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SUPERCONTINUUM GENERATION USING ELLIPTICAL SILICON CORE PHOTONIC CRYSTAL FIBER

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ABSTRACT

A new design of elliptical solid core photonic crystal fiber (PCF) is proposed using COMSOL Multiphysics software based on finite elementmethod. The cross section of the PCF is modeled with circular airholes and an elliptical core made of silicon. Results for the effectiverefractive index, dispersion properties of the PCF, Effective mode area and Nonlinearity arepresented. For Supercontinuum (SC) generation higher orderdispersion terms and nonlinear coefficient of the PCF arecalculated. Numerical simulation of SC generation for theproposed PCF is analysed using the generalized nonlinearSchrodinger equation and split step Fourier transform method.The SC generation of about 300nm is observed when the input pulse offemtosecond duration is pumped in the anomalous dispersionregime of the fiber.

Keywords :Dispersion(D),effective refractive index (Neff) effective area (Aeff), Photonic Crystal fiber (PCF),super continuum (SC).

I.INTRODUCTION

Photonic crystal is a periodic nanostructure that affects the motion of photons in the same way that ionic lattices affect electrons in solids. Photonic crystal fibers are being increasingly used in the place of optical fibers they consist of a periodic array of air holes running along the entire fiber length. There are two main light guiding mechanisms in PCF. The first one is Index guiding fibers that have a solid core and guides light through total internalreflection like conventional fibers. On the other hand, thesecond one is hollow core PCF which transmits light byphotonic bandgap effect. PCF provides enhanced designflexibility compared to standard optical fibers by changing thesize and distance between the air holes [1]. PCFs haveattracted significant attention because of their unique opticalproperties such as endlessly single mode operation [2],adjustable dispersion [3], anomalous group-velocity dispersionat visible wavelength [4,5], high birefringence [6], high or lownonlinearity, low confinement loss, etc. The combination ofthe unique dispersion properties and enhanced nonlinearitiescan be used to obtain Supercontinuum (SC) generation whenthe fiber is pumped with short pulses of laser light withwavelength near the zero-dispersion wavelength (ZDW) [7].Supercontinuum (SC) generation occurs when a high powerultrashort optical pulse propagates through a nonlinear opticalmedium and undergoes extreme nonlinear spectral broadeningto yield a broadband spectrally continuous output. The SCcharacteristics depend particularly on the position of the inputpulse wavelength relative to the fiber ZDW [8]. SC is anattractive coherent source for optical coherence tomography,spectroscopy and optical frequency metrology [9].In this paper, a PCF is designed using COMSOL Multiphysics andtherefractiveindex and dispersion property are calculated.The higher order dispersion parameters and nonlinearcoefficient of the proposed PCF is used for the numericalsimulation of SC generation using Generalized NonlinearSchrodinger equation (GNLSE). To solve the GNLSE we haveused the split step Fourier transform method. In theanomalous dispersion regime of the fiber the dispersionparameter β_2 is less than zero and fiber can support solitons.The SC generation is observed when the input pulse offemtosecond duration is pumped in the anomalous dispersionregime of the fiber.

II. PCF DESIGN

A solid core PCF consists of a periodic array of air- holes witha central defect acting as the core and the optical parameters ofthe fiber is determined by the pitch (Λ) 1.4um and diameter (d) 1.1um ofthe air holes. And the PCF has a central air core in the form of an ellipse as ellipse has the least confinement loss compared to other structures of major axis 1.5um and minor axis 0.3um. The diameter of the inner ring air holes is reduced to 0.84 um to provide better confinement. The geometry of the PCF used was a hexagonalpattern with a periodic triangular lattice arrangement of airholes as shown in Fig.1.

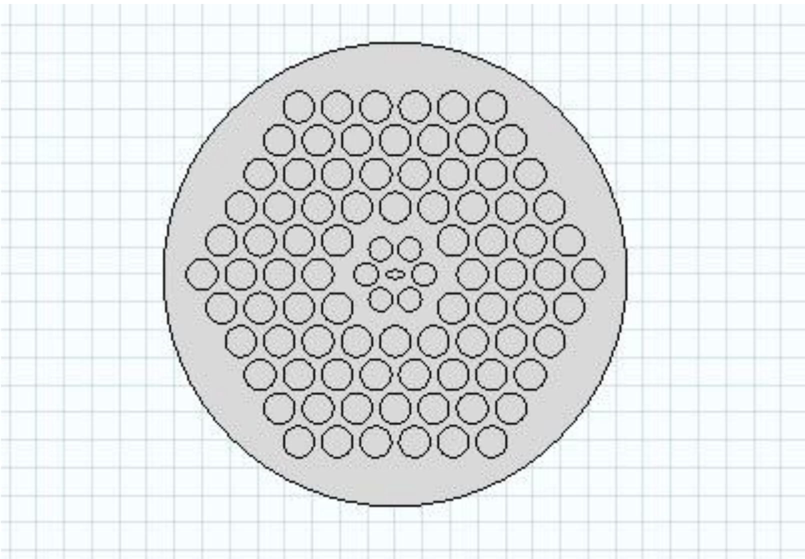

Fig 1 : Geometry of Hexagonal PCF with elliptical core

The material used for the PCF is silica and theelliptical core is made upof silicon. The refractive index of the material is determined using sellmier's equation, while the index of air is constant (n=1). Fig 2shows the field plot of time average power flow in z directionat wavelength λ= 1000 nm. It can be observed that the light iswell confined to the core region and penetrates only slightlyinto the cladding region and in the shorter wavelength the lightwill be more confined in the core part.

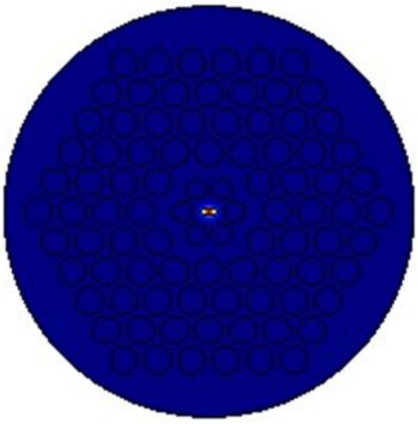

Fig 2 : Mode field distribution at **λ**=1000nm

From COMSOL we get the values of effective mode index (neff) for different values of wavelength. Fig.3 shows the variation of effective refractive index as a function ofwavelength for the PCF. It is important to calculate the effective index of a fiber accurately as waveguide dispersion is related to the second order derivative of effective index with respect to wavelength. From figure 3, it is noted that the effective index of refraction decreases with the increase in wavelength.

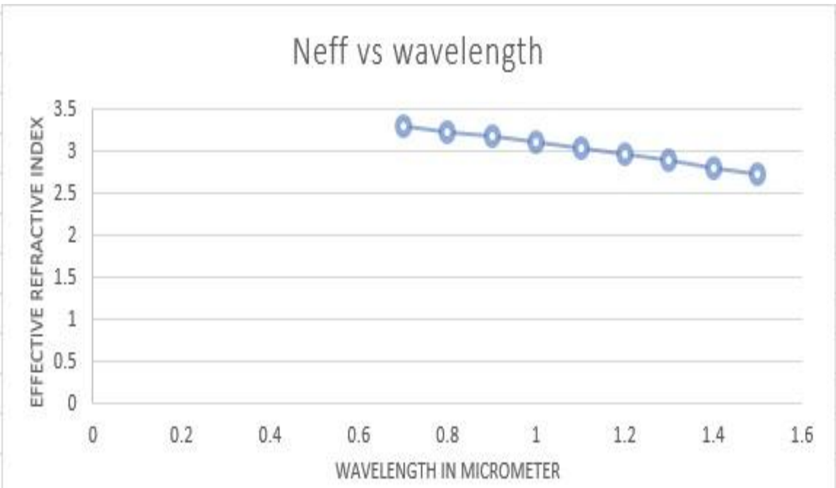

Fig 3: Effective refractive index Vs Wavelength plot

By using the effective refractive index waveguide dispersion D, is calculated from the following equation ,

$$D(\lambda) = -\frac{\lambda}{c}\frac{d^2\, Re[N_{eff}]}{d\lambda^2} \tag{1}$$

where N_{eff} is the effective refractive index of the guided mode, λ is the wavelength, and c is the velocity of light in vacuum. Fig.4 shows the dispersion characteristics of the PCF as a function of wavelength.

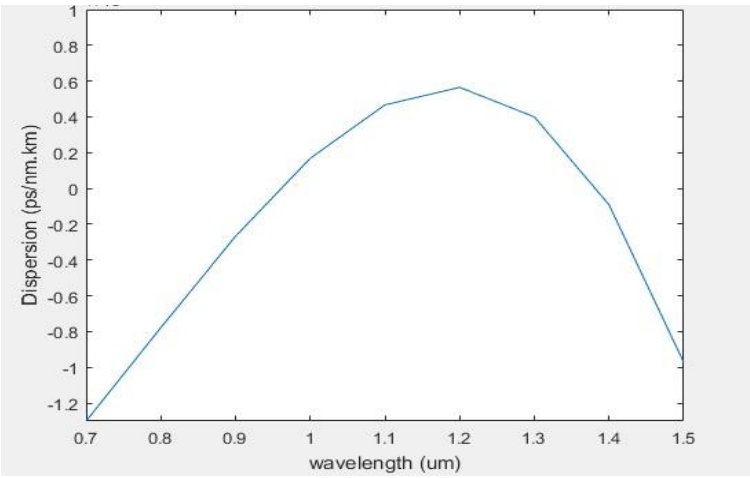

Fig 4: Dispersion of PCF Vs Wavelength

Fiber Nonlinearity is calculated using the formula,

$$\gamma = \frac{n_2\omega_0}{cA_{eff}} \tag{2}$$

Where n_2 for silicon is $4.5*10^{-18}$ m^2/W, c is the speed of light, $A_{eff}$is the effective mode area, ω_0 is the centre frequency.Fibers with high γ values are attractive for a broad range of applications in nonlinear fiber devicesIt is evident that the effective nonlinearity γ, decreases as the wavelength increases as in fig 6. This is due to the fact that the mode area becomes larger at higher wavelengths. For lower wavelengths, the small core diameters exhibit strong nonlinearity due to the strong mode confinement.

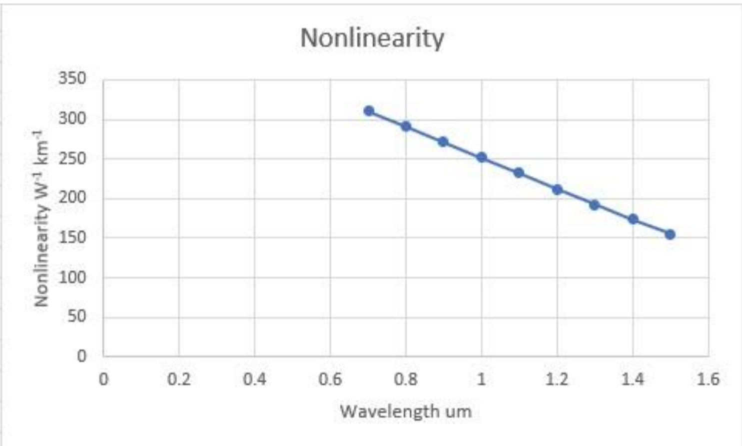

Fig 5: Nonlinearity of PCF vs wavelength

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The higher order dispersion coefficients are given by thefollowing equation,

$$\beta_m = \frac{\partial_m \beta}{\partial \omega^m} \quad (3)$$

Where m=2,3,4 represents the m^th order of dispersion coeffiecient,β is the mode propagation constant, n is the refractive index, ω is the angular frequency and m the degree of the derivative. The parameters β1 and β2 are calculated by the relations,

$$\beta_1 = d\beta/d\,\omega \quad (4)$$

$$\beta_2 = d\beta_1/d\,\omega \quad (5)$$

Where β_2 represents the group velocity dispersion. The Proposed PCF has two wavelengths at which the dispersion is zero, 0.961um and 1.381um.The higher-order dispersion parameters and the nonlinear coefficient at wavelength 1000 nm are calculated and are shown in Table.1.

β_2	-3.9462
β_3	5.8787e-3
γ	$251.9W^{-1}Km^{-1}$

TABLE 1 : Parameters for the Proposed PCF at 1000nm

The propagation of pulse in an optical fiber is described by thegeneralized nonlinear Schrodinger equation (GNLSE)

$$\frac{\partial}{\partial z}A(z,t) = -\frac{\alpha}{2}A(z,t) + \sum_{m\geq 2}\beta_m \frac{i^{m+1}}{m!}\frac{\partial^m}{\partial t^m}A(z,t) + i\gamma\left(1+\frac{i}{\omega_0}\frac{\partial}{\partial t}\right)\left[A(z,t)\int_{-\infty}^{+\infty} R(t')|A(z,t-t')|^2 dt'\right] \quad (6)$$

where A(z, T) is the electric field envelope in a retarded time frame $T=t-\beta_1 z$.Non- linear response R(t) can be defined as

$$R(T) = (1-f_R)\delta(T) + f_R h_R(\tau) \quad (7)$$

$$h_R(t) = \frac{\tau_1^2+\tau_2^2}{\tau_1\tau_2^2}\exp\left(\frac{t}{\tau_2}\right) sin\left(\frac{t}{\tau_1}\right) \quad (8)$$

Where $f_R = 0.43$is the fractional contribution of the Raman response and $h_R(t)$ is the Raman response function with Raman period ($\tau_1 = 0.01ps$) and lifetime (τ_2=3ps).

The GNLSEequation (6) is a nonlinear partial differential equation thatdoes not have known analytical solution. Therefore anumerical approach is often necessary for an understanding ofthe nonlinear effects in fibers. We used the split step Fouriermethod to solve the GNLSE.

III. SIMULATION RESULTS

Numerical simulation for SC generation process usingfemtosecond pulse taken in the anomalous dispersion regimeof the proposed PCF using equation (6) is presented.We consider the length of the PCF to be 0.01m. The initial input pulse used in the simulation isa hyperbolic secant pulse, whereT0 =20 fs, peak power P0 = 25W at 1000 nm wavelength. Theinput pulse is pumped in the anomalous dispersion regime ofthe PCF where fibers support solitons. A broad spectrum of nearly 300nm is obtained, SC generation involves various processesincluding the soliton breakup, self-phase modulation, self-steepeningeffect, intrapulse Raman Scattering, and dispersivewave generation due to higher-order dispersion. The solitonundergoes the fissionprocess and breaks up into a series oflower amplitude pulses because of the perturbations caused bythe higher order dispersion and nonlinear effects.

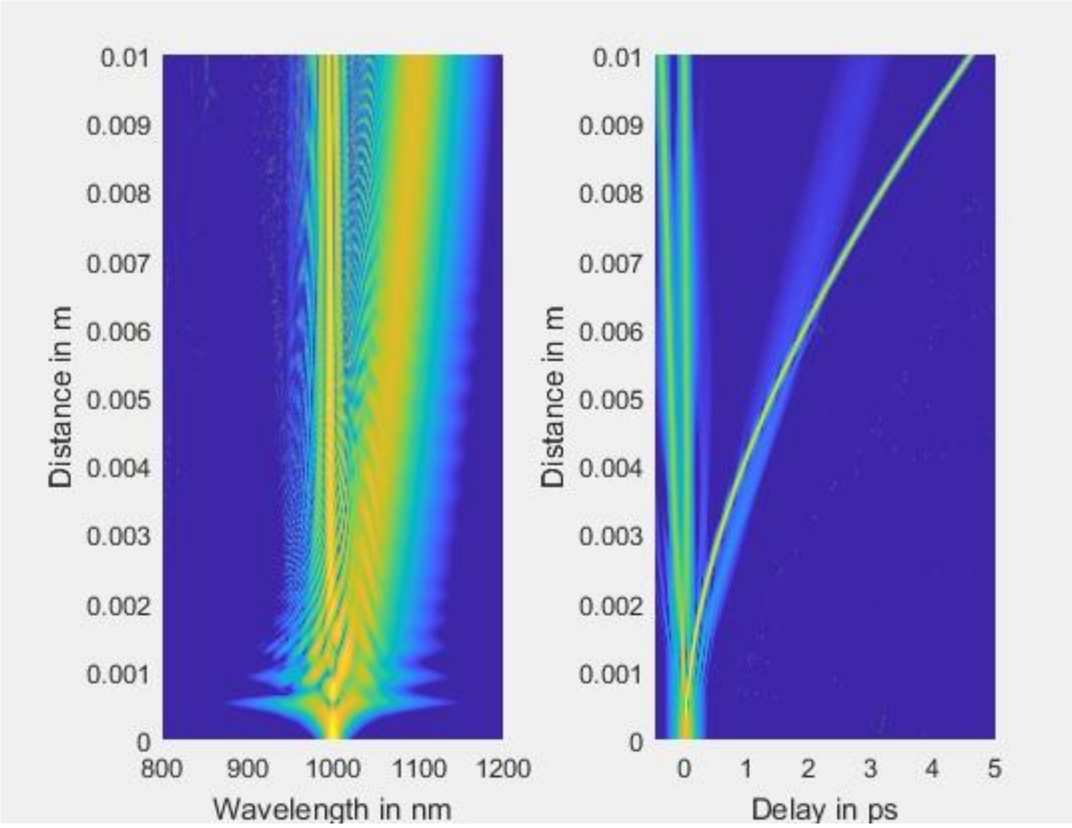

Fig 6: Supercontinuum Generation for the Elliptical core PCF

IV. CONCLUSION

We have designed the Elliptical Silicon core photonic crystal fiber withcircular air holes for Supercontinuum generation usingCOMSOL. The zero dispersionwavelength of the fiber was 961 nm and 1381 nm and thedispersion slope agrees with the published numerical result.For SC generation the input pulse is pumped in the anomalousdispersion regime of the PCF and the result of the higher orderdispersion parameters and nonlinear coefficient of the PCF atwavelength 1000 nm are presented. The SC generation isobserved using the proposed PCF of length 0.01 m and thespectrum of SC extends to about 300 nm, which can be used for various applications such Optical coherence Tomography etc.

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