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Characterization of Hexagonal Photonic Crystal Fiber for Zero Flattened Dispersion with Lower Confinement Loss and Residual Dispersion Compensation Over 500 nm Wavelength Bandwidth

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Abstract: *Design methodology and characteristics analysis of a hexagonal photonic crystal fiber (H-PCF) is presented in this paper. Here, chromatic dispersion, effective area and confinement loss are analyzed for 1.00 to 2.10 μm wavelength range. The PCF is simulated by finite element method (FEM) with perfectly matched layers (PML). Hexagonal PCF with five rings of air holes for near zero ultra-flattened dispersion over 1100 to 1600 nm wavelength range is shown. The special property of proposed PCF is the design simplicity with near zero ultra-flattened dispersion, which is much needed in wavelength division multiplexing (WDM) applications. According to simulation work it is shown that, the designed microstructure optical fiber (MOF) shows near zero ultra-flattened dispersion of 0±1.00 ps/(nm.km), nonlinearity of 12.15 $W^{-1}km^{-1}$ and confinement loss less than 10^{-2} dB/km at the operating wavelength of 1550 nm.*

Keywords: *photonic crystal fiber; residual dispersion; holey fiber;zero flattened dispersion;dispersion.*

I. Introduction

Photonic crystal fibers (PCFs) or microstructure optical fiber (MOF) or holey fibers (HFs) is a artificial photonic crystal structure. It is a single material optical fiber consisting of a silica air microstructure. It contains microscopic air-holes in a silica background running down length of the fiber that form the silica-air microstructure as well as the lower refractive index cladding [1]. Air-holes can be arranged in the cladding in a periodic (hexagonal arrangement being the common) or an aperiodic fashion. The core may either be a solid (made of silica) or a hollow (made of air). The former core type PCF guides light based on the modified TIR mechanism likewise conventional fibers. The later guides light based on a new mechanism which is known as the photonic band gap (PBG) [2]. Hence, for PCFs, it is not necessary that the core must be made of a higher refractive index material than the cladding. Similarly, it is also not necessary that only the TIR mechanism confines light into the core of all optical fibers [3].

PCFs can be classified as index guiding PCF (IG-PCF) and photonic band gap PCF (PBG-PCF). IG-PCF uses total internal reflection method for guiding light and PBG-PCF uses photonic band gap method for guiding light. IG-PCFs are classified as HNL-PCF (having very small core dimensions to provide tight mode confinement), LMA-PCF (having larger dimension of the core and small refractive index contrasts to allow spreading out of the guiding light to provide a larger effective area) and high numerical aperture PCF (HNA-PCF) (having a microstructure cladding surrounded by a ring of air-holes with larger dimensions). Again PCFs are also classified as single mode or multi-mode fibers depending on the number of modes supported by a particular PCF (IG or PBG) as conventional fiber [3][4][5]. Day by day photonic crystal fibers have increasing its attention because of their attractive properties for examples, very high or very low nonlinearities [4], wideband dispersion ultra- flattened or ultra-low chromatic dispersion [5], lower confinement loss [6], very high or low birefringence [7], endlessly single mode guiding [8], and many others. Photonic crystal fibers (PCFs) [9] consisting of a central defect region.

In this paper we have proposed hexagonal HF in order to nearly zero ultra-flatted dispersion, lower confinement loss, effective area and nonlinear coefficient in the range of telecommunication wavelength band.

II. Design Methodology Of Hexagonal PCF

According to the lattice structures, the photonic crystal fibers may be classified into two different types. They are triangular-lattice and square-lattice. The proposed MOF here is triangular-lattice type. Photonic Crystal fibers [1] or Holey fibers usually make of hexagonal arrangements of micro structured air-channels. A simple five ring structured dispersion flattened holey fiber (DF-HF) has been designed with optimized air-hole diameter d_1, d_2, d_3 and pitch Λ. The first and second air-hole diameter is d_1 and d_2 respectively. The third, fourth and fifth ring diameter is same and is denoted by d_3. Air holes are arranged in hexagonal rotational symmetry with vertex angle 60^0 in the fiber cladding with a common Pitch Λ. Here, pure silica is used for background material which refractive index is 1.46 and air holes act as a cladding in hexagonal PCF symmetry

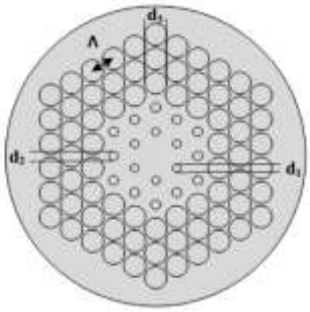

Fig.1(a) : Cross section of proposed PCF.

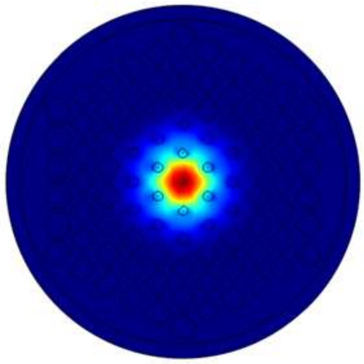

Fig.1(b): Transversal field intensity distribution at a wavelength of λ = 1550nm for the fundamental guiding mode of the proposed H-PCF.

In fig.1(a) there are three degrees of freedom for controlling dispersion behavior of five rings H-PCF, namely d_1, d_2 and Λ. The diameter of first and second ring is kept low for obtaining proper dispersion behavior and the diameter of the outer two rings are kept large for better field confinement and for reducing confinement loss. It is shown by simulation that it possible to design a simple H-PCF with five rings air-hole without distorting the dispersion flatness in communication band.

Fig.1(b) shows transversal field intensity distribution at operating wavelength of λ = 1550 nm for the fundamental guiding mode.

III. Analysis Of Hexagonal Photonic Crystal Fiber

In broadband communications systems, fiber dispersion plays very important roles. For example, in wavelength division multiplexing systems, it is essential to maintain a uniform response in different wavelength channels. This is strictly achieved by ensuring Ultra-flattened dispersion characteristics of fibers [3]. Theoretical study is very important to know various aspects of the problems for proper understanding of the research field. It is equally important in developing new fibers based devices. The simulation results are described below.

The effective index curve for optimum modes of the PCF is shown in Fig.2.It shows that effective refractive index decreases linearly with increase in wavelength. It is found that values of effective at 1100 nm wavelength is about 1.43 and at 1600 nm is about 1.41 within desired bandwidth.

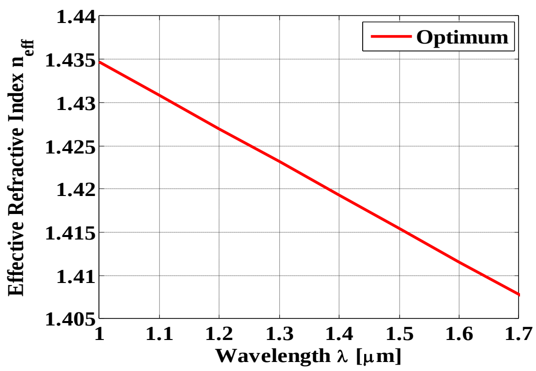

Fig.2: Effective refractive index curve of the PCF as a function of wavelength for Λ=1.63 µm, d_1/Λ=0.332, d_2/Λ=0.386, d_3/Λ=0.90.

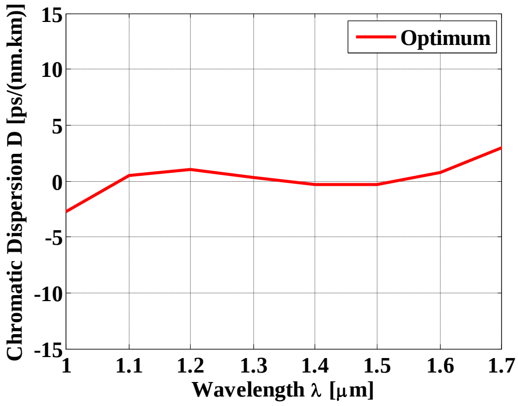

Fig.3: Chromatic dispersion curve of the PCF as a function of wavelength for optimum condition Λ=1.63µm, d_1/Λ=0.332, d_2/Λ=0.386, d_3/Λ=0.90.

The dispersion characteristic of the proposed PCF for its optimum value is shown in Fig.3. According to simulation result, the proposed PCF shows near zero ultra-flattened dispersion over 1100 nm to 1600 nm. The PCF shows flattened dispersion of about 0±1.00 for 500 nm wavelength range which exceeds the flattened dispersion values of Rahman et al. [4] Rifat et.al [21].

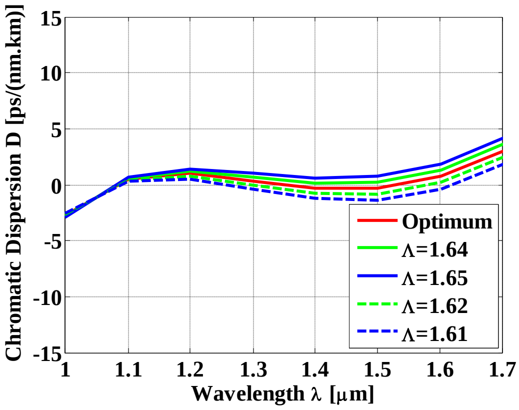

Fig.4: Chromatic dispersion curve of the PCF as a function of wavelength for pitch variation.

The dispersion characteristics of the proposed PCF for optimum parameters, variation of pitch are shown in Fig. 4. while remaining parameters are kept constant. Pitch variations are taken as 1.61, 1.62, 1.63 (optimum), 1.64 and 1.65 µm. It clearly indicates that optimum pitch is 1.63 µm.

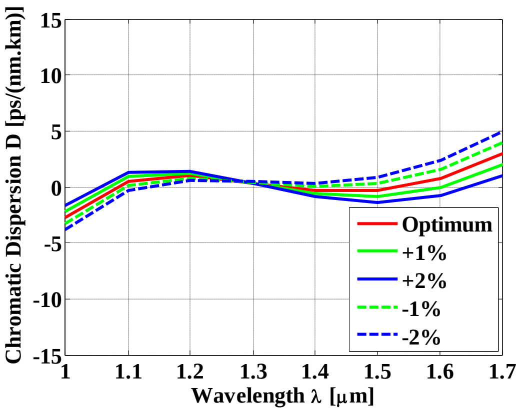

Fig.5: Chromatic dispersion curve of the PCF as a function of wavelength for first ring variation.

The dispersion characteristics of the proposed PCF for optimum parameters, variation of first ring radius are shown in Fig. 5 while remaining parameters are kept constant. First ring radius variations are shown for ±1% and ±2%.

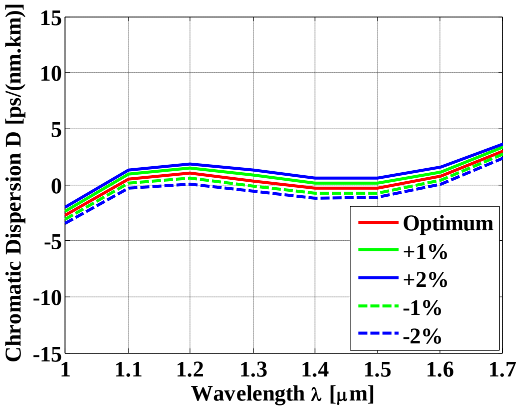

Fig.6: Chromatic dispersion curve of the PCF as a function of wavelength for second ring variation.

The dispersion characteristics of the proposed PCF for optimum parameters, variation of second ring radius are shown in Fig. 6 while remaining parameters are kept constant. Second ring radius variations are shown for ±1% and ±2%.

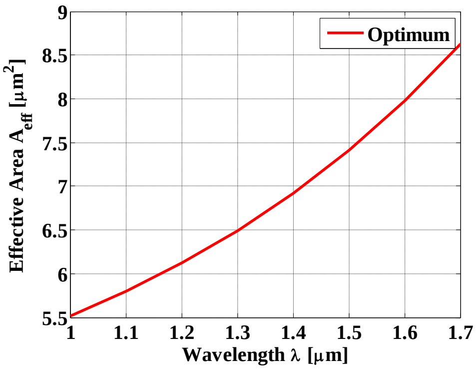

Fig.7: Effective area curve as a function of wavelength for optimum condition Λ=1.63μm, d_1/Λ=0.332, d_2/Λ=0.386, d_3/Λ=0.90.

Fig. 7 represents effective area of the proposed PCF as a function of wavelength for optimum design parameters. Here shows that effective area increases linearly with increase in wavelengths.

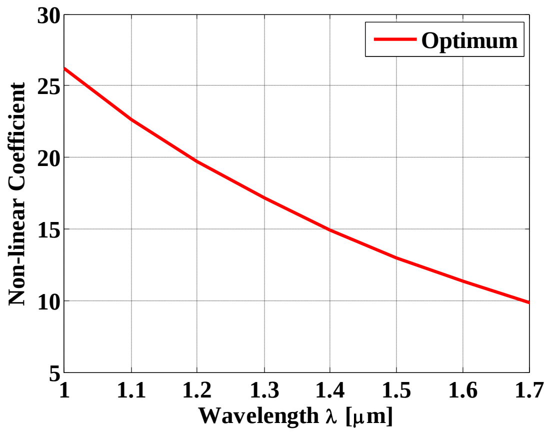

Fig.8: Nonlinear coefficient curve as a function of wavelength for optimum condition Λ=1.63μm, d_1/Λ=0.332, d_2/Λ=0.386, d_3/Λ=0.90.

Fig. 8 represents wavelength dependence of nonlinear coefficient γ as a function of wavelength for optimum design parameters. From these figure it is found that the proposed PCF has a nonlinear coefficient of 12.15 $W^{-1}km^{-1}$ at the operating wavelength 1550 nm.

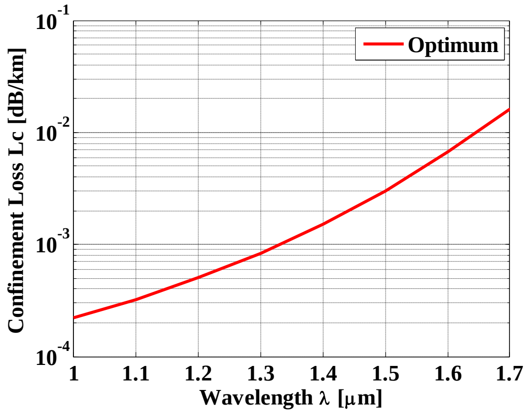

Fig.9: Confinement loss curve as a function of wavelength for optimum condition Λ=1.63 μm, d_1/Λ=0.332, d_2/Λ=0.386, d_3/Λ=0.90.

Confinement loss of the proposed PCF for y-polarization is shown in Fig.9 which shows confinement loss less than 10^{-2} dB/km at the operating wavelength of 1550 nm.

IV. Conclusion

A near zero ultra-flattened dispersion PCF has been also proposed here in simple design of HF. This fiber has a modest number of design parameters, five rings, three air-hole diameters, and a common air-hole pitch. It has been shown through numerical simulation results that a five-ring DF-HF can assume nearly zero ultra-flattened dispersion of 0±1.00 ps/nm/km in a PCF has been proposed for residual dispersion compensation over 500 nm bandwidth wavelength range with low confinement losses of the order less than 10^{-2} dB/km. PCF with nearly zero ultra-flattened chromatic dispersion and low confinement loss are crucial for broadband communication systems. Therefore it is desired that the proposed HF-PCF can be useful for WDM and broadband communication system.

V. Scope For Future Work

The proposed hexagonal PCF has moderate dispersion flattened characteristics of 0±1.00 ps/(nm.km) and it can be made more near zero flat as future work. The design can be replaced by square-lattice, octagonal and decagonal etc. Beside this, one can study to design ultrahigh birefringence PCF for sensing applications, and to shift the dispersion flattened characteristics towards visible regimes for medical applications as well. Design background material is used fused silica and holes are filled with air. Instead fused silica it can be used borosilicate glass, dense flint glass, calcium fluoride, sapphire etc. The holes can be filled with water, oil etc instead of air.

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