

BIREFRINGENCE PROPERTIES OF PHOTONIC CRYSTAL FIBER BASED ON HEXAGONAL AND OCTAGONAL AIR HOLE UNDER EXTERNAL STRESS

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ABSTRACT

In this research work an analysis is carried out to observe the effect of thermal and external stress on birefringence properties of hexagonal and octagonal air hole arranged photonic crystal fiber (PCF). The fiber design is based on air hole arrangement by varying air hole diameter. Stress is applied on the PCF boundary and the effective indices, birefringence are calculated as a function of stress. It is found that the external stress induces higher birefringence for hexagonal PCF than the octagonal one. From our simulation result we could infer that the effect of external stress on birefringence of hexagonal PCF is higher than octagonal for a fixed air hole diameter and this effect becomes lower for larger air hole diameter.

Keywords: Photonic Crystal Fiber, Finite Element Method, Elasto-Optic Effect And Birefringence.

1. INTRODUCTION

Photonic crystal fibers (PCFs) are micro-structured optical fiber which are constructed by single material with multiple air holes periodically arranged around the core. PCFs are generally divided into two main categories: index guiding fibers that have a solid core and photonic band gap or air guiding fibers that have periodic micro-structured elements and a core of low index material (e.g. hollow core). PCF has ability to be single mode over a broad range of wavelengths [1-2]. Large number of available design parameters of solid core PCF makes the dispersion, nonlinearity and confinement loss highly configurable. PCFs are of great interest for optical communication in new wavelength regions and for new optical devices. The strong wavelength dependency of the effective refractive index and the inherently large design flexibility of PCF allow for a whole new range of novel properties [3-4]. Such properties include endlessly single-mode fibers, extremely nonlinear fibers and fibers with anomalous dispersion in the visible wavelength region. Applications of PCF includes spectroscopy, metrology, biomedicine, imaging, telecommunication, industrial machining, military and the list keeps growing as the technology becomes a mainstream [5-7].

From some recent research, it is found that the stress and thermal effect on fiber can alter the propagation properties of PCF [8-10]. These works mainly carried out on effective index, birefringence, polarization mode dispersion and confinement loss properties only for

hexagonal arrangement of air-holes with few design parameters [11-12]. So there is a scope to work with other arrangements of air-holes for different design parameters under external stress. In this research work an analysis is carried out to observe the effect of thermal and external stress on birefringence for both hexagonal and octagonal air hole arranged PCF. The air hole diameter is varies in designing the air hole arrangements for both type of structures. Then different stress is applied on the PCF boundary and the effective indices, birefringence are calculated as a function of stress. It is observed that the external stress induces relatively higher amount of birefringence for hexagonal PCF than octagonal assuming all the parameters for both structures are same. Furthermore, it has been noticed that external stress effect is less on the birefringence properties of octagonal PCF.

2. FORMULATION

To study the distribution of stresses in an optical fiber, the finite element method (FEM) is a highly suitable method. The modal solution approach is based on the FEM, the intricate cross section of a PCF can be represented by using many triangles of different shapes and sizes. The total result is found by integrating all adjacent triangles result.

In ideal fibers with perfect rotational symmetry, the two modes are degenerated with equal propagation

constants and any polarization state injected to the fiber will propagate unchanged. External stress acting on the holey fiber induces a specific stress distribution in the fiber's cross section and makes deformation of the fiber's structure. These imperfections and stress break the circular symmetry of the ideal fiber and lift the degeneracy of the two modes. The new refractive index for x and y polarized light due to external stress can be calculated from the following equations [6],

$$n_x = n_0 + C_1\sigma_x + C_2(\sigma_y + \sigma_z) \quad (1)$$

$$n_y = n_0 + C_1\sigma_y + C_2(\sigma_x + \sigma_z) \quad (2)$$

$$n_z = n_0 + C_1\sigma_z + C_2(\sigma_x + \sigma_y) \quad (3)$$

where, C_1 , C_2 are the elasto-optic coefficient of the fiber or waveguide material, n_{x0} , n_{y0} and n_{z0} are the unstressed refractive indices of the material and n_x , n_y and n_z are the main diagonal element of the anisotropic refractive index tensor.

Effective refractive index is a number that quantify the phase delay per unit length in a waveguide. An effective refractive index for single mode fiber sometimes referred to as a phase index or normalized phase change coefficient. The modal effective refractive indexes are solved from Maxwell's equations and given by

$$n_{eff} = \frac{\beta}{k_0} \quad (4)$$

where, β is the propagation constant and k_0 is the free-space wave number.

Then the modal birefringence of the fiber is obtained by

$$B_m = n_{eff}^x - n_{eff}^y \quad (5)$$

where, n_{eff}^x and n_{eff}^y are the effective indices in x and y direction respectively.

3. RESULTS AND DISCUSSION

In this paper, the FEM has been used to find modal solutions using COMSOL Multiphysics modeling and simulation tool. Here, we have considered two types of PCF hexagonal and octagonal. Where, R is the fiber cross sectional radius, d is the air-hole diameter, r is the air-hole radius, Λ is pitch (distance between two air holes) and Nr is the number of air hole rings. Fig.1.(a) shows the cross-section of hexagonal PCF and (b) shows the cross-section of octagonal PCF, where $R=12\mu\text{m}$, $d=1.0\mu\text{m}$, $\Lambda=2.5\mu\text{m}$ and $Nr=4$.

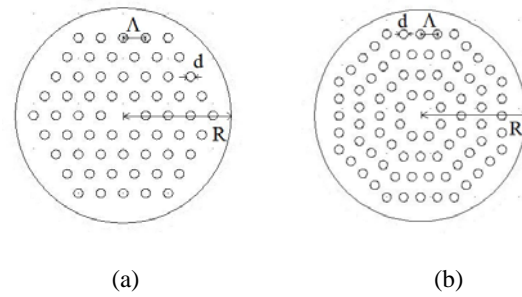


Fig 1. Cross section of PCFs (a) Hexagonal PCF and (b) Octagonal PCF.

3.1 Effective Index

At first we have performed the stress analysis to get the stress effect on PCF. The stress-induced corrections of the refractive index are used as input information for optical analysis by FEM. We have obtained the modal effective index the output of optical analysis. Fig.2 and Fig.3 shows that effective index increases with the increase of external stress for both structures which agrees with the result in [9]. Here, the results are shown for various air hole diameters. It shows that effective index decreases with the increase of air hole diameter. To compare this change for hexagonal and octagonal air hole arranged PCF, we have assumed all the parameters same (*i. e.* $\lambda=1.55\mu\text{m}$, $d=1.6\mu\text{m}$, $\Lambda=2.5\mu\text{m}$ and $Nr=4$) for both structures. Effective indexes for hexagonal air hole arrangement are greater than octagonal. The Fig.4 shows that effective index changes more sharply for hexagonal structure than that of octagonal with the increase of applied stress.

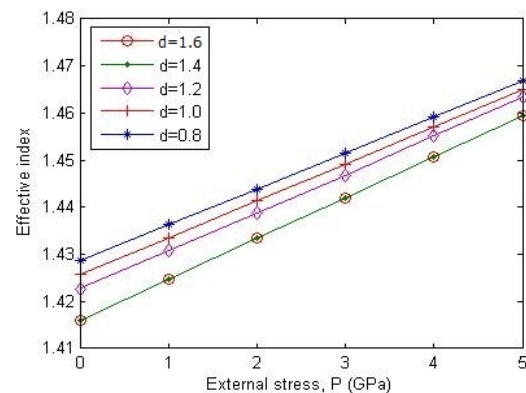


Fig 2. Effective index as a function of external stress for hexagonal air hole arrangement, where $\lambda=1.55\mu\text{m}$, $\Lambda=2.5\mu\text{m}$ and $Nr=4$.

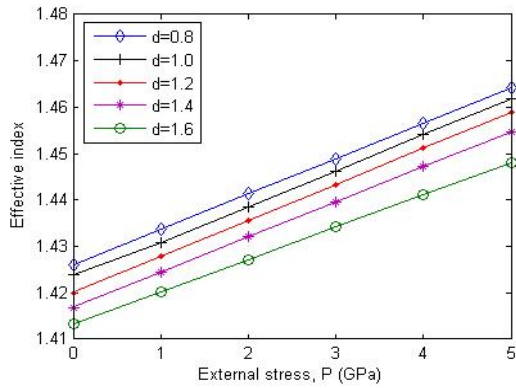


Fig 3. Effective index as a function of external stress for octagonal air hole arrangement, where $\lambda=1.55\mu\text{m}$, $\Lambda=2.3\mu\text{m}$ and $Nr=4$.

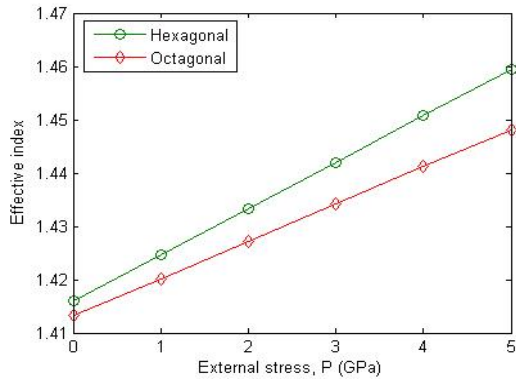


Fig 4. External stress effect on effective index for both hexagonal and octagonal air hole arrangement, where $\lambda=1.55\mu\text{m}$, $d=1.6\mu\text{m}$, $\Lambda=2.5\mu\text{m}$ and $Nr=4$.

3.2 Birefringence

External stress causes fiber structure deformation which breaks circular symmetry of the ideal fiber. Which makes different modal effective index in x and y axis that induce modal birefringence. The amount of deformation is different for different PCF structures. So that induced birefringence is not same for different structured PCFs. Fig.5 shows that birefringence increases as a function of stress and air hole diameter that agrees with the result of ref. [7]. It also shows that this change is relatively higher for larger air hole diameter. Fig.6 depicts that for octagonal arrangement birefringence also increases with the increase of stress but this change is comparatively smaller than hexagonal PCFs. This is clear in Fig.7 which shows, birefringence as a function of external stress changes more rapidly for hexagonal structure than octagonal structure with same design and operating parameters.

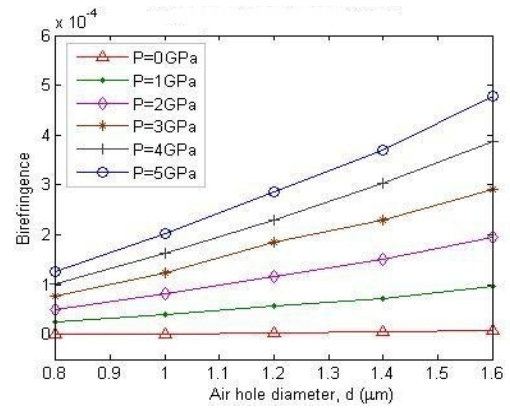


Fig 5. Birefringence of hexagonal PCF as a function of air hole diameter and external stress, where $\lambda=1.55\mu\text{m}$, $\Lambda=2.5\mu\text{m}$ and $Nr=4$.

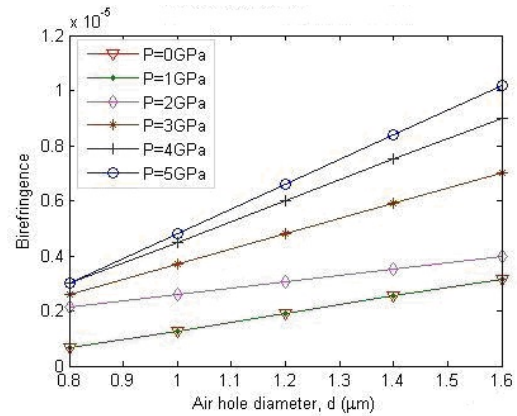


Fig 6. Birefringence of octagonal PCF as a function of external stress and air hole diameter, where $\lambda=1.55\mu\text{m}$, $\Lambda=2.5\mu\text{m}$ and $Nr=4$.

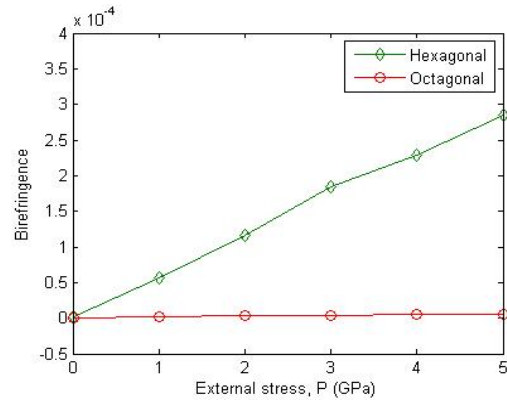


Fig.7. External stress induced birefringence for both hexagonal and octagonal PCF, where $\lambda=1.55\mu\text{m}$, $d=1.6\mu\text{m}$, $\Lambda=2.5\mu\text{m}$ and $Nr=4$.

4. CONCLUSION

It is found that effective index as a function of external stress increases more quickly in hexagonal

structure than octagonal but it decreases with the increase of air hole diameter. Again birefringence has been found to be larger for hexagonal PCF than octagonal one. However, this change is more for larger air hole diameter. The effect of external stress on hexagonal is more than octagonal PCF. The finding of this research will help to set the appropriate PCF design parameters for specific area of application.

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6. NOMENCLATURE

Symb ol	Meaning	Unit
n	Refractive index	Dimensionless
n_{eff}	Effective index	Dimensionless
P	Pressure	(GPa)
λ	Wavelength	(μm)
A	Pitch	(μm)
d	Air hole diameter	(μm)
Nr	Number of air hole rings	Dimensionless
D	Fiber cross section diameter	(μm)

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