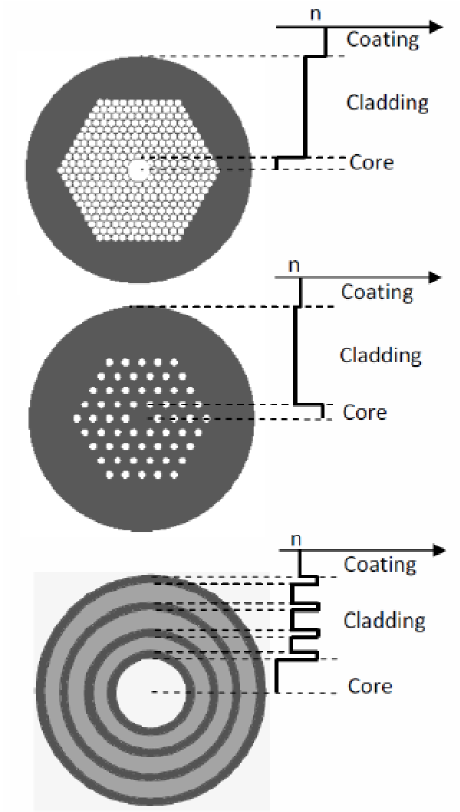


Fig1.4:Refractive index for HC-PCF (up), IG-PCF (middle),and Brag fiber(down).

(J.Sporik *et al*, 2011)

1.4. Fabrication of Photonic crystal Fiber:

Mainly photonic crystal fibers have been fabricated in silica glass, but other glasses (e.g. borosilicate, chalcogenide etc) have also been used to obtain particular optical properties such has high optical non-linearity. such fibers are also constructed by the same methods as other optical fibers: first, one constructs a "preform" on the scale of centimeters in size, and then heats the preform and draws it down to a much smaller diameter (often nearly as small as a human hair), shrinking the preform cross section but (usually) maintaining the same features. Photonic crystal fibers are made by stacking tubes and rods of silica glass into a large structure (perform) of the pattern of holes required in the final fiber. The perform is then bound with tantalum wire and then is taken to a furnace of fiber sketch overlook.

The furnace is filled with argon and achieve temperature about 2000 oC as result the glass rods and tubes get soften. Later, the preform is fused together and reduced to 1mm size with hole around 0.05 mm diameter . In other words by increasing the furnace temperature the air hole size can be reduced. After reducing the preform to a size that is 20 times smaller the structure thus formed (cane), the hole process is repetitive and spaces between the holes of 25 millionth of meter can be obtained. Defects are created by replacing tubes for solid rods as in the case of highly nonlinear PCF or by removing a group of tubes from the preform (hollow core photonic PCF). Since the fabrication process is quite strong complicated geometries can be achieved. For example the geometry of the center defect can be customized by the introduction of the thicker of thinner tubes at different position around the defect. In this way, kilometers of fiber can be produced from a single preform. The most common method involves stacking, although drilling/milling was used to produce the first aperiodic designs, by stacking capillary and/or solid tubes (stacked tube technique) and inserting them into a larger tube. This formed the ensuing basis for producing the first soft glass and polymer structured fibers.(A. Mahfoud,2003)

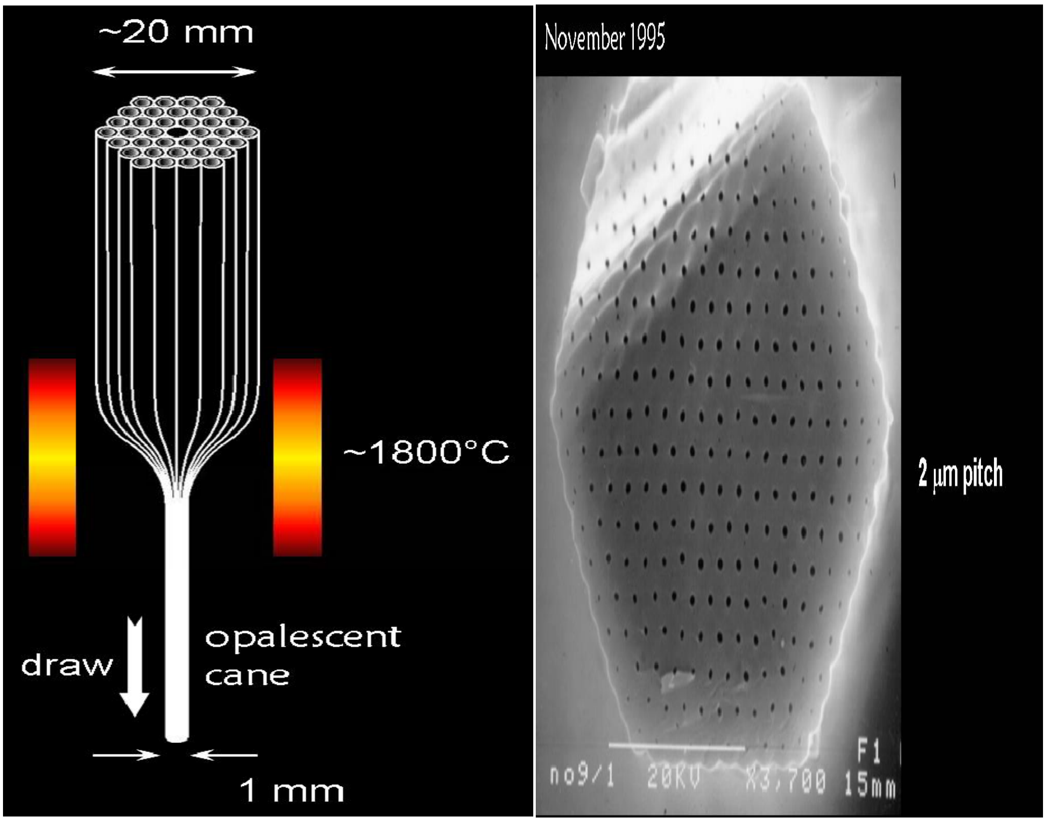


Fig1.5: Typical fabrication process in a photonic crystal fiber..(A. Mahfoud,2003)

1.5. Advantages of using PCF:

There are many advantages against a conventional optical fiber. The major ones are possibility to control optical properties and confinement characteristics of material.

- PCFs with larger cores may carry more power than conventional fibers.
- Guiding optical light through air.
- Reduction of Absorption losses.
- Reduction of non linearity effects.
- High power transmission. PCFs with larger cores may carry more power than conventional fibers
- Allow for guidance through hollow fibers (air holes).Smaller attenuation than with fiber with solid core.
- Attenuation effects not worse than for conventional fibers. Control over dispersion: size of air holes may be tuned to shift point of zero dispersion into visible range of the light.
- Larger contrast available for effective-index guidance.
- To control light, optical fiber uses total internal reflection The disadvantage of normal optical fiber is the interface must be smooth respect to the wavelength of light photonic crystal is totally a different mechanism, based on bandgap.

1.6. Applications of PCF:

Their particular properties make photonic crystal fibers very attractive for a very wide range of applications. Some examples are:

- Nonlinear devices e.g. for supercontinuum generation, Raman conversion parametric amplification, or pulse compression.
- Fiber lasers and amplifiers, including high-power devices, mode-locked fiber lasers, etc.
- Telecom components, e.g. for dispersion control, filtering or switching.

- Various kinds of fiber-optic sensors.
- Quantum optics, e.g. generation of correlated photon pairs , electromagnetically induced transparency, or guidance of cold atoms.

Even though PCFs have been around for several years, the vast range of possible applications is far from being fully explored. It is to be expected that this field will stay very dynamic for many years and many opportunities for further creative work, concerning both fiber designs and applications.

1.7. Borosilicate crown glass(BK7) Material:

PCFs are made of many types of glass material such as silica,chalcogenide, borosilicate etc. Borosilicate glass was first urbanized by German glassmaker Schott in the late 19th century.

Borosilicate glass represents unrivaled homogeneous glass for construction of plant and piping in the chemical, dyestuff, food pharmaceutical, petrochemical industries. Its gradually growing use is due to many advantages over conventional materials.

- Outstanding corrosion resistance
- Transparency.
- Catalytic dullness.
- Smooth pore free surface.
- No effect on taste and odour.
- Physiological inertness.

Borosilicate glass is chosen for its unique chemical and physical properties. Borosilicate glass can be considered as being calm of oxides. Silica (SiO_2) Magnesia (MgO) and lead oxide (PbO) are the principle modifiers/fluxes.

(i) CHEMICAL COMPOSITION

The composition of borosilicate glass used for chemical plants has following approximate composion.

SiO_2 - 80.6%

Na_2O - 4.2%

$B_2 O_2$ - 12.5%

Al_2O_3 - 2.2%

Most borosilicate glass is colorless 70 % silica, 10% boron oxide, 8% sodium oxide, 8% potassium oxide and 1% calcium oxide are used in the manufacture of borosilicate glass. Borosilicate glass is inert to almost all materials except hydroflouric acid (HF) phosphoric acid((H_3Po_4) and hot strong caustic solutions.

(ii) OPTICAL PROPERTIES OF BOROSILICATE GLASS

Borosilicate glass shows no appreciable absorption in the visible region of spectrum and therefore appears clear and colors less.

In photo chemical processes the transparency of ultra violet is of exacting importance. It follows from the transmittance of material in uv region that photo chemical reactions such as chlorination & sulpho chlorination can be performed in it.

Borosilicate crown glass (BK7) is an optical material used in a large fraction OPTICS product. It is relatively hard glass, doesn’t scratch easily. Another important feature of BK7 is very good transmission down to 350 nm. Due to these properties, BK7 are widely used in the optics industry. Borosilicate glass is less dense (at about 2.23g/cm3) than typical soda-lime glass due to the low atomic weight of boron. N-BK7 is a Schott description for the most 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

1.8. PROPERTIES OF PHOTONIC CRYSTAL FIBER.

1.8.1 Dispersion:

The spreading or broadening of light pulses, as they travel through the fiber is called dispersion, is a important factor limiting the quality of signal transmission. In optical fiber, dispersion is the incident in which the phase velocity of a wave depends on its frequency, or equivalently when the group velocity depends on the frequency such a property are termed dispersive media. Dispersion is a result of the physical properties of the transmission medium. There are generally two sources of dispersion: material dispersion and waveguide dispersion. Material dispersion comes from a frequency-dependent response of a material to waves. Single-mode fibers, used in high-speed optical networks, are subject to Chromatic Dispersion (CD) that causes pulse broadening depending on wavelength, and to Polarization Mode Dispersion (PMD) that causes pulse broadening depending on polarization. The mainly common example of dispersion is maybe a rainbow, in which dispersion causes the spatial separation of a white light into components of different wavelengths (different colors). Dispersion in optical fiber can be classified into two categories. One is intramodel dispersion and second is intermodal dispersion. Interamodel dispersion is occurring in optical fiber due to propagation delay difference between different spectral components of transmitted signal. Intermodal dispersion is occurring in optical fiber due to propagation delay difference between modes within a multimode fiber. There are three main types of dispersion: modal dispersion, chromatic dispersion and polarization dispersion. We will focal point only on one of them on the chromatic dispersion. (G.Chauvel,2008)

1.8.1.1. Chromatic (Intra modal) dispersion :

The speed at which light travels through optical fiber is depends on the its waveguide or on the design of the fiber. The primary cause of the chromatic dispersion (CD) is the fact that different spectral components of the light impulse or different wavelengths travel in the optical fibre at different speeds. As the result of different speeds wavelengths have different time of arrival to the end of fibre, impulse width increases and inter-bit spaces narrow . The receiver cannot correctly identify whether a transmitter in a specific bit interval sent a value of logical one or zero. The distortion of the transmitted information will then increase the bit error rate.(G.Chauvel,2008)

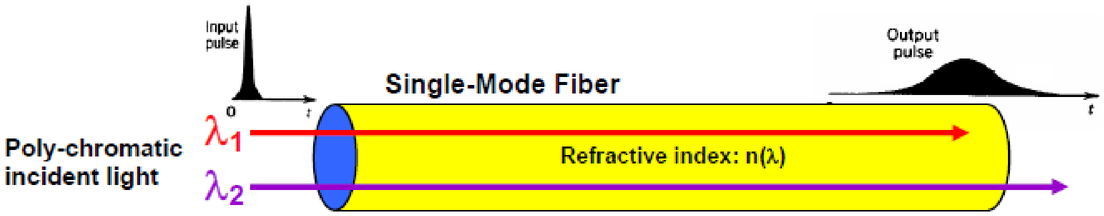
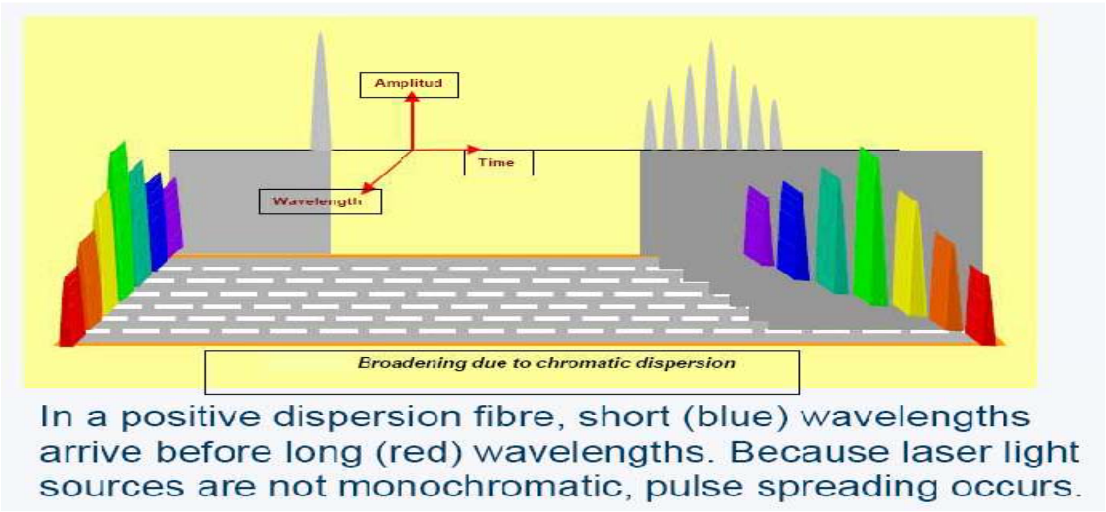


Fig.1.6:CD in single mode fiber.(G.Chauvel,2008)



In a positive dispersion fibre, short (blue) wavelengths arrive before long (red) wavelengths. Because laser light sources are not monochromatic, pulse spreading occurs.

Fig.1.7: Broadening due to chromatic dispersion.

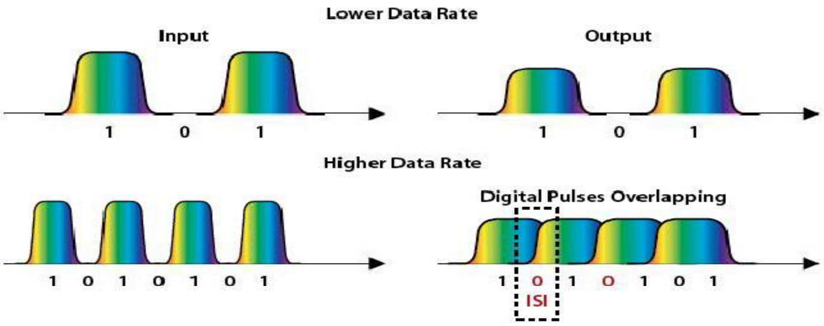


Fig.1.8: - The dependence of pulses overlap on transmission rate (L.Štěpánek,2012)

The Parameters of Chromatic Dispersion

The chromatic dispersion coefficient is a primary parameter of a fiber is expressed in ps/(nm-km). It determines the size of the CD and it is described by the equation.(L.Štěpánek,2012)

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

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 dispersion coefficient D is numerically equal to the Gaussian pulse (in ps) of an initial spectral half-width of 1nm width expansion after passing the fibre of a 1 km length. Pulse width increases with:

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

At the upper transmission speeds it is necessary to use narrower light pulses with shorter spaces. In this case the chromatic dispersion is a very strongly limiting factor of the transmission. The chromatic dispersion influences the use of appropriate sources of optical signal.on transmission system.(L.Štěpánek,2012)

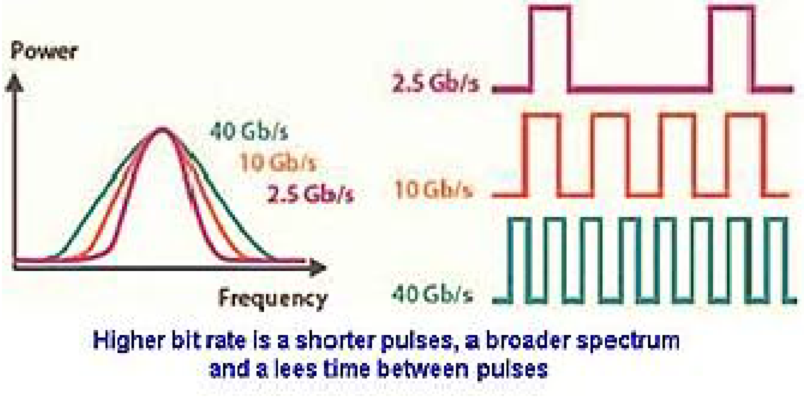


Fig.1.9:- Effect of increasing the transmission speed on pulse width and the width of the bit space. (L.Štěpánek,2012)

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

1.8.1.2. Material Dispersion:

Material dispersion comes from a frequency-dependent response of a material to waves. Material dispersion depends on the materials in built Refractive index and we are unable to change this if the variation in the refractive index with nonlinear wavelength then dispersion takes place.The velocity of propagation varies with wavelength and refractive index and in a dielectric medium the refractive index varies with wavelength as the results shows from the different group velocities of the various spectral components launched into the fiber by the source.

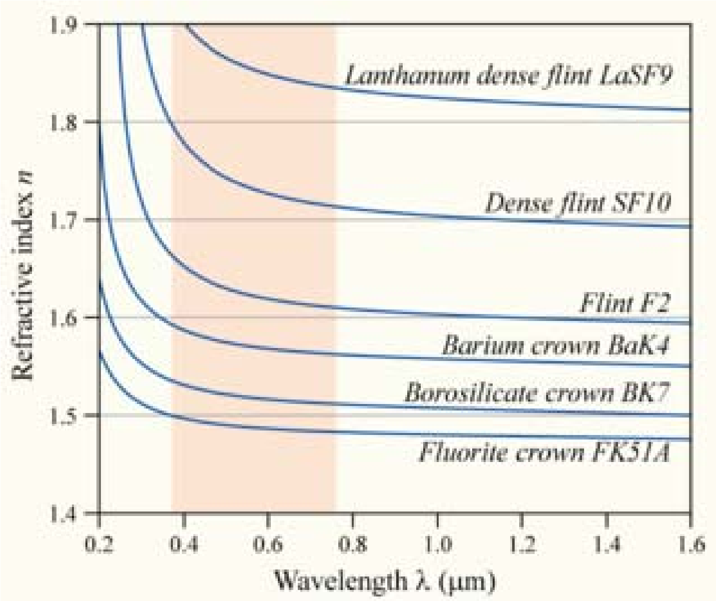


Fig.1.10 : The variation of refractive index vs. vacuum wavelength for various glasses.

Material dispersion can be a desirable or undesirable effect in optical applications . In general, the refractive index is some function of the frequency *f* of the light, thus $n = n(f)$, or alternatively, with respect to the wave length $n = n(\lambda)$. The wavelength dependence of a material's refractive index is usually quantified by its Abbe number or its coefficients in an practical formula such as the Cauchy or Sellmeier equations.

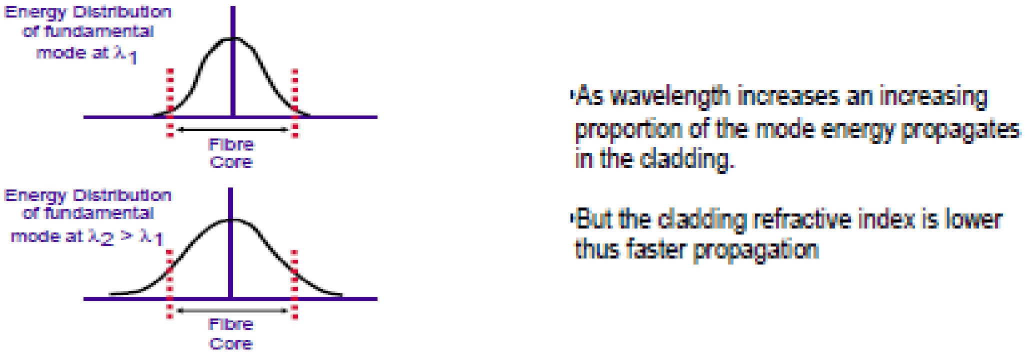
$$n^2 - 1 = \sum_i \left(\frac{A_I \lambda^2}{\lambda^2 - \lambda_i^2}\right) \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where is operating wavelength in µm.

1.8.1.3. Waveguide Dispersion:

Waveguide dispersion occurs when the speed of a wave in an optical fiber depends on its frequency for geometric reasons, independent of any frequency dependence of the materials from which it is constructed. Further generally, "waveguide" dispersion can occur for waves propagating through any inhomogeneous structure (e.g., a photonic crystal), whether or not the waves are confined to some region. Waveguide dispersion depends on the fibre’s refractive index profile and its this part that can be engineered to allow put on of speciality fibres with specific dispersion profile. A alike effect due to a somewhat different phenomenon is modal dispersion, caused by a waveguide having multiple modes at a given frequency, each with a different speed.

Mainly a problem for singlemode, in multimode mode dispersion into the cladding is very small in a comparative sense.



- As wavelength increases an increasing proportion of the mode energy propagates in the cladding.
- But the cladding refractive index is lower thus faster propagation

Fig1.11.: Effect of waveguide dispersion.

Waveguide and material dispersion are controlled to give required overall chromatic dispersion Altering the refractive index profile will alter the waveguide dispersion. Magnitude of waveguide dispersion is relatively independent of wavelength. The waveguide and material dispersion as a the same result have the same effect on signal transmission in optical fibre and therefore common word the chromatic dispersion is used.

1.8.1.4. **Birefringence**:

The key point realizing the birefringence is to destroy the symmetry of the fiber structure, which can be achieved either by altereing the air hole sizes near the core area or by destroying the shape of the air holes(such as elliptical air holes).

The Birefringence of a PCF is determined by the difference between the real part of the effective indexes. Polarized along x and y axis.(Feifei Shi *et al*,2011)

$$B=[\mathrm{Re}(neff^{x})-\mathrm{Re}(neff^{y})]$$

1.8.1.5.**Confinement Loss**:

When the optical mode is propagating in the core region, due to a finite number of layers of air holes,the mode leakage from the core region into the outer air hole region is necessary, and then , the confinement loss due to degree of the cladding is occurring.Confinement losses of photonic crystal fibre are often computed using the formula:

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

Where , $\mathrm{Im}[n_{eff}]$ is the imaginary part of n_{eff} , and k_0 is the free space wave length number equal to $2\pi/\lambda$. .(Feifei Shi *et al*,2011)

1.9.Work Scope

Telecommunications service providers have to face continuously growing bandwidth demands in all networks areas,from long haul to access.The broadening of light pulses,called dispersion, is a critical factor limilting the quality of signal transmission over optical links.To preserve the quality of transmission,the maximum amount of time dispersion must be limited to a small proportion of the signal bit rate of high speed networks mean that every possible sourse of pulse spreading should be addressed. There are so many reports have been available about PCFs with low confinement loss and ultra-flattened chromatic dispersion properties such as PCFs structures and materials with gradually increasing the diameter of the holes from the inner ring to the outer ring. In this report, we proposed a new design of elliptical hybrid-cladding PCF (HyPCF) of borosilicate glass in order to shape nearly zero ultra flattened dispersion in a broad range of wavelength.

1.10.Problem Statement

Development of photonic crystal fiber calculate waveguide dispersion, material dispersion and find out the total chromatic dispersion.

1.11 Objectives

The thesis embodies design of hybrid cladding photonic crystal fiber with the following prime objectives:

I. To Design a Hexagonal lattice Borosilicate Hybrid Cladding Structure of Photonic Crystal Fiber and calculate its waveguide dispersion.Parameters to calculate waveguide dispersion is the core diameter(d=1.5168),lattice pitch difference(Λ=2.0) and different -2 air cladding diameters.

II. To calculate the Material Dispersion (Borosilicate crown glass) for photonic crystal fiber by Sellimer Formula.Parameters to calculate the material dispersion is refractive index of material(R(neff)=1.5168),λ(0.2 µm to 2.0 µm) is the wavelength in units of µm.

III. To calculate the total Chromatic Dispersion of Photonic Crystal fiber structure through this phenomena Waveguide Dispersion+Material Dispersion=Chromatic Dispersion.

1.12.Thesis Organization

The thesis has been organized in to five chapters.

Chapter 1 is an introductory chapter

Chapter 2 literature review on to minimize the chromatic dispersion of photonic crystal fiber.

Chapter 3 gives the description about the calculate waveguide dispersion , material dispersion and find out total chromatic dispersion.

Chapter 4 discusses about the results obtained from the developed hybrid photonic crystal fiber to minimize the chromatic dispersion.

Chapter 5 gives the concluding remarks and recommends any future scope of the work

CHAPTER 2

REVIEW OF LITERATURE

Wang et al.(2007) In their designed, author presented the dispersion and polarization properties of photonic crystal fiber with one ring or more rings of elliptical air-holes using plane-wave expansion (PWE) method. By introducing three rings of elliptical air-holes, PCF with ultra-low and ultraflattened dispersion is designed and a total dispersion curve between ±0.5 ps/nm/km from 1315 to 1855nm wavelength range is demonstrated. Furthermore, the polarization property of these elliptical air-hole-containing PCFs is analyzed and the variation of the birefringence with the area and ellipticity of the elliptical air-holes are discussed. Designing Parameters of proposed pcf,three rings of elliptical air-holes, where L= 2.3, d= 0.908, a1= 0.7, a2= 0.723, a3= 0.71, b1= 0.55, b2= 0.55 and b3= 0.66 nm. The total dispersion curve . We get the total dispersion values between ±0.5 ps/nm/km from 1315 to 1855 nm.

Hai et al.(2007) In this paper ,the author shows the dispersion properties of the elliptical air holes containing PCF are investigated and a FDM method is applied to analyze. Ultra-low and ultraflattened dispersion properties with total dispersion value between ±0.28 ps/km/nm from 1.5µm to 1.8µm is presented by introducing three rings of elliptical air-holes disposed perpendicular alternately.

Designing Parameters of proposed PCF,it is composed of circular air holes in the outer rings arranged in triangular array with lattice constant Λ=2.3 µm and diameter d=1.8 µm. The inner ring is perturbed by including elliptical air holes with a1=0.55 µm, b1=0.7 µm, and the second and third rings with a2=a3=1.049 µm, b2=b3=1.335 µm. Still, it has been known that the size of air holes of several rings near the center core influence the dispersion significantly. If they increased wavelength until 2.0 µm, it is possible to get the same ultra-flattened dispersion. It is expected from result that the zero dispersion wavelength of the proposed structure can be shifted to less than 1.4µm and more than 1.8µm by changing sizes of elliptical air-holes in the second and third inner rings.

Chaudhari et al.(2009), designed a air cladding as well as borosilicate cladding chalcogenide As_2S_3 nanofibers shows larger chromatic dispersions as compare with large-diameter chalcogenide fibers. At a particular wavelength, the dispersion of the nanofiber can be made zero positive or considerably negative by proper selection of diameter and/or cladding material. Zero dispersion at communication wavelength of 1.5 m can be tailored in both air and borosilicate cladding nanofiber. Flattening of the zero dispersion in the telecommunication window is possible with the borosilicateclad chalcogenide nanofiber structure. Such dispersion tailoring may provide opportunities for developing a number of miniaturized, high-performance, and novel type of nonlinear photonic devices operating at low threshold power. The thermal properties of the chalcogenide(As_2S_3) and borosilicate glass reported that the fabrication of the structure is practicable.The zero dispersion is achieved at the core size of 500 nm for this nanofiber at the telecommunication wavelength of 1.5 m. They further present the flattening of the zero dispersion in the telecommunication window by cladding the(As_2S_3) core with borosilicate glass the thermal properties of which match with those of the (As_2S_3) glass. Zero-flattened dispersion centered at 1.408 m wavelength can be tailored for the nanofiber with this new structure when the nanofiber core diameter is 724 nm…

Xu et al.(2011) in the month of May present a simple design procedure of photonic crystal fibers (PCFs) with ultraflattened chromatic dispersion.They found Only four parameters(the air-hole diameters of the inner three rings and the pitch) are required, which not only considerably saves the computing time, but also distinctly reduces the air-hole quantity. The influence of the air-hole diameters of each ring of hexagonal PCFs (H-PCF, including 1-hole-missing and 7-hole-missing H-PCFs), circular PCFs (C-PCF), square PCFs (S-PCF), and octagonal PCFs (O-PCF) investigated through simulations. Results show that regardless of the cross section structures of the PCFs, the 1st ring air-hole diameter has the greatest influence on the dispersion curve followed by that of the 2nd ring. The 3rd ring diameter only affects the dispersion curve within longer wavelengths, whereas the 4th and 5th rings have almost no influence on the dispersion curve. The hole-to-hole pitch between rings changes the dispersion curve as a whole. H-PCFs are the most conventional type of PCF structures and are the most widely used. After the investigation on the variation in each ring air-hole diameter, we found that they had the same influence on the dispersion curve as H-PCF and C-PCF did. Therefore, S-PCF with ultraflattened dispersion can be obtained using the same procedure. The 1st ring air-hole diameter has the greatest influence on the dispersion curve, affecting the dispersion curve within the entire wavelength range considered. Within the shorter wavelength range, the dispersion value decreases as $f1$ decreases,whereas the curve shape changes minimally. However,within the longer wavelength range, the variation in $f1$ affects not only the dispersion value but also the curve shape. The 2nd ring air-hole diameter more considerably affects the dispersion curve within the longer wavelength range than within the shorter wavelength range, whereas the 3rd ring has only minimal influence on the dispersion curve within the longer wavelength range. The 4th and 5th rings' air-hole diameters have almost no influence on the dispersion curve but play an important role in confinement loss.

Monfared,Y.E.(2012) they proposed a new method to design hybrid cladding photonic crystal fiber with flattened dispersion characteristics by changing the diameter of circular air-holes of the second and forth central rings. Finite Difference Time Domain (FDTD) method is used to analyze the dispersion property in a high-index core PCF. This method produced ultra flattened and low dispersion characteristics over l000nm wavelength range that has better performance than conventional photonic crystal fibers. They produced PCFs with total dispersion between I ps/nmlkm over 200nm wavelength range, 4ps/nmlkm over 600nm wavelength range and 6ps/nmlkm over I000nm wavelength range, also it has three zero dispersion wavelengths around 1250nm, 2040nm and 2160nm. This method can also be used for the design ofPCFs with any desired dispersion characteristics. We demonstrated that changing the size of air-holes influences the dispersion significantly, the same thing occurs by adjusting the shape of air-holes or air-holes makeup, and these researches are stil under goes.

M**.** Chand et al. (2012),they designed a new borosilicate fiber which Structure parameter d1 = 0.7 µm, pitch difference = 2.0 µm and d2 = 1.3 µm get almost zero and flattened curve at 1.55 is ±5.0ps/km.nm.The results indicate that the proposed Borosilicate crown glass PCF has almost zero and flat dispersion in low wavelength range as silica glass PCF. But Borosilicate crown glass has good properties (like cheaper, good transmission, easy availability) compare to silica glass. So they can use

Borosilicate crown glass as a core material on the place of silica glass. Borosilicate crown glass can substitute of silica glass.

Sharma et al.(2012), they designed their new PCF and the results indicate that the proposed hybrid vertically elliptical air hole ring PCF has almost zero and flat dispersion compare to normal conventional As2Se3 glass PCF. It has been shown the results of flattened dispersion of 0.37317 ps/(km.nm) can be obtained in the range 2.5 μm to 2.9 μm.

CHAPTER 3

MATERIALS AND METHODS

3.1 Developed Method

In order to achieve the objective of the thesis, number of steps are involved to be carried out at different stages and phases. A consolidated pictorial view of the implementation stages is depicted with the help of the following flow chart.

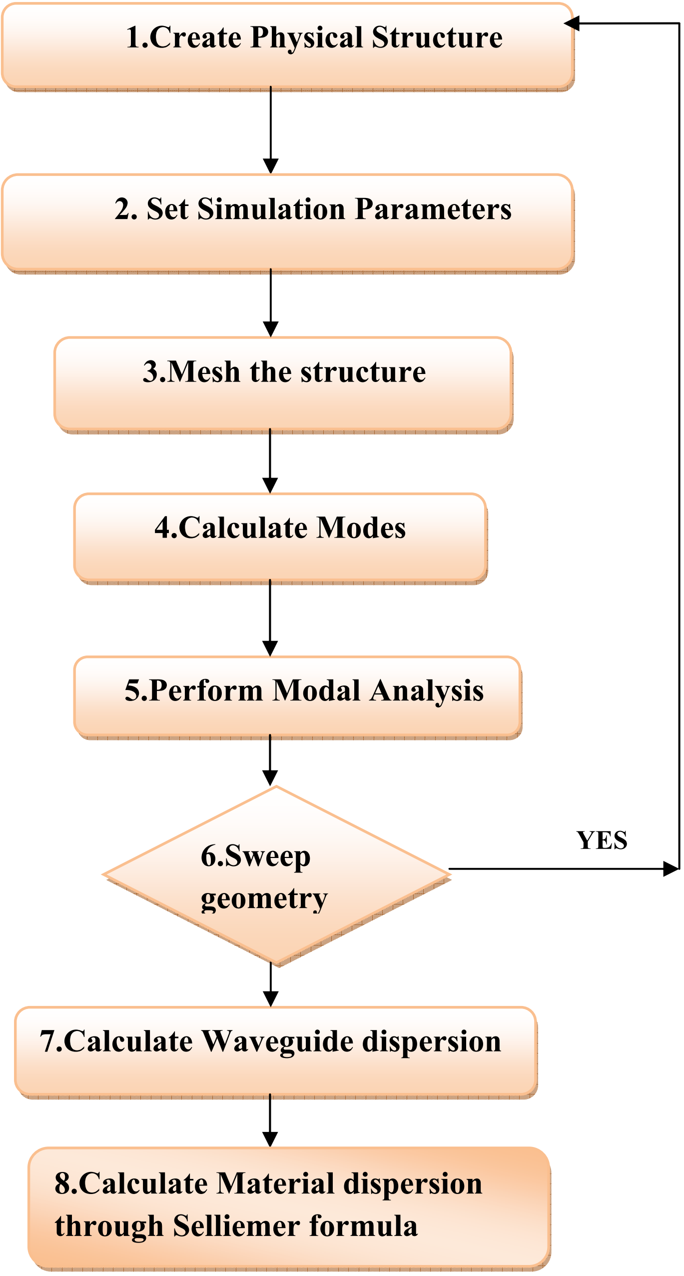


Fig 3.1: Flowchart of Designing process of PCF.

3.2 Procedure of Developed Method

The flowchart of developed method is shown in Fig 3.1.The procedure of calculating waveguide dispersion and material dispersion is described as follows:

3.2.1. Create Physical Structure:

In earlier times10 years, photonic crystal fibers (PCF) have much involved scientific and Commercial interest.Telecommunications and data communications using optical fibers as transmission media have become huge level, developing industries. The success of a given optical system depends directly on the choice of fiber parameters. Cross-sectional dimensions, material composition and the refractive index profile all manipulate the various linear and nonlinear phenomena, and must be carefully chosen in order to achieve optimal performance.

This process can now be greatly possible with the use of OptiFiber Optical Fiber Design Software or OPTIFDTD8.0 software. The examined and design work for PCF starts from accurate modal analysis of the fiber. Once the modes are found, all of the PCF properties such as loss, dispersion, and cutoff can be determined.

The PCF mode solver will mainly be used as an independent mode solver. OptiFDTD also provides an independent mode solver to allow user to solve and study the modal solutions outside of an FDTD calculation. Modal analysis requires mainly two steps:

a. Create the layout representing a PCF

b. Calculate the modes

We will use our Waveguide Layout Designer part from the software to define the PCF layout, and then convert the layout to a refractive index distribution file. The mode solver will load-in the index distribution file and perform the modal analysis.

The following segment will shows how a photonic crystal fiber can be analyzed in Opti FDTD

Sample 1- Photonic Crystal Fiber-Holey Fiber

The most common PCF is Holey Fiber as shown in Figure3.2 , the cladding region consists of a hexagonal array of air holes; One missing air-hole are called core region. The real layout may have more layers of air holes. Here we take six layers for the mode solving. We use the PBG array editor to define the hexagonal air hole. We need a graph (see Figure 3.3) for the detail dimension information of five layer. Such a graph can make the layout making easier, so it is highly suggested.

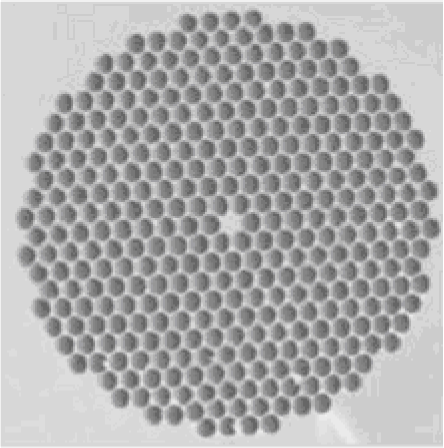


Fig. 3.2: Photonic Crystal Fiber cross-section

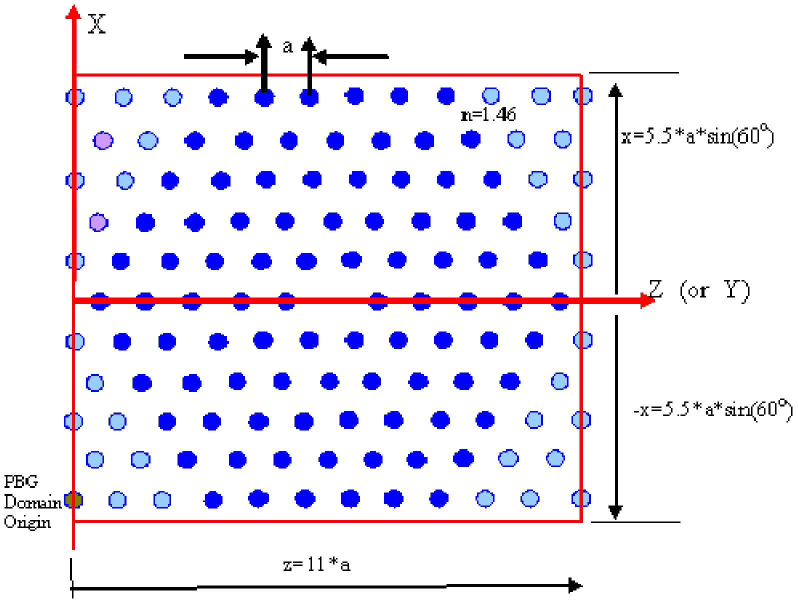


Fig.3.3: Five layers holey fiber.

Please note:

For this five layer holey fiber

(a) The background material refractive index n = 1.46

(b) Hexagonal Air hole, periodic: a = 2.3um, n = 1.0, radius R = 0.6um

(c) Simulation domain: z = 11*a, x = 11*a*sin(60º)

(d) The green dot is the hexagonal lattice original point: x = -5*a*sin(60^0); z = 0

3.2.1.1.Create the waveguide layout

To design a holey fiber structure(hybrid cladding PCF), follow these steps.

Step Action

1 Start **Waveguide Layout Designer**.

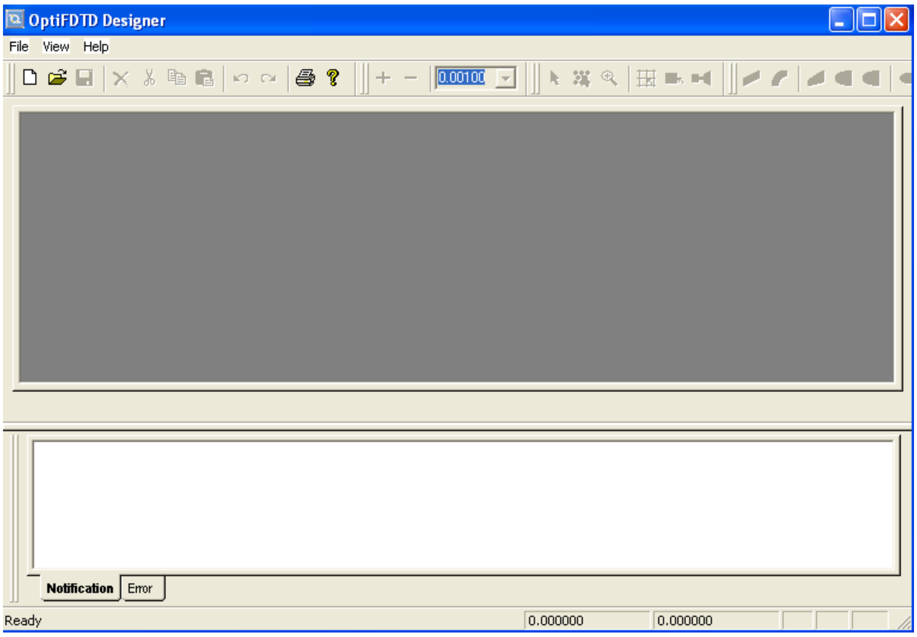
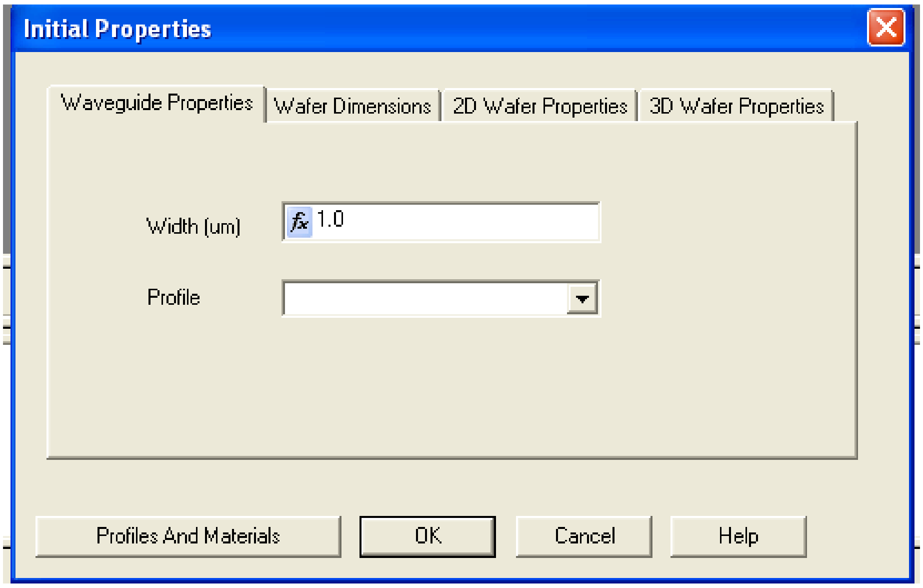


Fig.3.4:waveguide layout optiFDTD designer.

2. To create a new project, select **File** > **New**.

The **Initial Properties** dialog box appears.



Width (um) 1.0

Fig.3.5:Initial Properties

3 Click **Profiles and Materials**.

The Profile Designer window appears.

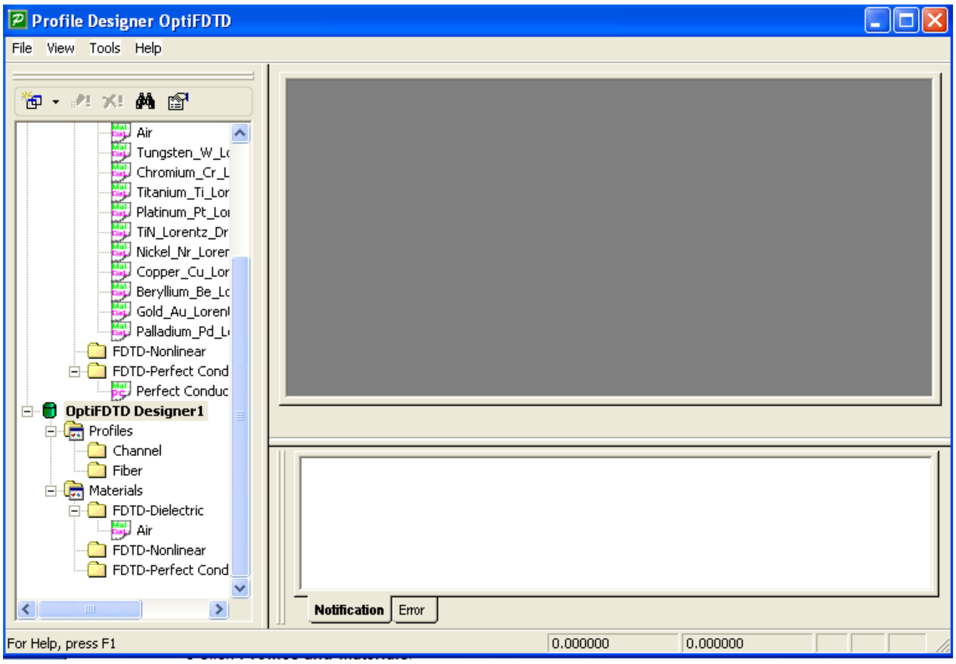
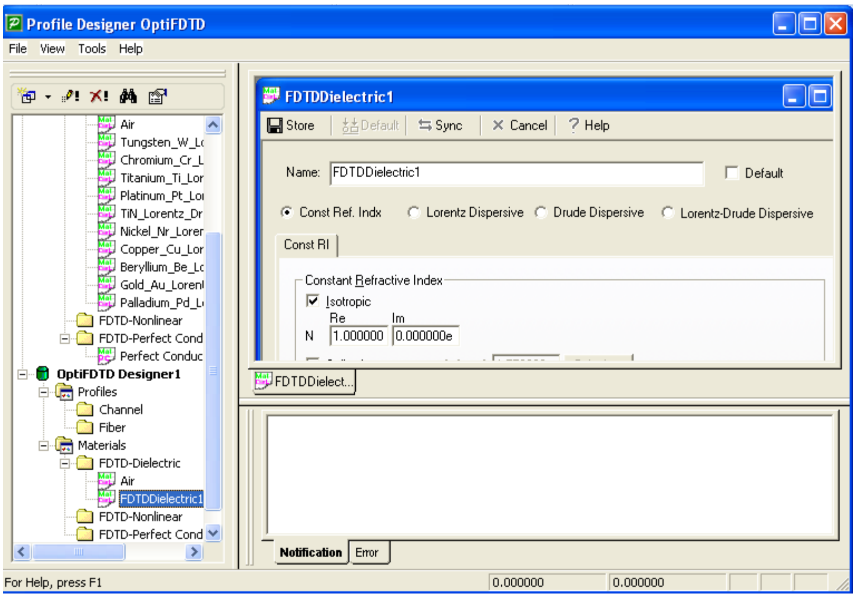


Fig.3.6:Profile designer optiFDTD

4 Under the **Materials** folder, right-click the **FDTD-Dielectric** folder and select **New**. A new Dielectric material dialog box appears



Name: FDTDDielectric1 ☐ Default

● Const Ref. Indx ○ Lorentz Dispersive ○ Drude Dispersive ○ Lorentz-Drude Dispersive

☑ Isotropic

N Re 1.000000 Im 0.000000e

Fig3.7: Profile designer optiFDTD for FDTD Dielectric Materials.

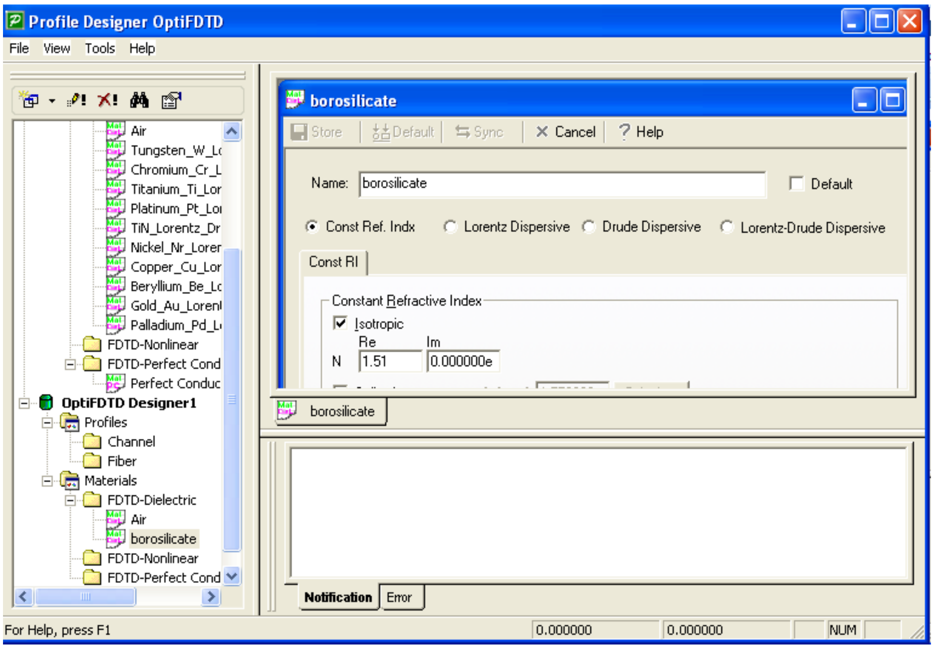
5.Type the following information:

Name: **Borosilicate**

Refractive index (Re:): 1.51.

6 To save the material, click **Store**

Borosilicate appears in the **FDTD-Dielectric** folder in the directory and in the dialog box title bar.



Name: borosilicate ☐ Default

● Const Ref. Indx ○ Lorentz Dispersive ○ Drude Dispersive ○ Lorentz-Drude Dispersive

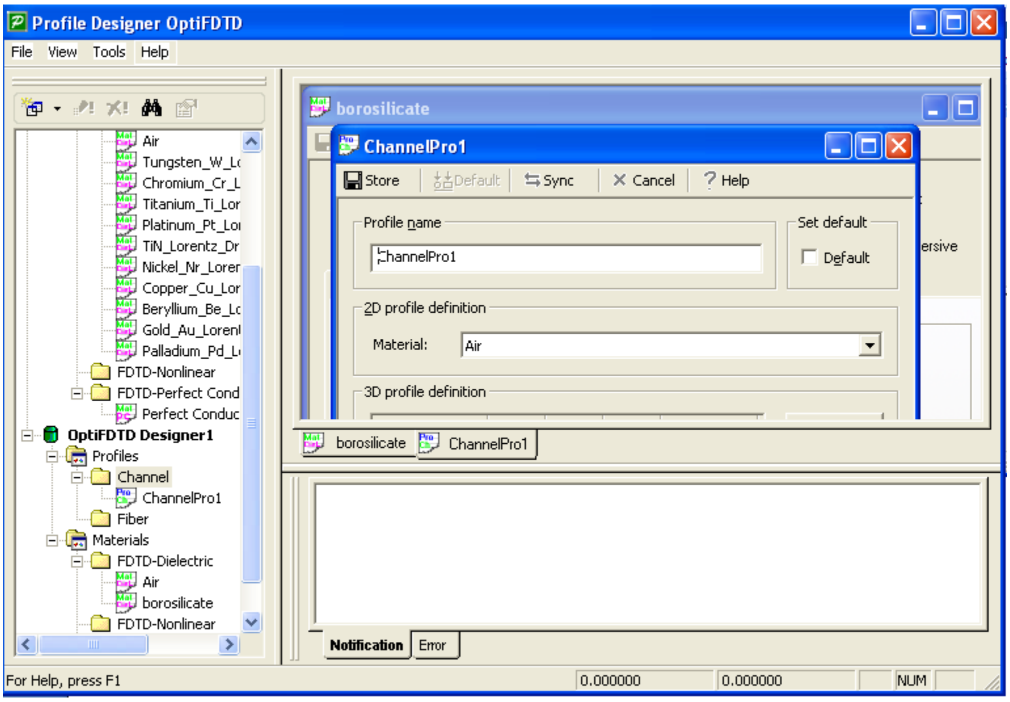
☑ Isotropic

N Re 1.51 Im 0.000000e

Fig.3.8: Borosilicate appears in the FDTD-Dielectric folder in the directory and in the dialog box title bar in Profile designer optiFDTD.

7. Under the **Profiles** folder, right-click the **Channel** folder and select **New**.

The **ChannelPro1** dialog box appears.



Profile name: ChannelPro1

Set default: ☐ Default

2D profile definition

Material: Air

Fig.3.9: The ChannelPro1 dialog box

8 .Create the following channel profile:

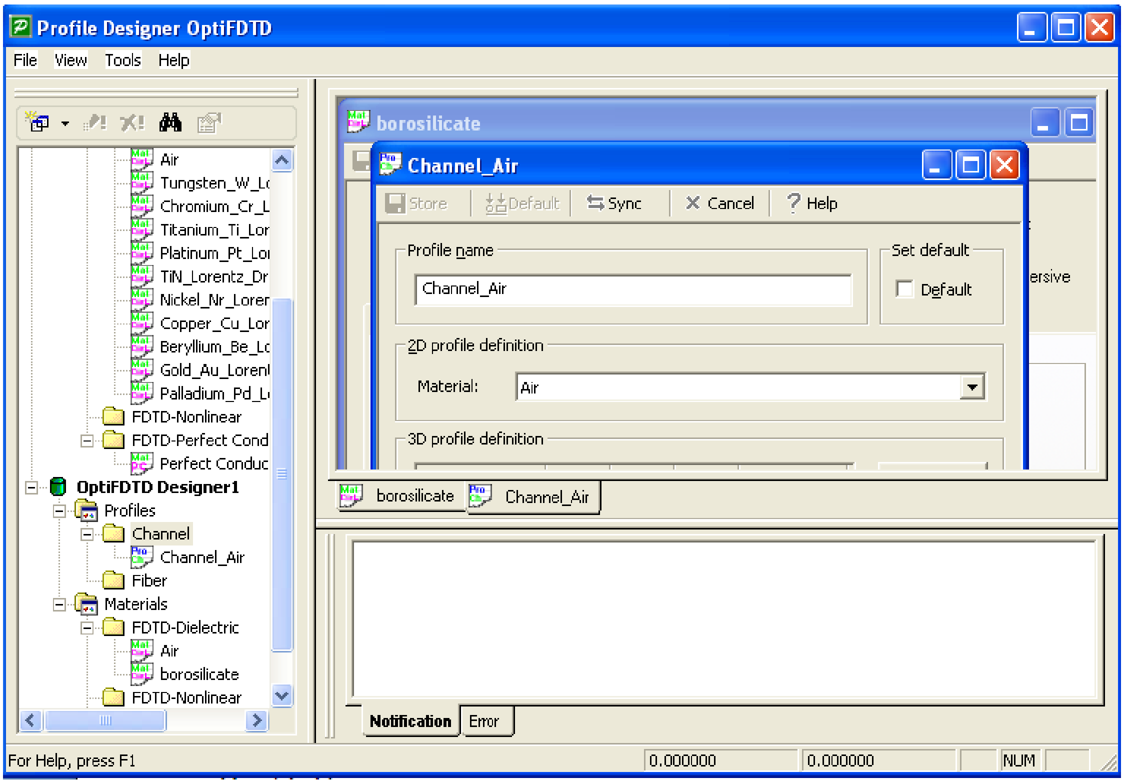
Profile name: **Channel_Air**

2D profile definition

Material: **Air**

9 Click **Store**.

(Close the **Profile Designer**.or leave it open)



Profile name: Channel_Air

☐ Default

Material: Air

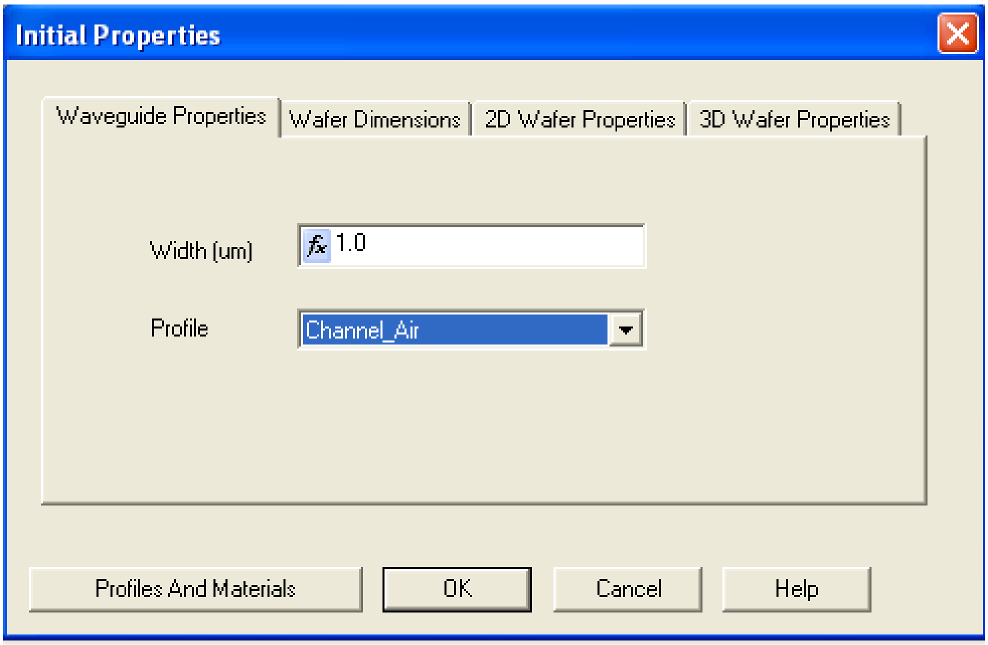
Fig.3.10: The ChannelPro1 dialog box with entries.

10. Switch to the Layout Designer, and in the **Initial Properties** dialog box type/select the following:

Waveguide Properties

Width [µm]: **1.0**

Profile: **Channel_Air.**



Initial Properties

Waveguide Properties

Width (um) 1.0

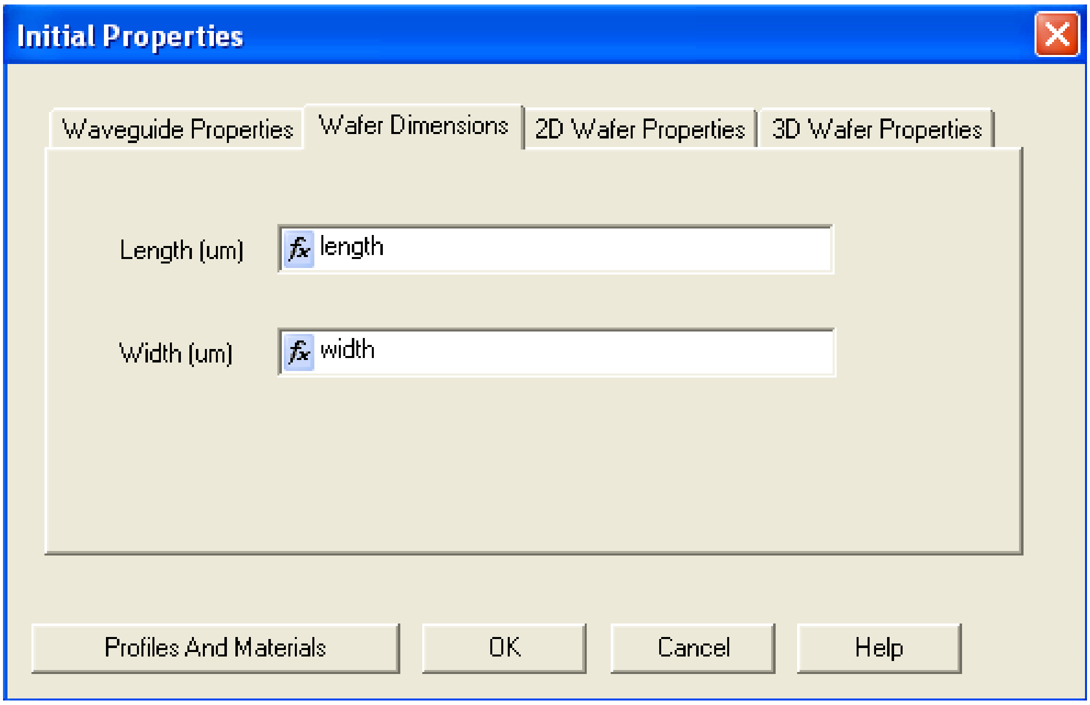
Profile Channel_Air

Fig.3.11:Initial Properties box with waveguide properties.

Wafer Dimensions

Length: **length**

Width: width



Initial Properties

Wafer Dimensions

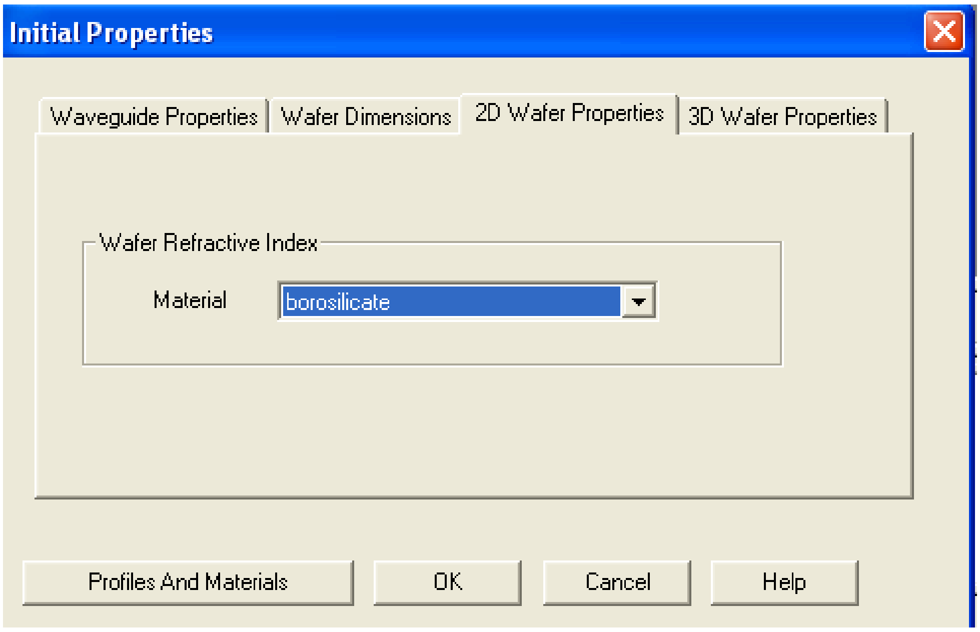
Length (um) length

Width (um) width

Fig.3.12:. Initial Properties box with wafer dimensions.

2D Wafer Properties

Material: **borosilicate**



Material borosilicate

Fig.3.13:. Initial Properties box with 2Dwafer properties

11**.** Click **OK** in the initial dialog box. Click **Yes** in the question dialog box to start define the variables. Variables and Functions dialog box appears *Because variable (length, width) is used in the initial dialog box .clicking OK will open the Parameter Editor dialog box*

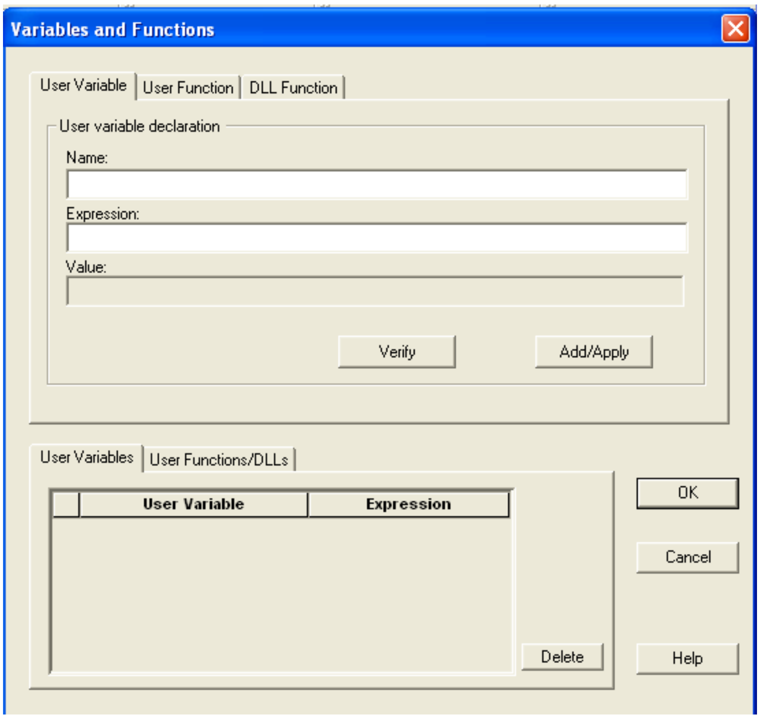
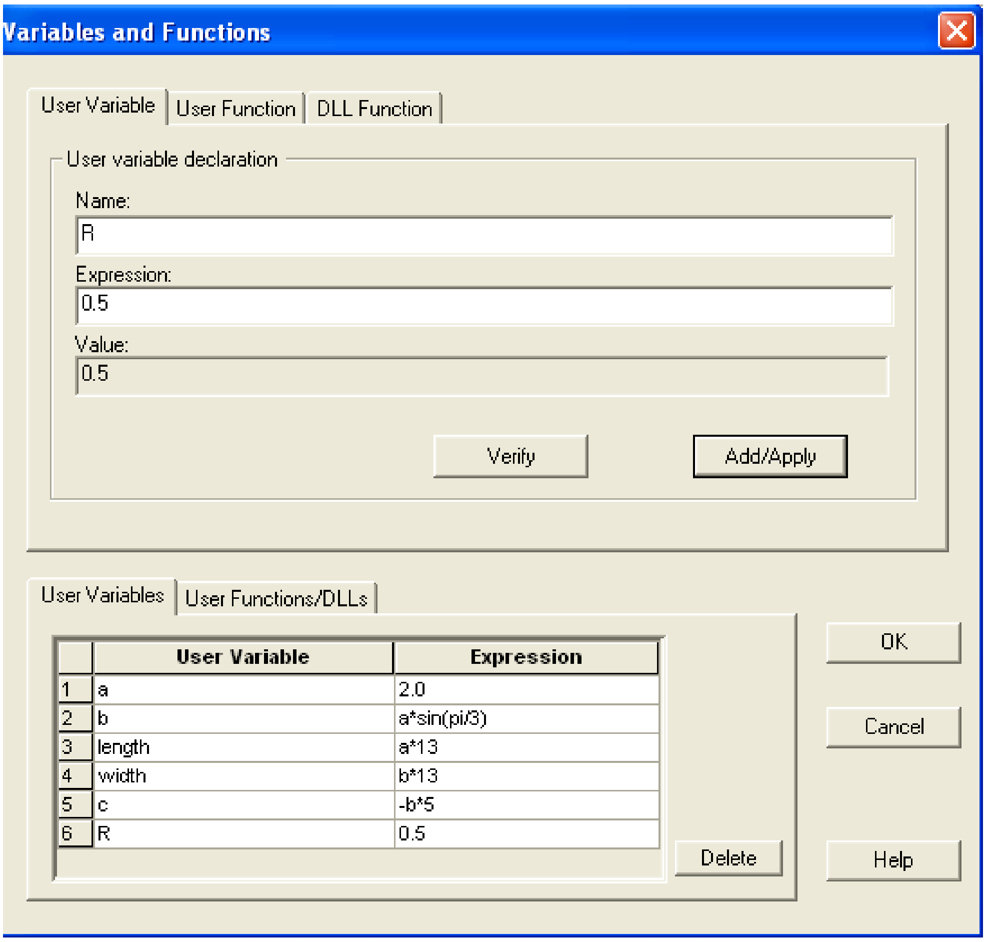


Fig.3.14.Variables and Functions dialog box appears

3.2.2.Set Simulation Parameters.

1. In the **Variables and Functions** dialog box, define the following variables in the specified order then click **OK** to close the dialog box(for six layers length= 13*a,width=13*b)

Name	value	
A	2.3um	~lattice constant
B	a*sin(pi/3)	~height of triangle cell
Length	13*a	~length of domain
Width	13*b	~width of domain
c	-5*b	~X original point of lattice
R	0.5um	~Radius of air hole



Name: R

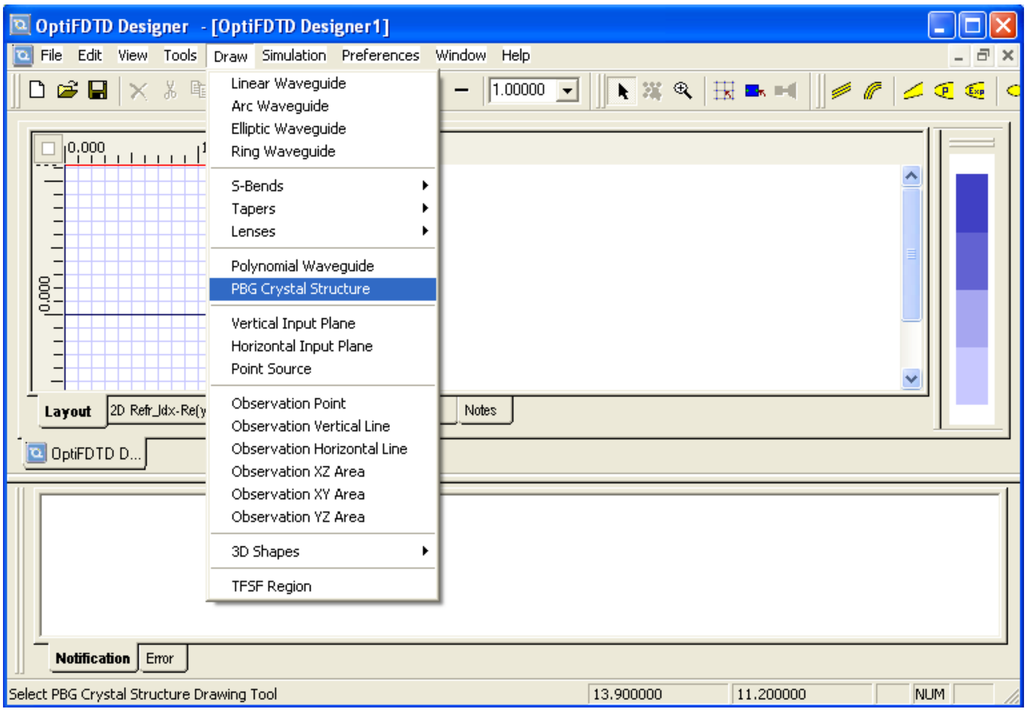
Expression: 0.5

Value: 0.5

	User Variable	Expression
1	a	2.0
2	b	a*sin(pi/3)
3	length	a*13
4	width	b*13
5	c	-b*5
6	R	0.5

Fig.3.15. Variable and function dialog box with enteries.

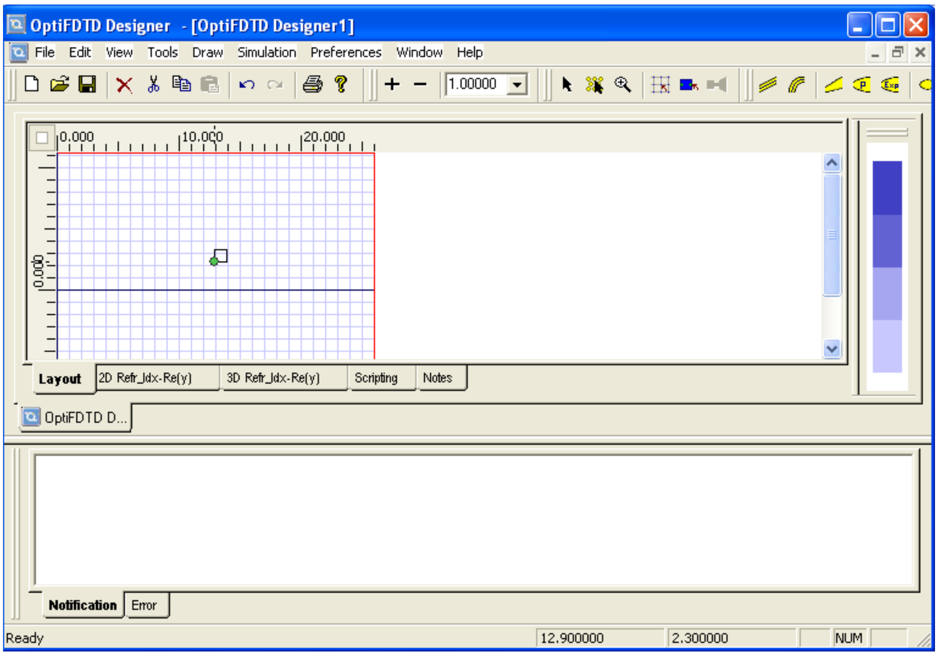
2. From the **Draw** menu, select **PBG Crystal Structure**



Select PBG Crystal Structure Drawing Tool 13.900000 11.200000

Fig.3.16. PBG Crystal Structure in the layout window.

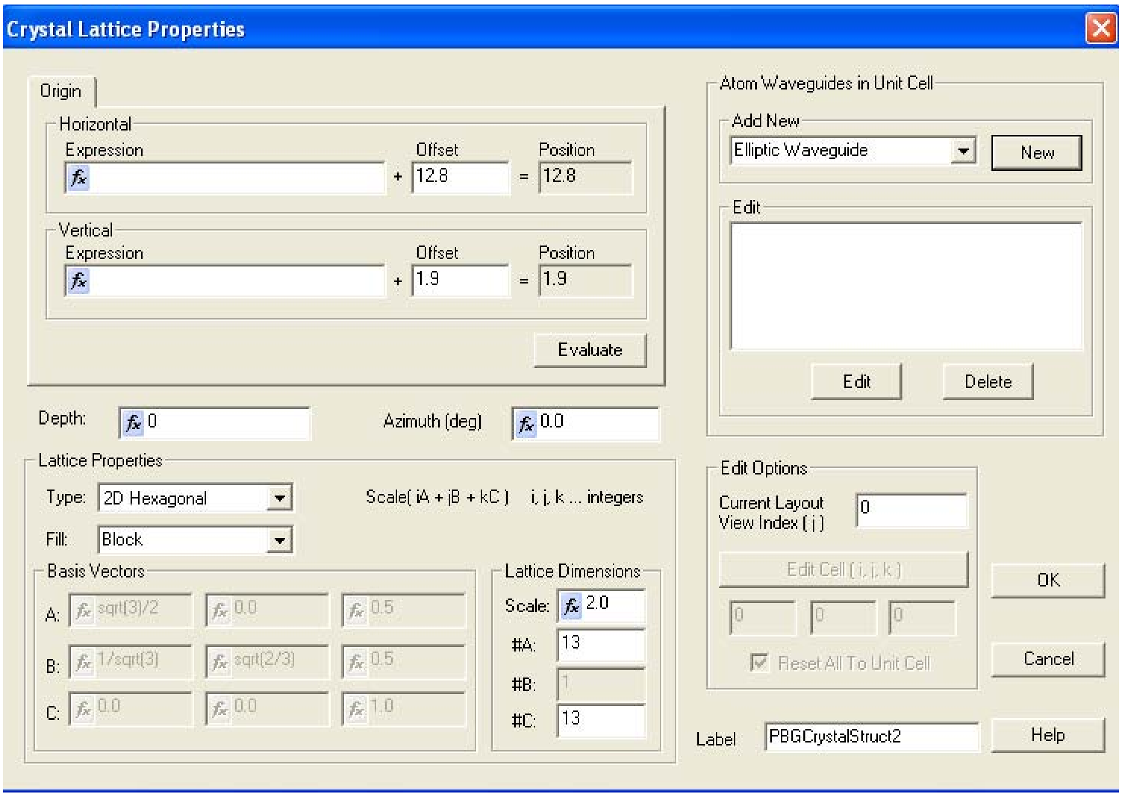
3. With the mouse cursor click once on the layout window, *The **PBG Crystal Structure** appears in the layout window* Click Select tool button (the arrow) on the shortcut toolbar to release the PBG selection.



Ready 12.900000 2.300000

Fig.3.17. Layout window with initial PBG layout.

4. To edit the crystal structure, double-click on the PBG structure (a rectangular shape) on the layout. *The **Crystal Lattice Properties** dialog box appears*


Crystal Lattice Properties

Origin

Horizontal: Expression + Offset 12.8 = Position 12.8

Vertical: Expression + Offset 1.9 = Position 1.9

Depth: 0

Azimuth (deg): 0.0

Lattice Properties

Type: 2D Hexagonal

Fill: Block

Scale(iA + jB + kC)   i, j, k ... integers

Basis Vectors

A: sqrt(3)/2   0.0   0.5

B: 1/sqrt(3)   sqrt(2/3)   0.5

C: 0.0   0.0   1.0

Lattice Dimensions

Scale: 2.0

#A: 13

#B: 1

#C: 13

Atom Waveguides in Unit Cell

Add New: Elliptic Waveguide

Edit Options

Current Layout View Index (j): 0

Edit Cell (i, j, k): 0   0   0

☑ Reset All To Unit Cell

Label: PBGCrystalStruct2

Fig.3.18: Crystal Lattice properties dialog box

5. In the Crystal Lattice Properties dialog box, Set the following parameters

Origin

Horizontal, expression:0

Horizontal Offset:0

Vertical Expression:c

Vertical Offset:0

Depth: 0.0

Azimuth: 0.0

Lattice Properties:

Type: 2D Hexagonal

Fill: Block

Lattice Dimension:

Scale: 2.0

#A 13

#C 13

6. In **Atom Waveguide in Unit Cell, Add New,** select **Elliptic Waveguide** from the drop-down menu and click **New**. The **Elliptic Waveguide Properties** dialog box appears In **Elliptic Waveguide Properties** dialog box set following value

In **Center**, **Offset**, type/select the following:

Horizontal: **0.0**

Vertical: **0.0**

Type/select the following:

Major radius: **0.5**

Minor radius: **0.5**

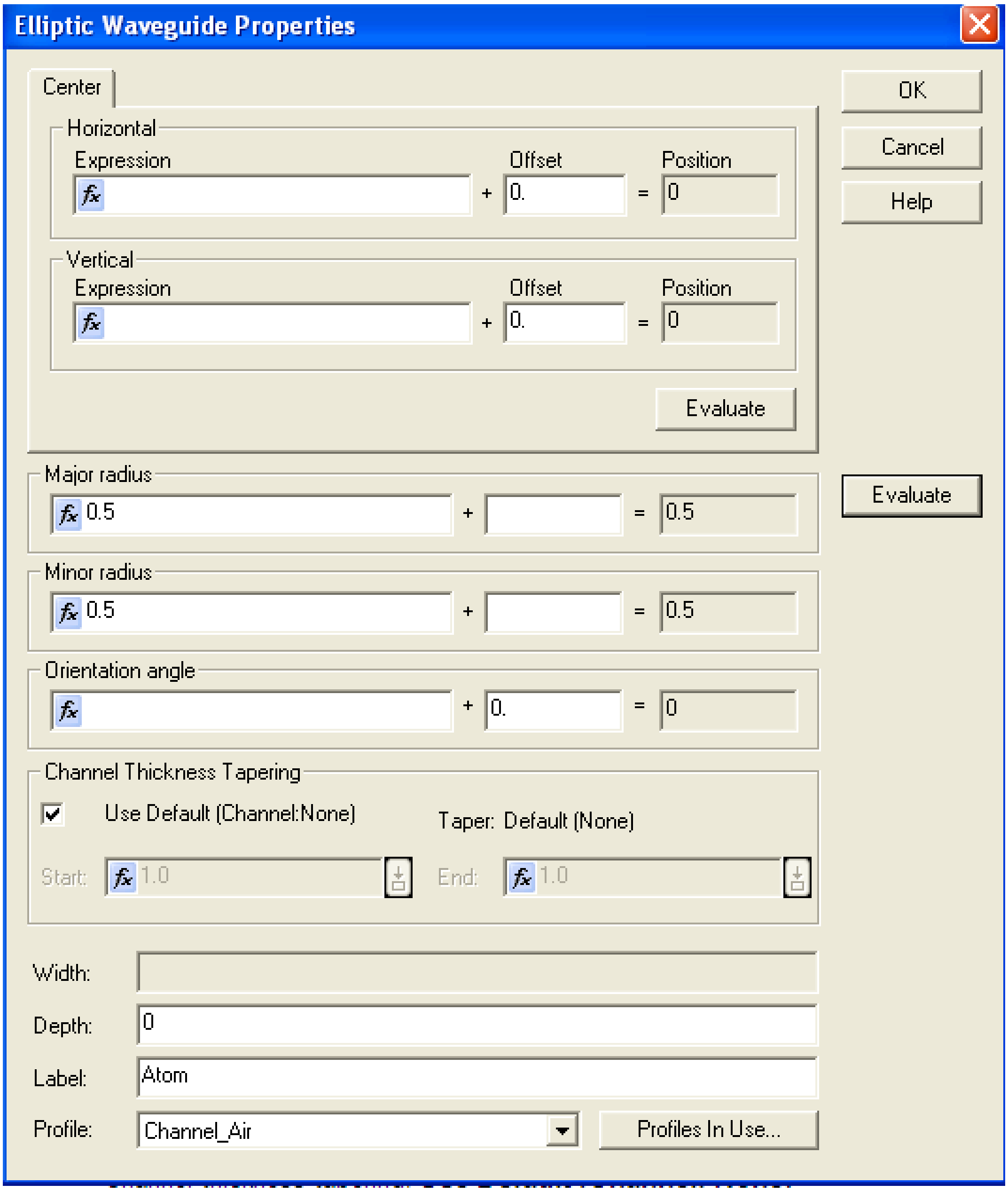
Orientation angle: **0.0**

Channel thickness tapering: **Use Default (Channel: None)**

Depth: **0.0**

Label: **Atom**

Profile: **Channel_Air.**



Horizontal: Expression + Offset 0. = Position 0

Vertical: Expression + Offset 0. = Position 0

Major radius: 0.5 + = 0.5

Minor radius: 0.5 + = 0.5

Orientation angle: + 0. = 0

Channel Thickness Tapering: ☑ Use Default (Channel:None) Taper: Default (None)

Start: 1.0 End: 1.0

Width:

Depth: 0

Label: Atom

Profile: Channel_Air

Fig.3.19:Elliptic Waveguide Properties dialog box

Click **OK**.

The **Elliptic Waveguide Properties** dialog box closes.

Note: When you return to the **Crystal Lattice Properties** dialog box, you will see the defined elliptic waveguide listed in **Atom Waveguide in Unit Cell**.

Note: If you close the **Crystal Lattice Properties** dialog box, you will see the defined PBG structure in the layout window .

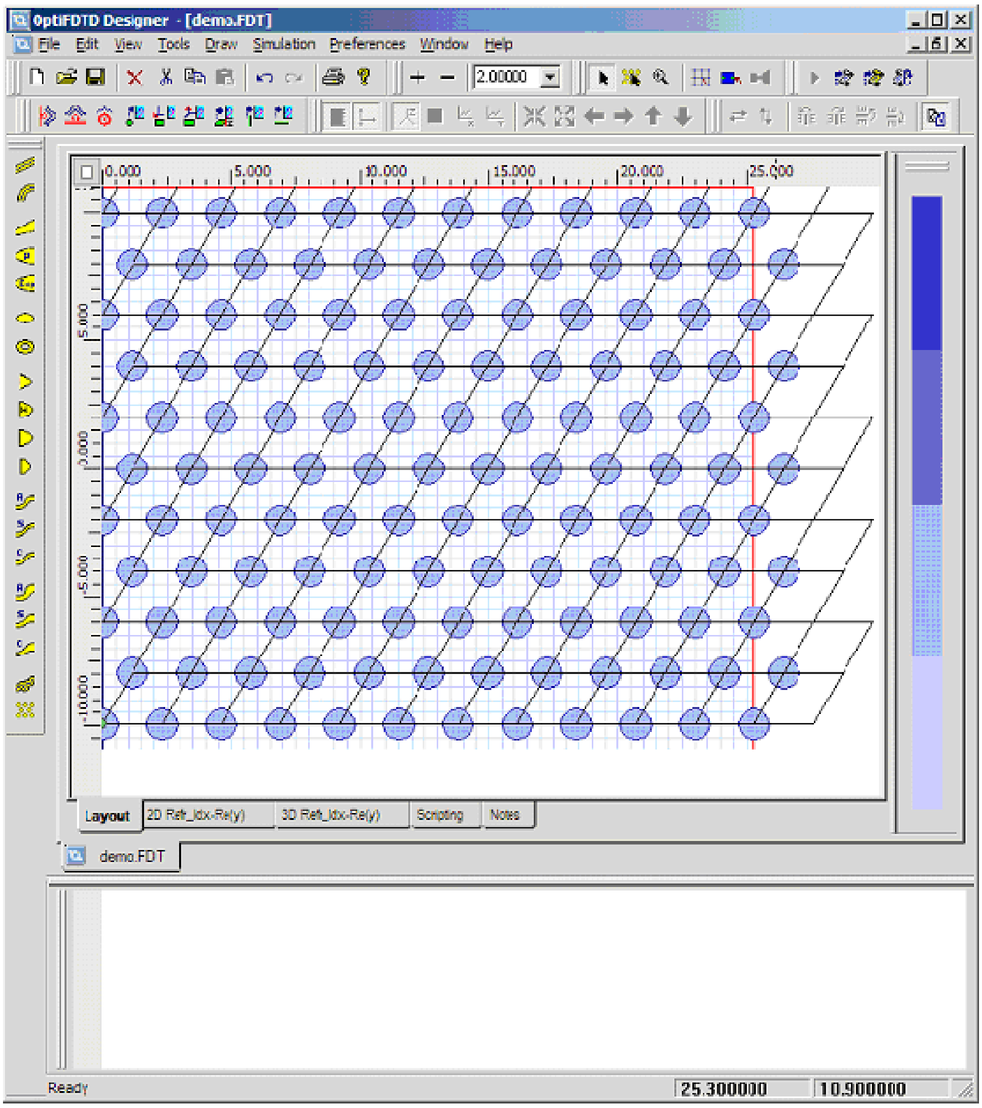


Fig.3.20:PBG layout in designer window.

3.2.3.Mesh the Structure:

1. In the layout designer, to select the PBG lattice, click the PBG area. The **PBG Crystal Structure Cell Editing Tool** *(a shortcut toolbar beside the Arrow select tool as shown in figure 8)* becomes active. Select this shortcut tool bar. When this tool is selected, right click on the photonic cell and click "Cells Off" to disable the cells. With this step, a five layer Holey fiber can be realized

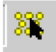


Figure 3.21 Shortcut toolbar button of "PBG Crystal Structure Cell Editing Tool"

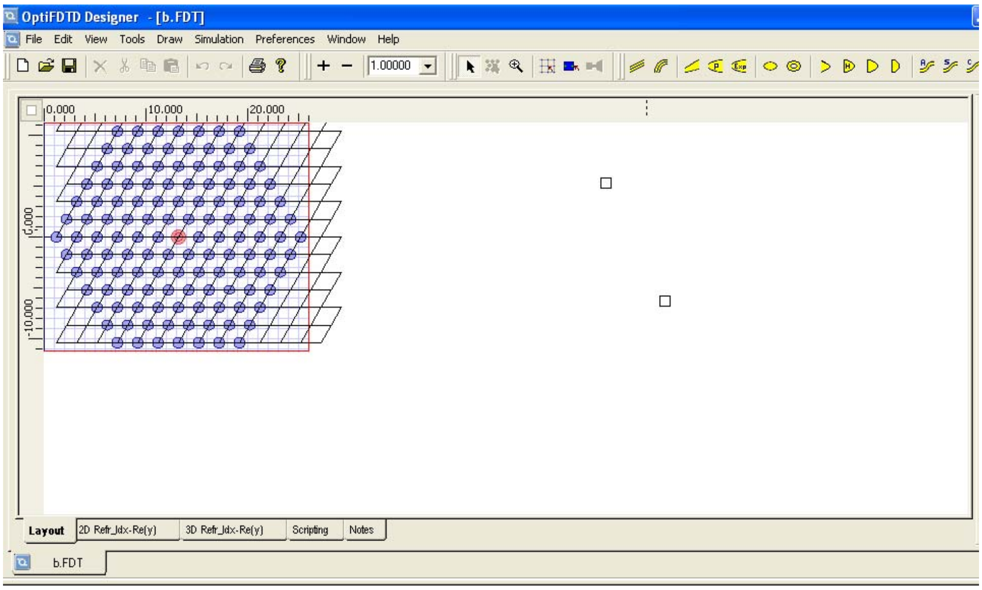


Fig.3.22. Six layers holey fiber structure.

2 .To observe the index distribution, please set a point source in the layout. The center **Wavelength** is 1.3um with Gaussian **Modulated Continuous Wave** as time domain waveform.

20 Click **2D Simulation Parameters** under **Simulation** menu, set following parameters and Click OK.

Mesh Delta X: 0.08um

Mesh Delta Z: 0.08um

Run for 1 time steps.

21**.** Click **"2D Refr_Idx_Re(y)"** tab under the layout window to observe the

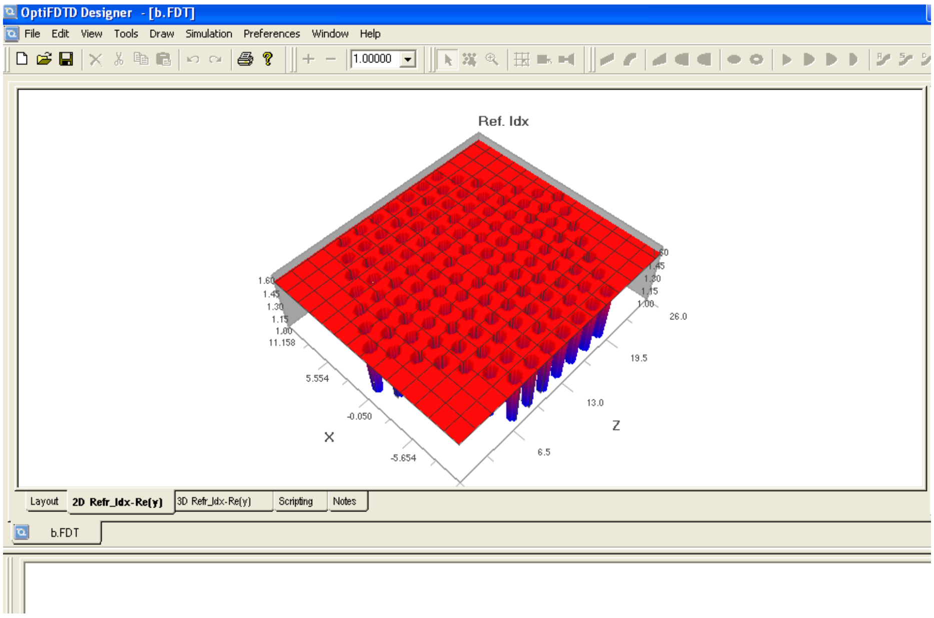


Fig.3.23:Refractive index distribution of six layer PCF

3.Now the proposed PCF structure is made up of six layer hexagonal lattice structure with inner 2 layer is circular holes which d=0.6. Third layer major axis=0.8 and minor axis =0.6. .forth layer major axis is d=1.2 and minor axis is d=0.8.fifth and sixth layer d=1.0.

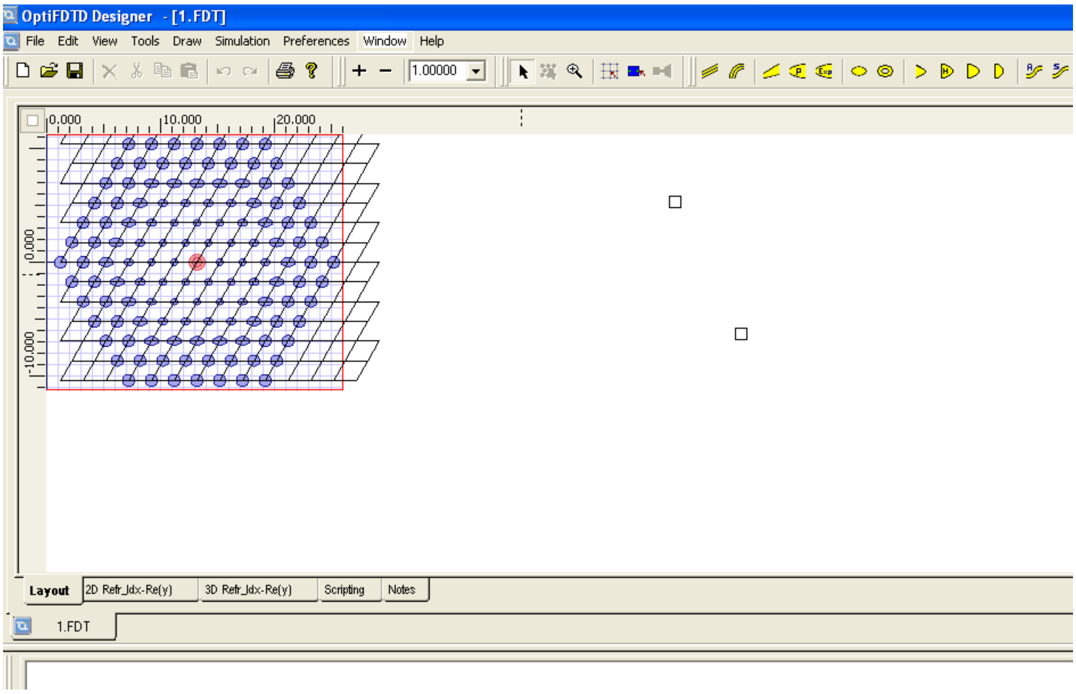


Fig.3.24:Hybrid cladding(proposed model) PCF structure.

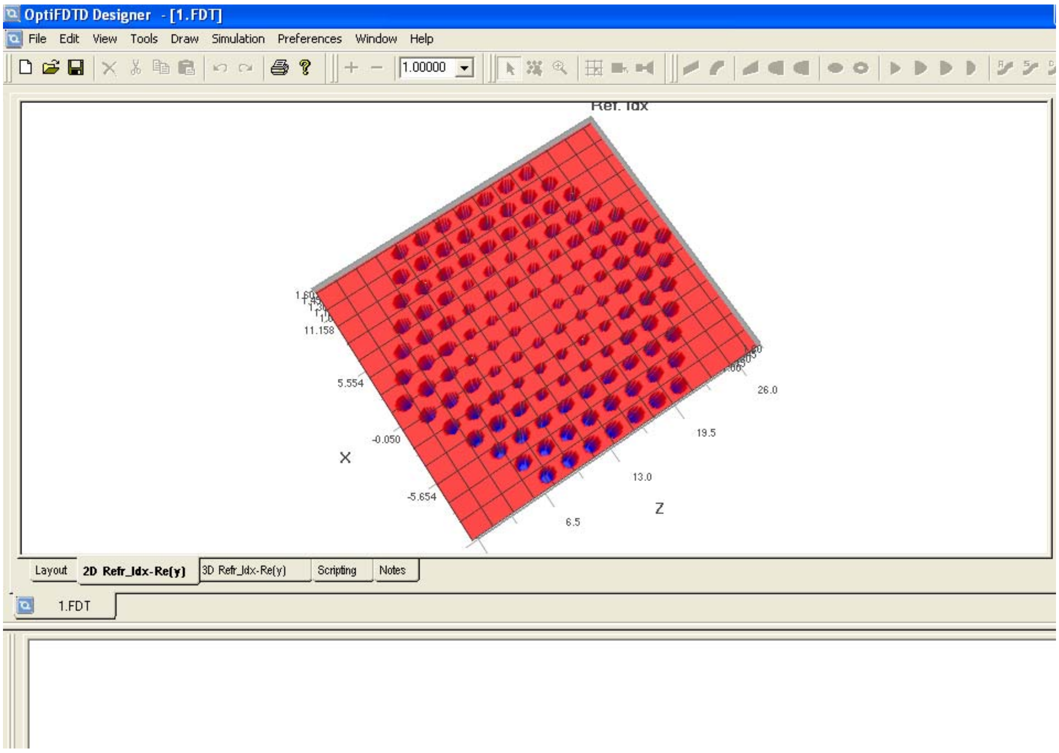


Fig.3.25: Refractive index distribution of six layer proposed PCF

Convert Refractive index distribution to a file

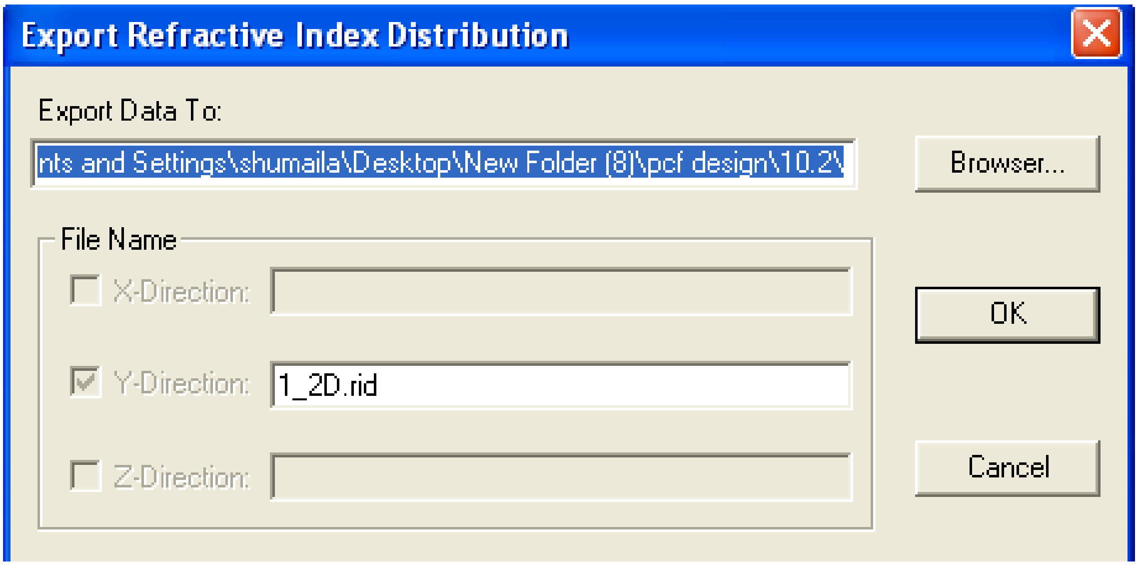
To perform modal calculations we will use the stand-alone Mode Solver application. We need to export the refractive index distribution of the PCF cross-section and transfer it to the Mode Solver. To export the refractive index, follow these steps:

Step Action

1. Set an input wave (with Gaussian Modulated Continuous Wave as time domain waveform) in the layout, (This work was done in step 18 in a previous section)
2. Set proper mesh size for mode solving (This work was done in step 19 in a previous section)
3. Click “**2D Refr_Idx_Re(y)**” tab to observe the refractive index distribution.

4. Select “File->**Export Refractive Index Distribution”** menu, **Export Refractive Index Distribution** dialog box appears .

5 Click OK, the refractive index distribution will be saved to a file called PCF_Holey_



Export Data To: nts and Settings\shumaila\Desktop\New Folder (8)\pcf design\10.2\

File Name

☐ X-Direction:

☑ Y-Direction: 1_2D.rid

☐ Z-Direction:

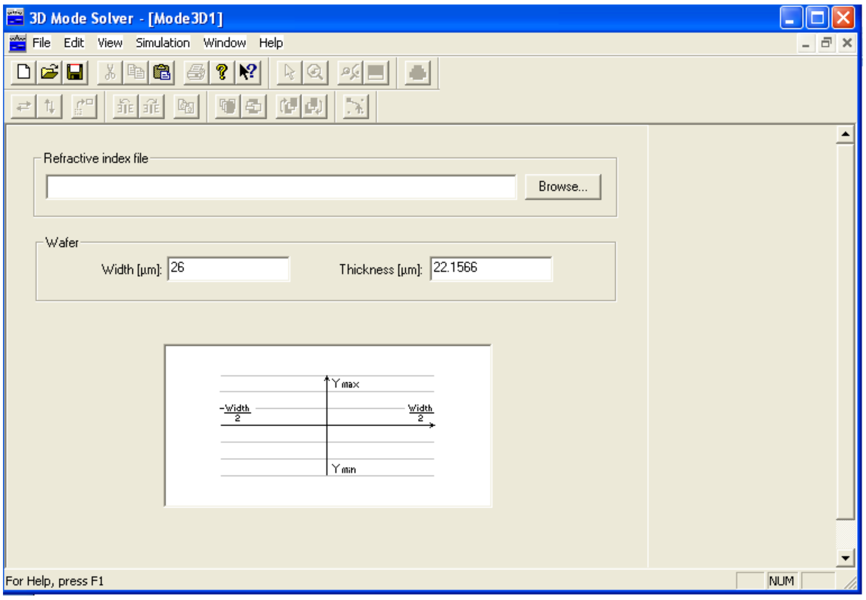
Fig.3.26.Export refractive index dialog box

5. Click OK, the refractive index distribution will be saved to a file called 1_2D.rid

3.2.4.Calculate modes:

Step Action

1 Open the individual 3D Mode Solver from Tools: from the **Start** menu, select **3D Mode Solver,** appears the box.click file select new in new dialog box select the user defined file then press ok.now we get a **3D Mode Solver** appears



Width [µm]: 26

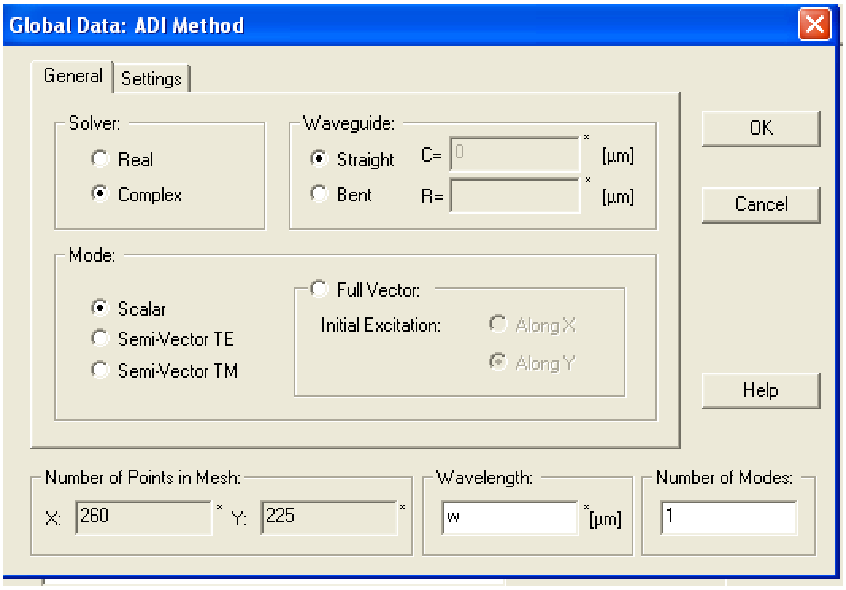
Thickness [µm]: 22.1566

Fig.3.27.:Export refractive index dialog box

3 Click **Browse** button to load the previously exported refractive index file1_2D.rid--- where it store)

4 Click **Simulation** menu and select **ADI Method** under **Global Parameters.**

Global Data:ADI Method dialog appears



Solver: ○ Real ● Complex

Waveguide: ● Straight ○ Bent

C= 0 [µm]

R= [µm]

Mode: ● Scalar ○ Semi-Vector TE ○ Semi-Vector TM

○ Full Vector:

Initial Excitation: ○ Along X ● Along Y

Number of Points in Mesh: X: 260 Y: 225

Wavelength: w [µm]

Number of Modes: 1

Fig.3.28. Global data: ADI Method dialog box

5. In the **Global Data: ADI Method** dialog box, enter the following values, then click **OK** button to accept settings and close the dialog box

Wavelength: w

Number of Modes: 1

General:

Solver: Complex

Mode: **scalar**

Initial Excitation:

Waveguide: Straight

Setting:

Start Field: Gaussian

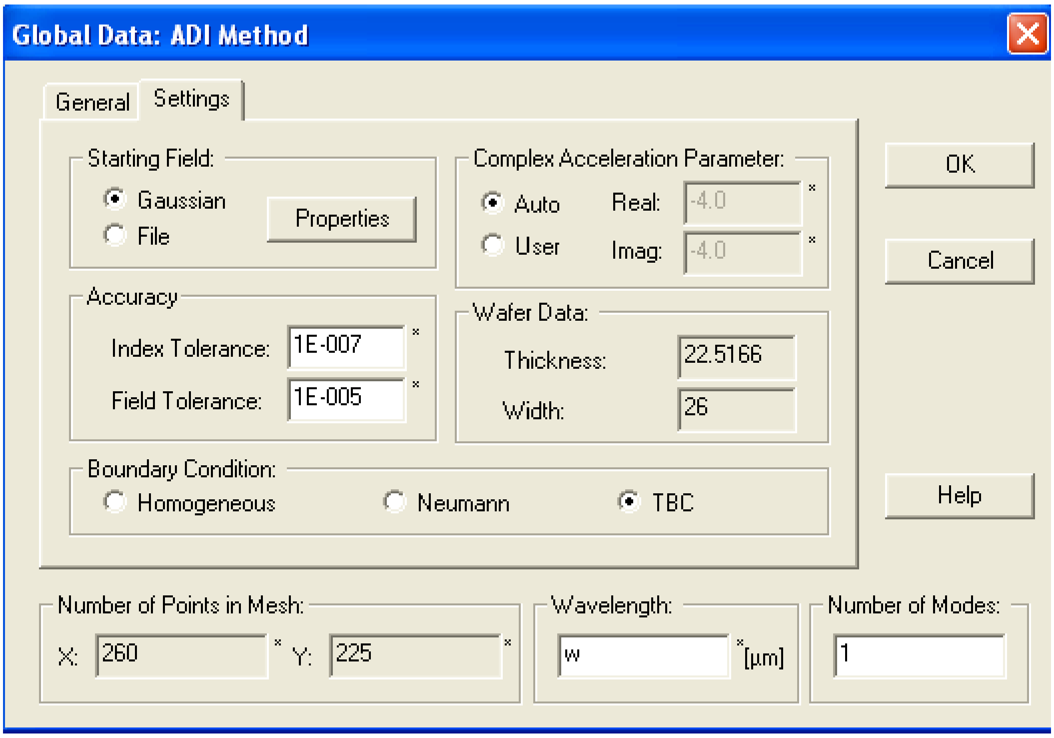
Accuracy:

Index Tolerance: 1E-007

Field **Tolerance**: 1E-005

Boundary Condition: TBC

Note: Other setting leave as specified by default



Starting Field: ● Gaussian ○ File

Complex Acceleration Parameter: ● Auto ○ User Real: -4.0 Imag: -4.0

Accuracy:
Index Tolerance: 1E-007
Field Tolerance: 1E-005

Wafer Data:
Thickness: 22.5166
Width: 26

Boundary Condition: ○ Homogeneous ○ Neumann ● TBC

Number of Points in Mesh: X: 260 Y: 225

Wavelength: w [µm]

Number of Modes: 1

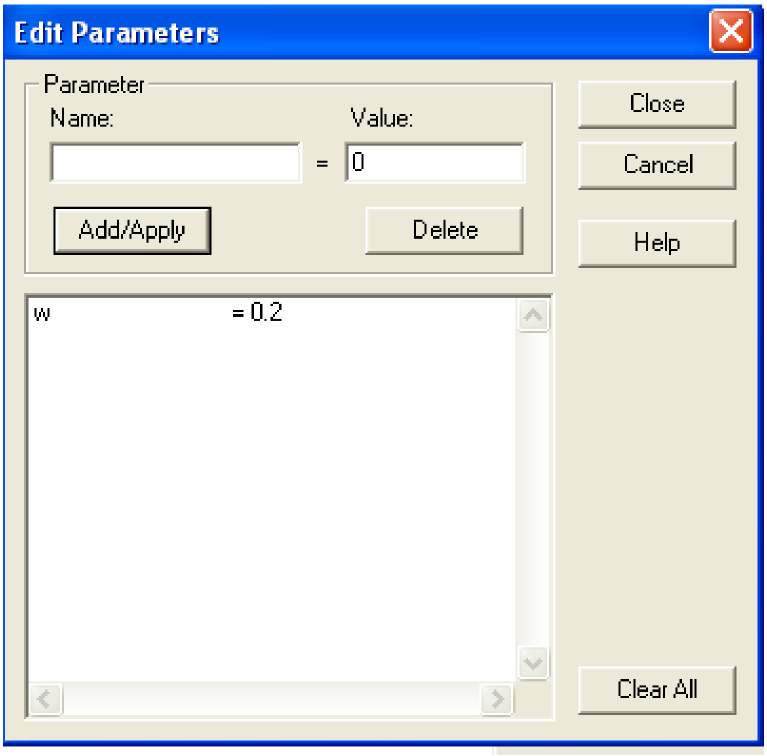
Fig.3.29. Global data: ADI Method dialog box with full enteries.

6. Select “**Calculate ADI**” under simulation menu. Click **Run** button to start the modal analysis. 3D mode solver resulting window appears.

3.2.5.Perform the wavelength scanning mode analysis(Modal Analysis):

Step Action

1 In the **3D Mode Solver** Window, click **Edit Parameters** under **Simulation** menu. **Edit Parameter** dialog box appears .

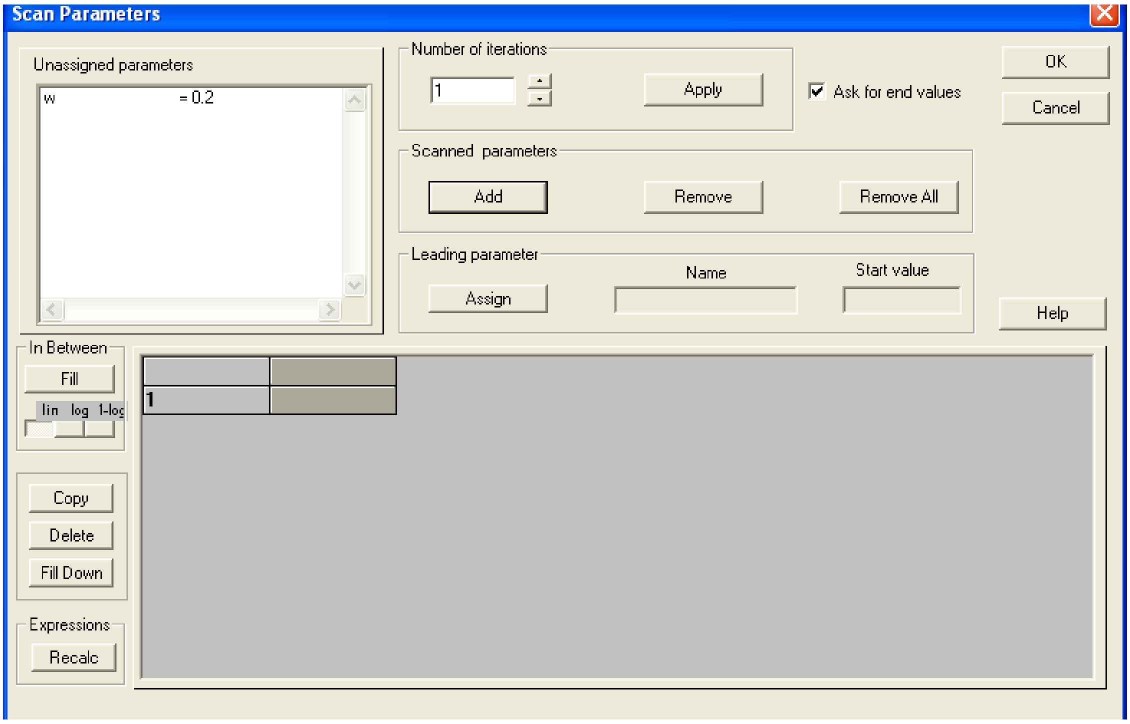


w = 0.2

Fig.3.30: Edit Parameters dialog box

2 In the **Edit Parameter** dialog box, **Name** field, enter “**wavelength**” and set its **Value** as **0.2.** Click **Add/Apply** button to make the defined variable to be listed. Click Close to close the dialog box

3 Click **Scan Parameters** under Simulation menu. Scan parameters dialog box appears .



w = 0.2

Number of iterations: 1

☑ Ask for end values

Fig.3.31.Scan parameters dialog box

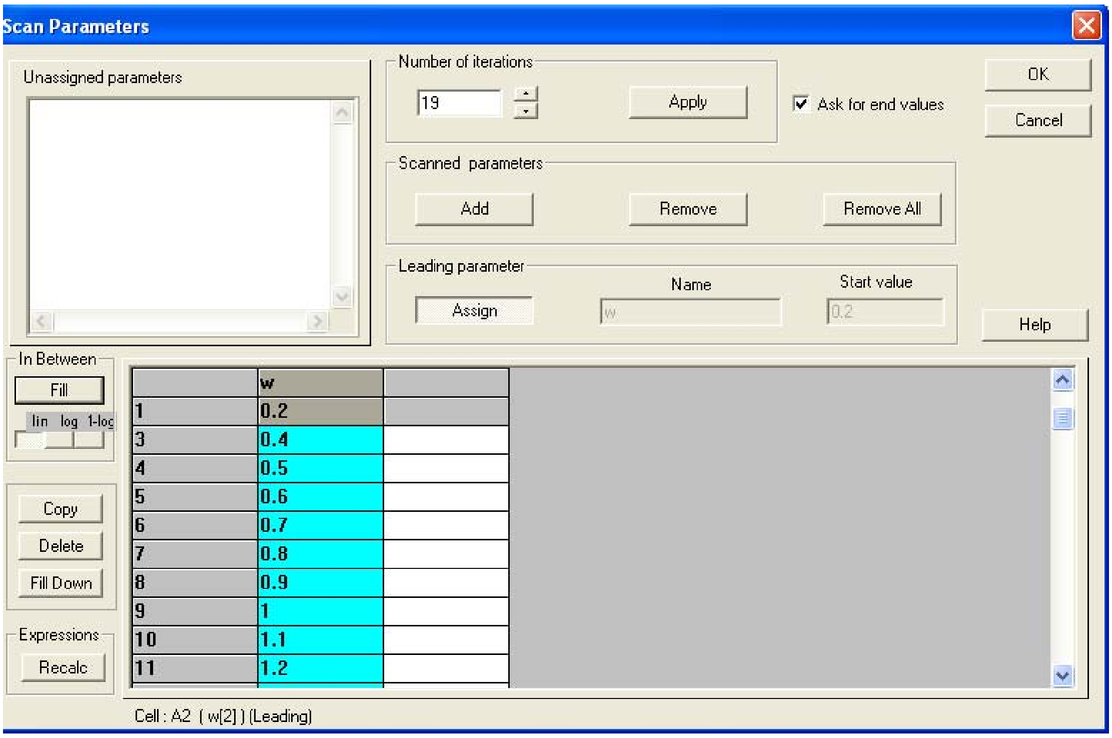
4. Select "wavelength" under **Unassigned Parameters** table, Click Add button to add variable wavelength as the scan parameter. Parameter "wavelength" will be listed in the bottom table.

5 Set **Number of Iteration** as 19 and click **Apply** button. The table will extend to 19 lines.

6 Click **Assign** button in the "Leading parameter" section, our "wavelength" will be set as **Leading Parameter**

7 In the table grid, click "wavelength", the whole column will be selected. inscroll to the line 19 Double click its edit cell and input iteration **End Value** of 2.0

8 Re-select the wavelength column and click **Fill** button. The data cells in the column will automatically be filled with the sampling points for each simulation sweep of the "wavelength" value.



Number of iterations: 19

☑ Ask for end values

Leading parameter — Name: w — Start value: 0.2

	w	
1	0.2	
3	0.4	
4	0.5	
5	0.6	
6	0.7	
7	0.8	
8	0.9	
9	1	
10	1.1	
11	1.2	

Cell : A2 (w[2]) (Leading)

Fig.3.32:Scan parameters dialog box

9. Click **OK** to close this **Scan Parameter** dialog box

10 .Select “**Simulations->Calculate ADI”** menu. In the Wavelength box enter the previously specified parameter name “wavelength”, select **scalar** Set **Complex Solver** with **TBC** boundaryconditions. Run the simulations

11 The Mode Solver will perform a set of modal calculations sweeping the wavelength value. This approach is used to obtain the cutoff wavelength

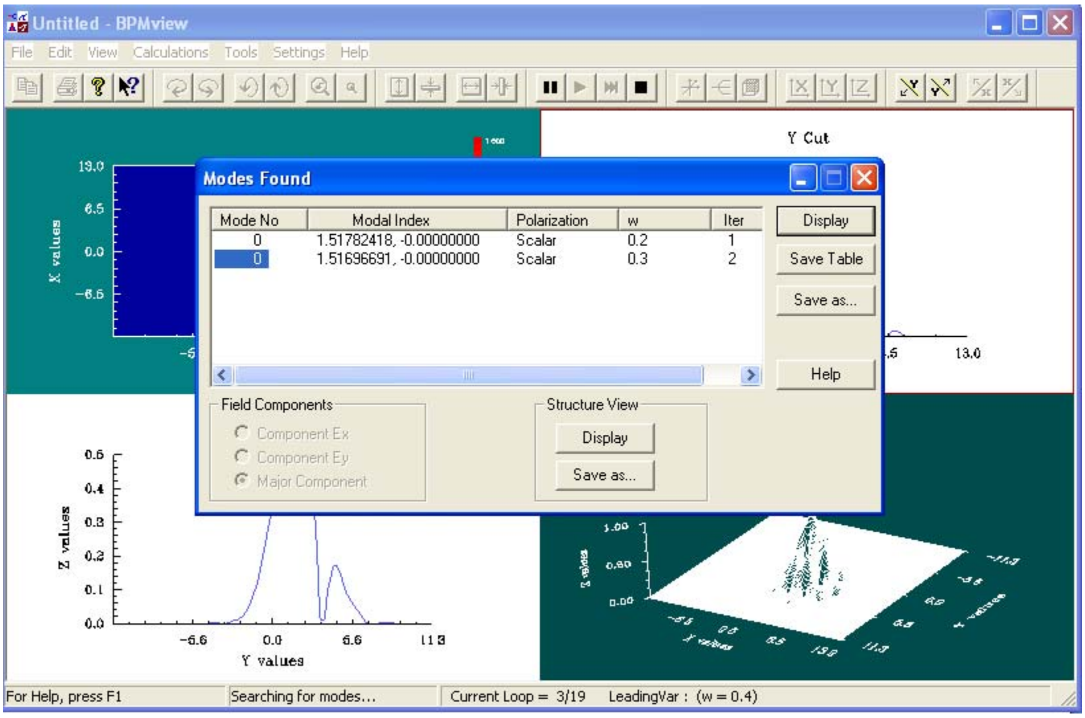
12.Select “**Calculate ADI**” under simulation menu. Click **Run** button to start the modal analysis. 3D mode solver resulting window appears. First, the refractive index distribution is displayed. Once the mode is solved (it takes a while), the view will change and display the modal field. (Clicking

Display under **Structure View** will display the refractive index distribution

structure again)

Note: :

- Save the field pattern by click **Save As** button
- Save the modal index by click “**Save Table**
- Click **Close** in the file menu to close this window



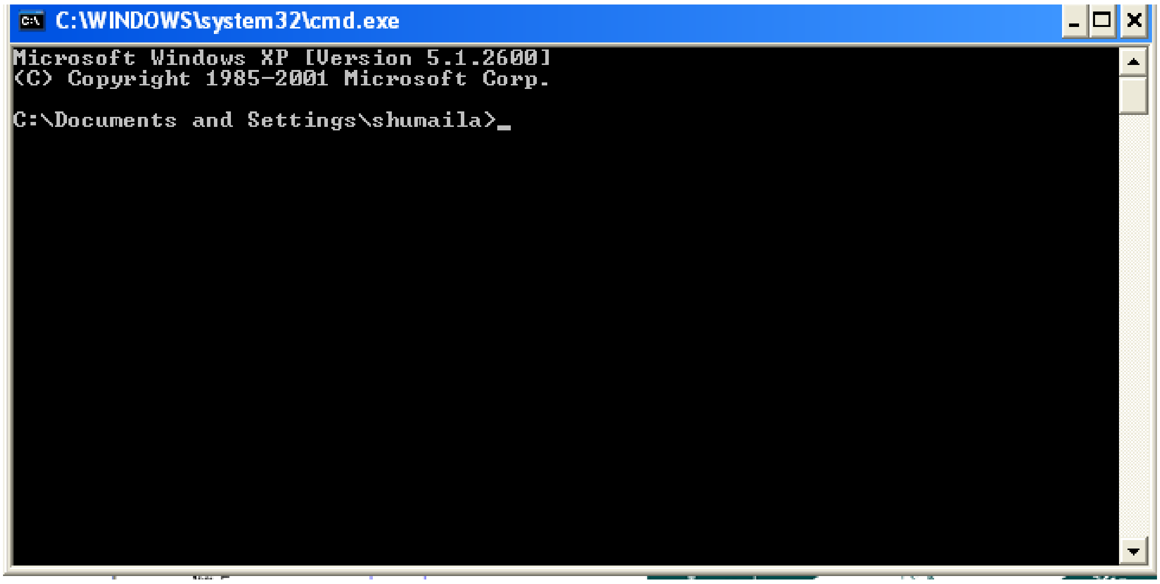
Mode No	Modal Index	Polarization	w	Iter
0	1.51782418, -0.00000000	Scalar	0.2	1
0	1.51696691, -0.00000000	Scalar	0.3	2

For Help, press F1 | Searching for modes... | Current Loop = 3/19 LeadingVar : (w = 0.4)

Fig.3.33:3D mode solver results window

13.Now save as the display and table notepad and copy the notepad file in c drive.

14.,To calculate waveguide dispersion. Next go to the start menu run option type cmd then click ok command window is open.(opti fdtd tutoraial).

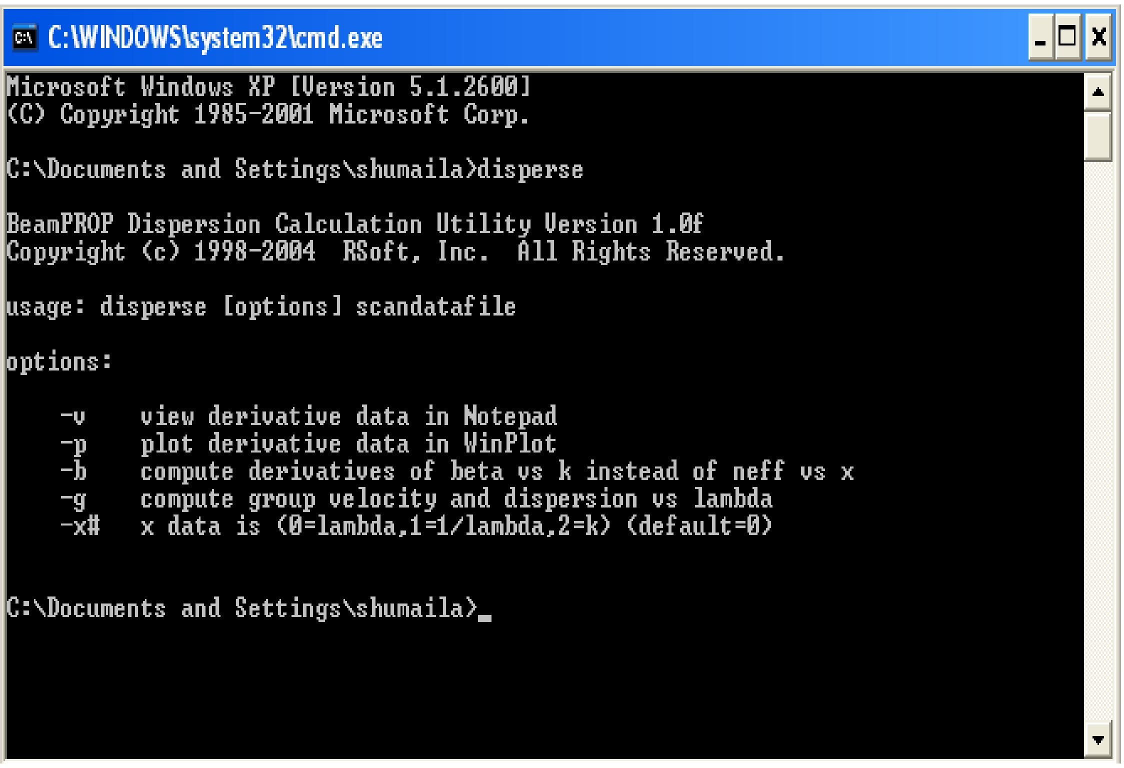


```
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.

C:\Documents and Settings\shumaila>_
```

Fig.3.34:Command window

15.In command window type disperse then enter next new box is appear.



```
Microsoft Windows XP [Version 5.1.2600]
(C) Copyright 1985-2001 Microsoft Corp.

C:\Documents and Settings\shumaila>disperse

BeamPROP Dispersion Calculation Utility Version 1.0f
Copyright (c) 1998-2004  RSoft, Inc.  All Rights Reserved.

usage: disperse [options] scandatafile

options:

    -v    view derivative data in Notepad
    -p    plot derivative data in WinPlot
    -b    compute derivatives of beta vs k instead of neff vs x
    -g    compute group velocity and dispersion vs lambda
    -x#   x data is (0=lambda,1=1/lambda,2=k) (default=0)


C:\Documents and Settings\shumaila>_
```

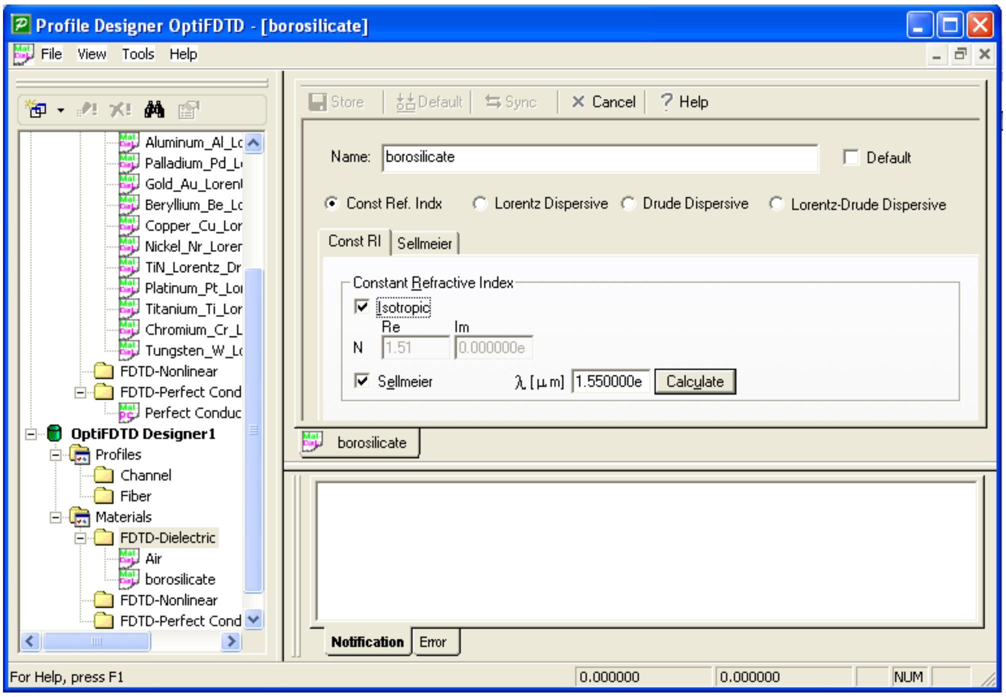
Fig.3.35:command window with disperse command.

16.Now write again disperse(space)-v(space)-p(space)-g(space).our's txt file(notepad file). We dispersion file only select wavelength and dispersion part then save as, these following steps give the only waveguide dispersion. For the material dispersion we follow these steps.

3.3.Analysis of material dispersion.

1.To determined the material dispersion we need a sellimer formula in OPTIFDTD 8.0 software.

2.Start with waveguide layout window. -open-file-new-initial properties-profile and material select FDTD dielectric material same as previous steps and then select the sellimer .



Name: borosilicate ☐ Default

● Const Ref. Indx ○ Lorentz Dispersive ○ Drude Dispersive ○ Lorentz-Drude Dispersive

Constant Refractive Index

☑ Isotropic

N Re 1.51 Im 0.000000e

☑ Sellmeier λ [µm] 1.550000e

borosilicate

For Help, press F1 0.000000 0.000000 NUM

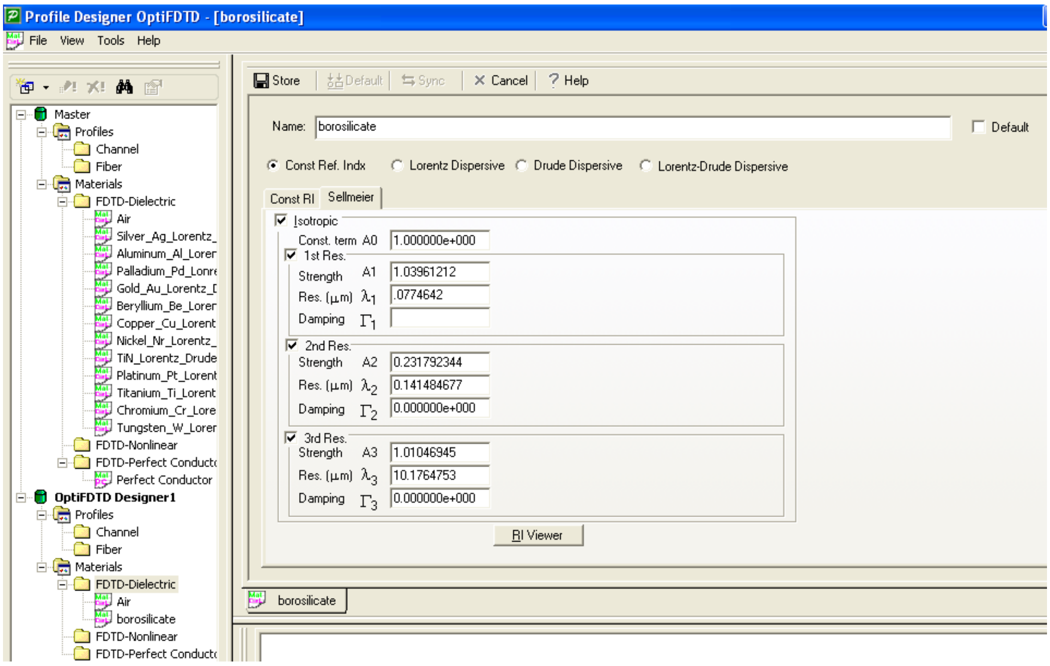
Fig.3.36:profile designer optiFDTD with sellmeier window box

3.Open a new window in it we fill a value of A1,λ1,A2,λ2,A3 λ3,coefficients.

Borosilicate crown glass: BK7

Refractive Index : 1.5168

A_1- 1.03961212	λ_1 – .0774642 µm - 6.00069867×10^{-3}µm^2
A_2- 0.231792344	λ_2 -0.141484677µm - 2.00179144×10^{-2}µm^2
A_3- 1.01046945	λ_3 -10.1764753µm - 1.03560653×10^{2}µm^2



Name: borosilicate ☐ Default

● Const Ref. Indx ○ Lorentz Dispersive ○ Drude Dispersive ○ Lorentz-Drude Dispersive

☑ Isotropic

Const. term A0 1.000000e+000

☑ 1st Res.

Strength A1 1.03961212

Res. (µm) λ_1 .0774642

Damping Γ_1

☑ 2nd Res.

Strength A2 0.231792344

Res. (µm) λ_2 0.141484677

Damping Γ_2 0.000000e+000

☑ 3rd Res.

Strength A3 1.01046945

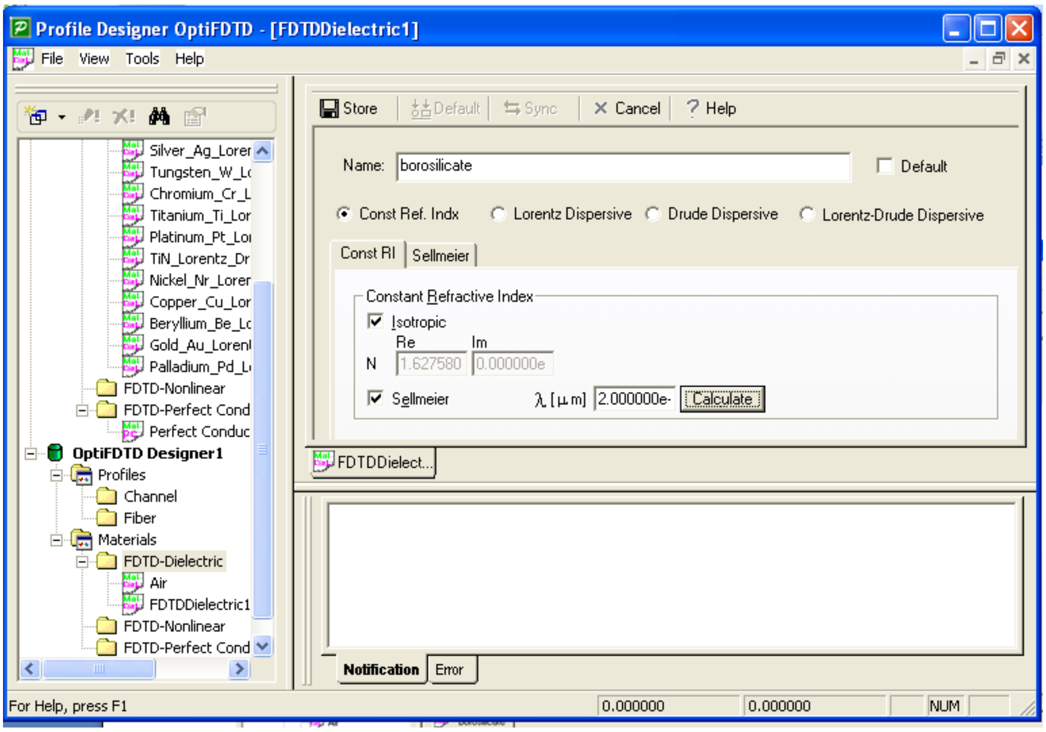
Res. (µm) λ_3 10.1764753

Damping Γ_3 0.000000e+000

borosilicate

Fig.3.37: Profile designer optiFDTD with coefficients entries.

4.Now back to the const RI window in it we fill the one by one λ(wavelength) starts 0.2 to 2.0 then press calculate and note the refractive index of each wavelength.for e.g. λ=0.2 Re=1.627580.see figure



Profile Designer OptiFDTD - [FDTDDielectric1]

Name: borosilicate ☐ Default

● Const Ref. Indx ○ Lorentz Dispersive ○ Drude Dispersive ○ Lorentz-Drude Dispersive

Constant Refractive Index

☑ Isotropic

N Re 1.627580 Im 0.000000e

☑ Sellmeier λ [µm] 2.000000e-

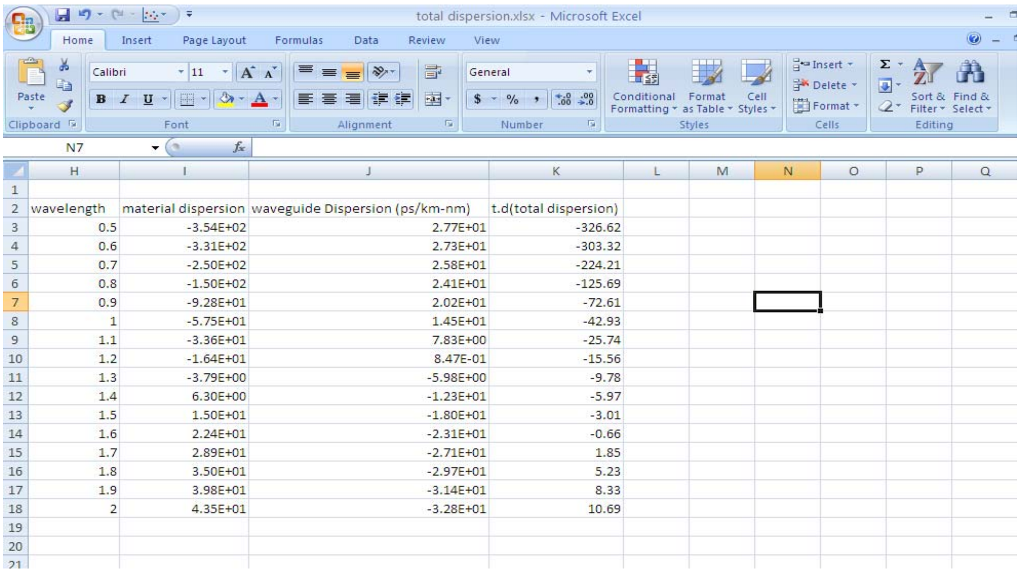
For Help, press F1 0.000000 0.000000 NUM

Fig.3.38: Profile designer optiFDTD with const RI window.

5.Write the all refractive index values upto 0.2 to 2.0 and make a table format in notepad then save the file in c drive.

6.Repeat the same process to find out the material dispersion as we do in previous steps.

Note both waveguide and material dispersion in excel sheet then find out the total or chromatic dispersion of PCF.



	H	I	J	K
1				
2	wavelength	material dispersion	waveguide Dispersion (ps/km-nm)	t.d(total dispersion)
3	0.5	-3.54E+02	2.77E+01	-326.62
4	0.6	-3.31E+02	2.73E+01	-303.32
5	0.7	-2.50E+02	2.58E+01	-224.21
6	0.8	-1.50E+02	2.41E+01	-125.69
7	0.9	-9.28E+01	2.02E+01	-72.61
8	1	-5.75E+01	1.45E+01	-42.93
9	1.1	-3.36E+01	7.83E+00	-25.74
10	1.2	-1.64E+01	8.47E-01	-15.56
11	1.3	-3.79E+00	-5.98E+00	-9.78
12	1.4	6.30E+00	-1.23E+01	-5.97
13	1.5	1.50E+01	-1.80E+01	-3.01
14	1.6	2.24E+01	-2.31E+01	-0.66
15	1.7	2.89E+01	-2.71E+01	1.85
16	1.8	3.50E+01	-2.97E+01	5.23
17	1.9	3.98E+01	-3.14E+01	8.33
18	2	4.35E+01	-3.28E+01	10.69

Fig.3.39:The resulted excel sheet of total chromatic dispersion.

7.Draw the graph between wavelength and Dispersion through origin pro8 software.

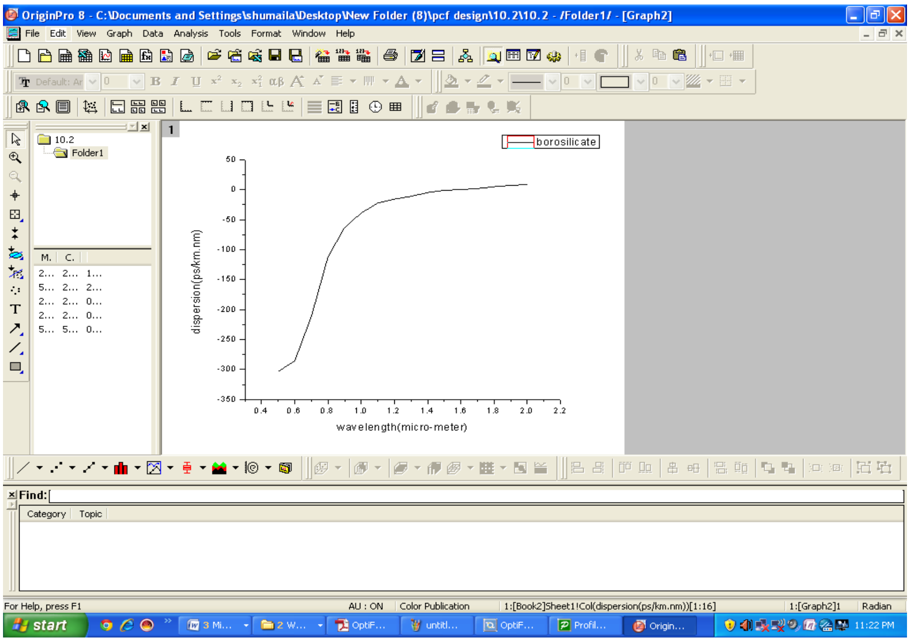


Fig.3.40:Originpro8 software window for making resulted chromatic graph

8. As we design our new elliptical hybrid cladding borosilicate Photonic crystal fiber to minimize chromatic dispersion by optiFDTD waveguide layout designer and3Dmode solver,

3.4 Software Used: OPTIFDTD8.0

For the designing of photonic crystal fiber OPTIFDTD 8.0 software was used. In this section of the thesis brief introduction of OPTIFDTD8.0 software is presented.

3.4.1 Introduction

OPTIWAVE CORPORATION is familiar as the world organizer in the development of innovative software for the design, simulation and optimization of optical networks, subsystems and components for the dynamic fiber optics telecommunications industry and other photonic applications.

Optiwave offers our customers an unmatched competitive advantage, by greatly shortening their time to market while improving quality, productivity and cost-effectiveness.OptiFDTD8.0 is one of the part of optiwave software.

OptiFDTD8.0 is a powerful, highly integrated, user-friendly software that allows computer aided design and simulation of advanced passive photonic components.The OptiFDTD8.0.Software package is based on the finite-difference time-domain(FDTD) method. The FDTD method has been established as a powerful engineering tool for integrated and diffractive optics device simulations. This is due to its unique combination of features, such as the ability to model light propagation, scattering and diffraction, and reflection and polarization effects. It can also model material anisotropy and dispersion without any pre-assumption of field behavior such as the slowly varying amplitude approximation. The method allows for the effective and powerful simulation and analysis of sub-micron devices with very fine structural details. A sub-micron scale implies a high degree of light confinement and correspondingly, the large refractive index difference of the materials (mostly semiconductors) to be used in a typical device design.

3.4.2. Benefits of using software

- Dramatic reduction of investment risk and time-to-market
- Rapid, low cost prototyping
- Performance evaluation of various types of fibers before actual manufacturing
- Assessment of parameters, sensitivities and tolerances

- Automatic parameter scanning and optimization
- Visual presentation of how the changes of design parameters affect fiber characteristics

3.4.3.Main Features

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

3.4.4.Application

- Telecomm grade SM fiber design
- MM fiber design
- Fiber sensor design
- Design of an arbitrary multilayer fiber with an arbitrary 2D refractive index profile
- Calculation of the following characteristics of any supported mode, fundamental or higher order:
- Mode field pattern, displayed in different ways
- Effective refractive index, propagation constant
- Group index, group delay
- Three types of group-velocity dispersion (material, waveguide and total)
- Mode field diameters according to various definitions and effective mode area
- Estimations of the cutoff wavelengths
- Macrobending, microbending and splicing losses
- Optimization of the dependence of these characteristics on numerous technological parameters of the fiber, including geometry, profile shape and composition
- Calculation of birefringence effects induced by intrinsic or extrinsic perturbations
- PMD calculations based on different models

CHAPTER 4

RESULTS AND DISCUSSION

To design new elliptical hybrid cladding borosilicate photonic crystal fiber, first we design different- 2 parameters configurations and see its results, in between we get my best result.The following configuration and its results are follows.

Configuration 1:

The PCF structure is made up of six layer hexagonal lattice structure with inner three layers are circular holes where d=0.6µm and forth layer is elliptical holes where a(major axis)=1.2µm,b(minor axis)=1.0µm and fifth,sixth layers diameter are 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= 1.55µm dispersion will be -4.31ps/(km.nm).

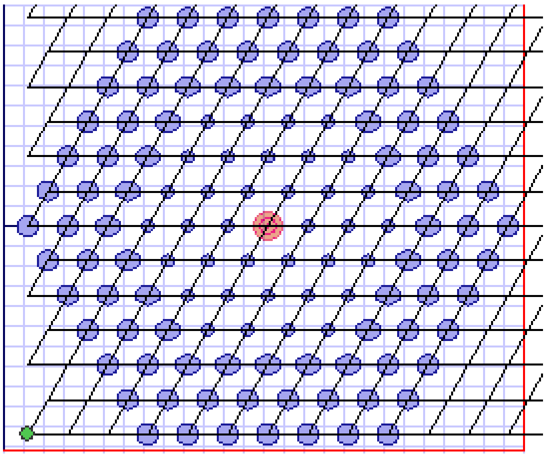


Fig4.1: The PCF six layer hexagonal lattice structure with inner 3layers are circular holes where d=0.6µm and 4th layer is elliptical where a(major axis)=1.2µm,b(minor axis)=1.0µm and 5th,6th layers d=1.0µm.

Configuration 2:

The PCF structure is made up of six layer hexagonal lattice structure with inner three layers are circular holes where d=0.6µm and forth layer is elliptical where a(major axis)=1.2µm,b(minor axis)=0.8µm and fifth, sixth layers diameter are 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= 1.55µm dispersion will be -6.44ps/(km.nm)

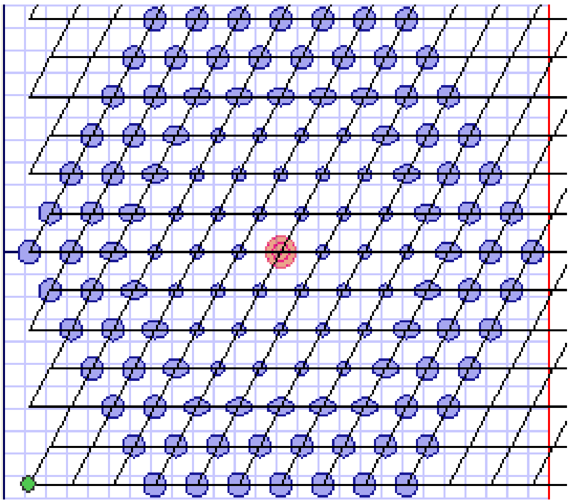


Fig4.2. The PCF six layer hexagonal lattice structure with inner 3 layer are circular holes where d=0.6µm and 4th layer is elliptical where a(major axis)=1.2µm,b(minor axis)=0.8µm and 5th ,6th layer are d=1.0µm.

Configuration 3:

The PCF structure is made up of six layer hexagonal lattice structure with inner two layers are circular holes where d=0.6µm.,third layer only six corners are change into elliptical holes were d of major axis=0.8µm and minor axis =0.6µm,forth layer major axis is d=1.2µm and minor axis is d=0.8µm.fifth and sixth layers 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= 1.55µm dispersion will be -4.24 ps/(km.nm)

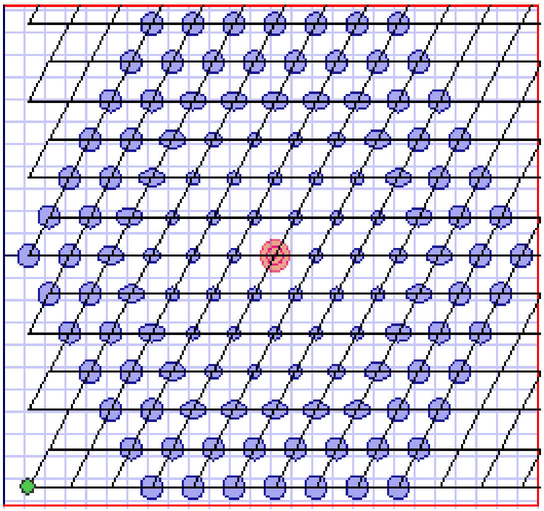


Fig.4.3.The PCF six layer hexagonal lattice structure with inner 2 layer are circular holes where d=0.6µm.3rd layer only six corners are change into elliptical holes where d of major axis=0.8µm and minor axis =0.6µm.4th layer major axis is d=1.2µm and minor axis is d=0.8µm.5th ,6th layer d=1.0µm.

Configuration 4:

The PCF structure is made up of six layer hexagonal lattice structure with inner 2 layers are circular holes where d=0.6µm., third layer major axis=0.8µm and minor axis =0.6µm. ,forth layer major axis is d=1.2µm and minor axis is d=0.8µm.fifth and sixth layer 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= 1.55µm dispersion will be -0.81 ps/(km.nm). This method produced best result at third attenuation coordinate (1.55µm) over 1.4 µm to 1.8 µm wavelength range and found the dispersion is minimum (±0.81ps/km.nm)and ultra flattened that has better performance than conventional photonic crystal fiber.

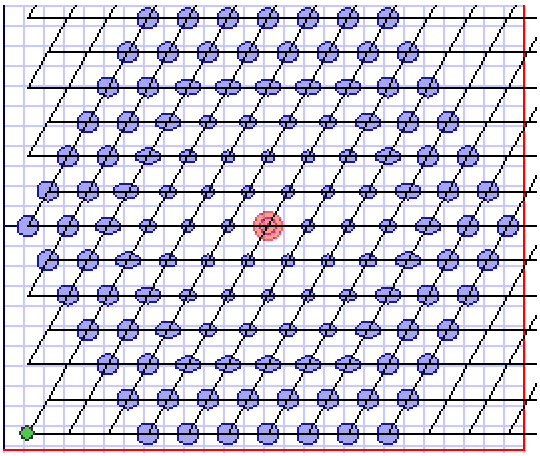


Fig.4.4. The PCF six layer hexagonal lattice structure with inner 2 layer are circular holes where d=0.6µm. 3rd layer major axis=0.8µm and minor axis =0.6µm. ,4th layer major axis is d=1.2 µm and minor axis is d=0.8µm.5th,6th layer d=1.0µm

Configuration 5:

The PCF structure is made up of six layer hexagonal lattice structure with inner two layers are circular holes where d=0.6µm.,third layer major axis is d=1.0µm and minor axis is d=0.6µm.forth layer major axis is d=1.2µm and minor axis is d=0.8µm.fifth and sixth layers 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= 1.55µm dispersion will be -1.28ps/(km.nm).

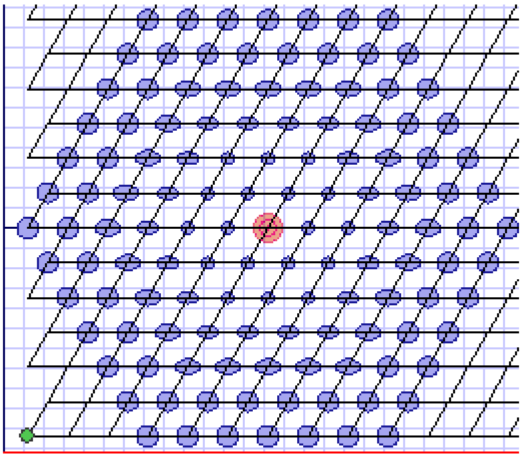


Fig4.5. The PCF six layer hexagonal lattice structure with inner 2 layer are circular holes where d=0.6µm,3rd layer major axis is d=1.0µm and minor axis is d=0.6µm.,4th layer major axis is d=1.2 µmand minor axis is d=0.8µm,5th,6th layer d=1.0µm.

Configuration 6:

The PCF structure is made up of six layer hexagonal lattice structure with inner three layers are circular holes where d=0.6µm and forth and fifth layer major axis is d=1.2µm and minor axis is d=1.0µm.,sixth layer 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=1.55 µm dispersion will be -3.98ps(km.nm).

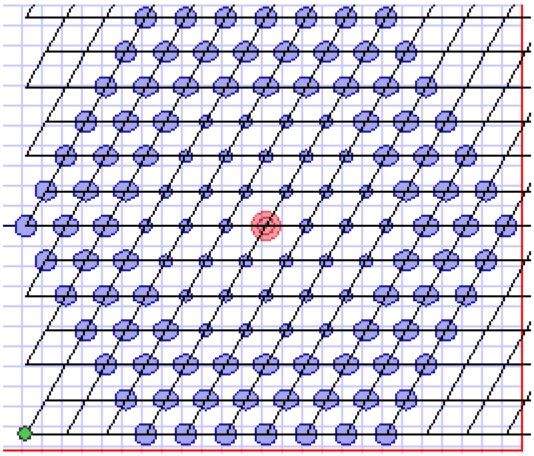


Fig4. 6. The PCF six layer hexagonal lattice structure with inner 3 layers are circular holes where d=0.6 µm and 4th,5th layer major axis is d=1.2µm and minor axis is d=1.0µm.,6th layer d=1.0µm.

Table.4.1:Results of configuration at λ=1.55µm.

Name of structure	**Structure parameters(d=µm)**	**Results(dispersion)at λ=1.55µm**
CONFIGURATION 1	Inner 3 Layer D=0.6µm,4 Layer major axis diameter A=1.2µm minor axis diameter B=1.0µm and5 ,6th layer d=1.0µm.	-4.31ps/(km.nm)
CONFIGURATION 2	Inner 3 Layer D=0.6µm,4thLayer major axis diameter A=1.2µm minor axis diameter B=0.8µm and5,6th layer d=1.0µm.	-6.44ps/(km.nm)
CONFIGURATION 3	Inner 2 layer are circular holes where d=0.6.3rd layer only six corners are change into elliptical holes where d of major axis=0.8 and minor axis =0.6.4th layer major axis is d=1.2 and minor axis is d=0.8.5,6thlayer d=1.0.	-4.24 ps/(km.nm)
CONFIGURATION 4	Inner 2 layer are circular holes where d=0.6. 3rd layer major axis=0.8 and minor axis =0.6.4th layer major axis is d=1.2 and minor axis is d=0.8.5,6th layer d=1.0.	-0.81 ps/(km.nm)
CONFIGURATION 5	Inner 2 layer are circular holes where d=0.6.3rd layer major axis is d=1.0 and minor axis is d=0.6. 4th layer major axis is d=1.2 and minor axis is d=0.8.5,6th layer d=1.0.	-1.28ps/(km.nm)
CONFIGURATION 6	Inner 3 layer are circular holes where d=0.6 and4,5th layer major axis is d=1.2 and minor axis is d=1.0.6th layer d=1.0.	-3.98ps(km.nm)

- **According to our design configuration the best one is configuration 4.**

Table 4.2: Simulation results values of configurations wavelength vs dispersion (ps/km.nm)

Wavelength	Confi.1	Confi.2.	Confi.3.	Confi.4.	Confi.5.	Confi.6.
0.5	-328.16	-331.49	-321.62	-303.41	-302.19	-328.16
0.6	-302.40	-304.52	-298.41	-285.52	-282.10	-302.40
0.7	-218.43	-219.38	-217.46	-210.98	-205.79	-218.43
0.8	-111.17	-111.50	-111.60	-111.79	-110.71	-111.17
0.9	-58.96	-58.11	-59.31	-62.81	-65.47	-58.95
1	-41.24	-40.70	-40.79	-38.71	-38.64	-41.23
1.1	-24.31	-25.34	-23.65	-21.81	-21.98	-24.31
1.2	-12.89	-13.03	-13.45	-15.57	-13.88	-12.87
1.3	-13.15	-13.06	-13.59	-10.68	-6.61	-13.04
1.4	-10.56	-13.26	-10.20	-4.62	-4.07	-9.94
1.5	-4.31	-6.44	-4.24	-0.81	-1.28	-3.98
1.6	0.41	2.41	0.71	0.48	2.96	-0.36
1.7	0.41	1.26	1.07	2.06	5.38	0.22
1.8	1.21	-1.70	0.77	5.08	7.76	1.86
1.9	5.17	0.03	4.29	7.32	10.85	5.61
2	9.04	1.27	8.86	9.00	13.30	9.29

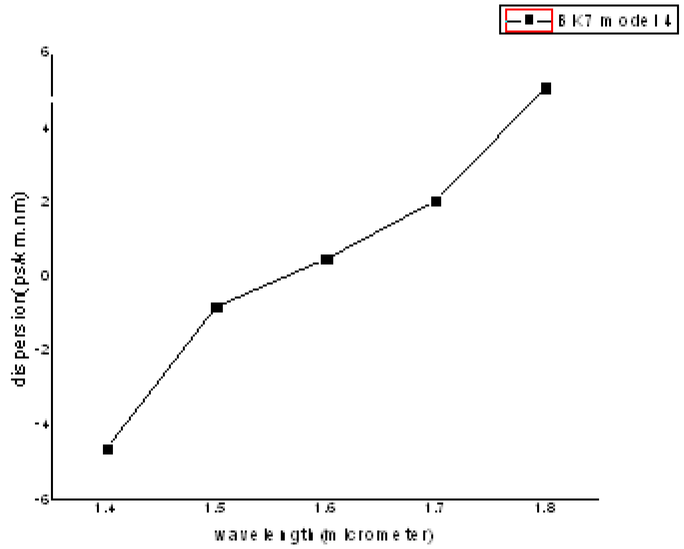


Fig.4.7: Zero ultra flattened dispersion graph of proposed model BK7 at 1.4 to1.8µm wavelength.

Table:4.3.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

Table :-4.4: Comparison of Silica With BK7(Borosilicate)

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

➢ Comparision between silica model with Proposed model.

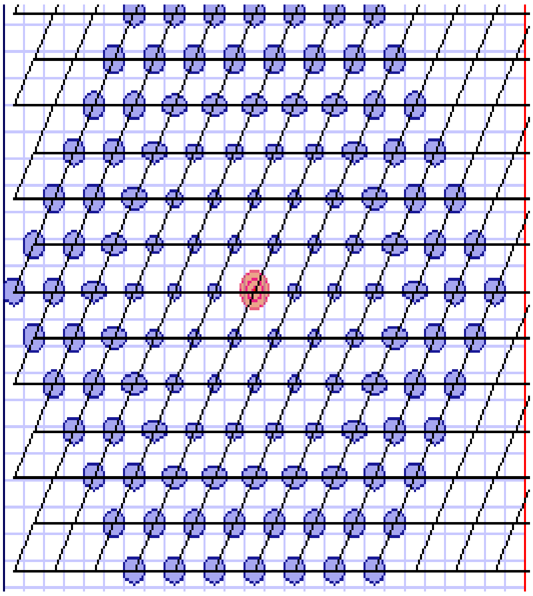


Fig.4.8: silica model

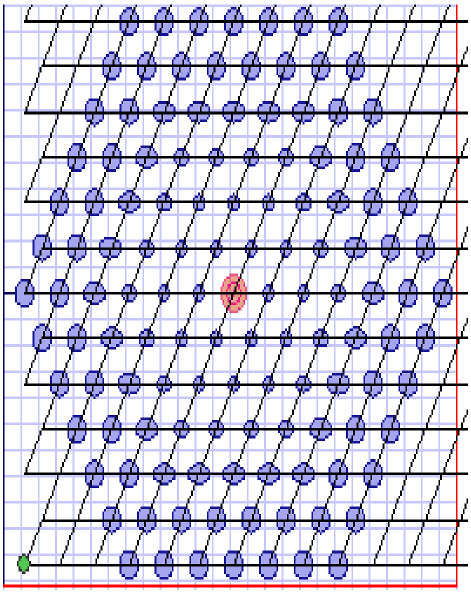


Fig4.9: proposed borosilicate model(confi.4)

Table :-4.5: Simulation results values of silica model and proposed model wavelength vs dispersion (ps/km.nm)

wavelength	silica model	Borosilicate model
0.5	-741.57	-303.41
0.6	-340.29	-285.52
0.7	-179.08	-210.98
0.8	-100.62	-111.79
0.9	-58.37	-62.81
1	-34.69	-38.71
1.1	-15.78	-21.81
1.2	-14.79	-15.57
1.3	-10.88	-10.68
1.4	-8.24	-4.62
1.5	-5.4	-0.81
1.6	-2.08	0.48
1.7	1.49	2.06
1.8	5.74	5.08
1.9	9.67	7.32
2	13.01	9

- **Comparision between conventional borosilicate PCF with proposed borosilicate PCF.**

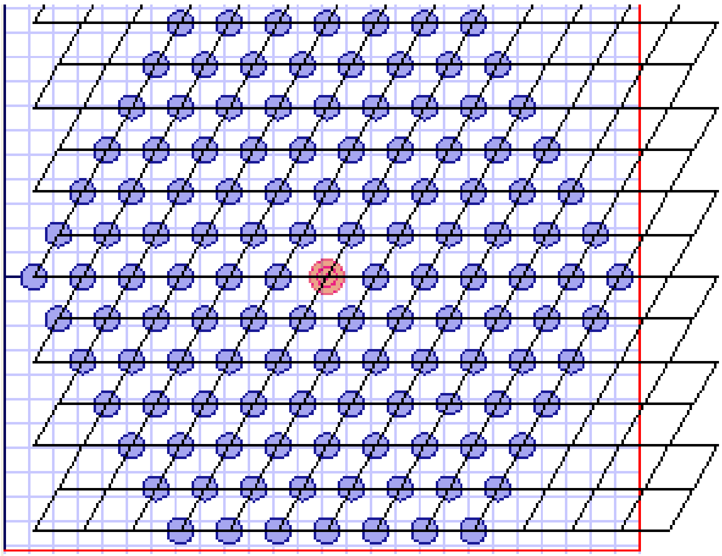


Fig4.10: Conventional borosilicate PCF with d=1.0µm and lattice constant 2.0µm.

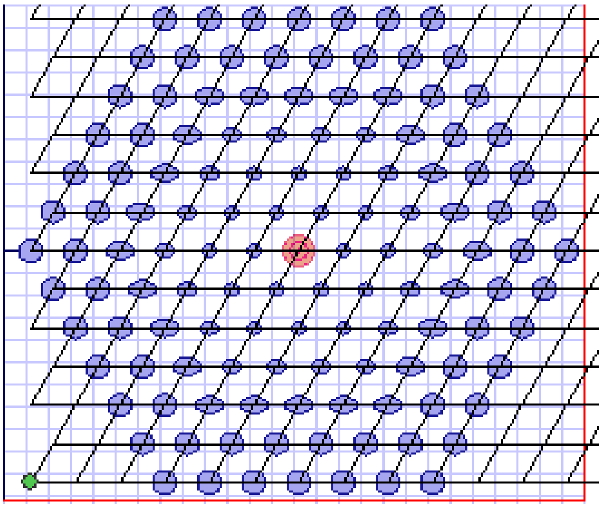


Fig4.11: Proposed borosilicate PCF with six layer hexagonal lattice structure with inner 2 layer are circular holes where d=0.6µm.3rd layer major axis=0.8µm and minor axis =0.6µm. 4th layer major axis is d=1.2µm and minor axis is d=0.8.5th ,6th layer d=1.0µm. lattice constant or pitch (Λ) = 2.0µm.

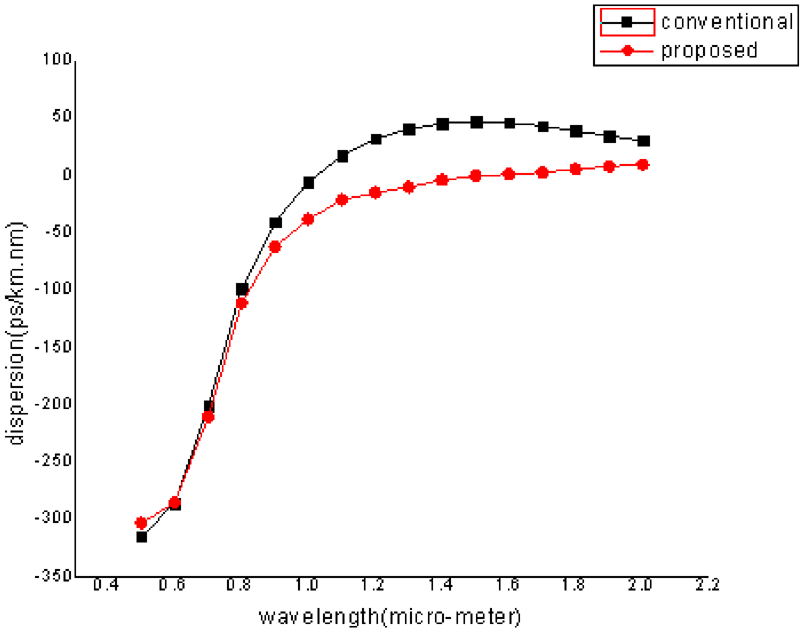


Fig4.12: Simulation results between conventional PCF and proposed PCF.

Here we designs many models of hybrid cladding borosilicate PCFs but our best one configuration is configuration 4 which gives best results among all these models that is show in Table 4.1&4.2 and Figure.4.7 .we also shows the comparison of borosilicate material and silica material in Table 4.3&4.4 and comparison between silica model with proposed model in Table 4.5 that's why we use borosilicate material next one is our hybrid PCF as compare to conventional Fig.4.12 shows how our proposed model results are best compare to conventional PCFs.so all these things make our PCF best to solve dispersion problem.

CHPATER 5

SUMMARY AND CONCLUSION

5.1 Summary and Conclusion

In this thesis, we design a new elliptical hybrid cladding borosilicate photonic crystal to minimize the chromatic dispersion, which gives the best result at third attenuation coordinate (1.55μm) over 1.4 μm to 1.8 μm wavelength range and found the dispersion is minimum (±0.81ps/km.nm)and ultra flattened that has better performance than conventional photonic crystal fiber. It is also shown that borosilicate glass PCF provides much better dispersion as compared to silica of the same structure, so such PCF have high potential to be used as a dispersion compensating fiber in optical window**.**

To design such PCF, firstly a waveguide layout structure is made at optiFDTD 8 or we can also say it a conventional model then convert this model into hybrid model by changing the layers and its diameter.By this method we design many configurations and check the dispersion result configuration 4 get the best result, after that we compare all these waveguide dispersion in excel sheet. secondly we measure the material dispersion of both silica and borosilicate through sellimer formula in optiFDTD and write into the excel sheet and sum the all waveguide dispersion or material dispersion of all these configurations and get its chromatic dispersion and plot the graph through origin pro8 software.

Here we designs many models of hybrid cladding borosilicate PCFs but our best one configuration is configuration 4 which gives best results among all these models that is shown in Table 4.1&4.2 and Figure.4.7 .we also shows the comparison of borosilicate material and silica material in Table 4.3&4.4 and comparison between silica model with proposed model in Table 4.5 that’s why we use borosilicate material next one is our proposed hybrid PCF. Figure.4.12 shows how our proposed model results are best compare to conventional PCFs. So all these things make our PCF best to solve dispersion problem.

Conclusion:

- According to our configurations the best one is configuration 4 that structure simulations results get zero dispersion (-0.8ps/km.nm) at 1.55μm and ultra flattened and low dispersion characteristics over 1.4μm to1.8μm wavelength range that has better performance than conventional photonic crystal fiber.
- To reduce fabrication complexity, we set outer rings to have same air hole diameter and for nearest zero and low dispersion we choose the hybrid structure.
- It is also shown that borosilicate glass PCF provides much better dispersion as compared to silica of the same structure.
- We can use Borosilicate crown glass as a core material on the place of silica glass because Borosilicate crown glass has good properties (like cheaper, good transmission, easy availability) and BK7 is very good transmission down to 350 nm compare to silica glass and low dispersion at 1.55μm

5.2 Future Scope

The results of this work shows the minimum dispersion of photonic crystal fiber.The study can be extended for better dispersion through new borosilicate hybrid cladding photonic crystal fiber at very low cost. There 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.

Literature Cited

Abdur Razzak,S.M. and Namihira,Y.2008.Tailoring Dispersion and Confinement Losses of Photonic Crystal Fibers Using Hybrid Cladding.*Journal of lightwave technology*. ISSN : 0733-8724.

Chand,M.Sharma,S.and R.K.Sharma,R.k.2012.Demonstration of Chromatic Dispersion in Borosilicate Crown Glass,Microstructure Optical Fiber *International Journal of Modern Engineering Research (IJMER)* pp-2591-2593 ISSN: 2249-6645.

Chaudhari,C. Suzuki,T. and Ohishi,Y.2009.Design of Zero Chromatic Dispersion Chalcogenide AS_2S_3 Glass Nanofiber. *Journal of lightwave technology.* ISSN: 0733-8724.

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

Hu,J.J. Shum,*P.* Lu,*C.* and Ren,G.2007.Generalized Finite-Difference Time-Domain Method Utilizing Auxiliary Differential Equations for the Full-Vectorial Analysis of Photonic Crystal Fiber. *IEEE photonics technology letters* . ISSN: 1041-1135

Kanyal,H.S. Katariya,A.and A.K.Bairwae,A.K.2012**.**Design and Comparison of CA-PCF and EA-PCF for Dispersion Property. *International Conference on Communication Systems and Network Technologies*. ISSN : 978-0-7695-4692-6/12

Monfared,Y.E.2012.Hybrid-cladding Photonic Crystal Fiber with Novel Dispersion Properties. *Department of Communication Engineering Shahre-rey Branch, Islamic Azad University Tehran, Iran*. ISSN : 978-1-4673-1176-2/12

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

N.H.Hai,N.H. Namihira,Y. Begum,F.Kaijage,S. Kinjo,T. Razzak, S.M.A. Miyagi,K. and Zou,A.2007. A Novel Ultraflattened Chromatic Dispersion Using Defected Elliptical Pores Photonic Crystal Fiber with Low Confinement losses *University of the Ryukyus, Okinawa, Japan, 903-0129*. ISSN : 1-4244-0878-4/07.

Olyaee,S.and Taghipour,F.2011.Ultra-flattened dispersion hexagonal photonic crystal fiber withlow confinement loss and large effective area. *Nano-photonics and Optoelectronics Research Laboratory (NORLab), Faculty of Electrical and Computer Engineering,Shahid Rajaee Teacher Training University (SRTTU), Lavizan, 16788-15811 Tehran, Iran.* ISSN :1751-8768.

Sharma,R.K,Mittal,A.and Agarwal,v.2012. A design of hybrid elliptical air hole ring chalcogenide As2Se3 glass PCFapplication to lower zero dispersion. *International Journal of Engineering Research & Technology (IJERT)* ISSN: 2278-0181

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.

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

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

Tiwari,S.Jalwania,S.and Bairwa**,**A.k**.**2012**.** A New Design of Borosilicate Crown Glass Photonic Crystal Fiber to Minimize the Dispersion, *International Journal of Soft Computing and Engineering (IJSCE).* ISSN: 2231-2307.

Wanga,J.Jiangb,C.Hub,W.Gaob,M.and Ren,H.2006. Dispersion and polarization properties of elliptical air-hole-containing photonic crystal fibers.*a Institute of Communications Engineering, PLA University of Science and Technology,Nanjing 210007, China State Key Laboratory of Advanced Optical Communication Systems and Networks, Shanghai Jiao Tong University, Shanghai 200030, China.* ISSN: 0030-3992.

Xiao,L.Jin,W.and Demokan,M.S.Photonic crystal fibers confining light by both index-guiding and bandgapguiding: hybrid PCFs," *Department of Electrical Engineering, The Hong Kong Polytechnic University, Kowloon, Hong Kong.* ISSN: 86249

Xu,H. Wu,J. Dai,Y. Xu ,C. and Lin,J.2010. Design procedure for photonic crystal fibers with ultra flattened chromatic dispersion", *Key Laboratory of Information Photonics and Optical Communications (Beijing University of Posts and Telecommunications),* Ministry of Education, Beijing 100876, China College of Science, Jimei University. ISSN: 1671-7694/2011/050603(4)

Scientific glassware borosilicate glass Glass.htm

PUBLICATIONS

Akbar, Shumaila, Agarwal, Dr. Navneet, and Gupta, Dr. Suriti.2014 "Elliptical hybrid cladding Borosilicate photonic crystal fiber Design for minimum chromatic dispersion". ***Eleventh International Conference of Wireless and Optical Communication Network(WOCN).Andhrepradesh India.*** **September 2014,pp.1-4, ISSN:978-1-4799-3156-9/14.**