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A Novel Design PCF with Composite Lattice

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Abstract: In this paper, a novel design of ultra low flattened dispersion photonic crystal fiber using hexagonal, square lattice and composite design is proposed. The Finite Difference Time Domain (FDTD) method is used to simulate and analyze the chromatic dispersion property using hexagonal square lattice and composite design.

Keywords: Photonic Crystal Fiber (PCF), Finite Difference Time Domain (FDTD), Chromatic Dispersion.

INTRODUCTION

Photonic crystal fibers are a new class of optical fibers. They can guide light not only through a well-known total internal reflection mechanism (index guided PCF) but also using photonic band gap effect (PBG fiber). The PCF is formed by a hexagonal array of air holes (with diameter d) embedded in a silica matrix, where the center-to-center spacing between the nearest air holes is referred to as pitch (Λ). Photonic band gap (PGB) theory has opened a numerous applications in the field of photonics, out of which one important application is PCF. PBG exhibits a unique characteristic that only certain wavelengths can be transmitted. So, in a PCF the guidance process is achieved by coherent backscattering of the light into the core. Photonic crystal fibers are divided into two different kinds of fibers. Index-guiding PCF guides light by total internal reflection between a solid core and a cladding region with multiple air-holes. Nearly zero dispersion and very low confinement loss properties can be obtained with these PCF's [1, 2].

In this paper a five ring PCF with composite lattice having Λ =1.6µm gives ultra low chromatic dispersion (0.01 ps/km-nm) when compared with hexagonal lattice and square lattice for wide wavelength range characteristics.

DISPERSION

Chromatic dispersion is calculated as the sum of material dispersion and the waveguide dispersion, which can be obtained from the effective index (η_{eff}) as give below [1-3]:

$$D(\lambda) = -(\lambda/c)(d2\eta_{eff}/d\lambda 2) \qquad (1)$$

where c is the light in vacuum and λ is operating wavelength the total dispersion is calculated as sum of the material and waveguide dispersion. Total dispersion can be written as [1- 3]:

$$D_T(\lambda) = D_w(\lambda) + \Gamma(\lambda)\, D_m(\lambda) \qquad (2)$$

where Γ is confinement factor of silica which is equal to 1 and D_m is the material dispersion which can be obtained from the three term Sellmeier formula and D_w is the waveguide dispersion [1, 2].

DESIGN PARAMETERS

A five ring schematic cross section of PCF with pitch 1.6 µm and air hole diameter to pitch ratio D/Λ=0.86 [2] is shown in Fig.1(a) with hexagonal lattice and in Fig.(b) with square Lattice

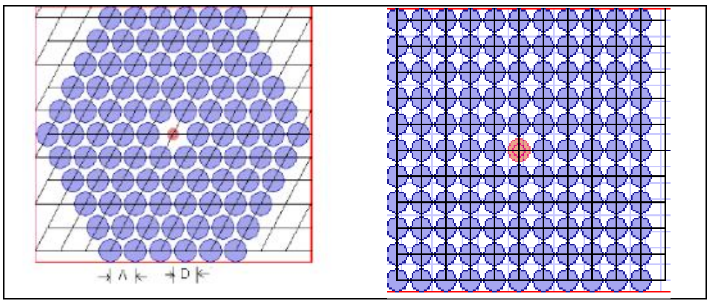

Fig 1 (a) **Fig 1 (b)**

Fig1(a) Section-structure of hexagonal lattice PCF with D1/Λ=0.86, D2/ Λ=0.86, D3/Λ=0.86, D4/ Λ =0.86, D5/ Λ=0.86;Fig 1(b) Section-structure of Square lattice PCF with D1/Λ=0.86, D2/ Λ=0.86,D3/Λ=0.86, D4/ Λ =0.86, D5/ Λ=0.86.

Four design parameters with different air hole diameter for both hexagonal and square lattice considered are [2]:

(i) Configuration 1: D1/Λ, D2/Λ, D3/Λ, D4/Λ and D5/Λ = 0.86.
(ii) Configuration 2: D1/Λ=0.37875, D2/Λ=0.40, D3/Λ=0.4375,D4/Λ=0.475,D5/Λ=0.86.
(iii) Configuration 3: D1/Λ=0.3125, D2/Λ=0.3625, D3/Λ=0.40, D4/Λ=0.45, D5/Λ=0.86.
(iv) Configuration 4: D1/Λ=0.3125, D2/Λ=0.3625, D3/Λ=0.40, D4/Λ=0.4126, D5/Λ=0.86.

where D1, D2, D3, D4 and D5 are the air hole diameter of ring 1, ring 2, ring 3, ring 4 and ring 5 respectively from the core and Λ is distance between the centres of two air holes.

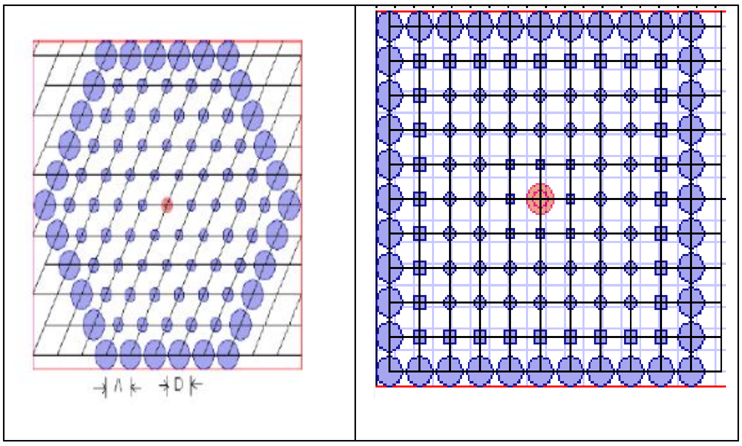

Fig 1 (c) **Fig 1 (d)**

Fig1(c) Section-structure of hexagonal lattice PCF with D1/Λ=0.3125, D2/ Λ=0.3625,D3/Λ=0.40, D4/ Λ =0.4126, D5/ Λ=0.86; & Fig 1(d) Section-structure of Square lattice PCF with D1/Λ=0.3125, D2/ Λ=0.3625,D3/Λ=0.40, D4/ Λ =0.4126, D5/ Λ=0.86.

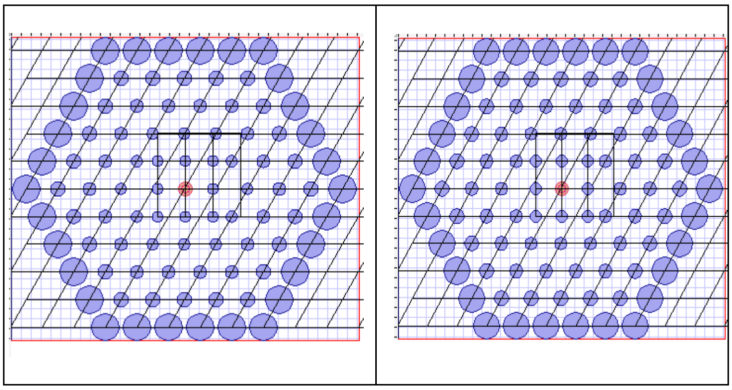

Fig 1 (e) **Fig 1 (f)**

Fig1(e) Section-structure of Composite lattice PCF with D1/Λ=0.37875, D2/Λ=0.40, D3/Λ=0.4375,D4/Λ=0.475, D5/Λ=0.86 ; & Fig1(f) Section-structure of Composite lattice PCF with D1/Λ=0.3125, D2/Λ=0.3625, D3/Λ=0.40, D4/Λ=0.45, D5/Λ=0.86.

In this paper, the PCF is first designed and analyzed using triangular lattice and square lattice and then a novel structure of PCF which uses composite lattice is designed, compared and investigated. The results obtained with composite lattice shows ultra flattened dispersion when compared with Hexagonal and Square lattice PCF. This makes the fiber suitable for broadband transmission platforms.

SIMULATION METHODOLOGY

FDTD (finite difference time domain) based simulation software OptiFDTD (version 8, official license available) is used with (transparent boundary condition) TBC boundary conditions for the simulation of proposed designs. OptiFDTD is a powerful, highly integrated and user friendly software application that enables the computer aided design and simulation of advanced passive and non-linear photonic components [1, 2].The main design parameters used for designing the layouts are:
Length (z) = 11*a (length of simulation domain).
Width(x) =11*b (width of simulation domain).
Mesh Delta X=0.08 (mesh resolution in X direction).
Mesh Delta Y=0.08 (mesh resolution in Y direction).

RESULTS AND DISCUSSION

These are the results discussed for above mentioned layouts:-

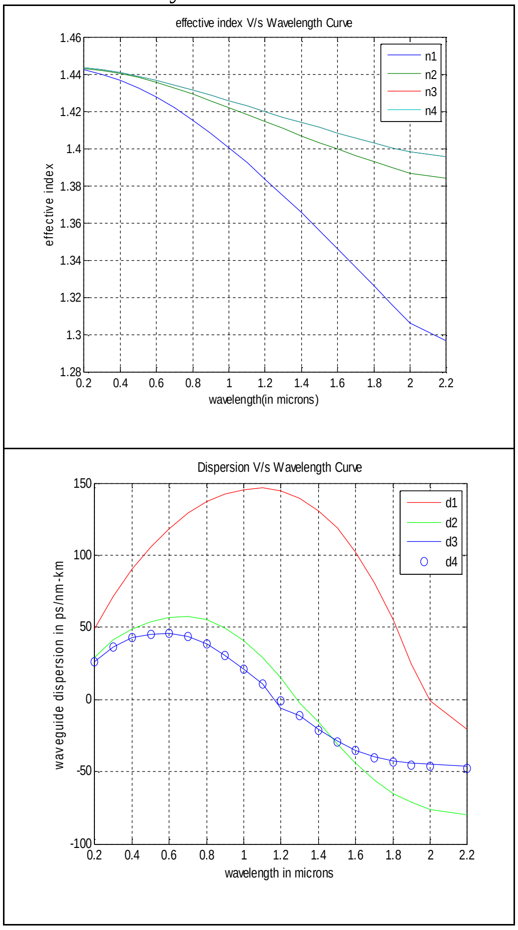

Fig2(a) & Fig2(b)

Fig2(a) *shows variation of the real part of the complex effective refractive index with wavelength λ and* ***Fig2(b)*** *shows variation in waveguide dispersion of PCF for different four designs considered with hexagonal lattice where pitch is 1.6µm.*

It is observed that maximum value of waveguide dispersion is 149ps/km-nm for configuration 1 and it reduces to 49ps/km-nm by manipulating the air hole diameter configuration 4.where d1, d2, d3, d4 are configuration1, configuration2, configuration3, configuration 4 respectively.

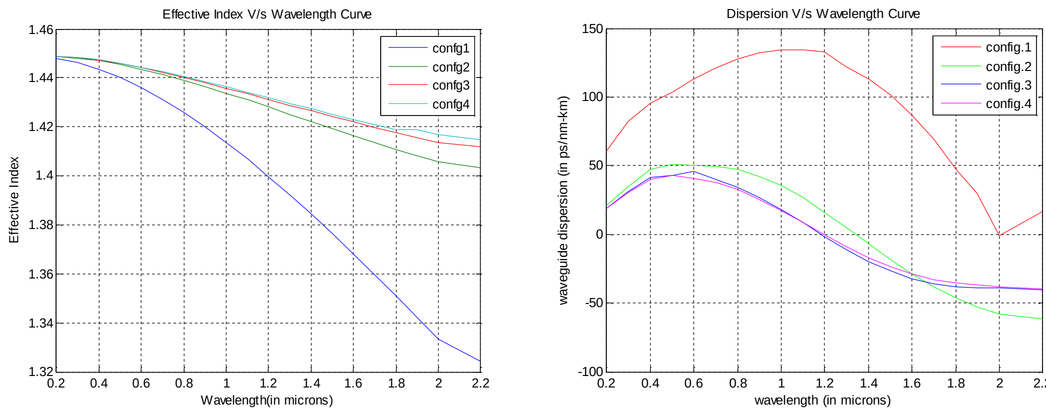

Fig 2 (c) & Fig 2 (d)

Fig2(c) *shows variation of the real part of the complex effective refractive index with wavelength λ and* ***Fig2(d)*** *shows variation inwaveguide dispersion of PCF for different four designs where ʌ=1.6µm. It can be observed that maximum value of waveguide dispersion is 135ps/km-nm and it decrease to 30ps/km-nm by changing the lattice type i.e. square lattice.*

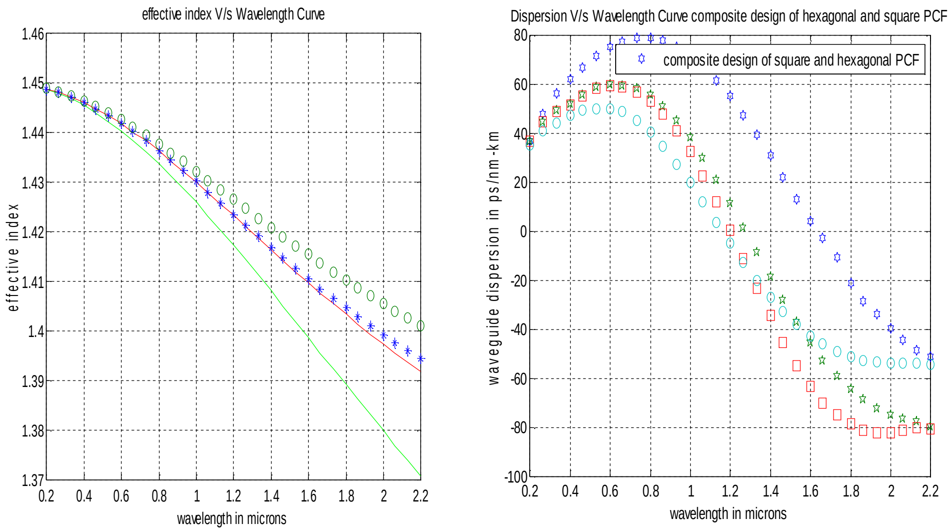

Fig 2(e) &Fig 2(f)

Fig2(e) *shows variation of the real part of the complex effective refractive index with wavelength λ and Fig2(f) shows variation in waveguide dispersion of PCF for different four designs where ʌ=1.6μm.*

It can be observed that maximum value of waveguide dispersion is 135ps/km-nm and it decrease to 78ps/km-nm by changing the lattice type i.e. composite design of hexagonal and square lattice.

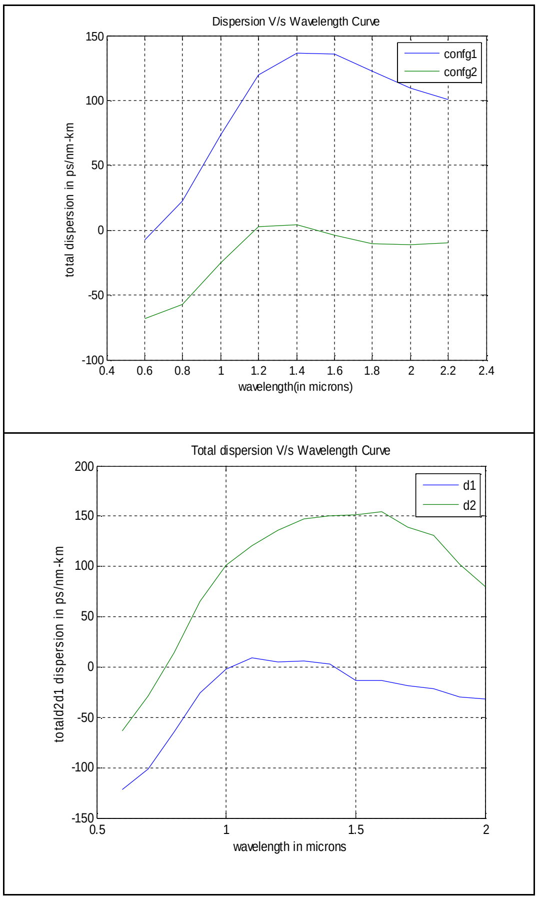

Fig2(g) & Fig2(h)

Fig2(g) Chromatic dispersion for Hexagonal lattice for configuration D1, D2 ; **Fig2(h)** chromatic dispersion for Square lattice for configuration D1,D2.

It can be observed that value of Chromatic dispersion is 0.5ps/km-nm and it decrease to 0.1ps/km-nm by changing the lattice type i.e. Hexagonal lattice to Square lattice in configuration 1 and configuration 2.

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Material dispersion which is calculated by sellmeier's equation given by:-

$$n_{Silica}^{2}(\lambda) = \varepsilon_r(\lambda) = 1 + \sum_{k=1}^{3} \frac{b_k \lambda^2}{\lambda^2 - \lambda_k^2}$$

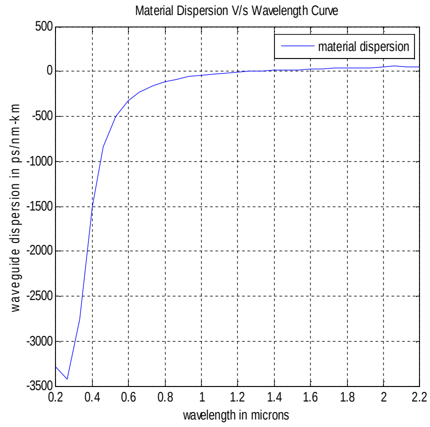

Fig 2(i) Fig 2(i) Material Dispersion.

Chromatic dispersion calculated by adding waveguide dispersion and material given by above equation (2) Chromatic Dispersion curve for configuration D1, D2:

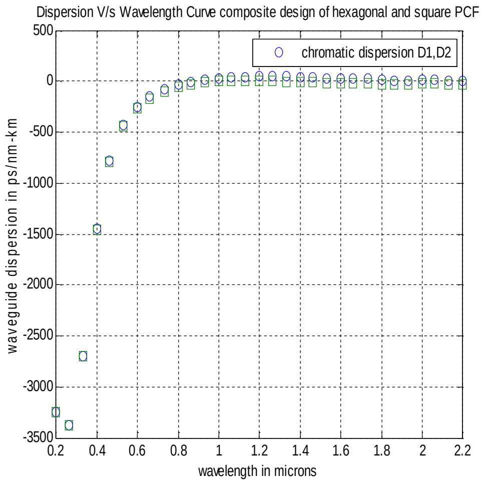

Fig 2(j)

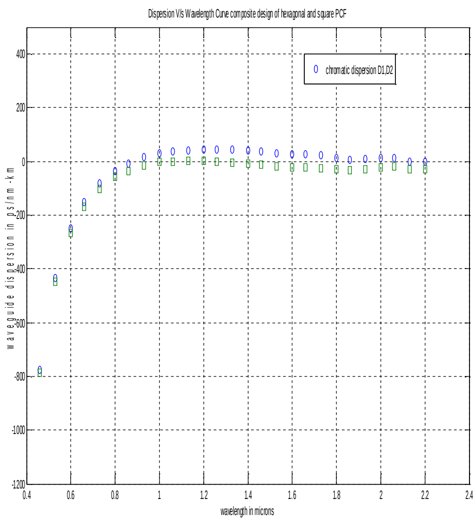

Fig 2(k)

Fig 2(j) Chromatic dispersion for configuration D1 and D2 for large range of wavelength; and **Fig 2(k)** for small range of wavelength.

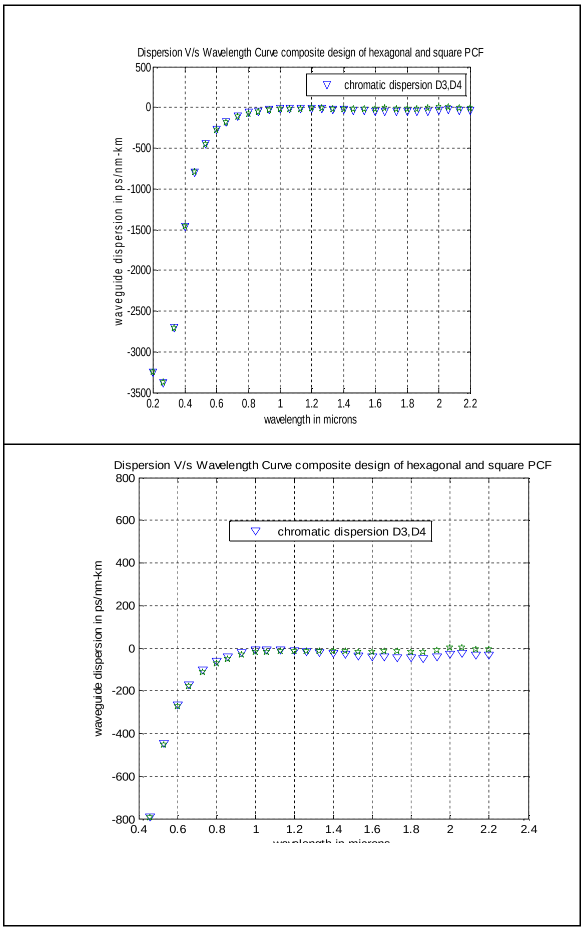

Fig 2(l) & Fig 2(m)

Fig 2(l) Chromatic dispersion for configuration D3 and D4 for large range of wavelength; and **Fig 2(m)** for small range of wavelength.

VI. CONCLUSION

In this paper, the dispersion properties of hexagonal, square lattice and composite lattice of hexagonal and square lattice PCF are investigated and analyzed for the proposed designs. The magnitude of Total dispersion with square lattice reduces to a very low value as the diameter of the inner rings is reduced compared to outer most rings i.e. configuration 1 and 2 gives the dispersion = 0.1ps/km-nm as compared to PCF with hexagonal lattice which gives dispersion = 0.5ps/km-nm for the same wavelength range. In the composite design of hexagonal and square lattice dispersion is ultralow 0.01ps/km-nm and flattened dispersion in the wide wavelength range .Hence The proposed designs can be used as ultra-low dispersion PCF over wide wavelength ranges.

VII. ACKNOWLEDGMENT

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