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HIGHLY NONLINEAR SQUARE LATTICE PHOTONIC CRYSTAL FIBER WITH NEGATIVE DISPERSION

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ABSTRACT

A solid-core square lattice square photonic crystal fiber is modeled by removing four air-holes at the center region is proposed in this paper. Various characteristics are observed for a wavelength range of 1150 to 1750 nm. Negative dispersion, low confinement loss, small effective area and high nonlinearity are obtained. Negative dispersion of -300 ps/nm/km for pitch value of 0.5, low confinement loss of 10^{-10} db/m and a high value of nonlinearity around 110$w^{1}km^{-1}$ at 1550nm wavelength for pitch value of 0.9 is observed. Birefringence value of around 10^{-4} is obtained. Proposed PCF can be suitable for dispersion compensation and non linear applications.

Keywords: photonic crystal fibers (PCF), dispersion, nonlinearity, confinement loss, perfectly matched layer (PML).

1. INTRODUCTION

Nowadays photonic crystal fibers (PCF) are of much attention all around the world. PCF also known as holey fiber or microstructured [1-2] fiber. It is a special type of fiber consisting of a central defect region surrounded by multiple air-holes, which run along entire fiber length. PCF can offer more flexibility than conventional fibers in design of optical properties such as birefringence [3] dispersion, confinement loss and non linearity [4-9]. It has achieved increased attention because of its novel optical characteristics. There are wide varieties of techniques for studying the properties of photonic crystal fiber such as the finite difference time domain method (FDTDM), plane wave expansion method (PWEM), the scalar effective index method (SEIM), the beam propagation method (BPM), the finite element method (FEM), the multiple methods (MPM) etc.

Most of the studies focus on PCF with triangular or square lattice with one missing air hole at the centre. Ytterbium-doped PCF with 19 missing air holes surrounded by 4 rings of air holes have [10] exhibited the largest effective mode area.

In this paper we have proposed a square lattice with four missing air holes with structural parameters of fixed diameter and varying pitch is analyzed. Negative dispersion with high nonlinearity and low confinement loss are obtained.

2. DESIGN OF PCF STRUCTURE

Proposed PCF structure is shown in Figure-1. It consists of a square lattice with four missing air holes at centre which acts as core. Structural parameters are d and Λ which denotes diameter and pitch (distance between adjacent holes) for this structure. Background material used is silica. For fixed diameter of 0.42μm and for pitch values of 0.5μm, 0.7μm and 0.9μm the structure is modeled. PCF characteristics such as dispersion, confinement loss, effective area, birefringence and nonlinearity are calculated. PML region which is the boundary for this structure is of thickness 2μm. The simulation of the model is done by Comsol multiphysics 3.5 based on FEM and Matlab 7 is used to analyse results.

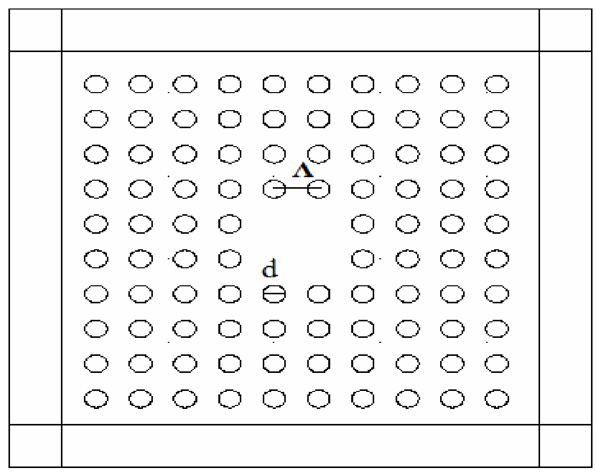

Figure-1. Proposed square lattice structure for d=0.42μm and Λ=0.5 μm.

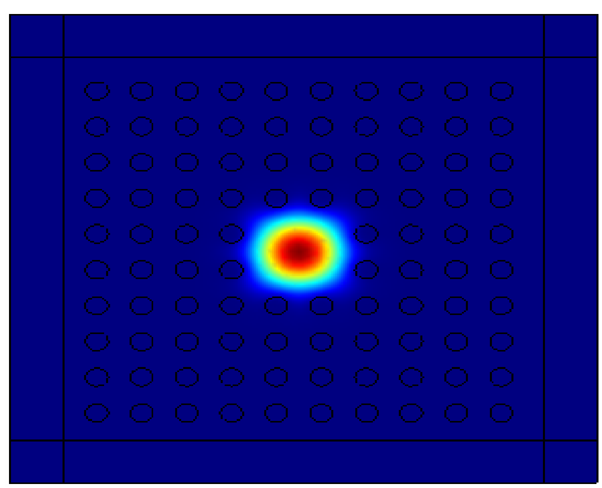

Figure-2. Intensity profile for the structure with d=0.42 μm and Λ=0.5 μm.

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Figure-2 shows the intensity and the shape of output light in two dimensions. We obtain the values for real and imaginary part of effective index values for a wide wavelength region between 1150 nm to 1750 nm.

3. EQUATIONS OF BIREFRINGENCE, CHROMATIC DISPERSION, CONFINEMENT LOSS, EFFECTIVE AREA, NONLINEARITY

Birefringence can be calculated from the difference between Re (n^x_{eff}) and Re (n^y_{eff}) as shown in equation, this two parameters are fundamental eigen values along x and y axis,

$$B = |Re(n^x_{eff}) - Re(n^y_{eff})| \qquad (1)$$

Where n^x_{eff} and n^y_{eff} are effective refractive index for the fundamental E_x and E_y mode.

Chromatic dispersion can be calculated by:

$$D(\lambda) = -\frac{\lambda}{c}\frac{d^2\mathrm{Re(neff)}}{d\lambda^2}\, ps/(nm\ km) \qquad (2)$$

where $\mathrm{Re(neff)}$ is the real part of effective mode index, λ is the wavelength and c is the velocity of light in vacuum.

Confinement loss depends on number of air holes rings, air hole diameter and hole to hole spacing. Confinement loss, which is a fraction of leaky modes, is calculated from the imaginary part of n_{eff} by using equation.

$$L_c = 8.686 K_0 Im(n_{eff}) \qquad (3)$$

Where Im is the imaginary part of effective mode index, and k_0 is the free space wave number, which is equal to 2π/λ.

Effective measure of the area over which the fundamental mode is confined during its propagation can be calculated from effective area. The effective area is defined by:

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

Where E is the electric field in the medium which is obtained by solving an Eigen value problem from Maxwell equations.

Nonlinear optical effects always appear when the power density of light is large enough, regardless of the material. Equation (5) shows that nonlinearity and effective area are inversely related [11] and is given as:

$$\gamma = \frac{2\Pi}{\lambda} X \frac{n_2}{A_{eff}}\ W^{-1}km^{-1} \qquad (5)$$

λ is the wavelength, and n_2 is the nonlinear refractive index co-efficient of the core region given as:

$n_2 = 2.7 \times 10^{-20}\ m^2/W$ for silica fiber

4. SIMULATED RESULTS

From Figure-3 the effective mode index of the fiber is plotted for wavelength range between 1150 nm to 1750 nm.

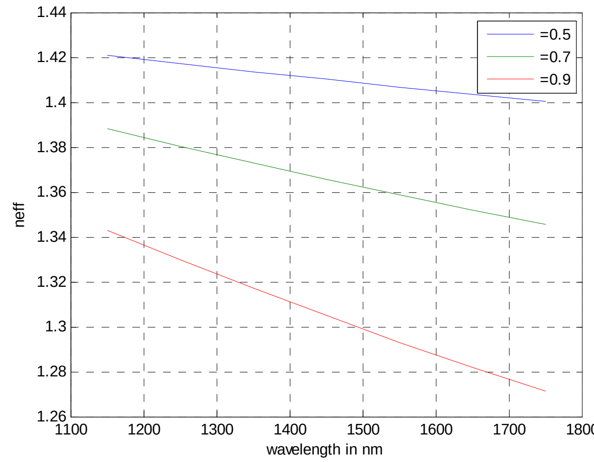

Figure-3. Neff vs wavelength for fixed diameter (d=0.42µm) and Λ values of 0.9 µm, 0.7 µm and 0.5µm.

It shows the relation of Neff varying with wavelength. From figure it is seen that maximum n_{eff} value is obtained for pitch of 0.9. Also it is observed that neff value decreases with increase in wavelength.

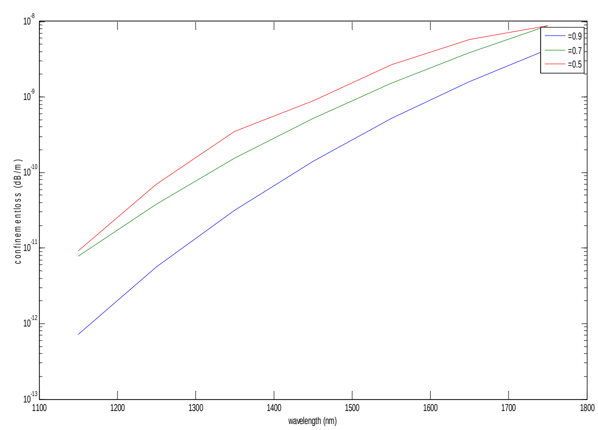

Figure-4. Confinement loss as the function of wavelength for fixed diameter (d=0.42µm) and Λ values of 0.9 µm and 0.7 µm.

Figure-4 shows confinement loss for fixed diameter (0.42µm) and pitch of 0.9µm and 0.7µm. From the results, for low values of pitch, confinement loss is reduced. Confinement loss of the order of 10^{-10} db/m at 1550nm wavelength is obtained. This shows that this structure offers low confinement loss. Confinement loss for the proposed structure is much lower than Rayleigh scattering loss which is of the order of 10^{-4}db/m at same wavelength.

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Figure-5 shows birefringence for pitch values of 0.5μm, 0.7μm and 0.9μm. Birefringence increases as wavelength increases and birefringence decreases as pitch value increases. Birefringence of the order of 10^{-4} at 1550nm wavelength for three cases is observed whose values are higher compared to the same type of PCF.

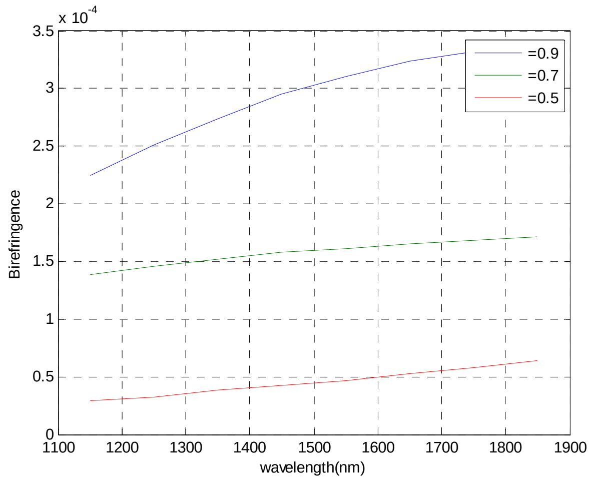

Figure-5. Birefringence as the function of wavelength for fixed diameter (d=0.42μm) and Λ values of 0.9 μm, 0.7 μm and 0.5μm.

Figure-6 shows dispersion curves. From the figure negative dispersion in the range of -48 ps/nm.km to -425ps/nm.km for wavelength range of 1150 nm to 1750nm is observed at Λ=0.5 and -45ps/nm.km to -275ps/nm.km for Λ=0.7 and -3 ps/nm.km to -75 ps/nm.km for Λ=0.9, respectively. Also at 1550nm the dispersion values are -300 ps/nm.km for Λ=0.5, -175 ps/nm.km for Λ=0.7 and - 75 ps/nm.km for Λ=0.9 are observed.

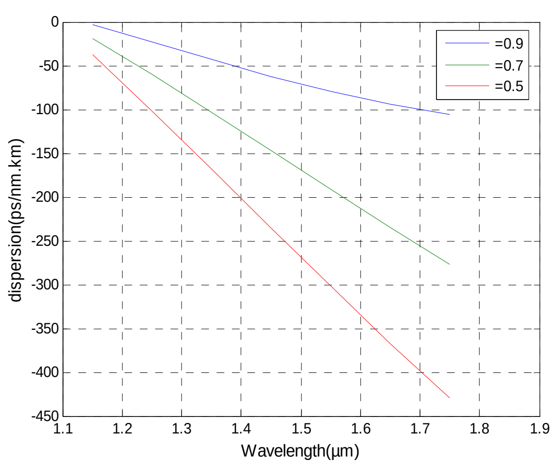

Figure-6. Dispersion variation with the wavelength for fixed diameter (d=0.42μm) and Λ values of 0.9μm, 0.7 μm and 0.5μm.

Figure-7 shows the wavelength dependence of effective area for the proposed structure. Effective area for pitch values of 0.5μm, 0.7μm and 0.9μm are 5μm^2, 2μm^2,1μm^2 respectively which are very small values compared to conventional fibers(around 86μm^2). So high nonlinearity can be achieved.

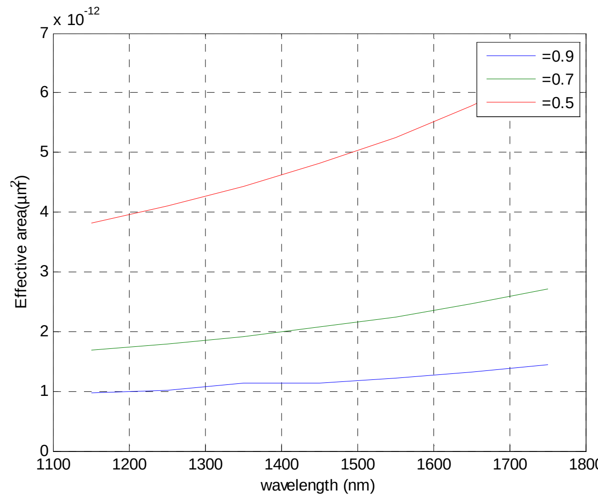

Figure-7. Effective area vs wavelength for fixed diameter (d=0.42μm) and Λ values of 0.9μm, 0.7μm and 0.5μm.

From Figure-8 it is seen at 1550nm nonlinearity of 110W^{1}km^{-1} for pitch value 0.9 is obtained. For pitch values of 0.7 and 0.5 nonlinearity of 50W^{1}km^1 and 25W^{-1}km^{-1} is obtained.

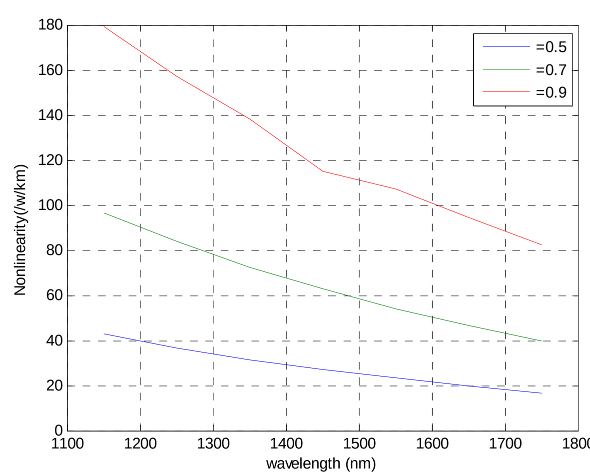

Figure-8. Nonlinearity vs wavelength for fixed diameter (d=0.42μm) and Λ values of 0.9μm, 0.7μm and 0.5μm.

5. CONCLUSION

A simple square lattice PCF structure has been proposed in which core is formed by 4 missing air holes. Optical properties have been studied. This structure offers low confinement loss, small effective area, high birefringence, and high nonlinearity. Negative dispersion of -300ps/nm/km at 1550 nm for Λ=0.5, low confinement loss of 10^{-10} db/m at and a very high value of nonlinearity of around 110 $w^{-1}km^{-1}$ is obtained at 1550nm for Λ=0.9. Birefringence value is of the order of 10^{-4} which is relatively high. This structure design is more effective and easier because lesser geometrical parameters need to be optimized. Proposed PCF can be suitable for dispersion compensation and non linear applications.

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