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Dispersion Compensating Defected Core Octagonal Photonic Crystal Fiber

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ABSTRACT : *This paper discusses a new defected core octagonal photonic crystal fiber (DC-OPCF) with six elliptical form air holes in the core area to improve the dispersion and nonlinear properties. The suggested DClight OPCF's directing properties are investigated using the COMSOL Multiphysics tool, which is based on the finite element method (FEM). By adjusting pitch and diameter, the optical characteristics of the proposed DCOPCF, such as nonlinearity and dispersion, have been observed. Without utilizing any doped materials, the simulation results show a very high nonlinear coefficient of 93W^{-1} $Km^{-1}$and significant negative dispersion of -1417 ps.nm.km^{-1}. As a result, the proposed DC-OPCF may be used for dispersion correction, supercontinuum production, and transmission at high bit rates.*

KEYWORDS – *Octagonal PCF, Dispersion, Nonlinearity, supercontinuum.*

I. INTRODUCTION

Researchers have been studying photonic crystal fiber (PCF) intensively due to its compelling applications in different sectors such as dispersion compensation [1-5], supercontinuum generation [6-10], bio-medical sensing [11-15], and chemical sensing [16-17]. The optimization of PCF is based on several geometrical factors, and light is confined inside the core based on total internal reflection, similar to that of an optical fiber. In the cladding interface of PCF, there are numerous tiny periodic air holes. By adjusting the geometrical parameters of PCFs, it is possible to achieve exceptional optical properties without changing the background material. Photonic Crystal Fiber can be widely used in high-bit-rate fiber optic transmission systems as the desirable negative dispersion can be accomplished by considering geometrical structure. Biswas et al. in 2018 reported in his research article that a large negative dispersion of 1200 ps/nm/km could be obtained by changing geometrical structure [6]. In 2019 Biswas et al. modified their previous structure to obtain the large negative dispersion value [7]. In another article, Biswas et al. reported that a large negative dispersion with large nonlinearity can be obtained using only circular shape airholes in the geometric structure [1]. In the same way, Faruk et al. reported very promising results using bored core [2]. Faruk et al. reported highly nonlinear PCF for fiber optic transmission applications using similar techniques [20]. To enhance the dispersion and nonlinear properties Biswas et al reported a square PCF by deploying defected core air holes inside the core [22]. Labib et al. also designed and investigated ultra-high negative dispersion-based octagonal fiber for various application purposes ^23ç. Wahid et al. also reported highly birefringent PCF using elliptical air holes inside the core [23]. In the same way, Faruk et al. demonstrated that dispersion can also be controlled by the core airhole defects in a PCF [24].

Recently in 2020 Talukder et al. reported a novel bored core structure to obtain a large nonlinearity and large negative dispersion [1]. Mia et al. in his research article proposed a square shape PCF structure and achieved large nonlinearity as well a large value of negative dispersion [19]. In the same year, Mia et al. also proposed an improved structure of octagonal PCF [23]. Himel et al. reported novel rectangular air holes based octagonal shape PCF and reported large nonlinearity for the application of supercontinuum generation [18]. In 2020, Akter et al. also developed several structures to obtain desirable optical characteristics using COMSOL

Multiphysics software [10]. PCFs are also doped with certain background material for example silica, germanium, and topas for getting better results.

Photonic crystal fiber can be utilized for biochemical sensors, gas sensors and monitoring systems, bacteria identification, communication system, lasers, eye treatment, skin treatment, dental portraying, and environmental studies for its special optical properties. PCF is also known as holed fiber which consists of organized micro-structured air cavities inserted throughout the fibers. For achieving the anticipated design, PFC is doped using silicon dioxide. Unlike optical fibers, the core and cladding of PCF are composed of the same material. Modifying the internal geometrical structural parameters of PCFs, such as air-holes diameter, pitch size, and the number of rings high sensitivity response required non-linearity value and less confinement loss for a wide range of wavelength can be achieved. Photonic crystal fiber shows excellent sensitivity to sense different types of chemicals, alcohol, liquids, etc. Anik et al. reported a new class of PCF sensor for detecting PH levels of acetic acid aqueous solution based on Surface Plasmon Resonance (SPR) [15]. Nuzhat et al. also proposed a dual-core surface plasmon resonance (SPR) based photonic crystal fiber (PCF) biosensor for biosensing applications [14].

A defective core octagonal photonic crystal fiber is presented in this paperwork. Five octagonal rings make up the planned PCF's cladding, while the core has five tiny circular air-holes and one big elliptical airhole. This circular air hole causes considerable imbalance within the core, resulting in severe nonlinearity and negative dispersion. At 1.55 m, the suggested O-PCF simulation reveals ultra-high nonlinearity of 93.00 w-1km-1 and negative dispersion of -1417 ps.nm.km-1. Because of the very negative dispersion at the main communication window's center wavelength, 1.55 m, the suggested PCF is ideally suited for dispersion correction.

II. GEOMETRY

The proposed defected core octagonal PCF design consists of five layers of circular air holes and this design is represented in fig. 1. Two different types of circular air holes and one huge elliptical air hole are utilized to obtain ultra-high qualities such as non-linearity and negative dispersion, where d_2 is the lowest circular diameter and d_1 is the largest circular diameter for better negative dispersion and non-linearity. To change the refractive index profile, the proposed PCF comprises five smaller air holes inside the core region. The elliptical air hole has a significant impact on the asymmetry of the core and cladding regions. Pitch is denoted by Λ which is represented as the center-to-center distance between conjugative two air holes.

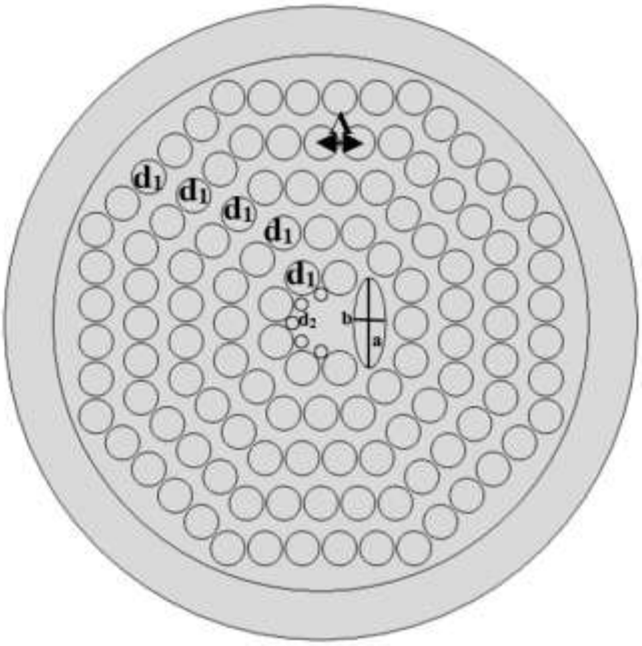


Fig. 1 Cross-section of the designed PCF.

III. NUMERICAL METHOD

To numerically analyze the light traveling properties of the designed DC-OPCF the finite element method-based software COMSOL Multi-Physics is used as a simulation tool. The following equation is used to calculate the light-guiding properties of the proposed PCF [25-27].

$$D(\lambda) = -\frac{\lambda}{c}\frac{d^2 Re[n_{eff}]}{d\lambda^2} \qquad (1)$$

Here, $Re[n_{eff}]$ is the real portion of the effective refractive index, n_{eff}, c is the velocity of light, and λ is the wavelength. Effective mode area is an important characteristic of PCF. The PCF effective mode area in μm^2 and represent as,

$$A_{eff} = \frac{(\iint |E|^2 dxdy)^2}{\iint |E|^4 dxdy} \qquad (2)$$

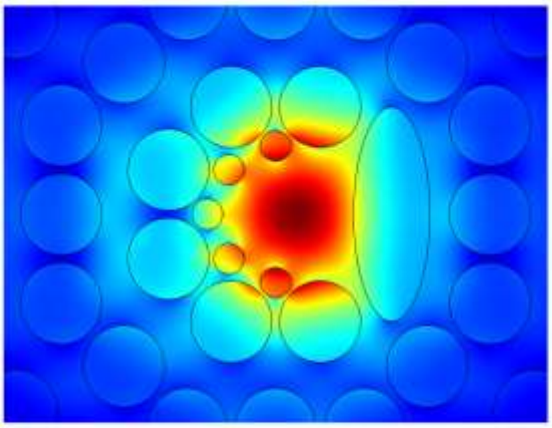
Here E is the Electric field amplitude. Nonlinearity is highly dependent on the effective mode area and defined as

$$\gamma = \frac{2\pi}{\lambda} \times \frac{n_2}{A_{eff}} \qquad (3)$$

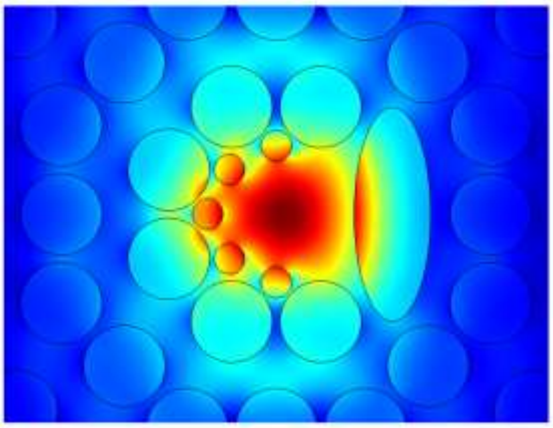
Where n_2 is the Kerr constant.

IV. RESULT ANALYSIS

Fig. 2 shows the temporal distribution of electric fields inside the center of the proposed PCF. The result shows that both x and y polarized mode is tightly confirmed in the core region. Reduction of Dispersion in optical fiber transmission system is a paramount issue. For reducing dispersion effectively-highly negative dispersion compensating fiber is required.



(a) X polarization



(b) Y polarization

Fig.2 Normalized electric field at 1.55 µm for X and Y polarization.

Fig. 3 represents that the dispersion versus wavelength curve for both slow and fast axis. A large negative dispersion was revealed for both X and Y polarization mode due to a change of refractive index profile inside the core. At 1.55 µm wavelength, the DC-OPCF shows a high negative value of 1417 ps. nm^{-1}. km^{-1} for both X and Y mode.

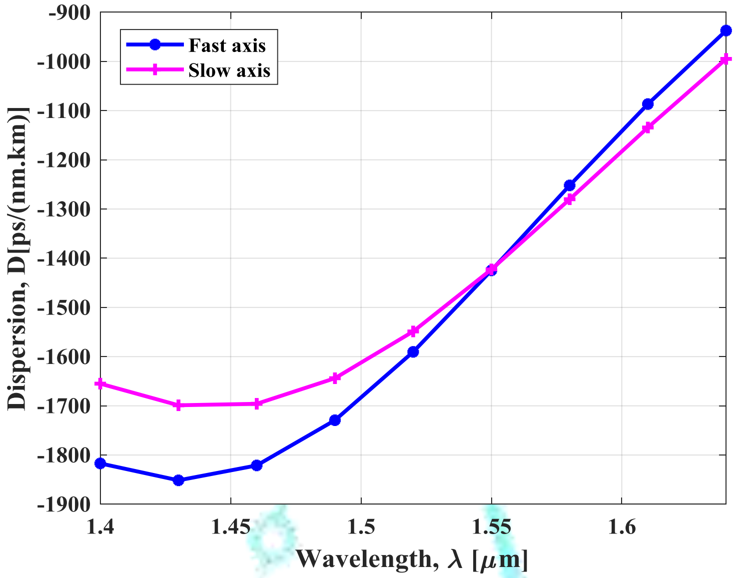


Fig.3 Chromatic Dispersion-wavelength curves for varying pitch sizes.

Fig 4 constitutes of curves of different pitch sizes, where each curve shows the chromatic dispersion values corresponding to wavelength. Different values of pitch 0.76 µm, 0.78 µm, and 0.80 µm are taken while other parameters remain the same. From Fig. 4 it can be clearly seen that the blue curve and green curve show the optimum dispersion for the proposed PCF, and the red curve shows the lowest dispersion for the designed PCF.

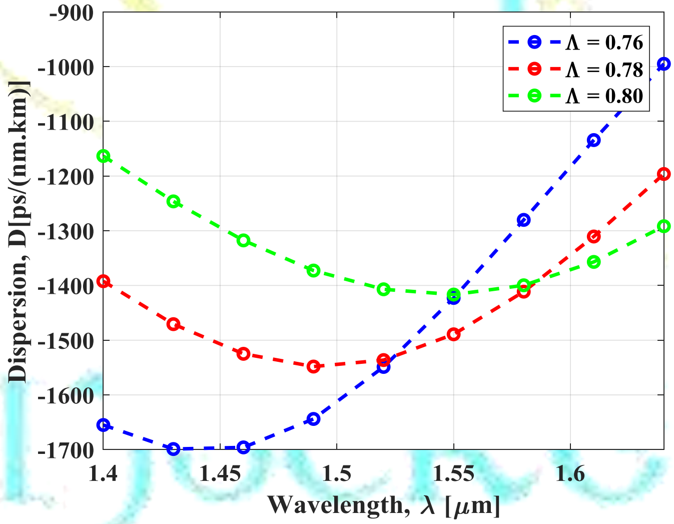


Fig.4 Chromatic Dispersion-wavelength curves for varying pitch sizes

Fig 5 represents the impact of pitch tolerance while other parameters are kept constant. Pitch values are changed from ±1% to ±2% to analyze the fabrication tolerance. From Fig 5 the result shows that a large negative dispersion value ps. nm^{-1}. km^{-1} found when the pitch is changed to +2% and smaller negative dispersion value ps. nm^{-1}. km^{-1} found when the pitch is changed to -2%.

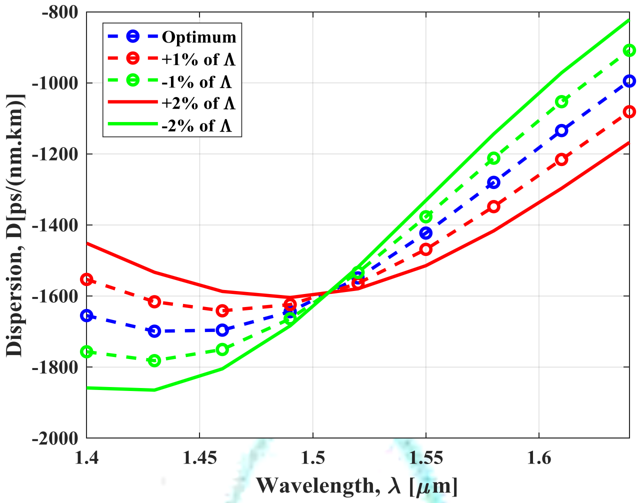


Fig.5 Dispersion characteristics for pitch tolerance ±1% to ±2%.

Fig 6 shows the impact of non-linearity on fiber pitch. From equation (3) nonlinear coefficient is closely related to the effective mode area which reveals that the nonlinear coefficient is decreasing as wavelength increases from 1.35 μm to 1.7 μm. Simulation results confirm that the proposed fiber shows a nonlinear coefficient of 93.00w^1km^{-1} at an operating wavelength of 1.55 μm.

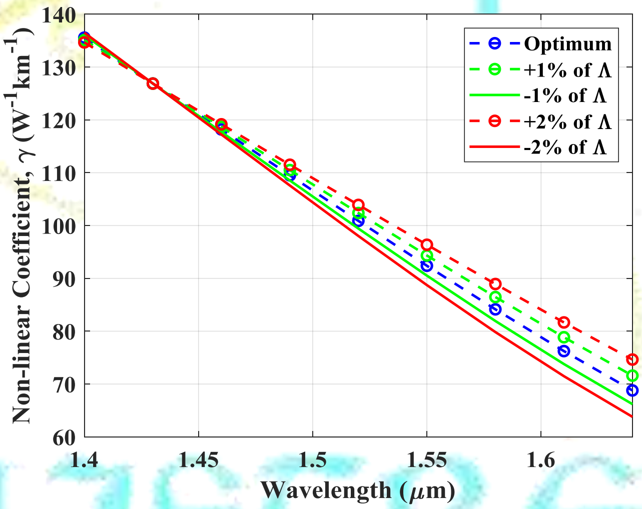


Fig.6 Nonlinear characteristics for pitch tolerance ±1% to ±2%.

The guiding properties of the proposed DC-OPCF are compared with some recent PCF's in Table 1. However, it can be observed from the table that the dispersion value of the proposed PCF is much larger than all the other traditional octagonal PCF designs. The fabrication of such PCFs can be achieved through stack and drawing, drilling, and sol-gel casting [15-16]. The designing of such PCFs is significantly less challenging compared to other designs comprising of rectangular or square air holes. Moreover, the circular shapes used in the proposed design make the manufacturing process much simpler.

TABLE I. COMPARISON OF DISPERSION PROPERTIES WITH RECENT PCFS.

Reference	Dispersion, $ps/(nm.km)$	Nonlinearity, $W^{-1}km^{-1}$
[6]	-753.20	96.51
[7]	-1044	77.85
[28]	-578.50	53.10
[29]	-650	45.50
Proposed PCF	-1417	93.00

V. CONCLUSION

In this paper, we propose a defected core octagonal lattice photonic crystal fiber (PCF) which shows high nonlinearity and negative dispersion. To introduce significant asymmetry in the core, five smaller circular air holes with one large elliptical air hole are placed which leads significant impact on nonlinearity and dispersion. The optimized DC-OPCF presents high nonlinearity of 93 W^{-1} km^{-1} and dispersion of −1417 (ps/nm.km) at a 1.55 μm wavelength. Due to its excellent characteristics, this proposed DC-OPCF fiber gives proficient transmission of broadband waves of signals. Moreover, for different kinds of optical communication applications, our designed DC-OPCF fiber will be highly perfect in the communication regions.

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