*International Journal of Advancements in Electronics and Electrical Engineering– IJAEEE*
*Volume 4 : Issue 1 [ISSN : 2319-7498]*
*Publication Date : 30 April, 2015*

# Hybrid Square Lattice Photonic Crystal Fiber With Elliptical Air Hole and Doped Core

Ritu Sharma[1], Anuradha Sharma[2], Varshali Sharma[3], Santosh C.[4]

***Abstract*: In this paper a hybrid square–lattice PCF with circular and elliptical air holes are analyzed by the inclusion of small Ge-doped core, Si-doped core and Schott $BK_7$ doped core at the center of a conventional photonic crystal fiber, and compared for their dispersion and birefringence properties. Numerical investigation shows high negative dispersion for Ge doped core by the increase in the ellipticity of air holes then Schott $BK_7$ and it is lower than Si doped core PCFs and the modal birefringence for Si-doped core is very high as compared to other doped core PCF material. The proposed structure may be used in a wideband due to its flat and highly negative dispersion. A full-vector TE, FDTD method is used for analysis purpose.**

***Keywords:* Photonic Crystal Fiber (PCF), Total internal reflection (TIR), Finite Difference Time Domain(FDTD), Effective Refractive index (neff), Transparent boundary condition(TBC), elliptical photonic crystal fiber (EPCF).**

## I. Introduction:

There has especially been a significant interest in a photonic-crystal fiber (PCF) consisting of a central defect region surrounded by multiple air holes running along its length [1]. PCF supports two guidance mechanisms: One is index-guiding PCFs, in which the core is solid and guidance of light is due to a modified form of total internal reflection (m-TIR) as the air holes surrounding the core lowers the effective refractive index of the cladding relative to that of the solid core [2]. Another PCFs that use a perfectly periodic structure exhibits photonic band gap (PBG) effect and these PBG–PCFs guide light in a low-index core region [3,4,5]. The polarization and dispersive properties of circular and elliptical air hole PCFs (EHPCF) with the inclusion of small Ge-doped core, Si-doped core and Schott $BK_7$ doped cores are investigated using full-vector TE, FDTD method, keeping the core diameter same in all three cases.

1,2 Department of electronics and communication Engineering

4 Department of Mathematics

Malaviya National Institute of Technology, Jaipur, Rajasthan, India

3 St.A.P.C.S.S.S. , Jaipur, Rajasthan, India

A hybrid square–lattice PCF with elliptical and circular air holes with solid core were compared and investigated for their dispersion and birefringence properties [6]. In this paper the solid core is changed in to hollow, by introducing a small Ge-doped core, Si-doped core and Schott $BK_7$ doped core with adjustable diameter and refractive index embedded in pure-silica at the center of a conventional photonic crystal fiber [6] with circular and elliptical air holes configurations and compared for their dispersion and birefringence properties .

In this paper, the PCF structure is designed and analyzed by well established method: FDTD (Finite difference time domain). A full vector TE mode with TBC (transparent boundary condition) is used to perform the modal analysis which generates the effective refractive index, which is further used to calculate the waveguide dispersion and birefringence.

## II. Analysis of dispersion and Birefringence

### *Theory:*

Some polarization maintaining fibers (PMFs) contains elliptical air holes in the cladding to produce a high birefringence, which is elliptical photonic crystal fiber (EPCF).The birefringence is defined as $|n^x_{eff} - n^y_{eff}|$ where $n^x_{eff}$ and $n^y_{eff}$ are the effective indices of x-polarized mode and y-polarized mode, respectively.

The effective refractive index of the fundamental mode is given as $n_{eff} = \beta/K_0$, where $\beta$ is the propagation constant, $k_0=2\pi/\lambda$ is the free-space wave number. First the modal effective indexes $n_{eff}$ are solved, and then the dispersion parameter D can be obtained [7]:

$$D(\lambda) = -(\lambda/c)\,(d^2n_{eff}/d\lambda^2) \quad (1)$$

Where c is the velocity of the light in a vacuum and $\lambda$ is the operating wavelength.

The total dispersion is calculated as the sum of the geometrical dispersion (or waveguide dispersion) and the material dispersion in the first-order approximation:

$$D(\lambda) \approx D_g(\lambda) + \Gamma(\lambda) D_m(\lambda) \quad (2)$$

Where Γ is the confinement factor in silica. In most index guided PCFs, the modal power is almost confined in the silica core and Γ is close to unity [7, 8]. In our simulation, Γ is set to 1. The material dispersion $D_m$ can be obtained directly from the three-term Sellmeier formula. Then we can calculate the waveguide dispersion $D_g$.

The waveguide dispersion is strongly related to the design parameters of the PCFs and therefore can be optimized to achieve desired dispersion properties.

# III Design parameter and Simulation results

The cross section of a hybrid square-lattice PCF (using OPTI FDTD Simulator version 8) with circular air holes having Ge-doped core is shown in

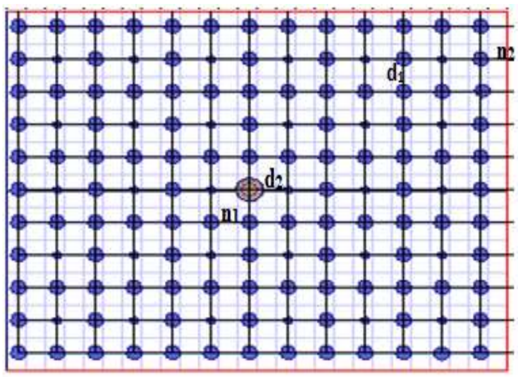


Fig 1 (a).

Fig 1(a): A hybrid square -lattice PCF with circular air holes having Ge-doped core diameter $d_2$=1.4 µm, $\eta_1$ = 1.054, $\eta_2$=1, $d_c$ /d =0.5 µm, pitch (Λ) =2 µm, $d_c$/ Λ=0.2[6].

The wafer chosen is of pure silica (non dispersive) with refractive index 1.45 and the refractive index of air holes is 1. The wafer is designed for length = 26µm and width=22µm. The refractive index of doped core and cladding are $n_1$ and $n_2$ respectively. The diameters of the small and large air holes are $d_c$ and d respectively. The pitch (Λ) which is center to center spacing between two nearest air holes is 2 µm. The mesh size is Δx =Δz =0.106 µm .The refractive index for Ge, Si and Schott $Bk_7$ are 1.5283, 1.45, and 1.51872 respectively. Hole diameter $d_1$, core diameter $d_2$=1.4 µm, $\eta_2$ =1.0 is used for all three materials. In the case of Ge doped core $\eta_1$ = 1.054 [here $\eta_1$ and $\eta_2$ are the normalized refractive index profiles for doped core and cladding respectively] is used.

The refractive index profile n(r, λ) of an optical fiber can be given as:

$$n(r, \lambda) = \eta(r)\, n_s(\lambda) \quad (3)$$

$n_s(\lambda)$ -Refractive index of pure silica
η(r) - Normalized refractive index profile
Thus the refractive index of the Ge-doped region is normalized with respect to the refractive index of pure silica [9].
Based on configurations II, III, and IV [6], the Layout designed on OPTIFDTD is shown in Fig. 1(b), 1(c) and 1(d) for Ge doped core PCF.

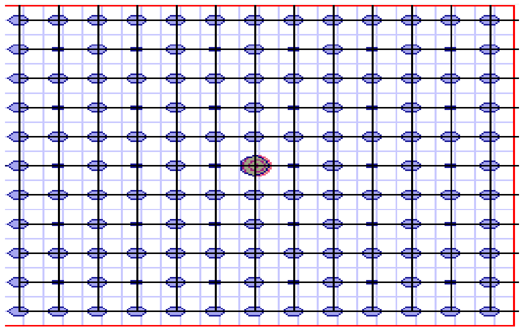

Fig 1(b): Layout design for a hybrid square lattice PCF with elliptical air holes having Ge doped core diameter $d_2$=1.4 µm, $\eta_1$ =1.054, $\eta_2$=1.0, a =0.1µm, b=0.4 µm for small air holes and a=0.3 µm, b=0.533 µm for large air holes.

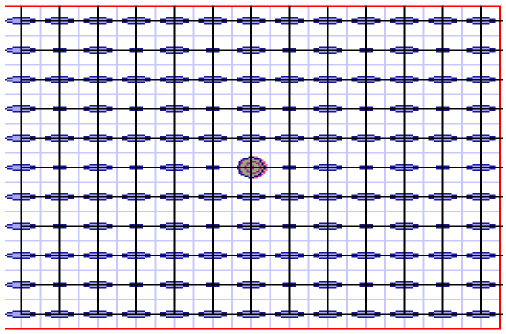

Fig 1(c): Layout design for a hybrid square lattice PCF with elliptical air holes having Ge-doped core diameter $d_2$=1.4 µm, $\eta_1$ =1.054, $\eta_2$ =1.0, a=0.1 µm, b=0.4 µm for small air holes and a=0.2 µm, b=0.8 µm for large air holes.

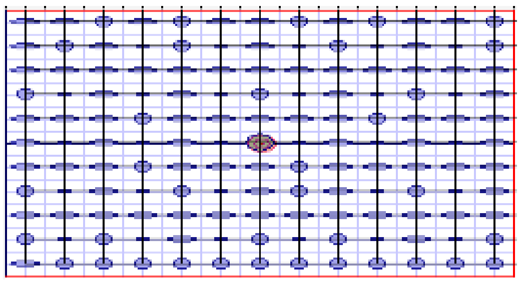

Fig 1(d): Layout design for a hybrid square lattice PCF with a random distribution of circular and elliptical air holes having Ge doped core diameter $d_2$=1.4 µm, $\eta_1$ = 1.054 $\eta_2$ = 1.0.

The Layout designed on OPTIFDTD is shown in Fig. 2(a), 2(b), 2(c) and 2(d) for Schott BK7 doped core PCF.

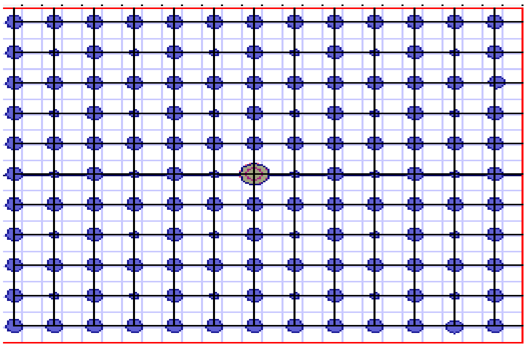

Fig 2(a): A hybrid Square -lattice PCF circular air holes having Schott BK7 (n=1.51872) doped core diameter $d_2$=1.4µm, $\eta_2$ =1.0, $d_c$/d =0.5 µm, pitch (Λ) =2 µm, $d_c$/ Λ=0.2.

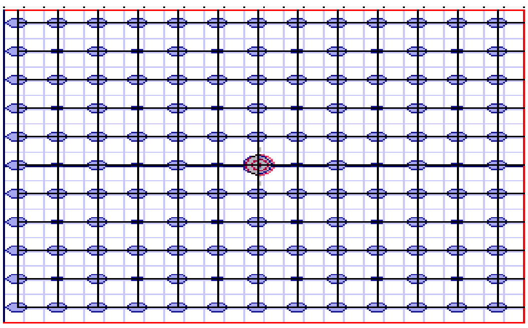

Fig 2(b): Layout design for a hybrid with square lattice PCF with elliptical air holes having Schott BK7 (n=1.51872) doped core diameter $d_2$=1.4 µm, $\eta_2$=1.0, a =0.1µm, b=0.4µm for small air holes and a=0.3 µm, b=0.533 µm for large air holes.

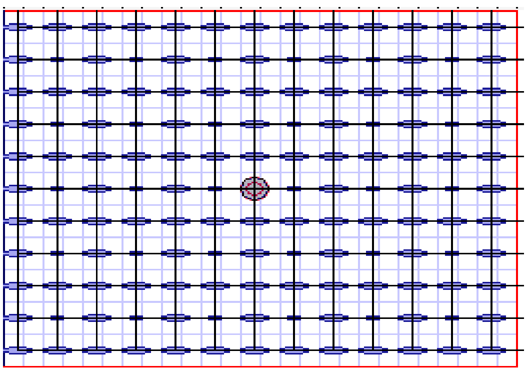

Fig 2(c): Layout design for a hybrid square lattice PCF with elliptical air holes having Schott BK7 (n=1.51872) doped core diameter $d_2$=1.4 µm, $\eta_2$=1.0, a = 0.1 µm, b = 0.4 µm for small air holes and a=0.2 µm, b= 0.8 µm for large air holes.

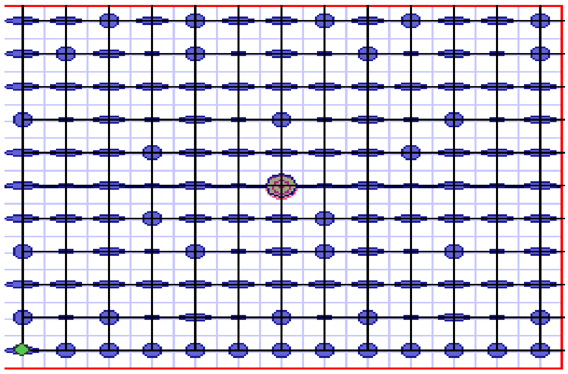

Fig 2(d) : Layout design for a hybrid square lattice PCF with a random distribution of circular and elliptical air holes having Schott BK7 (n=1.51872) doped core diameter $d_2$=1.4 µm, $\eta_1$ = 1.0.

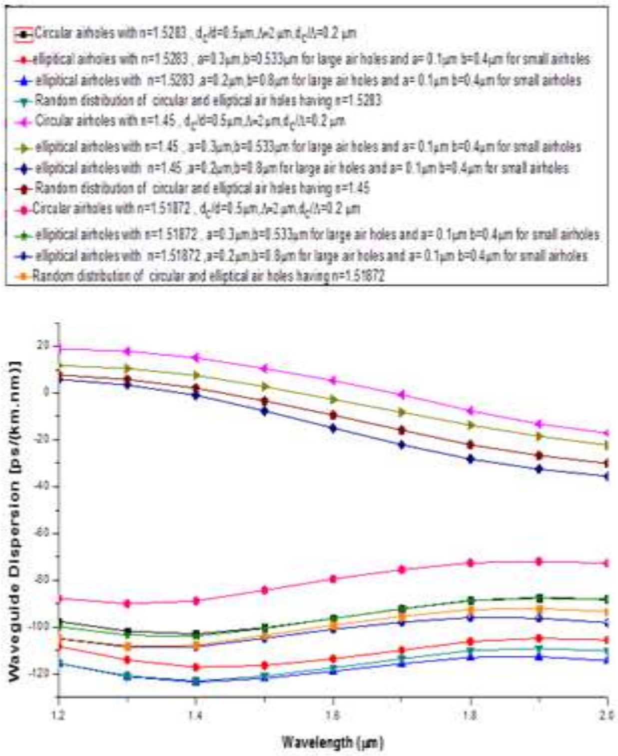


Fig 3: Waveguide Dispersion variation as a function of wavelength for Ge (n=1.5283), Si (n=1.45), Schott Bk7 (n=1.51872) doped core, $\eta_2$ =1.0, $d_2$=1.4 µm, $d_c$/d = 0.5, $d_c$/ Λ = 2µm, Λ=2 µm, a=0.1 µm 0.2 µm, 0.3 µm and b=0.4 µm, 0.533 µm, 0.8 µm.

The plots shows that dispersion gets decreased to -103.77964 ps / (nm.km) with increase in the ellipticity of air holes for Ge doped core then Schott BK7 doped core which is -86.65784 ps / (nm.km) and it is lower than Si doped core photonic crystal fiber which is 10.38431 over the wavelength range 1.2 µm to 2 µm.

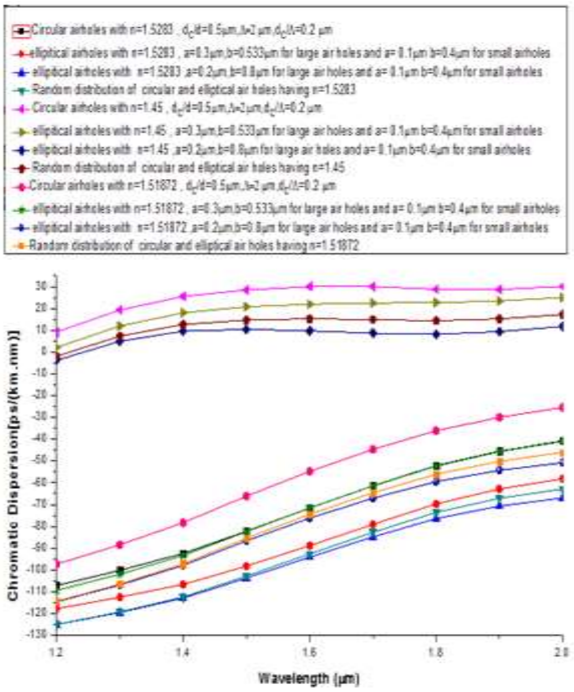


Fig 4: Chromatic Dispersion variation as a function of wavelength for the Ge (n=1.5283), Si (n=1.45), schott Bk7 (n=1.51872) doped core, $\eta_2$ =1.0 and $d_2$=1.4 µm, $d_c/d$ = 0.5, $d_c/\Lambda$ = 2µm, Λ=2 µm, a=0.1 µm 0.2 µm, 0.3 µm and b=0.4 µm, 0.533 µm, 0.8 µm.

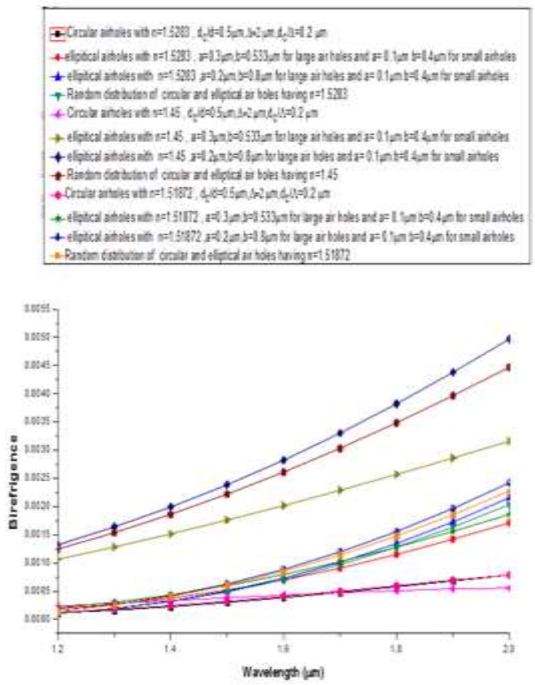


Fig 5 Modal birefringence variation as a function of wavelength for Ge (n=1.5283), Silica (n=1.45), Schott Bk7 (n=1.51872) doped core, Here $\eta_2$ =1.0, $d_2$=1.4 µm, $d_c/d$ = 0.5, $d_c/\Lambda$ = 2a=0.1 µm 0.2 µm, 0.3 µm and b=0.4 µm, 0.533 µm, 0.8 µm

The modal birefringence of a hybrid square-lattice PCF of elliptical air holes having Si-doped core increases to 4.97 x$10^{-3}$ which is high as compare to Schott Bk7 doped core that is 2.4 x $10^{-3}$ and for Ge doped core photonic crystal fiber, the birefringence is investigated as 2.16 x $10^{-3}$ over the wavelength range 1.2 µm to 2 µm. The birefringence of holey fiber increases towards longer wavelength range.

# Conclusion:

A hybrid square–lattice PCF with elliptical and circular air holes having small Ge-doped core, Si-doped core and Schott BK7 doped core, are compared and investigated for their dispersion and birefringence properties, with the Ge-doped core, designed in Fig 1(c) (Conf III), dispersion gets decreased to -103.77964 ps / (nm.km), so it can be used as dispersion compensation fiber in a wideband due to its flat and highly negative dispersion. The modal birefringence of a hybrid square-lattice PCF with elliptical air holes having Si-doped core is investigated to be equal to 4.97 x$10^{-3}$ at 2 µm wavelength which is very high as compared to other doped core PCF material. Therefore the proposed hybrid square lattice PCF with elliptical air hole and core doped with different materials can be used as high birefringence and low dispersion fiber .These scalable results also show that doping level in PCF provide an additional way to change chromatic dispersion excepting structural parameters, helpful to design and optimize for different applications.

# References :

[1] J. Broeng, D. Mogilevtsev, S. E. Barkou, and A. Bjarklev, “Photonic crystal fibers: A new class of optical waveguides,” Opt. Fiber Technol.,vol. 5, pp. 305–330, Jul. 1999.

[2]Purushottam josh,i R. k. sharma ,Jai kishore s, and Anjay kher “Fabrication of photonic crystal fiber”Raja Ramanna Centre for Advanced Technology, current science, vol. 93, no. 9,10 november 2007

[3] Bjarklev A, Broeng J, Bjarklev AS. Photonic crystal fibers. Dordrecht: Kluwer Academic Publishers; 2003.

[4] Knight JC, Broeng J, Birks TA, Russell PSJ. Photonic band gap guidance in optical fiber. Science 1998;282:1476–8.

[5]Philip R. Photonic crystal fibers. Science 2003;299:358–62.

[6] Ritu sharma, Vijay janyani. Anuradha sharma “Design of Elliptical Air Hole PCF with Hybrid Square Lattice for High Birefringence and a Lower Zero Dispersion Wavelength” International journal of Computer Science & Emerging Technologies, Volume 2, Issue - 2,pp – 238-241, April 2011.

[7] Ferrando M, Silvestre E, Andre´s P, Miret JJ, Andre´ s MV. "Designing the properties of dispersion-flattened photonic crystal fibers." Opt Express 2001;9:687–97.

[8] Shen LP, Huang W-P, Jian SS. Design and optimization of photonic crystal fibers for broadband dispersion compensation. IEEE Photon Technol Lett 2003;15:540–2.

[9] J. Patrocfnio da Silva, Diego Souza Bezerra, Iguatemi E. Fonseca "Photonic Crystal Fiber design with Ge-Doped Core for Residual Chromatic Dispersion Compensation" IEEE,2009.