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# Design and Analysis of a 2D-PhotonicCrystal Fiber Structure with Ultra-Flattened Dispersion and Single Mode Operation over a Wide Range of Wavelength

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**ABSTRACT**

**A photonic crystal fiber (PCF) presents a new way to guide light. The air holes in the fiber work as a cladding, but provide much more flexibility in the design. In this work, the plane-wave expansion technique for generating and analyzing photonic band structures is used. The simple 2D XY array with a hexagonal cross-sectional pattern of air holes in a silicon fiber is analysed for calculating parameters such as mode effective index, dispersion and single mode operation over wide wavelength range. The results of a design sample presented in this article, showing the better result to analyze this new class of fiber. This fiber can be used for biomedical application, spectroscopy, and super continuum generation.**

**Keywords:** Dispersion, Photonic Band Gap (PBG) , Photonic Crystal Fiber (PCF), Single Mode

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## I. INTRODUCTION

Photonic crystal fibers are a new class of optical fibers. Their artificial crystal-like microstructure results in a number of unusual properties. They can guide light not only through a well-known modified total internal reflection (MTIR) mechanism, but also using a photonic band gap (PBG) effect [1-2]..Conventional photonic crystal fibers are fibers with an internal periodic structure made of capillaries, which are filled with air, and laid to form a hexagonal lattice. Light can propagate along the fiber in defects of its crystal structure, which are realized by removing one or more central capillaries. Combining the properties of optical fibers and photonic crystals they possess a series of unique properties impossible to achieve in classical step index fibers [3]. During the last decade, lot of research work is going on in the field of photonic crystal fiber. In fact, the technological control of the PCF characteristics is nowadays comparable to that of standard Fibers: Photonic crystal fiber having attenuation loss below 0.3 dB/km has been recorded [4]. Index-guiding PCFs possess the attractive property of great controllability in chromatic dispersion by varying the hole diameter (d) and hole-to-hole spacing (?). Control of dispersion in PCFs is very important problem for realistic applications of optical fiber communications. Several designs for the PCF have been proposed to achieve the ultra-flattened dispersion properties. So far, various PCFs with remarkable dispersion properties such as, zero dispersion wavelengths shifted to the visible and near infrared wavelengths [5-6], ultra-flattened chromatic dispersion [7-8], and a large positive dispersion with a negative slope in the 1.55 μm wavelength range [9], have been reported. Obtaining photonic crystal fibers with required transmission characteristics is a difficult technological problem. One has to shape structures of microscopic size by controlling only macroscopic parameters such as temperature and stretching rate. [10].The main aim of designing these fibers is to improve the performance and reduce the cost of fibers in different applications. PCFs can exhibit unique dispersion characteristics, provide single mode operation over large wavelength range, offer very large or low nonlinearity, and can transport light with very low loss in certain wavelength ranges where the conventional optical fibers are very lossy.

## II. DESIGN

Since the designed PCF consists of a solid core with a regular array of air holes running along the length of the fiber acting as the cladding. In this type of PCF the mean cladding refractive index is lower than the core index. Under correct conditions (high air-filling fraction), PBG guidance may also occur in this case, but the TIR-guided modes will dominate [11]. Due to an operation based on total internal reflection, the properties of high index core triangular PCFs in many respects resemble those of step-index fibers. However, very important differences occur as a result of the complex geometry of the cladding structure. Their most important advanced properties are endlessly single mode (ESM), ultra low bending loss and capability of having large numerical aperture. [12].

The dispersion is strongly affected by the air/glass index contrast and the possibility to get small core. So, the dispersion can be controlled efficiently by using different air filling fraction. Moreover, it is relatively easy to change ?/?, d/? and it is even possible to change d (hole diameter) at each period. Changing the size of d at each period bears two advantages: a better control of the dispersion curve and fewer periods are required to have reasonable loss.

PCFs show much lower loss in comparison with conventional fibers. The chief reason for the ultra-low attenuation displayed by PCFs, compared to other waveguide structures, is the very large extension ratio from perform to fiber. This process has the effect of smoothing out imperfections, resulting in a transverse structure that is extremely invariant with distance along the fiber[11].

As we know that all the PCF guided modes are leaky. In solid core PCFs light is confined within a core region by the air-holes. Light will move away from the core if the confinement provided by the air-holes is inadequate. This means that it is important to design such aspects of the PCF structure as air hole diameter and hole-to-hole spacing, or pitch, in order to realize low confinement loss PCFs. In particular, the ratio between the air-hole diameter and the pitch must be designed to be large enough to confine light into the core. On the other hand a large value of the ratio makes the PCF multy-mode. However, by properly designing the structure, the confinement loss of single-mode PCFs can be reduced to a negligible level [12].

Figure 1. is of a proposed photonic crystal fiber with a triangular lattice of air holes, where d(0.5 µm) is the hole diameter, ?(2.3 µm)is the hole pitch, and the refractive index of silica is 1.45. In the centre, an air hole is omitted creating a central high index defect serving as the fiber core.

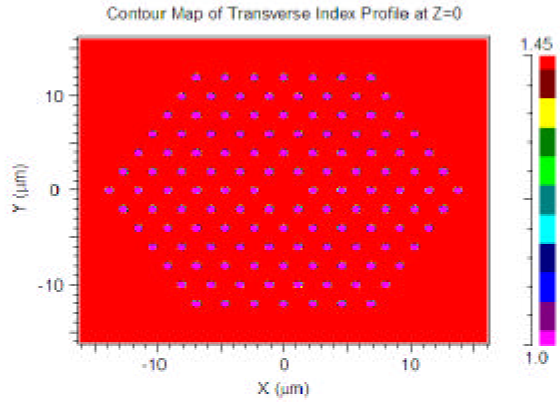


Fig 1: The index profile of 2D XY array hexagonal cross-sectional pattern of air holes in a silicon fiber.

The cross-sectional view of the proposed PCF design is shown in Fig. 1. The cladding of the proposed PCF consists of a hexagonal lattice of circular air holes with a diameter d in fused silica.

In this paper, the diameter of the air holes in the cladding is set to be 0.5µm where the hole pitch ? is 2.3µm. Using the plane-wave expansion technique, the field distribution as well as its model effective indices are calculated for different modes.

## III. NUMERICAL ANALYSIS

Properties of standard optical fibers (SIF) are often parameterized by the so called V-parameter (normalized frequency) and the entire concept is very close to the heart of the majority of the optical fiber community. The cut-off properties and single-mode over wide wavelength range of PCFs can also be qualitatively understood within this framework. For an operating wavelength, if the value of V parameter is less than or equal to 2.405, then the fiber is said to be operating in the single mode regime in standard optical fiber. The SIF is characterized by the core radius ?, the core index $n_{co}$ and the cladding index $n_{cl}$ which all enter into the parameter $V_{SIF}$ given by, [12]

$$V_{SIF} = \frac{2\pi\rho}{\lambda}\sqrt{{n_{co}}^2 - {n_{cl}}^2} \qquad (1)$$

However, using equation (1), it is not possible to analyze PCFs, as it has not taken pitch (?), and diameter (d) into consideration. The photonic crystal fiber is rather analyzed by equation (2) given below [14].

$$V = \frac{2\pi a_{eff}}{\lambda}\sqrt{{n_{co}}^2 - {n_{cl}}^2} = \sqrt{U^2 + W^2} \qquad (2)$$

Where U & W are known as normalized transverse phase and attenuation constants, given by equation (3). Where $a_{eff}$ is the effective core radius and is given by

$a_{eff} = \frac{\Lambda}{\sqrt{3}}$ , $n_{co}$ is core refractive index, $n_{cl}$ is cladding index, $n_{eff}$ is index of the fundamental guided mode, $\lambda$ is operating wavelength.

$$U = \frac{2\pi a_{eff}}{\lambda}\sqrt{n_{co}^2 - n_{cl}^2} \quad \text{and}$$

$$W = \frac{2\pi a_{eff}}{\lambda}\sqrt{n_{eff}^2 - n_{cl}^2} \qquad (3)$$

A plane-wave expansion technique for generating and analyzing photonic band structures and dispersion property is used. Alternately, we can also use empirical relations [13] for the analysis of dispersion property of photonic crystal fiber. By trial and error method, we get the values of V and W parameters comparable with the values obtained from plane-wave expansion method. Then, the values of $n_{cl}$ for different wavelengths are determined using equation (2)

Once we have the values of V, W, and $n_{cl}$, we can easily find out the effective refractive index from equation (2) and (3).

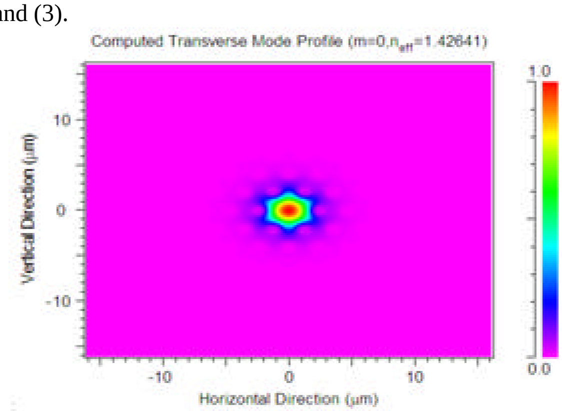


Fig 2: Mode Profile of 2D XY array with a hexagonal cross-sectional pattern of air holes in a silicon fiber.

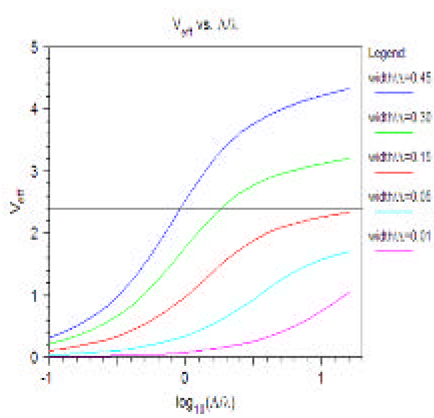


Fig 3: Effective V parameter for different values of air hole diameter (d)/ ?

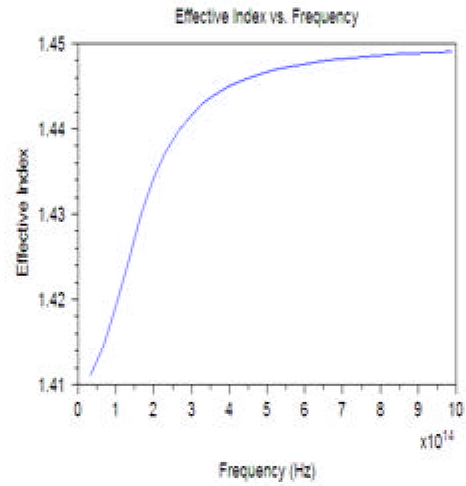


Fig 4: Effective index vs. Frequency graph

## IV. CONCLUSIONS

In conclusion, a novel six ring PCF with same air-hole diameters is proposed. The designed PCF presents desirable dispersion variation and low loss for telecommunication applications. In other words, the PCF shows ultra-flattened dispersion and ultra-low loss in wide range of wavelength (1.2 µm to 1.7 µm). It is believed that the proposed PCF will have promising future in ultra-broadband transmission applications. The proposed PCF is easy to fabricate because of the same size of the air hole diameters.

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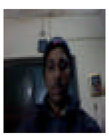

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