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Comparative Study on Octagonal Photonic Crystal Fiber with Different Air Holes for Supercontinuum Generation

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ABSTRACT: In this work a comparative study is made on supercontinuum generation in octagonal photonic crystal fiber (O-PCF) with circular air holes and O-PCF with elliptical air holes. Supercontinuum generation is investigated in each designed O-PCF and with femtosecond optical pulses of 50 fs at 830 nm for pump power of 10 kW obtained SC spectrum of wavelength ranges from 580 nm- 1200nm.

KEYWORDS: Photonic crystal fiber, Supercontinuum generation, Birefringence, Dispersion coefficient.

I.INTRODUCTION

Photonic crystal fibers consisting of a central defect region in a regular lattice of air holes have attracted many recent applications due to its flexibility in design.The photonic crystal fiber has made realised by introducing air holes of different shapes (like circular, elliptical etc.) arranged in certain lattice pattern (like hexagon, octagon etc.) around the solid pure silica materialand running along the entire fiber length[1].By varying the air hole size and shape, it is possible to obtain unique features like low confinement losses, zero dispersion at desired wavelength,ultra-flattened chromatic dispersion, endlessly single mode and so on. It attracts much attention in various applications in such diverse fields as pulse compression, spectroscopy, biomedical applications, supercontinuum (SC) generation which can be used as a source to create multi-wavelength optical sources for wavelength division multiplexing (WDM), optical communication systems and so on. Many novel designs like, hexagonal ring[2], square lattice[3], circular ring[4], octagonal lattice, PCF with elliptical air holes[5], PCF with square air holes[6]are being introduced to realize these unique properties based on the requirement of the applications. Comparing with hexagonal lattice PCF,non-hexagonal lattice like octagonal lattice has reported with many attractive features such as low confinement loss, smaller effective area, highly nonlinear, and wideband single-mode operation. This is mainly due to the presence of more number for air holes in a single ring than a hexagonal lattice ring does[7].

One of most advancing research on PCF is supercontinuum generation in under different photonic crystal fibers due to its numerous applications in the field of optical communication [8]and medical applications[9].There are many nonlinear processes like self-phase modulation (SPM),four wave mixing (FWM), modulational instability, self-steepening,stimulated Raman scattering (SRS), soliton fission and so on results in the generation for SC over a wide wavelength range[10]. M.A. Hossain*et al*[11] have presented theoretical calculation of a highly nonlinear germanium doped photonic crystal fiber with all-normal group velocity dispersion to design a SC light source at 1.55μm for medical and optical communication applications. In 2006 J.M. Dudley *et al*[12] have described evolution of SC and explained in detail the effect of pulse duration, pump power and all the nonlinear processes involved in the SC generation. RecentlyWang et al[13] experimentally demonstrated ultraviolet and visible SCs are efficiently generated from 180 to 1100 nm based on the higher-order modes of PCF using Ti:Sapphire laser with centre wavelength of 790nm. Also, Xu*et al*[14] have demonstrated square lattice PCF generated SC spectrum ranging from 1500nm to 1800 nm with a pump power of 6W.Due to dispersive properties of PCF, it is found to be a good choice for supercontinuum generation. A A Nair *et al*[15] have studied supercontinuum generation in O-PCF with a combination of circular and elliptical air holes and achieved SC spectrum ranging from 700nm-11500nm. Later M.Rashid*et al*[16] have demonstrated O-PCF with high birefringence 2.04x10^{-2} with nonlinear coefficient of 33 $W^{-1}km^{-1}$ at 1550nm suitable for supercontinuum generation.

In this work we focussed on the supercontinuum generation in the proposed PCF with elliptical air holes and circular air holes. We carried out the simulation using MATLABsoftware for supercontinuum generation using split step Fourier transform.The different PCF designs proposed are O-PCF with circular air holes of radius (i) R_{C1} =0.6 μm, (ii) R_{C2} = 0.4 μm and O-PCF with elliptical air holes of major axis radius of (iii)R_e =0.4 μm. SC spectrum generated for each proposed design and compared result of each design.

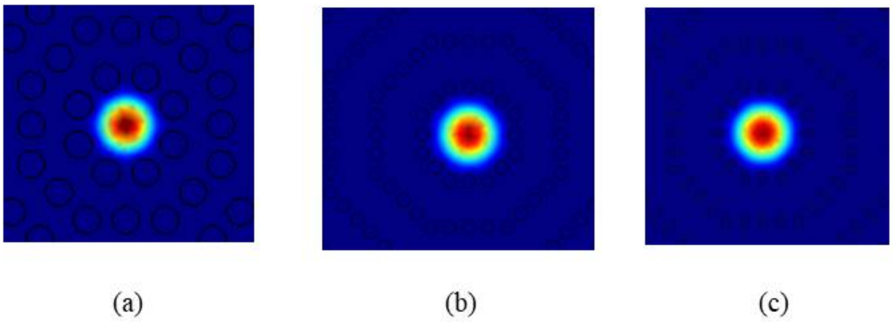

(a) (b) (c)

Fig.1 Typical mode pattern of the O-PCF with circular air hole radius of (a) R_{c1}=0.6 μm (b) R_{c2} = 0.4 μm and elliptical air hole radius of (c) R_e = 0.4 μm at 1000 nm.

II. THEORY AND DESIGN

Supercontinuum or white light generation is a phenomenon arises when high intensity monochromatic optical pulses passes through a nonlinear medium like highly nonlinear PCF generates an output of pulses of broad spectral bandwidth. This process results due to various nonlinear process likeself-focusing, stimulated Raman effect ,self-steepening, four wave mixing, stimulated Brillouin scattering, self-phase modulation (SPM), cross phase modulation (XPM) and so on[12]. The nonlinear phenomenon dominates for the spectral broadening is determined by the dispersive properties of the medium, pulse width, center wavelength of the laser etc.For example, in case femtosecond SC generation, four wave mixing and modulation instability plays important role in initial broadening of the spectrum. The propagation of optical wave through an optical medium is generally governed by Nonlinear Schrodinger equation (NLSE) is given by[17],

$$\frac{\partial}{\partial z}A(z,T) = -\frac{\alpha(\omega)}{2}A(z,T) + \sum_{n\geq 2}\beta_n \frac{i^{n+1}}{n!}\frac{\partial^n}{\partial t^n}A(z,T) + i\gamma(+\frac{i}{\omega_0}\frac{\partial}{\partial T})\int_{-\infty}^{\infty} R(T') \mid A(z,-T') \mid^2 dT' \quad (1)$$

This equation represents the propagation of optical pulse through the fiber where A (z,T) is the electric field envelop α is the frequency dependent loss, β_n is the n^{th} order dispersion at center frequency ω_o and R(T) is the Raman response function. The Raman response is defined as $R(T) = (1 - f_r)\delta(T) + f_r h_r$, for silica f_r =0.18 and $h_r(T) = \frac{\tau_1^2+\tau_2^2}{\tau_1{\tau_2}^2} e^{\frac{-\tau}{\tau_2}} sin\left(-\frac{\tau}{\tau_1}\right)$, τ_1=12.2 fs, τ_2 = 32 fs[18]. This equation is solved using split step Fourier transform method which is simple and accurate. The NLSE equation is solved in taking account of dispersive and nonlinear effects separately for very small step dz. The optical pulse used is of hyperbolic secant pulse profile which is given as,

$$A(z,T) = \sqrt{P_0}\text{sech}\ (\frac{T}{T_0}) \quad (2)$$

Where P_0,T_0 are peak power and pulse width of the input pulse respectively. When a pulse with sufficient peak power breaks up into a series of lower-amplitude sub pulses is termed as soliton fission[12] . The soliton order of the input pulse N is determined by both pulse and fiber parameters through is given by,

$$N = {}^{L_D}/_{L_{NL}} \quad (3)$$

where L_D is the dispersive length and L_{NL} is the nonlinear length.

The finite element method (FEM) with rectangular perfectly matched boundary layers (PML) is used to simulate each properties of the PCF. In order to obtain each photonic crystal fiber parameter, it is important to calculate the effective refractive index of the cladding. Fig.1 shows the modal intensity distribution of proposed O-PCF with circular air holes of radiusR_{c1}=0.6 µm ,R_{c2} = 0.4 µm and elliptical air hole radius of R_e = 0.4 µm.Effective refractive index represents the phase delay per unit length in a waveguide. An effective refractive index for single mode fiber is also known as phase index or normalized phase change coefficient. The modal effective refractive indexes are solved from Maxwell’s equations and given by,

$$n_{eff} = \frac{\beta}{k_o} \quad (4)$$

Where β is the propagation constant and $k_o$is the free space wave number.

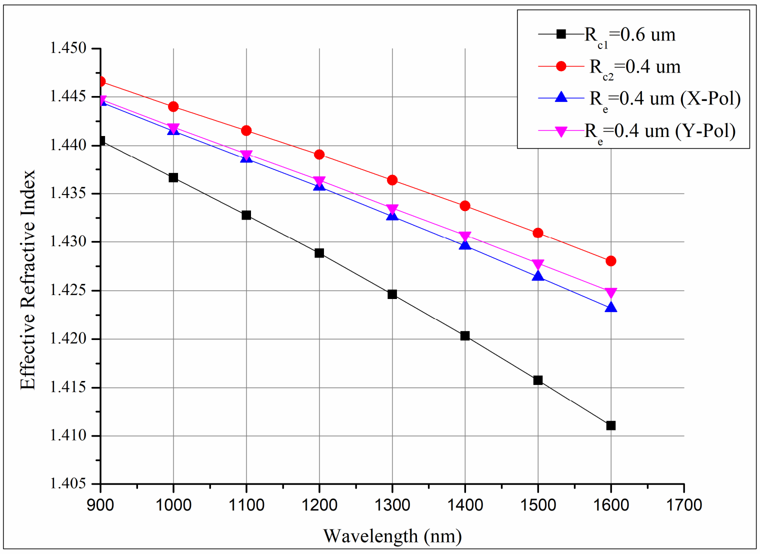
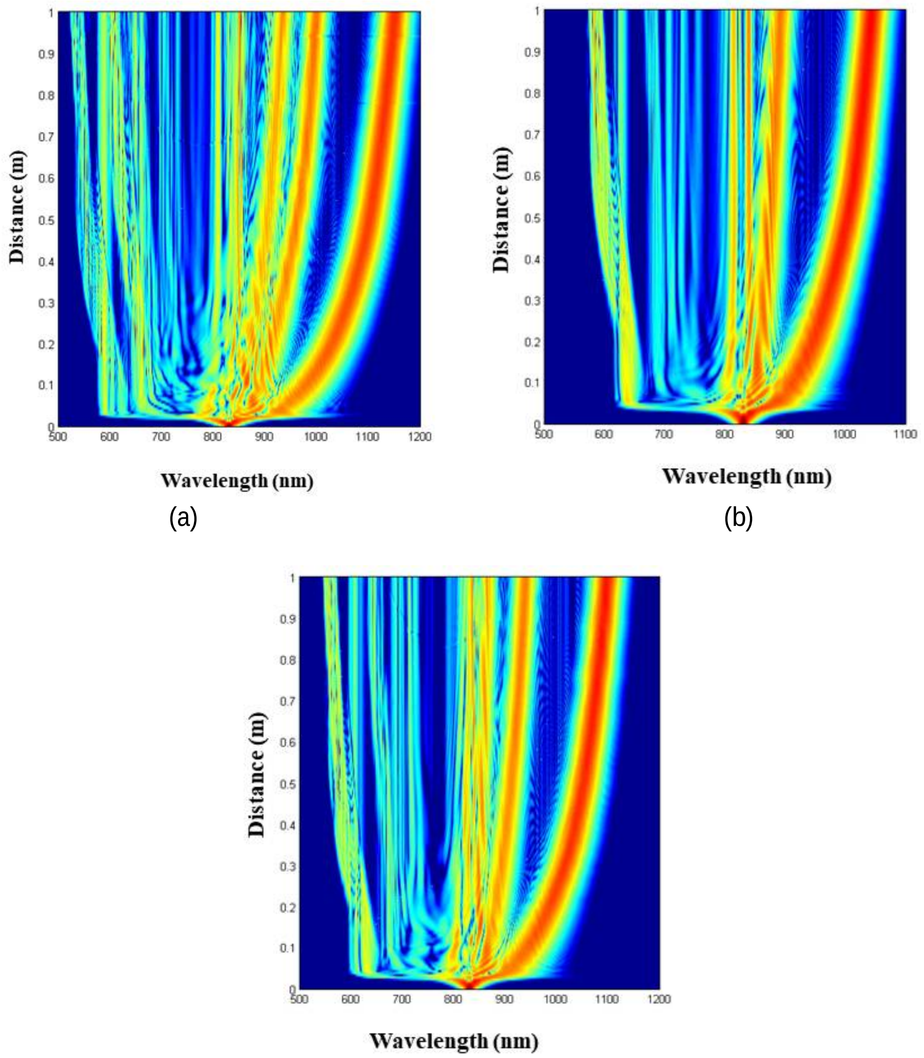


Fig:2 Effective Refractive index as a function of wavelength for each proposed design of O-PCF with circular air hole radius of R_{c1}=0.6 µm, R_{c2} = 0.4 µm and elliptical air hole radius of R_e = 0.4 µm.

III. RESULT AND DISCUSSION

Fig.2 shows the variation of effective refractive index with wavelength ranges from 900nm-1600 nm. The plot shows that the effective refractive depends on the air hole size and which is found to inversely proportional to the radius of the air hole.There is a drastic change due to the size of air holes in effective refractive from the refractive index of its base material, ie silica. For elliptical air holes there will be two refractive indices based on the polarisation(X-polarisation and Y-polarisation) which is plotted in the fig.2. Fig.3 (a), 3 (b) and 3 (c) shows the SC spectra of each proposed O-PCF of radius R_{C1} =0.6 µm, R_{C2} =0.4 µm and R_e =0.4 µm (X-polarisation) for pulse width of 50 fs and pump power of 10 kW at 830 nm wavelength. In fig.3 (a) the optical parameters like nonlinear coefficient is of 38 $W^{-1}km^{-1}$, second order dispersion β_2 = - 0.01363 ps^2/m, for Fig.3 (b) nonlinear coefficient is of 27 $W^{-1}km^{-1}$, second order dispersion β_2 = - 0.3104 ps^2/m, and fig.3 (c) nonlinear coefficient is of 23 $W^{-1}km^{-1}$, pump power 10 kW, second order dispersion β_2 = - 0.1218 ps^2/m and thus the soliton order for each design found to be N=10,6,6 using equation.3 respectively. The SC spectrum expands approximately from 580 nm-1200 nm, so nearly 620 nm bandwidth is achieved for PCF will circular air holes of radius R_{C1}= 0.6 µm whereas PCF with circular air holes of radius R_{C2} = 0.4 µm SC expands from 580 nm - 1100 nm so approximately 520 nm which is also found to be same for the SC spectrum of PCF with elliptical air holes.In femtosecond regime, pulse width of 50 fs Raman and higher order dispersion introduces perturbation which leads to soliton fission[12]. It is clear that as the soliton order, N increases the bandwidth of the generated SC also increases.



(a)

(b)

(c)

Fig.3 Spectral evolutions of the supercontinuum generated by proposed PCF of pump power of 10 kW and pulse duration 50fs at 830 nm wavelength for (a) circular air hole of radius $R_{C1} = 0.6$ µm (b) circular air hole of radius $R_{C2} = 0.4$ µm and (c) elliptical air holes of radius $R_e = 0.4$ µm.

IV.CONCLUSION

In this investigation we studied and compared O-PCF with circular and O-PCF with elliptical air holes by varying radius of air holes. The SC generation is obtained using a pump power of 10 kW for pulse width of 50 fs is applied to each proposed designat 830 nm. It is observed that O-PCF with circular air hole of radius R_{C1}= 0.6 µm produced a SC spectrum of wavelength ranging from 580nm-1200nm which is found to be broad comparing with other two designs. O-PCF with circular air hole of radius R_{C2}= 0.4 µm and O-PCF with elliptical air holes have same soliton order and thus it is observed that the bandwidth of SC spectrum of both O-PCF with circular air holes and O-PCF with elliptical air holes found to be same. This broadband and highly efficient SC generation finds extensive applications for the ultrafast for many ultrafast and optical communication applications.

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