CHARACTERISTICS ANALYSIS OF DUAL CORE PHOTONIC CRYSTAL FIBER (PCF)

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ABSTRACT

This paper presents the highly birefringent Dual Core Photonic Crystal (DC-PCF) structure operating in wavelength range of 1350-1700nm. The effect of structural parameters on birefringence and the coupling length of designed fiber is analyzed using coupling mode theory and the full-vector finite element method (FEM). Numerical simulation demonstrated that a high birefringence value of 0.0474 and a short coupling length of 19.801 µm is achieved at 1.55 µm. This design based on step by step optimization design, support single-endless transmission over a long length of fiber and covers communication band(S,C,L and U) .

Keyword: *Birefringence, Coupling Length, Normalized Power, coupling length ratio, Extinction Ratio*

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1. INTRODUCTION

Introduction Optical fibers are used as communication channel to transmit light waves over a long distance with possibly attaining a minimum loss. It is because the signal gets degraded during the transmission [1]. To solve this problem a new class of optical fiber with highly structured glass and a periodic distribution of air holes along its length is developed called Photonic Crystal Fiber (PCF). A defect region is formed in the center of the fiber through which light can propagate by total internal reflection principle [2-4]. PCF controls the optical properties, dispersion properties, transmission as well as non linear properties by controlling its structural parameter such as air hole diameter (d) and hole-hole spacing (^). PCF have numerous advantages over conventional fiber some of them are guidance through hollow core (air hole), high birefringence [5], low attenuation [6], more power transmission, dispersion management [7-8], large effective area with high non-linearity [9-10].

A high birefringence can be induced in index-guiding PCFs using different air hole sizes or elliptical air holes in the cladding region [11-13]. Now a day dual-core photonic crystal fibers (DC-PCFs) are designed by introducing two defects in the central region of PCFs and applied in optical fiber coupler[14]. In this paper, a new design of a high birefringence DC-PCFs is proposed using circular air holes. The field distribution, guided modes, birefringence and coupling length properties of fiber are analyzed numerically using the perpendicular wave module COMSOL MULTIPHYSICS software. Such dual-core PCF widely used in polarization maintaining optical devices, splitter and couplers. It is also used in digital electronics e.g. logic gates, Multiplxer-Demultiplxer etc.

2. PCF DESIGN

2.1 Selecting a Structure Parameter

Introduction The cross-sectional geometry of proposed DC-OPCF is shown in fig., 1, in which circular air holes are arranged in order to form a hexagonal lattice structure. Dual core is formed by removing three air holes neighbors to central horizontal air hole. DC-PCF is characterized by hole-hole distance i.e. lattice length (^) and the circular air hole diameter d.

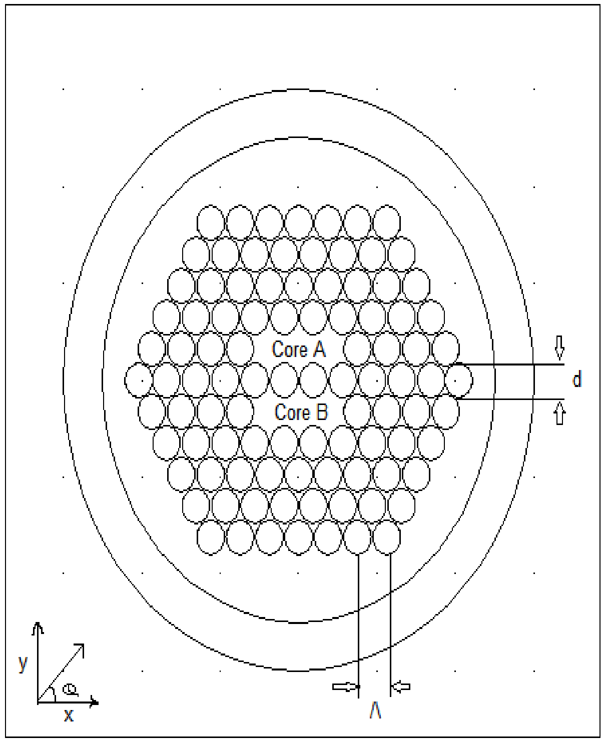


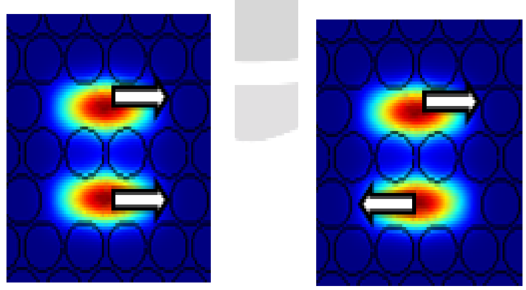
Fig.,1 Cross-section of designed DC-PCF.

The background material is pure silica and refractive index of pure silica can be determined by Sellmeier equation as follows:

$$n^2(\lambda) = 1 + \frac{B_1\lambda^2}{\lambda^2 - \lambda_1^2} + \frac{B_2\lambda^2}{\lambda^2 - \lambda_2^2} + \frac{B_3\lambda^2}{\lambda^2 - \lambda_3^2} \qquad (1)$$

With B_1=0.696166300, B_2=0.407942600, B_3=0.897479400, λ_1=0.0684043μm, λ_2=0.1162414μm, λ_3=9.896161μm. The effect of structural parameters on birefringence and the coupling length of designed fiber is analyzed using coupling mode theory and the full-vector finite element method (FEM) with perfectly matched layer(PML).

In Fig.,2 shows Electric Field distribution of designed structure for x and y mode respectively. The even mode and odd mode of designed DC-OPCF is evaluated and their corresponding x and y polarized electric field distribution is shown in fig. 2 b) and c) respectively, at design parameter of lattice length/pitch (Λ) =0.75μm, d=0.72μm.



a) **b)**

Fig., 2 a),b) simulation results of x-even and y-odd mode field distribution and vectors direction respectively at 1.55 μm.

The effect of incident light on one core is examined on the other core and it is seen that propagation mode excited in core A will enter into the core B. Power transfers back and forth between the two cores of the PCF, during transmission of light along the fiber. By using phase matching condition power will be transmitted completely from one core to other.

Design process of DC-OPCF consists of the following steps shown in the in Fig. 3. In the first step geometric parameters like size and shape of air holes, no of air hole rings, hole-hole distance and background material are chosen. Then the next step is setting simulation parameter (operating wavelength and field). Mesh analysis is done to by setting boundary condition. Mode analysis refers to evaluation of the DC-PCF guided modes and selecting a well confined mode is performed in the next step. If the simulated result satisfied then carry out further analysis, if not then change the geometrical parameter like air hole diameter, hole-hole distance to obtain desired results.

2.2 Characteristics Analysis of DC-PCF

High birefringence is required in order to maintain the polarization state of guided mode. PCF have large index contrast and flexibility, so high birefringence can be realized. The birefringence is given by:

$$B = |n_{eff}^{x} - n_{eff}^{y}| \quad (2)$$

Where n_{eff}^{x} and n_{eff}^{y} are effective refractive indices of x and y direction.

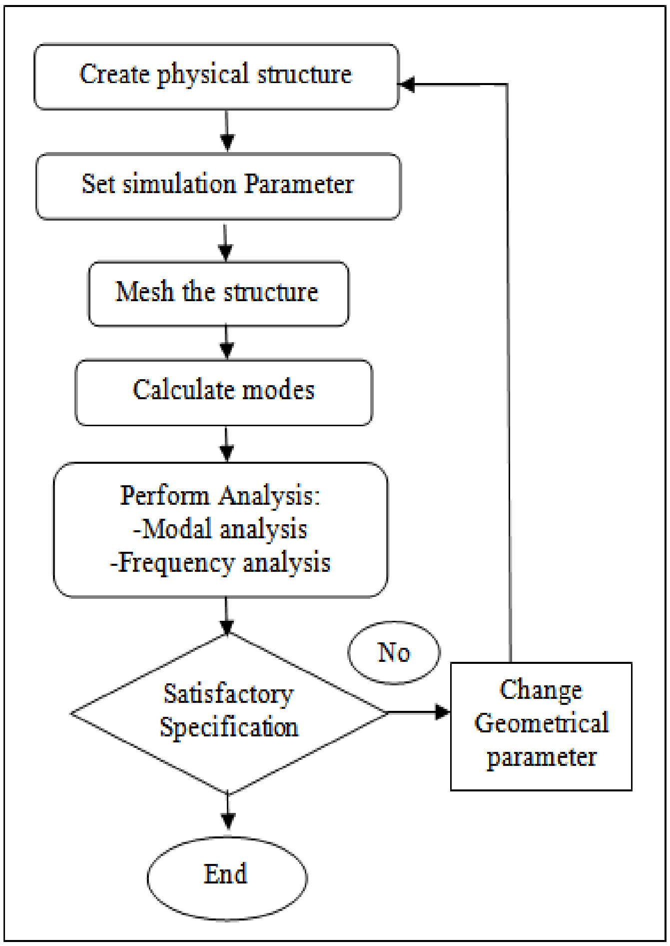


Fig.,3 Flowchart of design process of DC-PCF.

The effect of structural parameter birefringence is seen by varying lattice length (ʌ) and the circular air hole diameter. Fig.,4 shows the relation between birefringence(x and y mode) and wavelength for pitch(/\)=0.75µm and d=0.72µm.

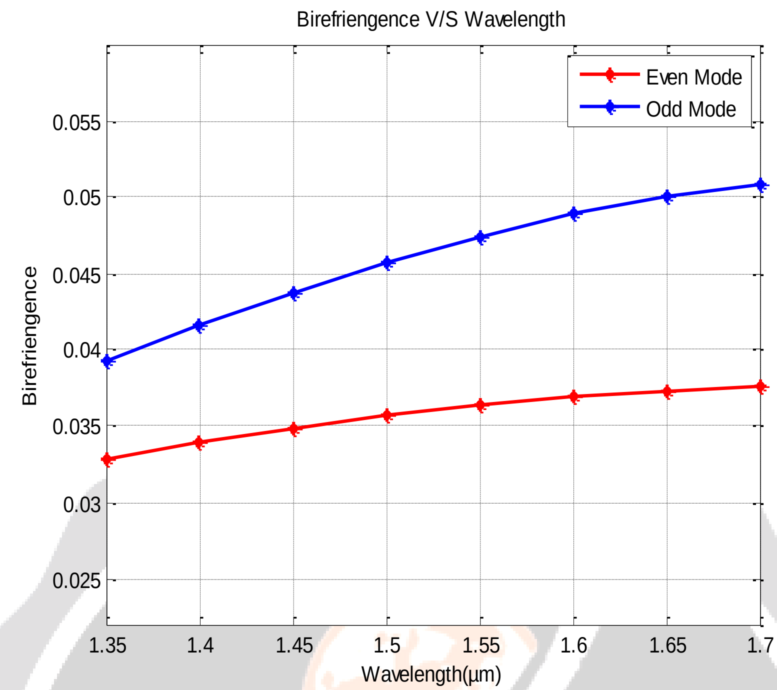


Fig.,4 The relation between birefringence and wavelength for pitch(/\)=0.75µm, d=0.72µm.

From fig 4, it is seen that there is index contrast between two modes (x and y).Out of which y-mode dominate over the x-mode. Modal birefringence increases with wavelength.A high birefringence of 0.0430 is observed at 1.55 µm is observed. To see the effect of pitch value on the birefringence, we vary pitch value from (^)= 0.75, 0.80, 0.85µm and it is shown in Fig.,5.

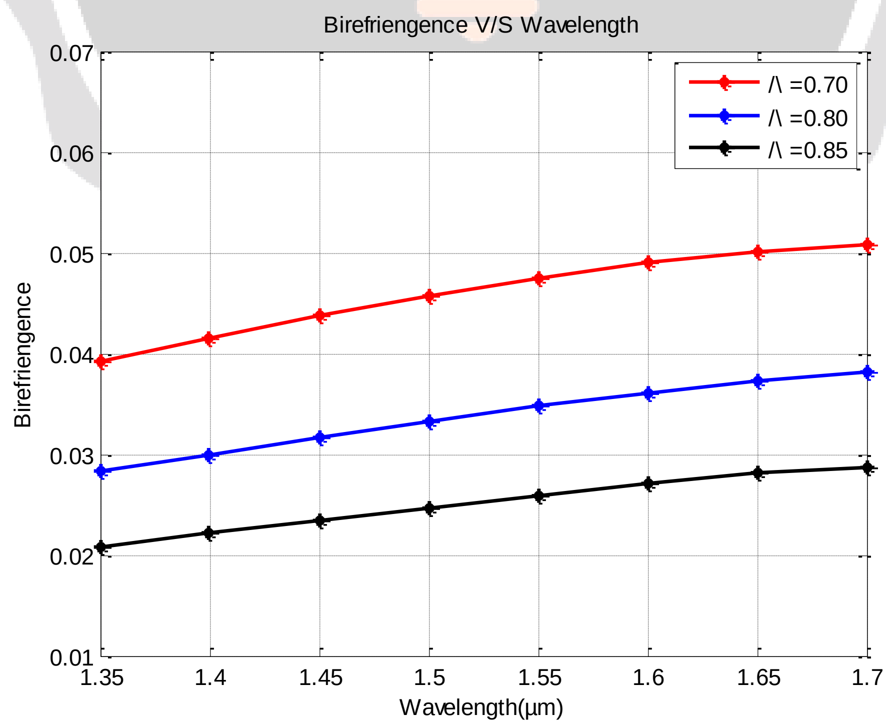


Fig.,5(a) The relation between birefringence and wavelength(λ) for pitch(/\)=0.75, 0.80,0.85µm, d=0.72µm.

As the pitch value (lattice length) increases the birefringence of DC-PCF decreases and vice-versa. Air hole diameter also control the birefringence property. Fig.,5(b) shows the birefringence for different values of air hole diameter(d)=0.68,0.70,0.72 µm.

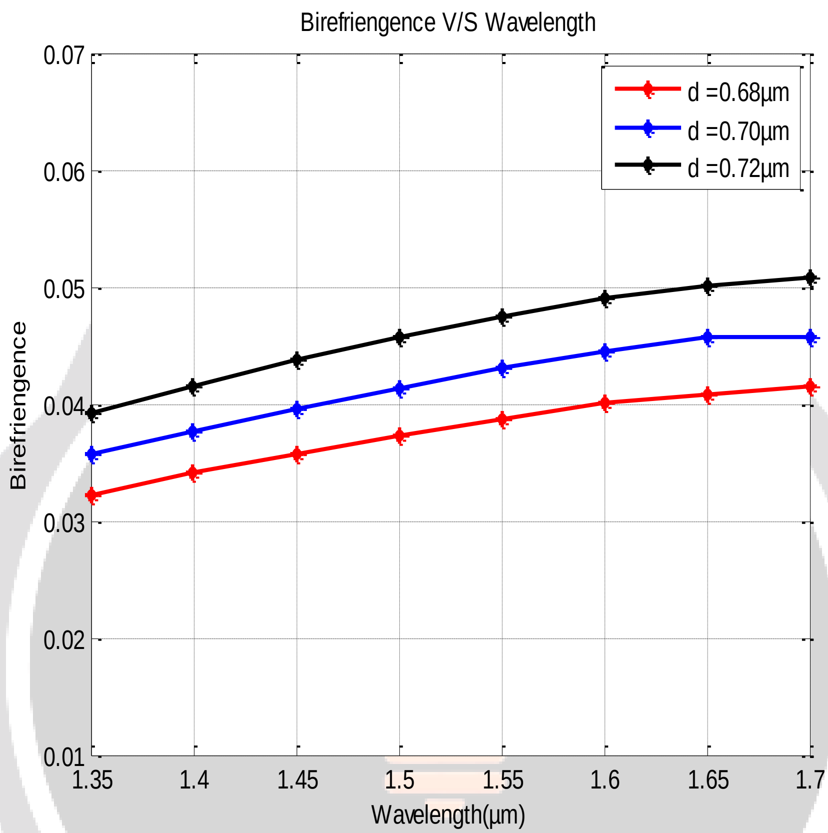


Fig.,5(a) The relation between birefringence and wavelength(λ) for d=0.68, 0.70,0.72µm, /\=0.75µm

As the air hole diameter increases the modal birefringence increases.

In DC-PCF there are four modes of distribution even modes E^{x}_{even} E^{y}_{even} and odd modes of E^{x}_{odd}, E^{y}_{odd} respectively. The coupling length is given as,

$$L_{ci} = \frac{\pi}{\beta^{i}_{even} - \beta^{i}_{odd}} = \frac{\lambda}{2(n^{i}_{even} - n^{i}_{odd})} \quad (3)$$

Where i= *x* and *y* polarization modes, β is propagation constant and n is refractive index. When polarized light incident on any core, mode field enhanced in that core by superposition of two modes. Thus power transferred from one core to another[15]. From eq.3 the coupling length is function of wavelength(λ) and refractive index. The coupling length L_{cx} and L_{cy} increases with decrease with wavelength because mode field extends in cladding. Coupling between these modes becomes difficult and lattice length gets squeezed[16-17]..It results in more compression of field distribution in horizontal direction than vertical direction.Fig.,6(a) shows the coupling length as a function of wavelength for different values d=0.68,0.70,0.72 µm.

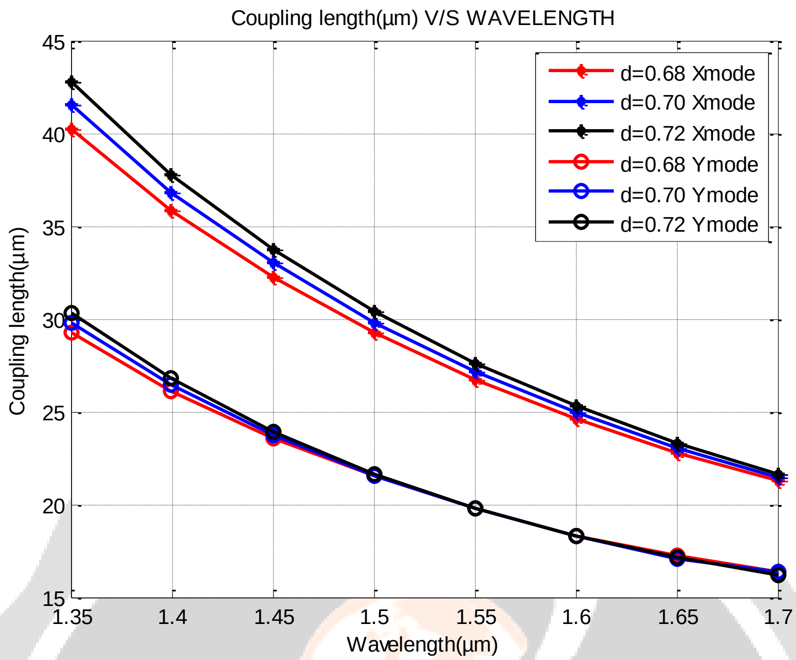


Fig., 6(a) Relation between coupling length(Xmode) and wavelength for different values of d=0.68, 0.70, 0.72 µm.

From figure it is seen that the coupling length increases as air hole diameter increases up to 1.55µm afterwards changes are very small. Lattice length also affects the coupling length. Fig 6(b) shows coupling length as a function of wavelength for different values /\=0.75,0.80,0.85 µm.

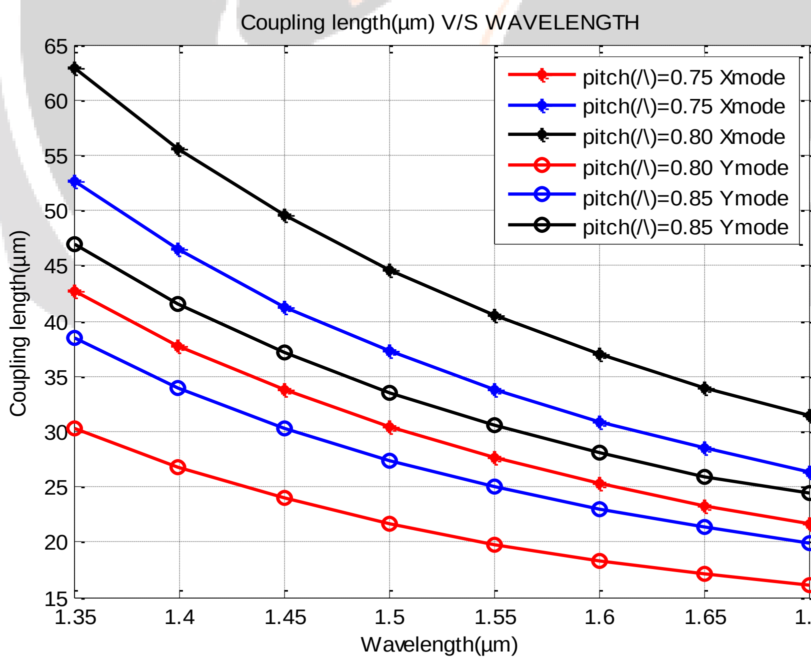


Fig., 6(b) Relation between coupling length(Xmode) and wavelength for different values of /\=0.68, 0.70, 0.72 µm.

Coupling length decreases with lattice length i.e. as lattice length(/\) increases, coupling length also increases. So lattice length value should be proper(below 0.75 µm)

Non-linearity depends on the effective area of optical fibers. A_{eff} related to spot beam width w (where $A_{eff} = \pi w^2$). where, w is beam width parameter determined by curve fitting of Gaussian distribution for specific value of V number. The A_{eff} depends upon fiber parameters such as core radius(d/2) and core cladding refractive index difference [18]. V Number defined as,

$$V = \left(\frac{2\pi\alpha_{eff}}{\lambda}\right)\sqrt{n_{core}^2 - n_{eff}^2} \qquad (4)$$

Where, λ is operating wavelength (nm), α_{eff} is the effective core radius, n_{core} and n_{eff} are from refractive index (eq.1) of core and effective index of simulated value respectively. From fig. 7 V-number decreases with increase in wavelength and As increase in pitch(Λ) the value of V-number decreases. It shows that, our proposed structure is used for single-endlessly transmission over a long fiber length.

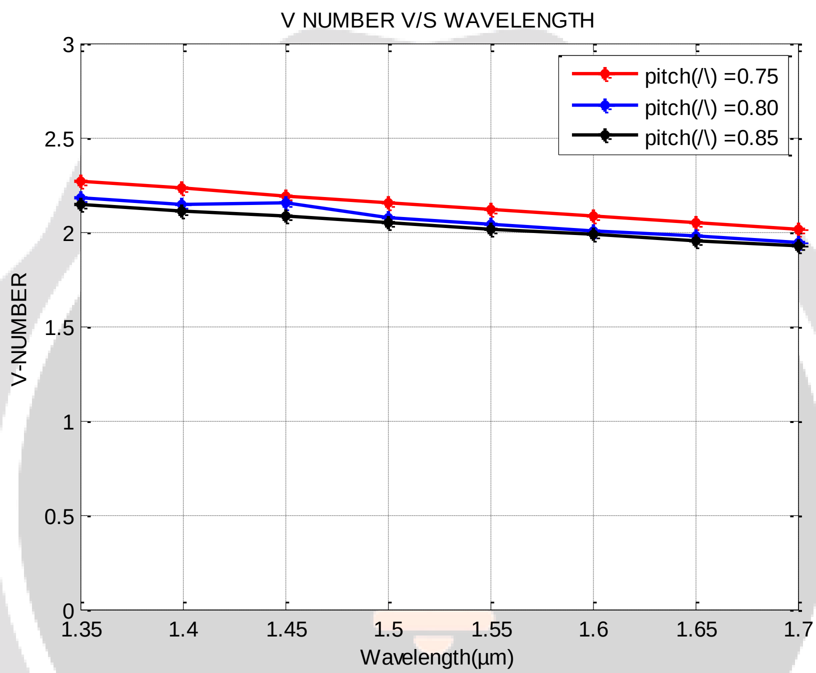


Fig., 7 the relation between V Number and wavelength for different values of pitch=0.75,0.8,0.85 μm.

The V parameter used to find either fiber supported single or multimode propagation which is guided by fiber. For example, for step-index fiber supports a single mode propagation if V<2.405. Value of $V \cong 2$ shows that, around 70-75 % optical power confined within core and larger values of V shows higher confinement in core it shows that the design has low loss recorded. In our proposed design V= 2.0741 (2.0741< 2.405) shows that fiber supports only single mode propagation and 70% power is confined in core [19].

Now we find output power in x and y polarization modes. Let, P_{in} is the input power in. The output power of of x polarized and y polarized in core is [20],

$$P_{i-out} = P_{in}\cos^2\left(\frac{\pi L}{2L_i}\right) \qquad (6)$$

L_i can be calculated from eq.(1) and Normalized power (NP_i) can be defined as,

$$NP_i = \frac{P_{i-out}}{P_{in}} = \cos^2\left(\frac{\pi L}{2L_i}\right) \qquad (7)$$

where , i=x, y. As shown in fig. 11 the peak amplitude of P_x and P_y lies between 1 and 0 respectevely.

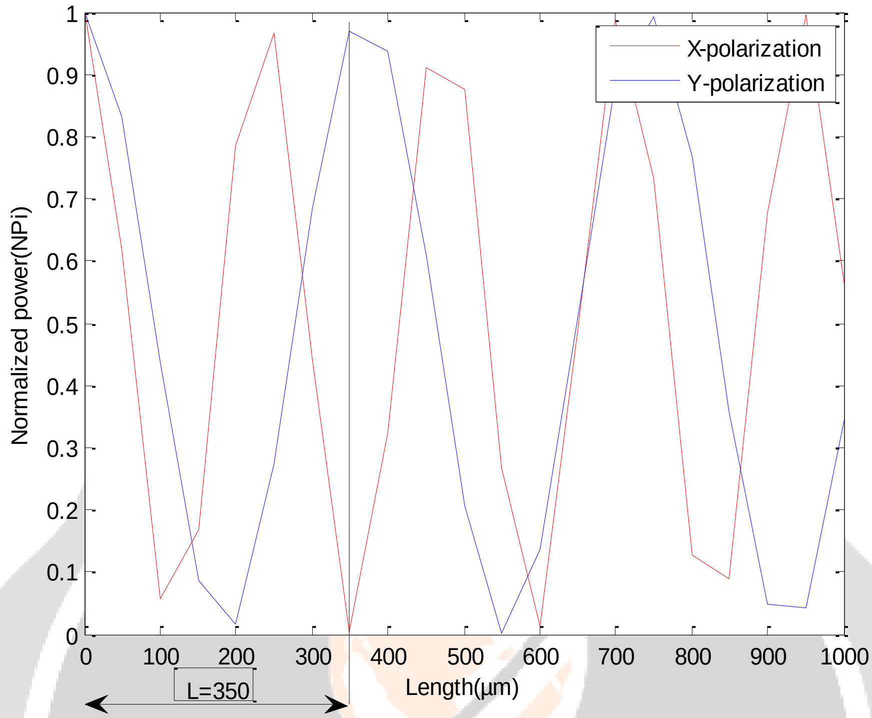


Fig.,8 Variation of Normalized Power (NPi) with distance propagation.

It is seen that the power exchanges periodically with the wavelength 1.5 µm. At fiber length of L= 350 µm the power in x and y mode completely seperated out for pitch(/\)=0.85µm and d==0.72 µm.

3. CONCLUSIONS

In our proposed DC-PCF structure, we investigated modal birefringence is improved up to 10^{-2} with short coupling length of (15-45) µm at lattice length(Λ) =0.75µm.Hence power coupling between two cores improved. So that, structure combine both high birefringence and short coupling length perfectly, which is greatly used in high performance optical devices. Apart from birefringence, proposed design maintaining single mode polarization in fiber for all values of pitch (V<2.405). Our proposed structure covers some S, C, L and U. length of 350 nm at pitch= 0.85µm and d=0.72 µm, two polarized (x and y) modes separated completely (180^0 phase shift). So this design is also used as polarization splitter, multiplexer and demultiplexer applications.

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