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Emerging Prospects of Photonic Crystal Fibers

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Abstract- Photonic crystal fibers are the periodic structures of air holes running along the fiber around a solid or hollow core. These present a diversity of new and improved features beyond what conventional optical fibers can offer. Due to their unique geometric structure, and superior control of guiding properties,PCFs present special properties and capabilities that lead to an spectacular potential for various applications. in optical communications and various other areas.This paper will review recent developmentsand discuss the emerging prospects in this field.

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1. Introduction

A remarkable development has taken place in the last few decades within the field of optical components having a full or partly periodic structure incorporated. Such artificial optical materials are often called photonic crystals, because they form an optical equivalent to the electronic crystals in semiconductors, and they appear both as key elements in novel optical fibres and in integrated optical devices[9]. The most mature class of components are the optical fibres (often named photonic crystal fibres, microstructured fibres, or holey fibres). The appearance of photonic crystal fibers (PCFs) in 1996 was a breakthrough in fiber optic technology given that these fibers not only had new properties as they could overcome many limitations intrinsic to conventional optical fibers. PCF geometry is defined by a periodic arrangement of air holes running along the entire length of the fiber, centered on a solid or hollow core. The major difference between both kinds of fibers relies on the fact that the waveguide properties of photonic crystal fibers are not from spatially varying glass composition, as in conventional fiber, but from an arrangement of very tiny and closely spaced air holes which go along the whole length of fiber. In comparison with standard optical fibers, photonic crystal fibers can be made of a single material and have several geometric parameters which can be controlled offering large flexibility of design. These fibers also offers the possibility of light guiding in a hollow core, giving new perspectives in fields such as nonlinear fiber optics, fiber lasers, supercontinuum generation, particle guidance, and fiber sensors [3,4]. Therefore, there is a high curiosity of the research and scientific community in employing photonic crystal fibers in all kind of fields.

2. PCF Modes

2.1 Index Guided Mode (Holey Fiber)

This comprise a arranged 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 totally 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 measures the phase delay per unit length in PCF relative to phase delay in vacuum.

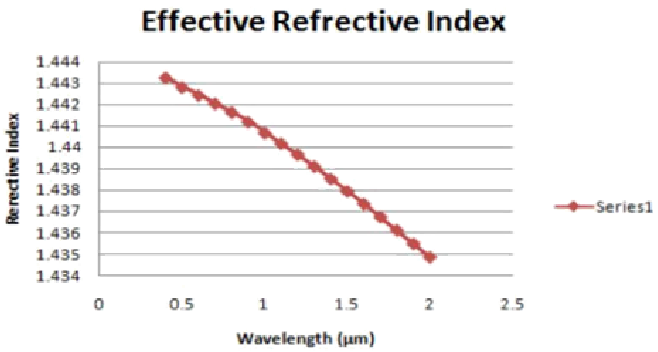

Fig. 1. Graph for Effective Refractive index distribution profile for PCF structure (Circular air holes)[4]

This differs PCF from the conventional fibers wherein light is propagated by the mechanism of total internal reflection at the core cladding interface

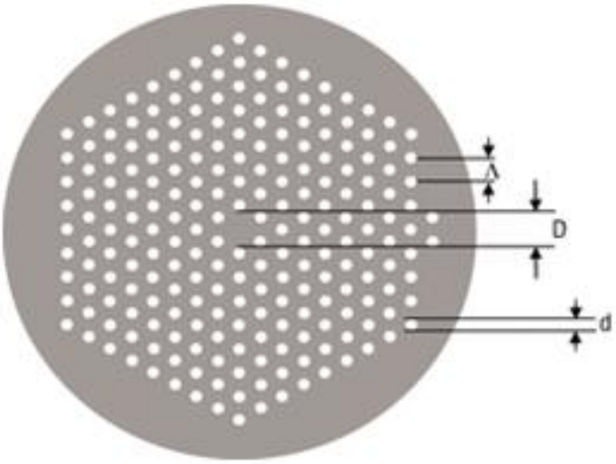

Fig. 2. Holey fibers [5]

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

In this the central part of the array of air holes is replaced by a bigger hole of much bigger diameter as compared to the encompassing holes, then the fiber so obtained is called the Photonic band-gap fiber. As here the periodicity of the structure is broken, the flaw so introduced causes a change in its optical properties [3], [6]. The method 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 . Therefore there is no need of having a greater refractive index of the core. The figure given below is a PBG fiber with a hollow cavity in the center. Fig. 3 illustrates the PBG Fiber showing a large air hole in the center surrounded by an array of air hole

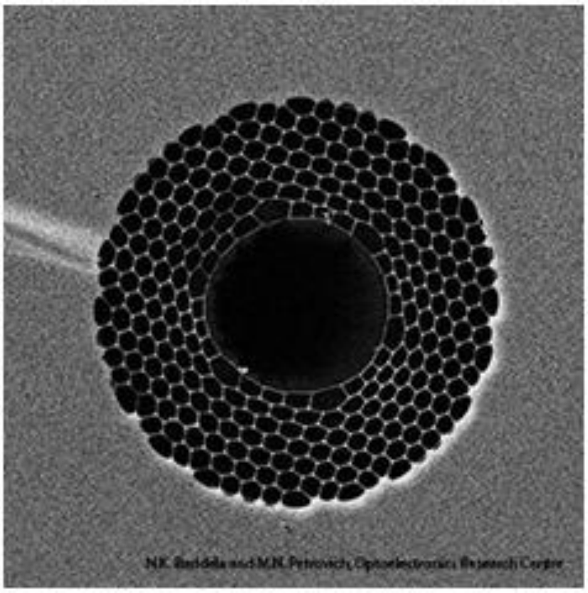
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Fig. 3. Band Gap Fibers [7]

3. Features gained through PCF structure

A very important 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.

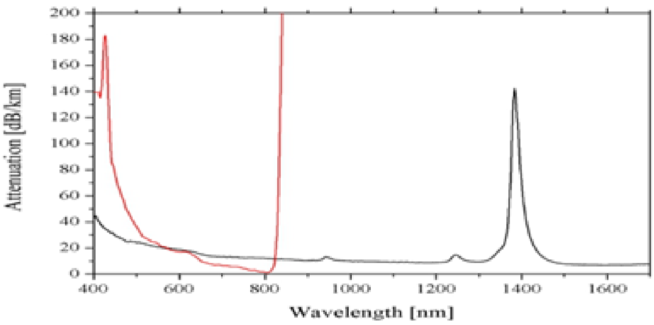

Fig. 4. Difference in Attenuation spectral of conventional optical fiber (red) and PBG fiber (black)

The above Fig. 4 shows the difference in Attenuation spectral of conventional optical fiber(red) and PBG fiber (black).The attenuation is lesser 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 controlled and adjusted so as to minimize dispersion by shifting the point of zero dispersion in the visible light region. PCFs can easily attenuate higher wavelengths and so they can control 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 different liquids and gases. Gas filled PCFs are greatly used in Fiber Optics Sensor, non linear spectral broadening and variable power attenuation.

4. Application areas

The use of microstructures in optical fibres have opened new developments in various areas of fiber applications, and it is interesting that each of these areas actually takes advantage of different aspects of the increased physical performance enabled by the location of microstructures in the fibers. One of the highly interesting possibilities of the photonic crystal fibers lies in the ability to confine light in a very small cross section area through the use of high index contrast between holes and glass. This is used in the so- called highly nonlinear photonic crystal fibers HNL-PCFs [2]. The opposite possibility is explored in the case of so-called large-mode-area photonic crystal fibers, LMA-PCFs, which moves the nonlinear limitations to higher power levels by spreading of light to larger areas than possible in conventional fibers.

The possibility of microstructuring does, however, hold further interesting possibilities, and one is to obtain very high numerical apertures. When these possibilities are combined in an optimal manner, one of the most promising applications of photonic crystal fibers appears in the rapidly developing area of compact high-power doped PCF fiber lasers and amplifiers [3]. These may have primary applications in areas such a high-power laser-based material processing and biomedical applications, but will also find unique applications within optical communications, including, for example, broadband video distribution in the cable TV’s hybrid-fiber-coax (HFC) networks or free-space optical communications.

In future optical networks one of the enabling technologies is tunable component elements or subsystem modules including reconfigurable routers, switches etc. Thus, the development of a technology platform that allows construction of tuning components is critical. Lately, photonic bandgap fibers, filled with liquid crystals, have proven to be candidates for such a platform. Photonic bandgap fibers provide specific wave-propagating properties that are powerfully related to the design of the air holes in the cladding of the fiber. These wave-guiding properties may be altered by filling the air holes with a material, for example a liquid crystal that changes optical properties when subjected to, for example, an optical or an electrical field [4]. The usage of these two basic properties allows design of tuneable optical devices for reconfigurable optical networks.

Among the very fascinating topics in the area of research on photonic crystal fibers are the possibilities for crafting the waveguide dispersion in these devices. This is already used in the design of dispersion controlled highly nonlinear PCFs [2]. Several applications of these dispersion-flattened high-nonlinearity PCF for optical communications have been demonstrated in nonlinear optical signal processing, including wideband tunable wavelength conversion, nonlinear signal conditioning and reshaping, optical signal regeneration, ultrashort optical pulse compression, etc. [5-8,10-11].

With the flexibility in design and the ability to tailor the dispersion properties of these fibers it may also be visualized that better and more efficient dispersion compensating elements can be developed by the use of very high dispersion values obtainable in PCFs. Suchdispersion compensating fiber or DCM (dispersion-compensating module) may substitute the current DCFs in future high-capacity DWDM systems for long-haul and metro networks.

Photonic crystal fiber-based sensing technology is still at its emerging stage when compared to fields such as supercontinuum generation.Nevertheless, the perspectives to achieve commercial availability of sensing solutions based in these fibers are optimistic.
The area of sensing is the one with more patents using PCFs:for the detection of adsorbates on the interior surfaces of the PCF air holes;by the functionalization of the air holes in the cladding of the PCF for detection of chemical and biological agents through SERS ; an analyte can be inserted in the half-core of the PCF in order to be identified by a spectroscopy interaction;or even by producing a resonator using a solid core PCF coil to measure an analyte
Temperature sensing with PCFs also has some patents. Temperature measurement was developed by filling the fiber

with a temperature-sensitive fluid or accordingly with its fluorescent characteristic and, even more, by using Hi-Bi PCF Sagnac loop mirrors with a partial perfusion or with a PCF long-period grating differential demodulation . Humidity sensors patents based on tapered and perfuse PCFs and on injection-type PCFs were also formulated. Patents were completed for a PCF refractive index sensor based on polarization interference, as well as for a real-time measurement of fluid flow concentration based in a PCF . An all-fiber liquid level sensorand a current sensor through a PCF .Bragg grating weredeveloped.A hollow-core PCF was used for a Fabry-Perot interferometer in order to obtain a displacement sensor patent ; and a multiparameter sensor patent was completed based in a PCF.The number and content of patents based on PCFs is growing through the years, showing an open possibility for future commercial exploitation.

5. Conclusions

The variety of unaccustomed features of PCF, beyond what conventional fibers can offer, leads to an increase of possibilities for new and improved applications in various field. The amount and quality of photonic crystal fiber sensors developed nowadays, shows that photonic crystal fiber is a technology with an outstanding potential for sensing applicationswhich unlock the path for a commercial scenario.They can be used as the basic long-distance optical signal transmission medium. Thepotential for using PCF for telecom-level transmission seems to be there.Recent research results indicated that using hole- assisted structured, “holey fibers” with much more bending tolerance (low loss even at a very small bending radius) have been developed and deployed .

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