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EVALUATION OF PROPAGATION CHARACTERISTICS OF PENTAGONAL TO DODECAGONAL SHAPED CORE WITH HEXAGONAL CLAD PHOTONIC CRYSTAL FIBERS WITH DIFFERENT PITCH

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Abstract

In this study, four rings each Pentagon, Hexagon, Octagon, Nonagon, Decagon and Dodecagon shaped core with hexagonal clad pure silica Photonic Crystal Fibers (PCF) are designed with different pitch values 1.8 and 2.2µm for the evaluation of different application purposes. The simulations and calculations are done using the FEM technique, which is one of the advanced vectorial methods to study the light propagation characteristics in PCFs. The basic light propagating characteristics of PCF structures such as birefringence, effective mode area, non-linear coefficient and chromatic dispersion are numerically analysed using finite element method (FEM). The simulation studies reveal that all the fibers work in single mode regime over the entire operated wavelength range.

Keywords: Photonic Crystal Fiber, Birefringence, Dispersion compensating fiber, Nonlinearity

I. INTRODUCTION

The new class fiber named photonic crystal fiber (PCF) has revealed its unbeatable optical properties in the last couple of decades. The custom made structural and optical properties of PCF had made them a reliable tool in the field of optical communication and optical engineering [1]. The studies on dispersion, effective area, non-linear coefficient and birefringence of the waveguide give us an overall idea of the various applications of the designed fibers. The properties such as supercontinuum generation, zero flattened dispersion, ultra-high birefringence and nonlinearity, which cannot be obtained in the conventional fibers, are fulfilled by the birth of PCFs. Many designs of internal air hole cladding patterns in PCFs had been already reported. Here we have analyzed the optical properties of a specially designed elliptical air hole hexagonal pattern PCF with different inner core pattern. For this the first ring of the PCF is intentionally arranged in pentagon, hexagon, octagon, nonagon, decagon and dodecagon forms.

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II. GEOMETRIC STRUCTURE

The 2D electric field pattern views of the designed fibers are shown in the Fig 1. Here we had designed a silica based four ring hexagonal elliptical air hole cladding solid core PCF. To obtain different core pattern such as pentagon, hexagon, octagon, nonagon, decagon and dodecagon forms, the inner air hole ring of the fiber is changed according to the desired shape [2]. The pitches of the outer rings are 1.8 and 2.2μm. To make a uniform air filling fraction the dimensions of the first ring is calculated according to the hexagonal PCF structure, keeping the dimensions of elliptical air holes unaltered.

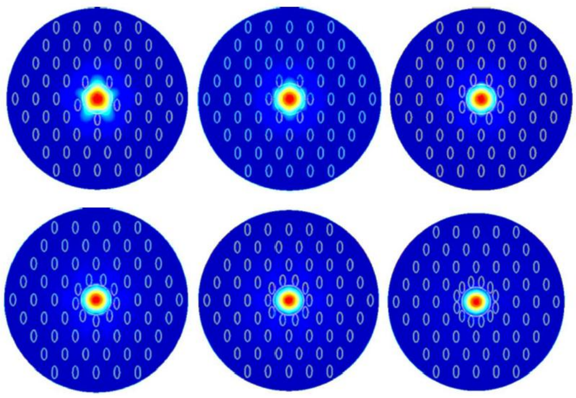

Fig 1 : 2D electric field pattern of designed fibers

The numerical analyses of the designed fibers are done by finite element method (FEM). From the results of the numerical analysis, the optical properties are calculated by using the following equations [3].

Birefringence: $B = |n_x - n_y|$ (1)

Effective Mode Area : $A_{eff} = \frac{\left(\iint |E|^2 dxdy\right)^2}{\left(\iint |E|^4 dxdy\right)}$ (2)

Nonlinear Coefficient : $\gamma(\lambda) = \frac{2\pi}{\lambda}\frac{n_2}{A_{eff}}$ (3)

Chromatic dispersion :

$$D(\lambda) = -\frac{\lambda}{c}\frac{d^2 \,\mathrm{Re}[n_{eff}]}{d\lambda^2} + D_m(\lambda) \quad (4)$$

III. RESULTS AND DISCUSSIONS

The simulation results reveal that all the designed fibers work in the single mode regime over the entire operating wavelength. The postprocessing results give the x and y refractive index n_x and n_y of the respective polarization modes. The variation of refractive index with core structure is shown in the Fig 2. From figure, it is clear that the difference in n_x and n_y (birefringence) is very less for Pentagonal and Hexagonal core. Hence in the applications such as sensor, nonlinear fibers, etc where high birefringence are required, we have to prefer either the structures other than these two or have to heavily dope the core.

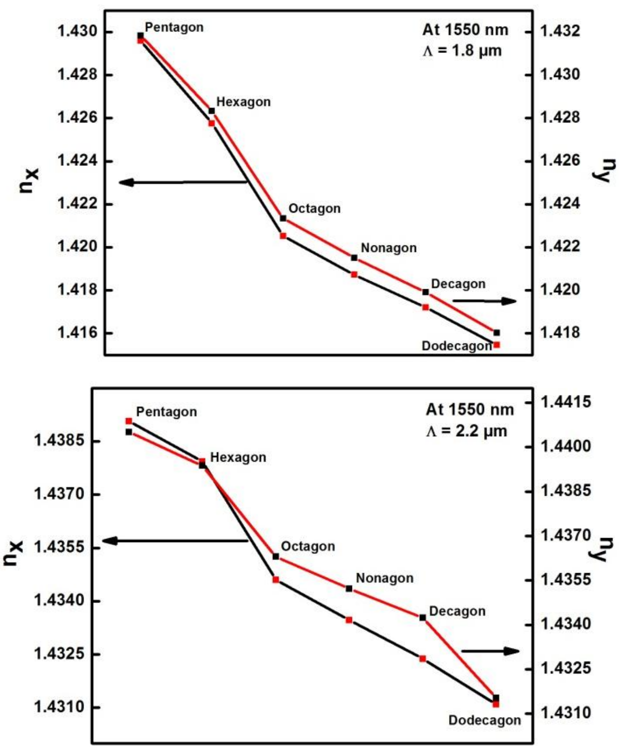

Fig 2: Variation of refractive index in the x- and y-polarization for the pitches 1.8 μm and 2.2μm.

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The birefringence studies are shown in Fig 3(a). From fibers pentagon to decagon core the variation of birefringence with wavelength is in a systematic fashion. But the birefringence of the dodecagon fiber suddenly drops down to an order of magnitude 10^{-4}at 1550nm, maintaining it up to 1750nm and then starts to increase. This is explained from the refractive index profile.

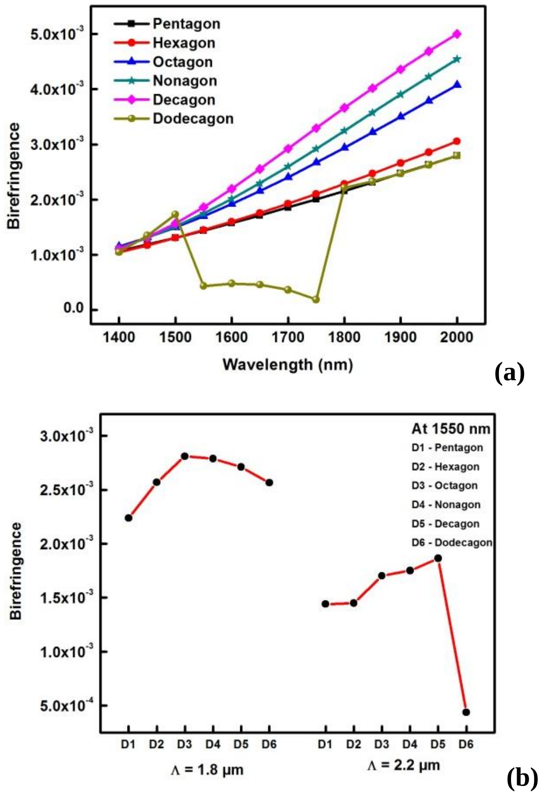

Fig 3: Variation of birefringence (a) for wavelength from 1400 – 2000 nm for pitch 2.2μm (b)for different core patterns of pitch 1.8 μm and 2.2μm

The dispersion profiles of the designed fibers are shown in Fig 4. The pentagon and hexagon fibers show almost flat dispersion response. So they can be used as dispersion flattened fibers. The value of dispersion decreases with wavelength considerably and all the structures from octagonal to decagonal show negative dispersion at higher wavelength. Due to very low dispersion and birefringence of dodecagon at higher wavelength, they can be used for communication purposes.

The mode effective area profile of the fibers shows the conventional variation with the wavelength. The effective area decreases from hexagonal to decagonal core fibers. But the pentagonal core fiber has an effective area considerably less than that of decagonal core for higher pitch values. The dodecagonal fiber has a dip at 1800nm, which shows a strong light confinement at this wavelength. Hence the power density at this wavelength is very high. The small values of effective area can be made use for the nonlinear applications of fibers.

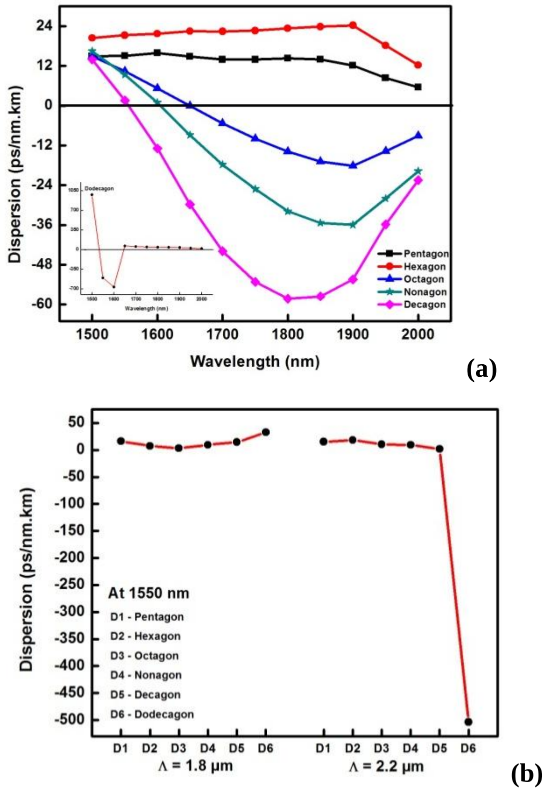

Fig 4: Variation of dispersion (a) for wavelength from 1500 – 2000 nm for pitch 2.2μm (inset graph is the dispersion of dodecagon) (b) for different core patterns of pitch 1.8 μm and 2.2μm

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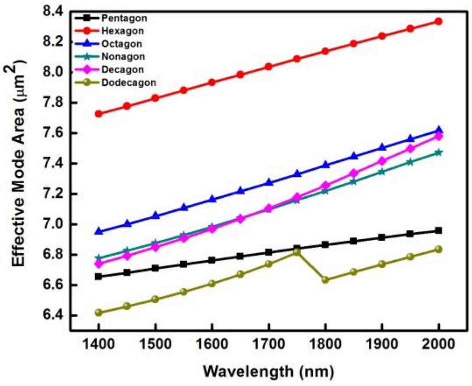
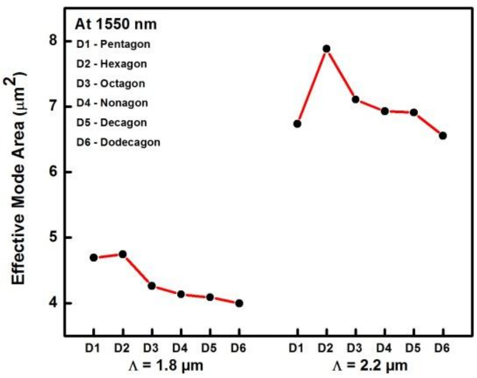


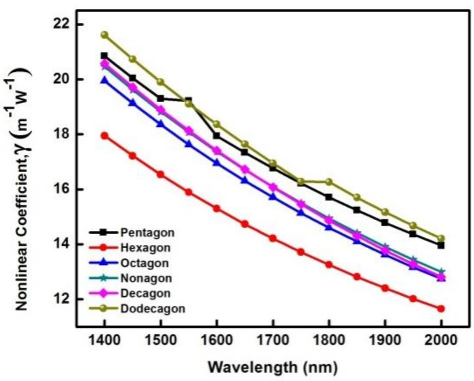
(a)



(b)

Fig 5: Variation of effective mode area (a) for wavelength from 1400 – 2000 nm for pitch 2.2μm (b) for different core patterns of pitch 1.8 μm and 2.2μm

The hexagonal fibers are mostly preferd for large mode area (LMA) applications due to its low nonlinear coefficient (Fig 6). With increasing structural pattern, the nonlinearity of the fiber increaes and we can prefer suitable structure depending on the application.



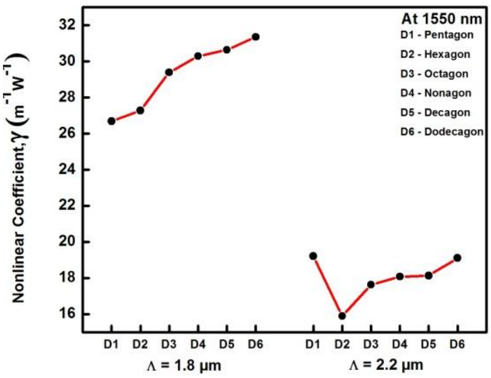


Fig 6: Variation of nonlinear coefficient (a) for wavelength from 1400 – 2000 nm for pitch 2.2μm (b) for different core patterns of pitch 1.8 μm and 2.2μm

VI. CONCLUSION

A hexagonal elliptical air hole microstructure PCFs are designed for pitch values of 1.8 and 2.2μm. To study the variation of optical properties with core structure, the structure of the inner ring of the cladding is modified in the form of pentagon, hexagon, octagon, nonagon, decagon and dodecagon with constant air filling fraction. From the results, it is clear that the dodecagonal structures have unpredictable optical characteristics with large negative dispersion of −503 ps/nm.km at 1550nm. Decagonal structures are polarization maintaining fibers due to their high birefringence. For nonlinear application purposes, the structures from octagon to dodecagon can be preferred. For laser and amplification purposes Hexagon PCFs can be put forward from the simulation results.

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