International Journal of Scientific & Engineering Research, Volume 6, Issue 2, February-2015
ISSN 2229-5518

Photonic Crystal Fiber Characteristics Benefits Numerous Applications

Nidhi Sharma[1], Neetu Rajawat[2], Kavita Agrawal[3]
[1, 2, 3] B.Tech Students Vivekananda Institute of Technology (East), Jaipur, India

Abstract—This paper is emphasized on the basic properties of Photonic Crystal Fiber (PCF) and applications related to them. This gives us idea about how PCF came into existence and advantages we get in thousands of application. Apart from this we also see the guidance mechanism and how it is different from those of conventional fibers.

I. INTRODUCTION

Photonic crystal fiber, also known as holey or microstructure fiber, are based on combined properties of both optical fiber and photonic crystal. PCFs have found application in numerous fields like fiber-optic communications, fiber lasers, nonlinear devices, high-power transmission, sensors, and other areas. Due to its ability to confine light in hollow core as well as solid core fiber in different ways and altering characteristics by structural modifications it is far better than conventional fibers.

Lord Rayleigh, an English Physicist, did an experiment in 1887 on periodic multilayer dielectric stack showing photonic bandgap in 1-Dimension. After 100 years in 1987, Yoblonovitch's and John's work on periodic optical structures with more than 1-D is today known as Photonic Crystal. Photonic crystals can be fabricated as 1-D, 2-D or 3-D. One dimensional photonic crystals can be fabricated by deposition of multilayer, two dimensional ones can be made by drilling holes in appropriate substrate while three dimensional ones by drilling holes at particular angles. Two dimensional photonic crystals are widely used as PCFs for non-linear application as cladding in the fiber. [1]

Photonic crystal fibers (PCFs) are periodic microstructure made of air filled capillaries to form a hexagonal lattice. Light propagates along the defects of crystal structure. Defect can be realized by removing one or more central capillaries. [2]

PCFs can be categorized as Index guiding fiber and Photonic Bandgap Fiber. In High-index guiding fibers light is guided in much similar way as in conventional optical fibers but some modifications are there in PCFs guiding mechanism. In PCFs light is confined in solid core by a mechanism of Modified Total Internal Reflection. Refractive Index difference between core and cladding is positive but because of presence of air holes which causes lower refractive index. Refractive index of cladding is not constant but changes with wavelength. [3] The group of wavelength which can pass through fiber is called modes while the group of wavelength which cannot pass or is blocked is called bandgap. PCFs properties can be opposite by changing the diameter or position of air holes, thus providing a new range of features and properties in PCFs.

When the refractive index of core is lower than that of photonic crystal cladding the light is guided by a mechanism different from total internal reflection mechanism. This mechanism is photonic bandgap mechanism because air holes microstructures with photonic crystal cladding are two dimensional photonic crystal

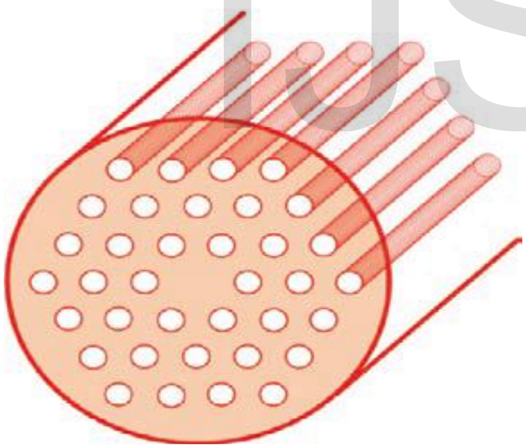

Fig 1. Schematic of a solid-core PCF with a triangular lattice of air-holes, which guides light for modified total internal reflection

with photonic bandgap properties. In periodic dielectric properties or photonic bandgap properties of air holes microstructure certain wavelength range cannot propagate. Similarly light can be guided in PCFs with air core or hollow core providing numerous application such as high-power transmission, low-loss guidance and extreme dispersion properties. [3]

II. Guiding Mechanism

Unlike Conventional fibers where light pulse in fiber is guided by following the phenomenon of total internal reflection, In PCFs light guidance can be achieved in two ways. First one is by modified total internal reflection and second one is by bandgap property.

A. MODIFIED TOTAL INTERNAL REFLECTION

In this type of light guidance mechanism of PCFs, fiber cladding can be made of two dimensional photonic crystal with a core having higher refractive index than that of cladding. These fibers are also called as Index-Guiding Fiber as difference in refractive index leads to the phenomenon of total internal reflection. Thus light travels through the fiber following a modified form of total internal reflection, called Modified total internal reflection. This leads to a property of endlessly single mode fiber where only fundamental mode is guided and multimode transmission is not possible.

For example solid core PCF having triangular lattice of air-holes multimode transmission is not possible. This is due to the fact that light is evanescent in air so cannot propagate through air holes which act as barriers so only the fundamental mode which fits into the silica core and not escape into nearby holes is guided while the modes of higher order have smaller lobe dimensions so they can slip between the gaps and successive higher order modes become trapped. Thus proper design of fiber cross-section guarantees guidance of only fundamental mode. [3]

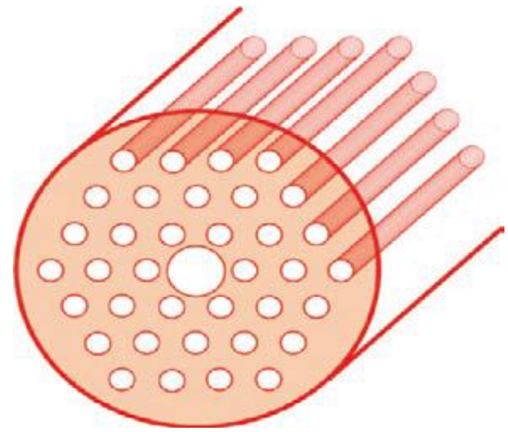

Fig 2. Schematic of a hollow-core PCF with a triangular lattice of Air-holes, which guides light through the photonic bandgap effect.

B. PHOTONIC BANDGAP GUIDANCE

Photonic crystal cladding have gaps for both positive and negative refractive index difference between core and cladding which leads to the formation of hollow core fiber with photonic crystal cladding having bandgap properties. These fibers which cannot be made using Conventional optics are related to Bragg fibers in which light guidance do not depend on Total Internal Reflection. In order to guide light by Total Internal reflection it is necessary to have a core with higher refractive index than cladding but there are no suitable low-loss material having lower refractive index than air at optical frequencies. [1] The first PCF by exploiting Photonic bandgap effect to guide light was reported in 1998 having core with additional holes but could guide light in silica i.e. in higher refractive index. [4, 5]

In 1998 hollow core guidance become possible by PCF fabrication led to have larger filling factor required to achieve Photonic bandgap for air guiding. It is required that in this guidance refractive index difference between core and cladding must be negative. The first PCF with hollow core was having air holes of triangular lattice and large core was formed by removing seven central capillaries. When white light was introduced in fiber core it showed that only limited wavelength range light was guided which coincide with photonic bandgap.

III. PROPERTIES

PCFs having large variation of air holes pattern and arrangement offers wide possibility to control the refractive index difference between the core and the cladding made of photonic crystal. This offers improved features and properties in PCFs which is not attainable in conventional fibers makes the fiber usable in wide variety of applications.

In both solid-core and hollow-core fibers unique properties can be achieved. The two dimensional microstructure and refractive index contrast due to air-holes arrangement effects or improves the fiber properties like the dispersion, the number of guided modes, non-linearity, the birefringence, the numerical aperture and the smallest attainable core diameter.

A. Dispersion

The dispersion can be defined as spreading or broadening of wavelength. The light pulse carrying digitized information when travels through a fiber broadens as a result of chromatic dispersion thus interferes the other pulse. In conventional fibers the dispersion is due to waveguide and material dispersion and due to limitations in modification of parameters analogue properties cannot be obtained, but in PCFs due to the flexibility in variation of air-holes pattern and arrangement dispersion can be modified.

The dispersion in both conventional fiber and PCF is shown in Fig.

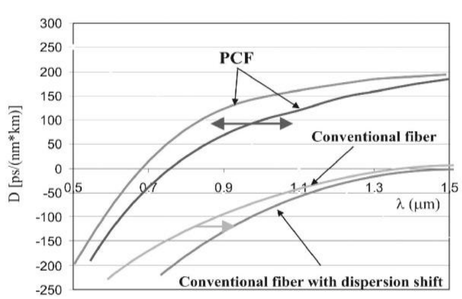

Fig 3. A comparison of dispersion in 4conventional fiber and in an index-guiding PCF [1]

By increasing the air-holes size the zero-dispersion wavelength can be shifted to the visible, On the contrary, very flat dispersion can be obtained with small air-holes. [6]

B. Non- Linearity

The high intensity of core by strongly confining light enhances the nonlinearity property of fibers. Moreover different non-linear effects can also be achieved by proper design of dispersion characteristics. PCF is a very promising medium for super-continuum generation. Super-continuum Generation is a result of several different non-linear phenomena including soliton transmission. Soliton transmission requires balanced non-linear and dispersion characteristics which are obtained by modifying air-holes. Super-Continuum is the generation of continuous broad spectra of high power pulse when transmitted through non-linear media. [2]

C. High Birefringence

In photonic crystal fibers the birefringence obtained is highly insensitive to temperature. By slightly changing the air-holes geometry a wide range of birefringence can be obtained. The birefringence of the photonic crystal fibers is obtained due to non-axisymmetric distribution of the effective refraction index that depends on the size and spatial distribution of holes. Birefringent fibers, where the two orthogonally polarized modes carried in a single-mode fiber propagate at different rates, are used to maintain polarization states in optical devices and subsystems. [3]

D. Large Mode Area

At any particular wavelength, large core conventional fiber and PCF can have a similar Mode Field Diameter (MFD). However, PCF remains single mode over a large range of frequencies, while conventional fiber starts to be multimode close to the designed wavelength. In PCFs by replacing holes and introducing rods in core, large MFD can be obtained. It is clear that the conventional fibers and PCF with similar mode areas experience similar

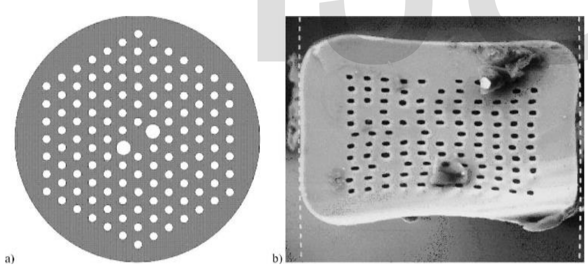

Fig 4. Examples of highly birefringent PCF: (a) HB PCF with hexagonal lattice and circular (b) test samples of rectangular-shape HB PCF with rectangular lattice and elliptical holes of IEMT

In PCFs by replacing holes and introducing rods in core, large MFD can be obtained. It is clear that the conventional fibers and PCF with similar mode areas experience similar band losses but it does not limits the PCF performance. PCF mode area can be increased by increasing the lattice pitch of cladding and decreasing air hole diameter. [2]

E. Hollow-Core Fiber

The fibers having core filled with air always having lower refractive index than that of cladding. In these fibers light propagate through the photonic bandgap mechanism. Since only a small part of light can be transmitted through glass, all effects related to interaction between glass and light like scattering, dispersion etc. are highly reduced. A hollow core with large diameter transmits about 99% of energy in air. By this the most common reason of attenuation is diminished. In conventional fibers this attenuation is due to Rayleigh scattering and multi-photon absorption but this is not the case with PCF. In hollow-core PCFs the main sources of attenuation are roughness of surfaces between core and cladding and size variation. [2]

IV. APPLICATIONS

Due to the improved and unique properties provided in PCF by a small variation PCFs are finding an increasing number of applications in always-widening areas of science and technology.

- PCF with a positive dispersion can be used for dispersion compensation in the telecommunication lines.

- PCFs can be successfully exploited to realize nonlinear fiber devices, with a proper dispersion, and this is presently one of their most important applications.
- The birefringence obtainable with PCFs is highly insensitive to temperature, which is an important feature in many applications.
- Hollow core fiber is of great interest in medicine, biology, and spectrometry, where broad band spectrum of light or specific wavelengths have to be transmitted.

V. REFERENCES

[1] P. St. J. Russell and R. Dettmer, "A neat idea [photonic crystal fiber]," IEE Review, vol. 47, pp. 19–23, Sept. 2001.

[2] R. Buczynski, Proceedings of the XXXIII International School of Semiconducting Compounds, Jaszowiec 2004

[3] Federica Poli, Annamaria Cucinotta, Stefano Selleri, "Photonic crystal fibres,"Springer-2007

[4] P. St. J. Russell, "Photonic crystal fibers," Science, vol. 299, pp. 358–362, Jan. 2003.

[5] J. C. Knight, J. Broeng, T. A. Birks, and P. St. J. Russell, "Photonic band gap guidance in optical fibers," Science, vol. 282, pp. 1476–1478, Nov. 1998.

[6] W. H. Reeves, J. C. Knight, P. St. J. Russell, and P. J. Roberts, "Demonstration of ultra-flattened dispersion in photonic crystal fibers," Optics Express, vol. 10, pp. 609–613, July 2002. Available: http://www.opticsexpress.org/abstract.cfm?URI=OPEX-10-14-609