Photonic Crystal Fiber: Developments and Applications

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Abstract. Optical fiber is a thin hair-like fiber made of silica or plastic that is used to transmit data. It consists of a transparent core surrounded by a transparent cladding. There are many kinds of fiber like Step Index MMF, Graded Index MMF, Silica doped fiber, plastic fibers, Photonic Crystal fiber, Fluoride fibers etc. Among the various types of fibers used in communication system, Photonic Crystal Fibers (PCF) are widely used due its unique structure and tendency to work in two different modes i.e. Index Guided Mode and Band Gap Mode. PCFs are widely used in spectroscopy, meteorology, bio-medicine, imaging, telecommunication, industrial machinery etc. This paper is an overview of PCF modes and its various properties.

Keywords: Photonic Crystal Fiber, Photonic Band-Gap Fiber, Index Guided Fiber.

1. Introduction

The term Photonic Crystal Fiber was first coined by Philip St. J.Russell in the 1990's [1]. Photonic Crystal Fiber (PCF) is a kind of fiber which has a number of microscopic air holes throughout its entire length. Its structure is such that there is periodic refractive index or structural variation along its axis which makes it different from conventional fibers. Most PCF's have been fabricated in silica glass. These are categorized as Holey Fiber and Photonic Band Gap Fibers. Photonic Band-Gap Fibers follows Photonic Band Gap Mechanism and here the light is guided in air holes. Whereas in case of Holey Fiber (also called the index-guided fiber) light is guided in the solid core made of pure silica by modified Total Internal Reflection Mechanism [2]. Here Section 1 introduces the PCF. Section 2 describes the different modes of PCF. Further Section 3 illustrates the various properties achieved through its unique structure and Section 4 is the Literature Review part.

2. Different PCF Modes

2.1 Index Guided Mode (Holey Fiber)

Holey Fiber contains a micro structural array of air holes called the solid core surrounded by pure silica cladding of refractive index 1.462. Owing to the large refractive index contrast between air (1.000) and silica (1.462) here the light is guided by modified total internal reflection which is entirely a function of wavelength [3]. The Fig. 1 refers to the effective refractive index profile for Photonic Crystal Fiber. Effective Refractive Index is a number that quantifies the phase delay per unit length in PCF relative to phase delay in vacuum.

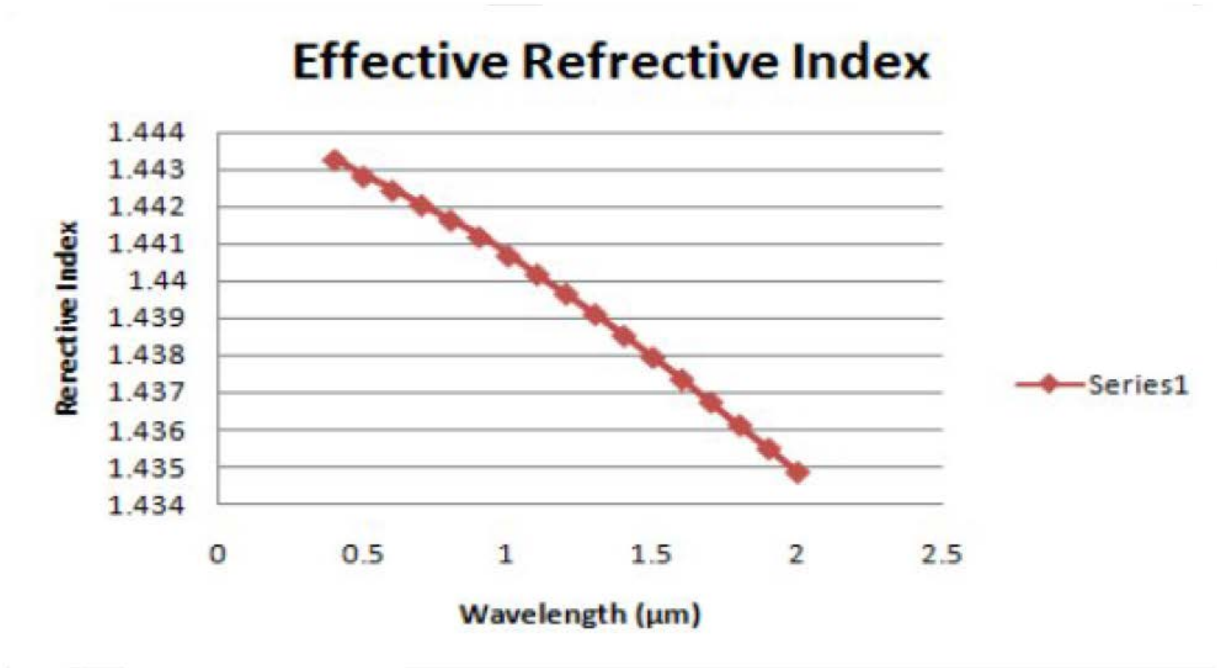

Fig. 1. Graph for Effective Refractive index distribution profile for PCF structure (Circular air holes)[4]

This differs it from the conventional fibers wherein light is guided by the mechanism of total internal reflection at the core cladding interface.

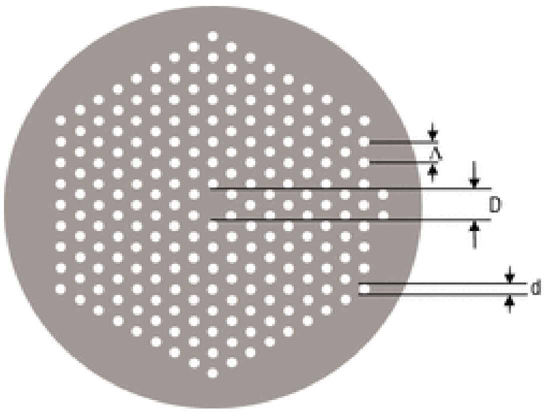

Fig. 2. Holey fibers [5]

In Fig. 2, the PCF consists of a missing air hole in the center of diameter 'D' and the pitch is labeled as 'Λ' which measures the distance between the centers of the neighboring air holes. The hole size is labeled as 'd'.

2.2 Photonic Band gap Mode

If the central part of the array of air holes is replaced by a bigger hole of much larger diameter in comparison to the surrounding holes, then the fiber so obtained is called the Photonic band-gap fiber. Since here the periodicity of the structure is broken, the defect so introduced causes a change in its optical properties [3], [6]. The phenomenon that guides light in the fiber is photonic band-gap according to which if the frequency of the external light matches the band-gap frequency, the light gets trapped in the hole and thus is guided throughout the length of the fiber. Therefore there is no need of having a greater refractive index of the core. The figure given below is a Photonic band-gap fiber with a hollow cavity in the center. Fig. 3 illustrates the Photonic Band Gap Fiber showing a large air hole in the center surrounded by an array of air holes.

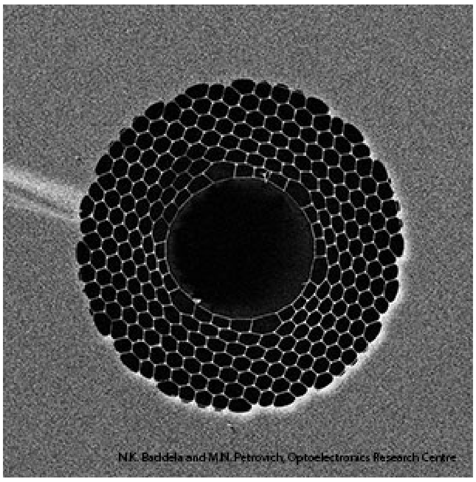

Fig. 3. Band Gap Fibers [7]

3. Properties achieved through its structure

A very eminent property observed in PCF's is that it acts as Single Mode Fiber for a wide range of wavelengths from about 300 nm to beyond 2000 nm and that too with a large mode-field diameter.

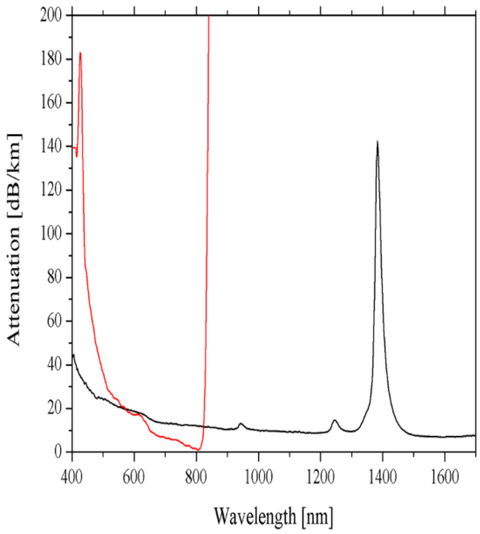

Fig. 4. Difference in Attenuation spectral of conventional optical fiber (red) and PBG fiber (black) [8]

The Fig. 4 indicates the difference in Attenuation spectral of conventional optical fiber(red) and PBG fiber (black).The attenuation is smaller in case of Photonic Band-gap fibers as the light is guided through the hollow core. PCF's with larger core carry more optical power. Size of the air holes can be adjusted so as to reduce dispersion by shifting the point of zero dispersion in the visible light region. PCFs can easily attenuate longer wavelengths and hence they can suppress Raman Scattering. They have no. of air holes which provide large surface area to gather more amount of light and thus an increased Numerical Aperture (NA) is obtained i.e. 0.6 or 0.7 of MMF. Larger holes may be filled with liquids and gases. Gas filled PCFs are widely used in Fiber Optics Sensor, non linear spectral broadening and variable power attenuation.

4. Literature Review

The PCF industry emerged long time ago in the 1990's with the introduction of Bragg Fiber. Till date many researches have been made on Photonic Crystal Fiber. These researches modified the PCF technology one way or the other. Some of the important advances in this field are illustrated in the following table.

Table 1. Overview of photonic crystal fibers development .

Year	Development	Description
1978	Idea of Bragg fiber	These fibers revolutionized the telecom with components sensors and filters. But the major drawbacks faced were large nc modes traveling in it, their huge size and greater loss[9]
1992	Idea of the photonic crystal f with air core	The proposed fiber designs followed the mechanism of Tot Internal Reflection and performed well in telecommunica except for a few drawbacks like limited material choice, limited core diameter for Single Mode Operation [10]
1996	Fabrication of a single-mode f with photonic coating	Photonic coating on the fiber provided increased durability, temperature resistance, high strength designed accordingly use in harsh chemical environments, nuclear radiations, Me applications and many more [11]
1997	Endlessly singe mode PCF	A very attractive feature of Endlessly Single Mode PCF is th absence of higher order modes irrespective of the op wavelength, low loss and low non linearities. These properties are significa used in mode filtering, sensors, interferometers, etc [12].
1999	PCF with photonic band gap air core	A different type of wave-guide structure was introduced with additional hole in the center of an array of air holes to be use differently for different applications [13].
2000	Highly birefringent PCF	PCF made highly birefringent by having different air diameter along the two orthogonal axes or by asymmetric core design provided high data rates and manufacturing fiber loop Mi [14].
2000	Super continuum generation PCF	Super continuum was generated due to PCF's high non line and Zero Dispersion Wavelength find applications in Laser sou Spectroscopy, Pulse Compression, and WDM etc [15].
2001	Fabrication of a Bragg fiber	Prior to this development manufacturing of fiber and the wr of the

		fiber Bragg grating were done in two different steps. But in work both fabrication and writing of the Bragg Grating are done single step. Bragg fiber finds extensive application in Optical sen and fiber lasers [16].
2001	PCF laser with double cladding	Ytterbium doped double clad PCF Lasers based on a un Fabry Perot configuration provide high power. The cavity was forı between an external high reflecting dichroic mirror at pumped end of fiber [17].
2002	PCF with ultra flattened disper	Zero Dispersion was obtained at a much wider wavelength ra of 1µm-1.6µm used for primarily for Super continuum genera [18].
2003	Bragg fiber with silica and air c	This new class of Bragg Fibers reduce non linearity propagation loss and further serves as a model to study the non linear op phenomenon in gas phase materials [19].
2004	Chalcogenide Photonic Cr Fibers (CPCF)	CPCFs offer several distinctive optical properties such as a transmission window that extends far into the infrared spectral region and exhibit an extremely high nonlinear refractive-inc coefficient [20].
2005	Kagome Lattice PCF introduce	Hypo-cycloid shaped Gas filled fiber having three very str Band gap which overlap to provide low loss at a very broad wavele range By controlling the temperature and pressure of the gas, contribution of gas to the refractive index could be controlled used designing bright spatially coherent optical sources [21].
2006	Hybrid Photonic Crystal Fiber	This type of PCF composed of air holes and germanium-do silica rods disposed around an undoes silica core guides light in a s core by two mechanisms concurrently which are Total Inte Reflection (TIR) andanti resonant reflection [22].
2007	Silicon Double Inversion (S Technique for manufacturing Polym templates for Photonic crystals	The techniques used for manufacturing Polymer Templates couldn't withstand high temperatures required for infiltrat Thus SDI was introduced as an intermediate step where Inversion silica was

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		made via Atomic Level Deposition (ALD) at room tempera [23].
2009	Hollow core Photonic Band Fiber free of Surface modes	Due to the elimination of the surface modes, there will be a considerable increase in bandwidth of the fiber and redu dispersion leading to more carrying capacity [24].
2013	Double Cladding Seven-core P	In double clad Seven core fiber, each core is made to propag only the fundamental mode called the super mode and provi a great help in creating a Multi core fiber with proper guid properties for high power super continuum generation [25].
2014	PCF based nano displacem sensor	A highly effective nano-displacement sensor can work for b horizontal as well as vertical displacement. Different senstiv can be obtained in different displacement regions as requirement [26].
2015	Design of equi-angular s Photonic Crystal Fiber	An Equi-angular 8mm long PCF was designed for mid-infraredsupercontinuum generation. It could produce la pulses of 500W peak power [27].
2015	Integration of Photonic Cr Fibers (PCF) in Fiber Laser	A fully monolithic fiber having 40μm core with Yb-do photonic Crystal fiber amplifier module producing up to 210 W ave power at 1064 nm was introduced for High Power Applications [28].

5. Conclusion

Here we have reviewed some of the progress attained in the field of PCF. We have introduced the Basic guiding properties of this new class of fibers which are radically different from the conventional fibers. Emphasis has been on structural aspects of PCF and its applications. Thus, many new and old telecommunication companies install many thousands of kilometers of fiber each year in the ground, along bridges and highways, through high-rise buildings, through natural-gas pipes, along rivers, by train rails, and under the oceans, interconnecting continents, countries, cities, and homes. Thus, one can deduce conclusively that the future of fiber is truly very right.

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