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# Study the Effect of Some Photonic Crystal Arrangements on the Dispersion and Effective Refractive Index of Photonic Crystal Fiber

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**Abstract:** ***The recent optical fibers are the microstructure optical fibers (MOFs). They are consistingof a hexagonal arrangement of air holes along the length of a silica fiber surrounding a central core of solid silica. They can guide light through the total internal reflection mechanism and photonic band gap effect. PCFs contain axially air channels which provide alargedegreeoffreedomindesignto achieveavarietyof peculiar properties,numerous PCF-based sensors have been proposed, developedand demonstrated fora broad range of sensing applications,PCF is depends on different parameters such as the diameter of air hole, number of holes, and the distance between the air holes. This paper presents the results of the customizing of a photonic crystal fiber. This customizing is essential to know the actual parameters of the PCF for its use in the application.***

## 1. Introduction

Fibers made of photonic crystal (PCs) are fibers having internal periodic structure made of fine tubes[1] filled with air, laid to form a hexagonal lattice. To confine the propagating light in a narrow region the photonic structure is used in the graphene layer for the sake of enhancing light–matter interaction[2]. They much attention have been paid in recent years to PCFs due to these flexible structure, easy on-chip integration, outstanding light confinement capability, and compact size [3]. There exist several parameters to manipulate lattice pitch, air hole shape and diameter, refractive index of the glass, and type of lattice[4]. Freedom of design allows one to obtain endlessly single mode fibers, which are single mode in all optical range and a cut-off wavelength does not exist[5].Moreover, there are two guiding mechanisms in PCF, there are index guiding mechanism (similar to the one in classical optical fibers) and the photonic bandgap mechanism. The holey Fiber (also called the index guided fiber) light is guided in the solid core made of pure silica by modified total internal reflection mechanism [6-8],light guidance in solid-core PCF can still be well explained with the total internal refraction of light on the interface between the core which has refractive index of silica and the cladding which has lowered effective refractive index due to air holes [9], this type shown in figure (1a).

While Photonic Band-Gap Fibers follows Photonic Band Gap Mechanism and here the light is guided in air holes. When replacing central part of the array of air holeswith a bigger hole of much larger diameter in comparison to the surrounding holes, so obtained fiber is called the Photonic band-gap fiber. The structure periodicity of is broken, sodefect introduced causes a change in its optical properties[11-12].Figure (1b) illustrates the Photonic Band Gap Fiber.

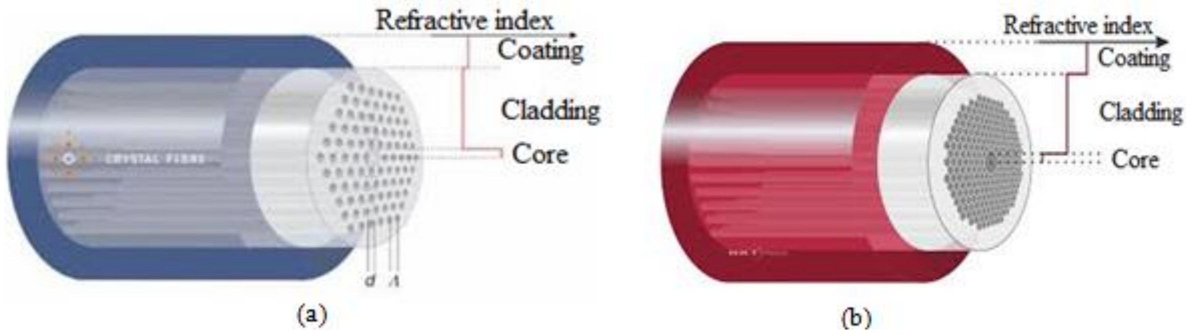


**Figure 1:** PCF microstructured cladding (a) solid core and (b)hollow core PCF [10]

## 2. Theory

The nonlinear Schrödinger equation (NLSE) is approximately describes the propagation of an optical signal, through a fiber[13], by neglecting, third and fourth order dispersion coefficient of the medium so the equation appeared in the form (1):

$$\frac{\partial A}{\partial z} = -\frac{\alpha}{2}A(z,t) - \frac{i}{2}\beta_2\frac{\partial^2 A}{\partial t^2} + i\gamma|A|^2 A \; \ldots (1)$$

Where theapproximation slowly-varying envelope is used with assumptiveinstantaneous nonlinear response. A(z, t) is the electric field amplitude complex envelope of the optical signal at a retarded time (a temporal frame of reference moving with the group velocity of the pulse), t, and after propagating a distance, z, and α, $\beta_2$, and γ arethe medium parameters of in which the pulse is propagating.$\beta_2$is the second-order dispersion coefficient, while α is the loss parameter, and γ isthe nonlinear coefficient.

Depending on the width of input optical pulse (50fs), one can neglect delayed nonlinear response and Raman response, and the NLSE (1) can be used[14]. To approximate the NLSE (1),equation (2) below can be useedunder suitable conditions and for the purposes of computer modeling and simulation. When the loss of the medium and the instantaneous signal power are negligiblethese conditions resultand when the pulse is of significant duration. The pulse propagation through the fiber is referred to as being in the linear regimein such a situation. Equations (3) and (4) can be used to analyze the equation in the Fourier domain to come up with an expression to describe the spectrum of the output waveform in Equation (5). ω is taken to be the frequency relative to the center frequency of the optical signal.

$$\frac{\partial A(z,t)}{\partial z} + \frac{i}{2}\beta_2\frac{\partial^2 A}{\partial t^2} + i\gamma|A|^2 A = 0 \ldots\ldots\ldots (2)$$

$$\tilde{A}(z,\omega) = \int_{-\infty}^{+\infty} A(z,t)e^{i\omega t}\,dt \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$\frac{\partial \tilde{A}}{\partial z} - \frac{i}{2}\beta_2\omega^2\tilde{A}(z,t) = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\tilde{A}(z,\omega) = \tilde{A}(0,\omega)exp^{\left(\frac{i\beta_2\omega^2}{2}z\right)} \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Split - Step Fourier Method:

The nonlinear Schrodinger equation can be solved via the Split - Step Fourier Method (SSFM), is based on separating the two components viz., dispersive and nonlinear of the equation from one another. Such assumption means over a very small distance these components may be independent. So,one writes[15-17]:

$$\frac{\partial A}{\partial z} = (\hat{D} + \hat{N})A \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

where,

$$\hat{D} = -\sum_{m=2}^{M} i^{m-1}\frac{\beta_m}{mi}\frac{\partial^m}{\partial t^m} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

is the linear part, and the nonlinear part is given by:

$$\hat{N} = i\gamma(1-f_R)(|A|^2 + \frac{i}{\omega_\circ A}\frac{\partial}{\partial t}(A|A|^2) + i\gamma f_R(\int_0^\infty h_R|A(z,t-t')^2|\,dt' + \frac{i}{\omega_\circ A}\frac{\partial}{\partial t}[A\int_0^\infty h_R|A(z,t-t')^2|\,dt']) \ldots\ldots (8)$$

The solution of equation (6) leads to

$$A(z,h,t) = \exp[h(\hat{D}+\hat{N})]A(z,t) \ldots\ldots\ldots (9)$$

For two non- commuting operators the Baker – Hausdorfftheorem (Weiss and Maradudin,1962) states that:

$$\exp(h\hat{D})\exp(h\hat{N}) = \exp(h[\hat{D}+\hat{N})] + \frac{h^2}{2}[\hat{D}\hat{N} - \hat{N}\hat{D}] + \cdots) \ldots\ldots (10)$$

Ignoring $h^2$and higher terms in the exponential lead to the approximate equation:

$$\exp(h[\hat{D}+\hat{N}]) \approx \exp(h\hat{D})\exp(h\hat{N}) \ldots\ldots\ldots (11)$$

Which leads to the SSFM having an accuracy of approximately second order, as the $h^2$ terms in the Baker – Hausdorff expansion have been neglected. One can note that the nonlinear and dispersive terms do not in fact commute. So that solution for pulse envelope will be:

$$A(z+h,t) \approx \exp\left(\frac{h}{2}\hat{D}\right)\exp\left(\int_z^{z+h}\hat{N}(z')dz'\right)\exp\left(\frac{h}{2}\hat{D}\right)A(z,t) \ldots\ldots (12)$$

Equation (12) will have an accuracy of approximately third order, according to the use of Baker – Hausdorff formula twice.

## 3. Numerical Simulations

This study includes investigating the effects of the various parameters of the photonic crystal; i.e. the air hole diameter, the number of air holes, and the hole-hole spacing (pitch) on the curves of the dispersion and the effective refractive index, the dispersion coefficient, the group velocity, and the shape of the output pulse, moreover, the effect of that on the possibility of obtaining isolated waves. In order to investigate the effect of the diameter of the air holes, values in the range(d=0.5,0.8,1)µm were chosen for them based on theoretical and practical studies, while the pitch and the number of air holes were fixed. A relationship between the dispersion curve and the wavelength within the mentioned range was observed in which increasing the diameter of the holes leads to the shifting the zero dispersion towards the shorter wavelengths, as shown in figure (2).On the other side, the effective refractive index of the core does not affected within the mentioned range of the diameter of the holes, while the effective refractive index of the cladding varies with the diameter,d, in which the difference between the refractive indices of the core and the cladding is increased by increasing the diameter of the holes, as shown in figure (3).

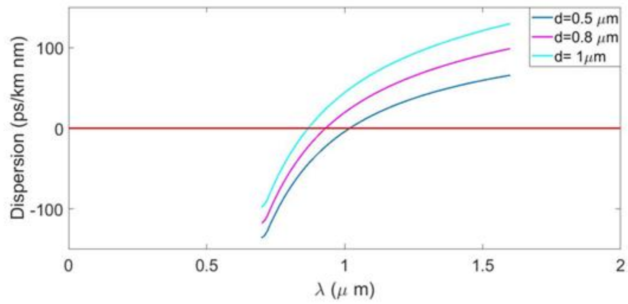


**Figure 2:** Variation of dispersion against wavelength for diameter air holevary as d=(0.5,0.8,1)µm,$\Lambda$= 3µm, and N =6

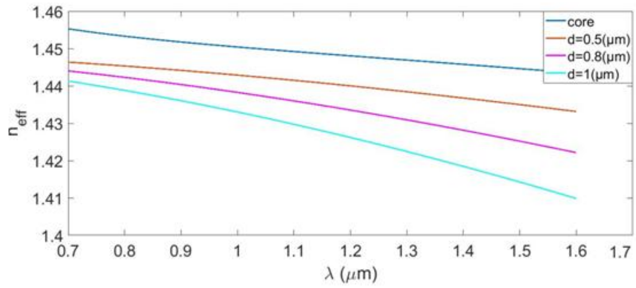


**Figure 3:** Variation of effective refractive index against wavelength for diameter air hole vary as d=(0.5,0.8,1) µm,$\Lambda$= 3µm, and N=6.

While investigating the effect of the holes pitch on the dispersion and the effective refractive index within the dispersion curve values in the range of (Λ=3,3.5,4)µm, it was found when the air hole pitch increases, the dispersion curve shifts toward the longer wavelengths and the wavelength of zero dispersion increases, as shown in figure(4). On the other side, while instigating the relationship between the effective refractive index and the pitch, it was noticed that the effective refractive index of the core remains almost constant for all the pitch values within the range mentioned previously, while the effective refractive index of the core and the cladding is reduced with increasing pitch as shown in figure(5).

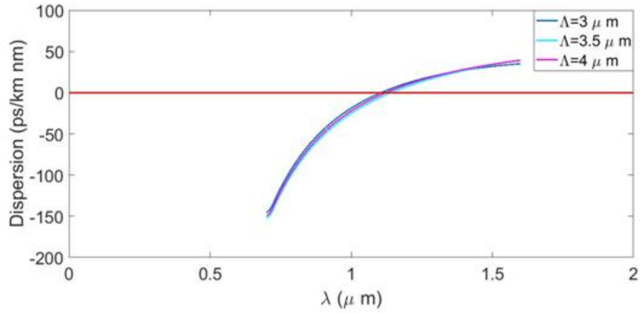


**Figure 4:** Variation of dispersion against wavelength for pitchvary as Λ($\mu m$)=3,3.5,4, d=0.3 $\mu m$,and N=6.

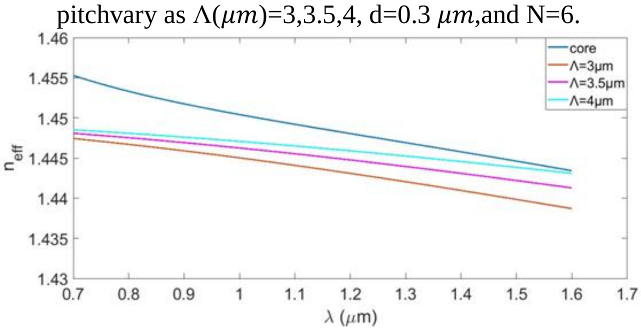


**Figure 5:** Variation of effective refractive index against wavelength for pitch vary as Λ=(3,3.5,4) $\mu m$, d=0.3 $\mu m$,N=6.

In figure(6) observed the effect of the number of the air holes on the dispersion curve and the effective refractive index, certain values of the number of holes of (N=5,8,12), were selected while the air holes pitch and diameter of the holes were fixed at the (Λ=3μm) and (d=0.3μm), and respectively. It was noticed that the curves intersect and match on each other. Moreover, one point of zero dispersion at wavelength ($\lambda$=1.2μm), were observed. In addition, while the holes pitch increases, the dispersion curves shift toward long wavelengths. Regarding the relationship between the effective refractive index and the number of holes, it was noticed that the difference between the effective refractive indices of the core and cladding decreases by increasing the number of holes, while for large number of holes, it was noticed that the curves match each other. The refractive index of the core remains constant for all values of number of gaps, as shown in figure (7).

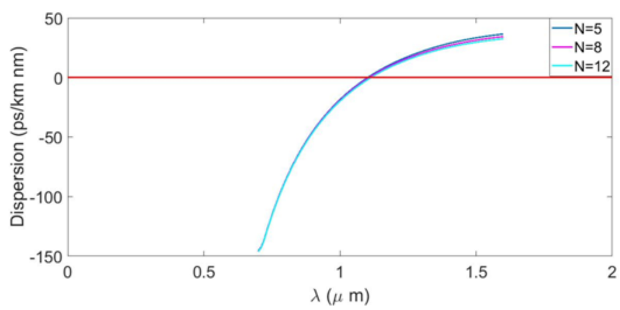


**Figure 6:** Variation of dispersion against wavelength for the number of air holes vary as N=5,8,12, Λ=3$\mu m$, and d=0.3$\mu m$.

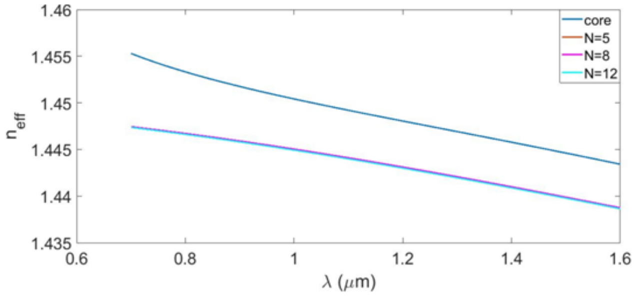


**Figure 7:** Variation of effective refractive index against wavelength for the number of air holes vary as N=5,8,12, $\Lambda$=3$\mu m$, and d=0.3$\mu m$

## 4. Conclusions

Photonic crystal fibers (PCFs) is still very young and we may expect many new developments, more accurate and efficient methods for modeling and characterization. Light guidance in PCFs wascontrolled by some parameters such as the diameter of hole(d), hole-hole space(Λ), and number of holes(N) which deal together with in this paper,but for deeper insight, advanced numerical simulations must be performed. PCFs have numerous interesting feature which can be tailored only by geometry of transverse microstructure. These features are being intensively investigated and first applications of PCFs are emerging. PCFs are promising technology for high power laser and high-power light transmission. In telecommunication, PCFs can be used for auxiliary devices, whilst for usual waveguides, the attenuation at telecom frequencies must still be reduced and the cost effectiveness on the market must be achieved.

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