iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** XI **Month of publication:** November 2017

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue XI November 2017- Available at www.ijraset.com

Photonic Crystal Fibre: Developments, Properties and Applications in Optical Fiber Communication

Laxmi Chaudhary[1], Dr. Arun JB[2], Dr. Hemant Purohit
[1]Lecturer, Dept. of ECE, JIET group of Institutions,Jodhpur, Raj, India
[2]Lecturer, Technical Education, TTC& LRDC, Ajmer, Raj, India
[3]Prof., Dept. of ECE, JIET group of Institutions, Jodhpur, Raj, India

Abstract: The increasing demand of demand for internet and high data rate is offered by optical technology but it faces some deficiencies like the flexibility in designing and efficient use of complete optical spectrum. Photonic crystal fibers comes in a new category of optical fiber system that reduces all the drawbacks of the conventional optical fibers. Photonic crystal fiber is fabricated with periodically arranged low index material in a background with high refractive index material. Light can be guided inside the PCF by either modified total internal reflection or photonic band gap guidance. PCFs are widely used in spectroscopy, meteorology, bio-medicine, imaging, telecommunication, industrial machinery etc. This review paper gives an overview on Photonic Crystal Fiber (PCF) & its applications. This paper discusses the importance of photonic crystal fibers,its, guided mechanism, its structural properties and its applications in optical fibre communication.
***Keywords*: Photonic crystal fiber (PCF), reflection, core, dispersion, communication systems.**

I. INTRODUCTION

Photonic crystal fibers (PCF) also called as micro structured optical fibers is a major research topic since last few years[1]. Basically PCF were fabricated using a single material (glass or polymer). The cross section of this micro structured optical fibers consists of a core area surrounded by a periodic array of holes, and air holes running along the length of the fiber called as cladding, where the light can be either guided based on index or band gap guidance mechanism depending on the refractive index contrast between the core and the cladding [2].

The nonlinear coefficient and dispersion property is controlled by the holey cladding in PCFs as the conventional fiber does not do this. Such PCFs can control the chromatic dispersion keeping high non-linear coefficient, which is most important application for nonlinear optics.

Now a day, the highly nonlinear PCF is commonly used type. Their use are wide field of applications ranges from spectroscopy and sensor [4] to direct telecom. The high nonlinear coefficient and designable dispersion properties make these fibers attractive for many nonlinear applications of which super continuum(SC) generation has been the most intensively investigated and this has been used in application like optical coherence tomography, spectroscopy, metrology [4].In a telecommunication era, the spectral slicing of broadband spectra has also been proposed as a simple way to create multi wavelength optical sources for dense wavelength division multiplex ing applications [5].The feature of high nonlinear PCFs can be used to obtain super continuum generation pumped with ultrafast laser pulses and longer laser pulses, however super continuum generation in PCFs is restricted by dispersion properties. The key factor Mode field area of PCF is to generate the nonlinear coefficient i.e. as small as the mode field area, the increase in the nonlinear coefficient which leads to super continuum generation[17].

II. LITERATURE REVIEW

Many researches have been made on Photonic Crystal Fiber and those researches modified the PCF technology. In 1978 the Idea of Bragg fibers that revolutionized the telecom with components sensors and filters but the major drawbacks encountered were large no modes travelling in it, their huge size and greater loss[2].Later in 1992 the fiber design include the mechanism of Total Internal Reflection with a good perforation in telecommunication except with few problems like limited material choice, limited core diameter for Single Mode Operation [1] .The photonic coated fiber were fabricated in 1996 with additional feature of increased durability, high strength designed, high temperature resistance accordingly use in nuclear radiations ,harsh chemical environments, Medical applications etc. Single Mode PCF with the absence of higher order modes irrespective of the optical wavelength, low non linearity's and low loss were used in 1997 as mode filtering, sensors, interferometers, etc [5].PCF with photonic band gap air core was introduced in 1999 that was a different type of wave-guide structure with additional hole in the centre of an array of air holes to be use differently for different applications. In year 2000, PCF made highly birefringent with different air hole diameter along the two orthogonal axes or by uneven core design provided high data rates and manufacturing fiber loop. In the same year .Super continuum was generated due and due to PCF's high non-linear and Zero Dispersion Wavelength it find applications in Laser sour Spectroscopy, Pulse Compression, and WDM etc[6].Later in year 2001 work of fabrication of Bragg fiber find applications in Optical sensor and fiber lasers and PCF laser with double cladding (Ytterbium doped double clad) provide high power was based on Fabry Perot configuration.PCF with ultra-flattened dispersion was introduced in 2002 in which Zero Dispersion was obtained at a much wider wavelength range of 1μm-1.6μm used for primarily for Super continuum generation [4].

Bragg fiber with silica and air core was introduce in 2003 and it reduced non linearity propagation loss and also serves as a model to study the non-linear optical phenomenon in gas phase materials [3]. Chalcogenide Photonic Crystal Fibers (CPCF) was developed in 2004 offered a number of unique optical properties such as a transmission window that extends far into the infrared spectral region and demonstrates an extremely high nonlinear refractive-index coefficient. In 2005 Kagome Lattice PCF was introduced with a Hypo-cycloid shaped Gas filled fibre contained three very strong Band gap that overlap to provide low loss at a very broad wavelength range[9].The temperature and pressure of the gas can be controlled, contribution of gas to the refractive index can also be controlled which was used for designing bright spatially coherent optical sources. Further the invention of Hybrid Photonic Crystal Fibre in the year 2006 which was a type of PCF composed of air holes and germanium-do silica rods prepared around an undoes silica core guides light within a core by Total Internal Reflection (TIR) and anti-resonant reflection mechanism[2].Later in 2007 Silicon Double Inversion was used to manufacture Polymer templates for Photonic crystals which were an intermediate step where silica was made through Atomic Level Deposition (ALD) at room temperature. Hollow core Photonic Band Fiber that was free of Surface modes was developed in the year 2009[7].Due to the elimination of the surface modes, there will be a considerable increase in bandwidth of the fibre and reduce dispersion may leading to more carrying capacity [10].

In 2013 the Double Cladding Seven photonic crystals fibre was introduced where each core was made to propagates only the fundamental mode called the super mode and provided a great support in making a Multi core fibre with proper guiding properties for high power super continuum generation. A very effective nano-displacement sensor that can work for horizontal as well as vertical displacement were developed in2014 named as PCF based nano displacement sensor with different sensitivity can be obtained in different displacement regions as requirement [16].In year 2015,Photonic Crystal Fiber-with an Equi-angular 8mm long PCF was designed for mid-infrared super continuum generation. It could produce laser pulses of 500W peak power [11] .Later the Photonic Crystal Fibers (PCF) were integrated in Fiber Laser. A monolithic fiber having 40μm core with Yb-do photonic Crystal fiber amplifier module produced up to 210 W average powersat 1064 nm was introduced for High Power Applications [4].Helically twisted photonic crystal fibres (PCFs) were reviewed based on the Helical Bloch theory in year 2016. In this twisted periodic 'space', cause light to spiral around the fibre axis and includes the presence of dips in the transmission spectrum and coreless PCF may have low loss guidance [13].

III. TYPES OF PHOTONIC CRYSTAL FIBRES

Photonic Crystal Fiber (PCF) can be demonstrated as structure consist of a core and clad, following the propagation law of total internal reflection as same as in normal fiber. It is periodic nanostructures that affect the motion of photons like as that ionic lattice affect electrons in solids. It occurs in nature in the form of structure coloration [2]. The core of this specific fiber is made of silica as a single material and can either be solid or hollow. The core is surrounded by air holes which goes through the fiber so it is called as 'holey' or' micro structured fiber and due to this structure the light is confined and transmitted through the core which acts as a cavity.

It can be organised to two types according to different structures: • Index guiding photonic crystal fiber
Photonic band gap fiber

A. *Index guiding photonic crystal fiber*

In index guiding PCF light is guided by the total internal reflection between the solid core and multiple air holes cladding .The solid core of index-guiding PCF with a micro structural array of air holes is surrounded by pure silica cladding with refractive index of 1.462[12]. Due to the large refractive index contrast between air (1.000) and silica (1.462) the light is guided by modified total internal reflection which is entirely a function of wavelength [3]. Effective Refractive Index basically quantifies the phase delay per unit length in PCF relative to phase delay in vacuum.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue XI November 2017- Available at www.ijraset.com

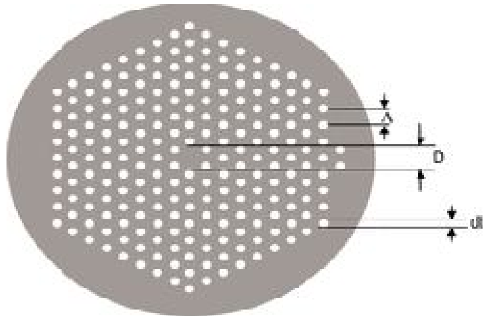

Fig.1. Holey fibers [5]

In Fig. 1, the PCF consists of a missing air hole in the centre of diameter is denoted by 'D' and the pitch is labelled as 'Λ' which measures the distance between the centres of the neighbouring air holes. The hole size is labelled as 'd'[9].

B. Photonic band gap fiber

Photonic band-gap fiber is obtained by the structure formed as 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. There is a change in its optical properties due to the defect of broken structure of periodicity. No electromagnetic modes are allowed to have frequency in the gap. Its effect is exhibited in photonic crystal band gap fiber where the wavelength guides light in a low index core region[11]. The light guiding phenomenon in the fiber is based on frequency of the external light if matches the band-gap frequency, the light gets confined in the hole and accordingly is guided throughout the length of the fiber. So there is no requirement higher refractive index of the core[8].

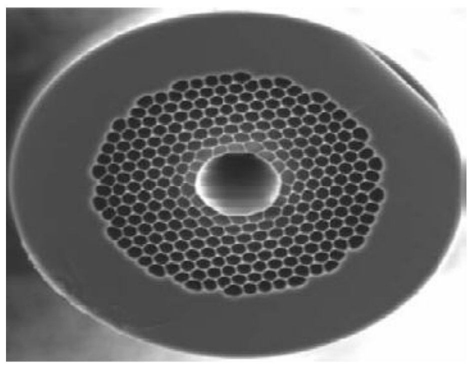
Fig.2 .Photonic band-gap fiber with a hollow cavity in the center.

IV. ANALYSIS OF STRUCTURAL PROPERTIES

Several properties of PCF like birefringence, dispersion, effective mode area and nonlinearity are discussed.

A. Birefringence

Birefringence is a essential property in fiber optics and many sensing applications where light has to maintain a linear polarization state, often high birefringence is required [12].Normally materials with uniaxial anisotropy-- have an axis of symmetry is termed as optical axis of a particular material have no equivalent axis in the plane perpendicular to it-- exhibits this optical phenomenon. Linearly polarized light ray in parallel and perpendicular direction will express uneveneffective refractive indices ne and no for unexpected and regular emerging rays respectively. When an un-polarized beam of light passes through material with a nonzero acute angle to the optical axis, the perpendicularly polarized component may face refraction at an angle as per the normal law of refraction and its opposite component at a non-standard angle shown by the difference between the two effective refractive indices called as the birefringence magnitude.[2],[15].

$\Delta n = ne - no$ (1)

The difference between the real part value of the effective indices of the pronounced fundamental core Eigen modes along x and y axis- LP01x and LP01y

$B = | Re(nxeff) - Re(nyeff) |$(2)

B. *Confinement Loss*

The occurrence of finite air holes in the core region causes leakage of optical mode from inner core region to exterior air holes and that is unavoidable which results in confinement losses. Fundamental mode is used to calculate confinement loss from the imaginary part of the complex effective index neff, [1] using

Confinement loss = (40π/ln (10) λ) Im (neff) [dB/km] (3)

where Im is the imaginary part of the neff

Confinement loss is the leaking of light from core to exterior matrix material. Confinement loss can be changed according to the parameters like number of air holes, number of layers, air hole diameter and the pitch.

C. *Chromatic Dispersion*

The sum of waveguide and material dispersion contributes to the chromatic dispersion or total dispersion. The material dispersion is characteristic to the material used to fabricate the fiber whereas the waveguide dispersion can be varied by changing the design parameter of the waveguide thus total dispersion is allowed to be altered. The material dispersion can be neglected when nm (λ) becomes constant and the real part of the effective index of refraction neff contains the dispersion information D [15].

D= - (λ/c) (d2 Re (nyeff)/ dλ2) (4)

Where c is the speed of light in vacuum and λ is the operating wavelength.

V. APPLICATION OF PCF

A. A highly nonlinearly designed PCF with 4 layers of air holes with different diameters can be used for broadband super continuum generation that is used in dermatology, ophthalmology, dental and detection of dermatology [16].

B. A PCF-in-PCF structure shows ultra-flattened negative dispersion at wide range of wavelength ranging from 1360 nm to 1690 nm and can be used for residual dispersion compensation in optical transmission[15].

C. By changing the diameters of the air hole can be used for super continuum generation and gives a flat dispersion profile for mid-infrared range from 1- 10 µm [13].A highly nonlinear hexagonal photonic crystal fiber (Ge11.5As24Se64.5) with five rings lattice structure can be used.

D. Photonic crystal fiber with central core region doped with GeO2, abutter fly lattice structure, and fiber Bragg grating (FBG) etched in the core can be used as optical fiber pressure sensor.

E. A chalcogenide glass PCF with square lattice and hexagonal lattice structure with the pitch of 0.2 µm can be used as dispersion compensating fibers. In comparison to the silica this fiber make available high negative dispersion in the wavelength range 1.2 – 1.6 µm [14].

VI.CONCLUSION

The unique properties and features of photonic crystal fibres as spot-size, novel cut-off and dispersion properties, and also allows leakage-free wave guidance in a low-index core region has increased the use of photonic crystal fibre in future applications .We have highlighted the various developments attained in the field of PCF in last few decades and some of the fundamental and structural properties of these new fibres, with the comparison to conventional fibers and indicated some of their prospective future applications. We have also discussed the basic guided properties of this new class of fiber. These fibers can be used in multidisciplinary applications in various fields with its specially designed features. Also, these fibers are under extensive research and have a truly bright future in the field of optical fibre communication.

REFERENCES

[1] J. C. Knight, T. A. Birks, P. S. J. Russell, and D. M. Atkin, “All-silica single-mode optical fiber with photonic crystal cladding,” Optics Letters, vol. 21, no. 19, pp. 1547–1549, 1996.
[2] R. Buczynski , “ Photonic Crystal Fibers”Acta Physics Polonica No. 2,Vol. 106 ,2004.
[3] Kaneshima, K.,Namihira, Y.,Zou, N., Hoga, H. and Nagata, Y. “Numerical Investigation of Octagonal Photonic Crystal Fibers with Strong Confinement Field” .IEICE Trans. Electron, 2006.
[4] P. S. J. Russell, “Photonic-crystal fibers,” Journal of Lightwave Technology, vol. 24, no. 12, pp. 4729–4749, 2006.
[5] J. M. Dudley, G. Genty and S. Coen, “Super continuum Generation in Photonic Crystal Fiber,” Review Modern Physics, Vol.78, No.4, 2006.
[6] H. F. Wei, H. W. Chen and P. G. Yan, “A Compact Seven-Core Photonic Crystal Fiber Super continuum Source with 42.3W Output Power,” Laser Physics Letters, , Vol. 10, No.4, p. 04, 2013.
[7] Transmission Record for Hollow-Core Photonic Bandgap Fiber, “www.osa-opn.org”, August 3, 2015.

[8] Ming-Yang Chen, Rong-Jin Yu, Member, OSA, and An-Ping Zhao, Senior Member, IEEE "Confinement Losses and Optimization in Rectangular-Lattice Photonic-Crystal Fibers," journal of lightwave technology,Volume.23,no.9, september 2005.

[9] R. Buczynski, "Photonic Crystal Fibers", Vol. 106 Acta Physica Polonica, Warsaw, Poland No. 2, 2004. Progress in Electromagnetics Research, PIER 99, 225,244, 2009.

[10] H. Ademgil and S. Haxha, "Design and Optimisation of Photonic Crystal Fibres for Applications in Communication Systems", Proceedings of the World Congress on Engineering 2007.

[11] Tripathy SK, Achary JSN, Muduli N and Palai G, "Nonlinear Rectangular Photonic Crystal Fiber (PCF) for OpticalCommunication Exclusively Super Continuum Generation" J Laser Opt Photonics 2015,

[12] Limin Xiao, M. S. Demokan, Wei Jin, Yiping Wang, and Chun-Liu Zhao "Fusion Splicing Photonic Crystal Fibers andConventional Single-Mode Fibers:Microhole Collapse Effect."Journal of Lightwave Technology, Vol. 25, 2007.

[13] P. St.J. Russell, R. Beravat and G. K. L. Wong , "Helically twisted photonic crystal fibres,'' Phil. Trans. R. Soc. 2017.

[14] Md. Rabiul Hasan , Sanjida Akter , Ahmmed A. Rifat , Sohel Rana and Sharafat Ali , "A Highly Sensitive Gold-Coated Photonic CrystalFiber Biosensor Based on Surface Plasmon Resonance"Optica Applicata, Vol. XLIV, No. 3, 2014.

[15] Kuang-Yu Yang, Yuan-Fong Chau, Yao-Wei Huang, Hsiao-Yu Yeh,and Din Ping Tsai, "Design of high birefringence and low confinement loss photonic crystal fibers with five rings hexagonal and octagonal symmetry air-holes in fiber cladding", Journal of Applied Physics, 2011.

[16] Ana M.R. Pinto and Manuel Lopez-Amo, "All-fiber lasers through photonic crystal fibers" Science Wise Publishing & Nanophotonics 2013.

[17] Libori, Stig E. Barkou; Broeng, Jes; Bergbäck Knudsen, Erik; Bjarklev, Anders Overgaard; Simonsen, Harald R. , "High-birefringent photonic crystal fiber", Published in: Proceedings on Optical Fiber Communication Conference and Exhibit, 2001.

10.22214/IJRASET

INDEX COPERNICUS
45.98

IMPACT FACTOR:
7.129

TOGETHER WE REACH THE GOAL
IMPACT FACTOR:
7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY