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ANALYSIS OF PROPAGATION CHARACTERISTICS IN PHOTONIC CRYSTAL FIBER STRUCTURE FOR LARGE NEGATIVE DISPERSION

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ABSTRACT

A photonic crystal fiber is a special class of fiber which is made of a single material and having air holes in the cladding. All the propagation characteristics such as the effective index mode, confinement loss, effective area, dispersion, mode field diameter, splice loss, bending loss are studied by varying the structural parameters. To achieve the light propagation with low confinement loss, high nonlinearity, large negative dispersion, the proposed. Photonic crystal fiber structure is modeled using COMSOL 3.2a simulation software and MATLAB 7 tool. The propagation characteristics are thus analyzed.

KEYWORDS: *Photonic Crystal Fiber PCF, Micro-Structured Fiber MF.*

1-INTRODUCTION

Optical fibers with silica-air microstructures called photonic crystal fibers (PCFs) have attracted a considerable amount of attention recently, because of their unique properties that are not realized in conventional optical fibers[1]. PCFs also called endlessly single mode fibers[4], which are also called holey fibers or micro structured fibers, are divided into two different kinds of fibers[8]. The first one guides light by total internal reflection between a solid core and a cladding region with multiple air-holes. On the other hand, the second one uses a perfectly periodic structure exhibiting a photonic band gap (PBG) effect at the operating wavelength to guide light in a low index core region[3], which is also called photonic band gap fiber (PBGF). The distance between the holes pitch and the diameter of the air holes d is termed as the structural parameter of the PCF[2] and the ratio d/λ as air filling fraction. All the propagation characteristics can be controlled by the variation of the structural parameters. The light in the fiber will be more confined in the core at the shorter wavelengths and the light confinement in the core can be increased by the increasing of the air filling ratio in the cladding. Structural parameter plays an important role of confining the light in the core which affects the propagation characteristics. Because of its ability to confine light in hollow cores, PCF is now finding applications in fiber-optic communications, fiber lasers, nonlinear devices, high-power transmission, and highly sensitive gas sensors.

2 STRUCTURAL DESIGN

2.1 Confinement Loss

Confinement loss is the light confinement ability within the core region and occurs in single material fibers. The increase of air hole rings help the confinement of light in the core region, which results in smaller losses than those with less air hole rings. The confinement loss is

$$Lc = \frac{20x\,10^{6}}{\ln(10)}\,k_0\,\mathrm{Im}[n_{eff}] \quad \text{-------(1)}$$

$$= 8.686\,k_0\,\mathrm{Im}[n_{eff}] \quad \text{--------(1.1)}$$

At the shorter wavelength the light will be more confined in the core part hence the confinement loss will be low and loss will increase as wavelength increases. Changing the air filling ratio causes the change in the confinement loss of the PCF.As the size of the air holes in the cladding part of PCF increases the modes tends to be more confined in the core part and hence the confinement loss reduces.Hence confinement loss can be controlled by varying the air hole size in the cladding part of photonic crystal fiber.

2.2 Dispersion

Dispersion is one of the major parameters for optical communication systems as it limits the network capacity[7].Chromatic dispersion can be determined from effective index by

$$D(\lambda) = -\frac{\lambda}{c}\frac{d^2 n_{eff}(\lambda)}{d\lambda^2} \quad \text{-----------(2)}$$

A high negative dispersion could be achieved by varying the structural parameters.[6]

2.3 Mode Field Diameter and Spot Size:

Mode field diameter is the charactersics of a fiber which describes the confinement of mode or light in the core part of an optical fiber.By using the Marcuse formula.

$$WM = (0.650 + 1.619/V^{-3/2} + 2.879/V^{6})a_{eff} \text{------}(3.1)$$

Where V the normalised frequency is given by

$$V_{eff} = \frac{2\pi}{\lambda} a_{eff} \sqrt{n_{co}^{2} - n_{cl}^{2}} \quad \text{--------(3.2)}$$

Where WM is half of the mode field diameter which is called effective modal spot.Due to the high index contrast between the air holes, PCF offers a small MFD compare to the conventional optical fiber. Less MFD is useful for broadband super continuum and in soliton pulse generation.

2.4 Effective Area

Effective area determines the optical performance of microstructured fiber. The effective area is an important parameter of non linearity in PCF[5]. In PCF, the effective area is lower compared to the standard fibers. The optical nonlinearity also depends on the power density. The effective mode area is given by

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

where E is the transverse component of the electric field.

2.5 Splice loss

Splicing PCF to other PCF or standard SMF is important to many applications in optical telecommunications and integrated sensor systems. Therefore, the evaluation of splice losses that occur due to misalignment when two fibers are spliced, is an important.Lateral splice loss occurs when the fiber is having some transverse offset between their axis.The lateral or the transverse offset splice loss can be defined as follows

$$\eta_{offset} = \frac{4w_1^2 w_2^2}{(w_1^2 + w_2^2)^2} e^{-\frac{2r_d^2}{w_1^2 + w_2^2}}$$

------(5)

where the w1 and w2 are the spot sizes of the fibers which are going to be spliced and r_d is the transverse offset between these fibers.

2.6 Bending loss

Optical fiber suffers radiation losses on the bend and curves on their path.This is due to the energy in the evanescent field at bend exceeding the velocity of light in the cladding and hence the guiding mechanism is inhibited which causes light energy to be radiated from the fiber.

The part of the mode in the cladding outside the dashed arrow line may be required to travel faster then the velocity of the light in order to maintain a plane wave front as this is not possible hence the energy associated through this part is lost through radiation.

Bending loss in the PCF is given as

$$Bend\ loss\left(\frac{db}{m}\right) = 4.343\sqrt{\frac{\pi}{4a_{eff}R_C}}\left(\frac{U_{eff}}{V_{eff}K_1(W_{eff})}\right)^2\left(\frac{1}{W_{eff}}\right)^{\frac{3}{2}} exp^{\left(\frac{-4R_C W_{eff}^{3}}{3a_{eff}V_{eff}^{2}}\right)}$$

-(6)

3. NUMERICAL RESULTS

The modelling and simulations of proposed photonic crystal fiber structure with different structural parameters have been carried out by Finite element method (FEM) with perfectly matched layers (PML) using comsol and matlab software. The results are discussed in this section.We have discussed two structural parameter with air filling ratio d/p as 0.5 and 0.7 at 1000 nm respectively.

3.1 Effective Index Of Fundamental Guided Mode:

The Figure 3.1 shows the electric field pattern of PCF for d/p ratio of 0.5 at 1000nm.we can see the light more confined in the core part of the PCF. From Fig 3.2 we can see that the variation of effective index with wavelength and observe that effective index decreases for increase in wavelength from 0.4 to 2μm. It is clear from this figure that at shorter wavelength the modes tends to be more confined in the core part due to its waveguide structure. The effective index also decreases with increase in d/p value .

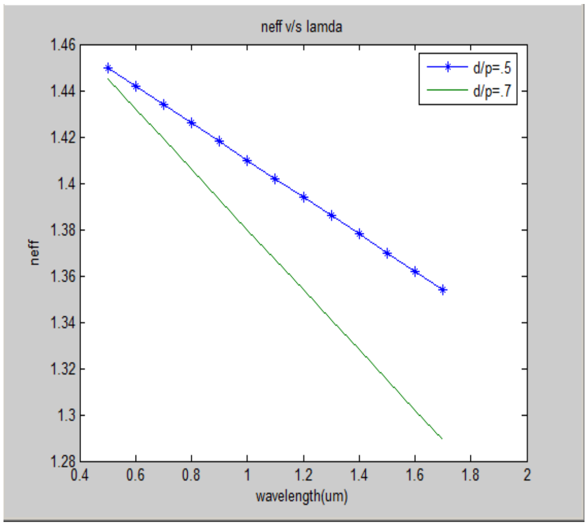

Figure 3.1 Electric field pattern of PCF with air filling factor of 0.5 at 1000nm

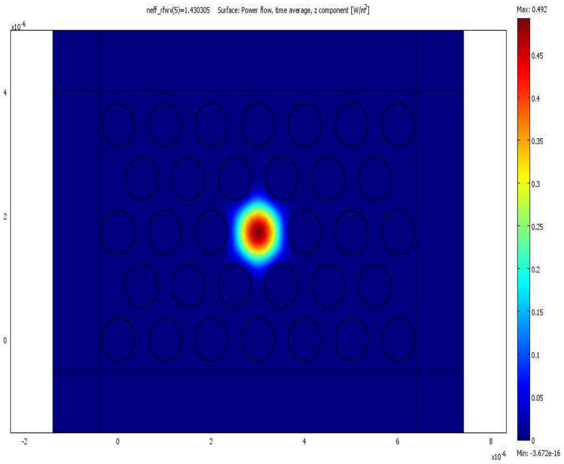

Fig 3.2Variation of neff with wavelength

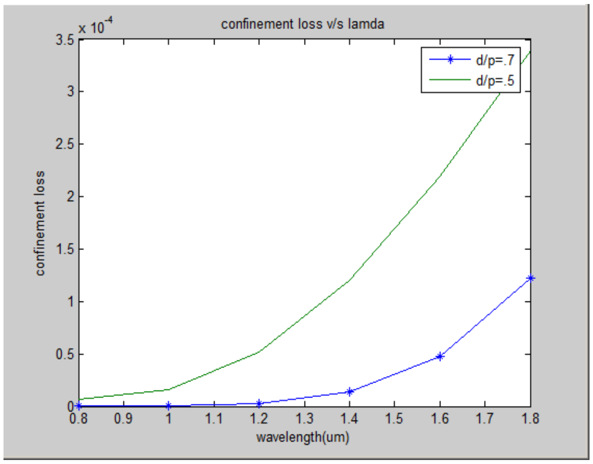

Figure 3.3 Confinement loss with wavelength

Figure 3.3 shows variation of confinement loss with wavelength and we observe that confinement loss becomes less for high values of d/p=0.7.From 0.8μm to 1.2μm the confinement loss is nearly zero for d/p value of 0.7

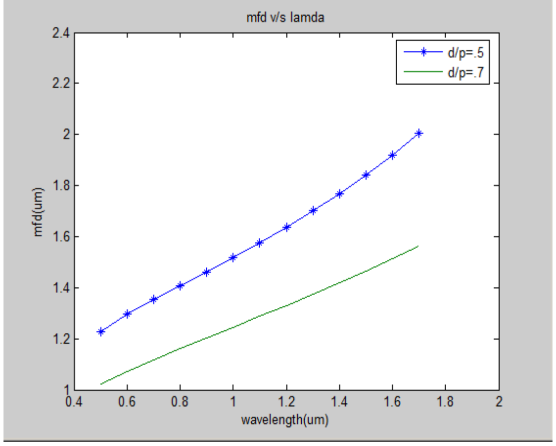

Figure 3.4 Mode field diameter with wavelength

Figure 3.4 shows variation of mode field diameter with wavelength and for high values of d/p=0.7 mode field diameter varies from 1 to 1.5 for wavelength range of 0.4 µm to 1.7µm.But for d/p=0.5 the mode field diameter varies from 1.2 µm to 2 µm.

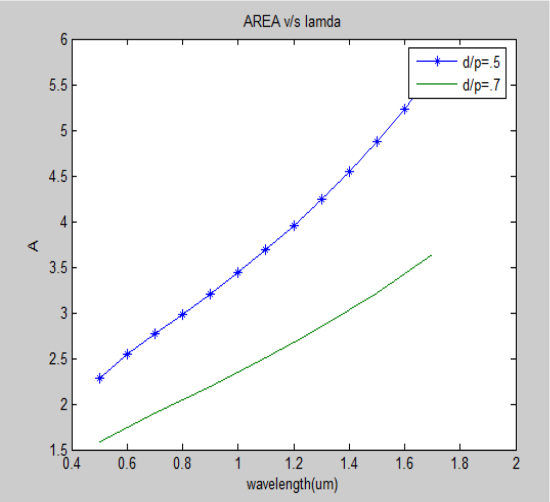

Figure 3.5 Effective area with wavelength

Figure 3.5 shows effective area with wavelength and we observe that effective area increases for low values of d/p=0.5.The effective area for 1000 nm is 3.5 µm^{2}for a d/p ratio of 0.5 and 2.2 µm^2 for d/p ratio of 0.7.

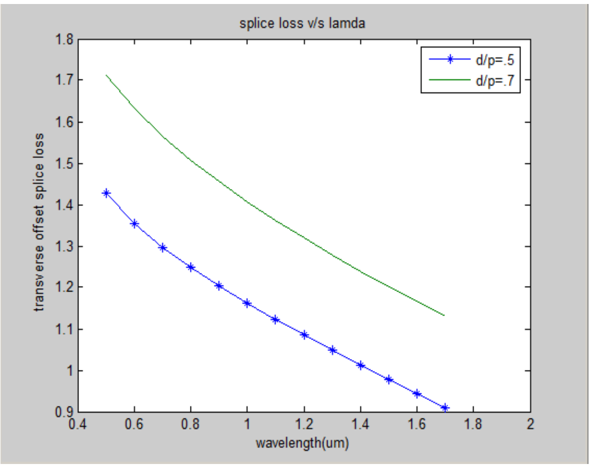

Figure 3.6 Splice loss variation with wavelength

Figure 3.6 which shows variation of splice loss with wavelength .For d/p=0.7 splice loss varies from 1.7 and decreases to 1.1 for wavelength range of 0.4 µm to 1.7µm.For d/p value of 0.5 the value still decreases.

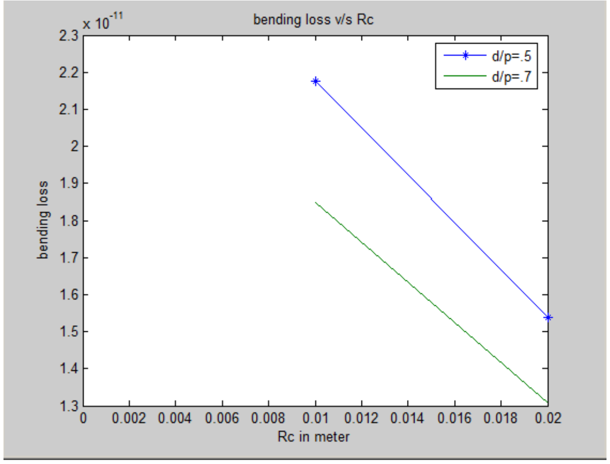

Figure3.7 Bending loss variation with wavelength

Figure 3.7 shows variation of bending loss with radius of curvature. For d/p=0.7 bending loss decreases from 0.01 to 0.02 of radius of curvature

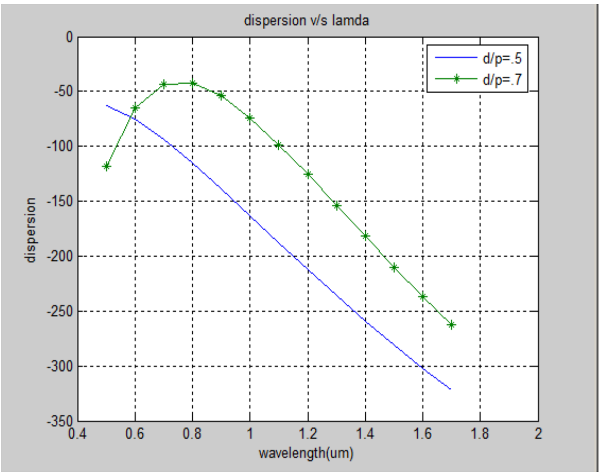

Figure 3.8 Dispersion variation with wavelength

Figure 3.8 which shows variation of wave guide dispersion with wavelength .It is seen that with the structure designed we could achieve a high negative dispersion. For high values of d/p=0.7 dispersion becomes more negative for wavelength between range of 0.4 µm to 1.7µm.

4. CONCLUSION

By varying the structural parameters, propagation characteristics such as, dispersion, confinement loss, effective area, splice loss, bending loss are determined and presented for PCF by using finite element-based approach. As the wavelength decreases the mode will be more confined in the core area of the PCF.Increase in the value of air filling factor the mode effective index decreases , thus the light will be confined in the core area mode. Hence cladding parameters controlling is important to confine light in the core part. The small air holes in the cladding region of the photonic crystal fiber gives large negative dispersion, low attenuation, low transverse offset splice losses while on increasing the air hole sizes confinement loss can be reduced.

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