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Ultra Flattened Dispersion over Telecom Wavelength in Ring Based Photonic Crystal Fiber

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Abstract: *A new dispersion flattened PCF is proposed by introducing ring core and circular air holes based cladding. By tailoring the width of ring in the core of fiber, ultra-flattened dispersion is obtained for telecomm wavelength 1.5 μm while a zero dispersion is being reported at optical telecommunication wavelength of E-Band(1.3 μm).By controlling the width of ring, endlessly single mode propagation condition is obtained with large MFD.FDTD method with perfectly matched boundary layer is used to investigate the guiding properties of the proposed PCF.*

Keywords: *PCF, FDTD, dispersion, Mode Field Diameter, Effective Area*

I. Introduction

In the recent years, photonic crystal fibers have attracted growing attention due to its unique properties. Photonic crystal fiber or holey fiber or microstructure optical fiber(Mof's),with periodic arrangement of air holes running along the longitudinal direction, shows many interesting features then conventional optical fiber.[1]. One of the important characteristics to be reported for the PCF was its potential to be single moded.This characteristics is useful for many applications in fiber lasers, fiber-optic-communication and other areas. Standard single mode fiber has positive chromatic dispersion that leads to greater dispersion magnitude as the optical signal travel over longer distances. Therefore a dispersion management system has to be designed to minimize the accumulated positive dispersion in order to ensure signal integrity[1-3].

An ultra-flattened negative dispersion PCF with average dispersion of -98.3$(\mathrm{ps\,nm^{-1}km^{-1}})$ and absolute variation(ΔD)of $\sim 1.1(\mathrm{ps\,nm^{-1}km^{-1}})$ over 1480nm-1630nm was reported in [4].The design by Franco et al.[5]reports higher average dispersion of-179$(\mathrm{ps\,nm^{-1}km^{-1}})$ and (ΔD)around $\sim 2.1(\mathrm{ps\,nm^{-1}km^{-1}})$ over wide bandwidth from S to U bands. Both the designs have limited wavelength bands and low negative dispersion, which restricted their application as efficient residual dispersion compensation. Later a high negative dispersion of -212$(\mathrm{ps\,nm^{-1}km^{-1}})$ and ΔD of $\sim 11(\mathrm{ps\,nm^{-1}km^{-1}})$ over E+S+C+L+U wavelength bands was obtained with Ge-doped core by using genetic algorithm for optimization[6]. More recently an equiangular spiral typed PCF was designed to have average dispersion of -227$(\mathrm{ps\,nm^{-1}km^{-1}})$ and ΔD of $\sim 11.9(\mathrm{ps\,nm^{-1}km^{-1}})$over the entire E+S+C+L+U wavelength bands. However, the equiangular-spiral typed PCF is difficult to fabricated by using the conventional stack and draw method.[7]

In this paper a new type of photonic crystal fiber is proposed and its properties like dispersion, mode field diameter, effective area and V-Parameter are numerically simulated by using FDTD (finite difference in time domain). Numerical simulation reveals that the proposed PCF has lower dispersion and high V parameter. Pure silica is used as the base material, in which air holes are embedded.

II. Modelling Method

In order to study optical properties of the designated fibers, we have employed finite difference in time domain (FDTD) method [8]. By using FDTD method, the propagation of electromagnetic signals inside these PBG structures and the penetration depth of the field modes can be conveniently and efficiently studied. FDTD is a time domain numerical method which acts by discretization of Maxwell's equations [9]. The time evolution of the field can be obtained by using leapfrog time step. For fixed no. of time steps, the computational time is proposional to the no. of discretization points in the computational domain. For stable method, the time steps should follow:[10]

$$\Delta t \leq \frac{1}{\upsilon\sqrt{\frac{1}{\Delta x^2}+\frac{1}{\Delta y^2}+\frac{1}{\Delta z^2}}} \qquad \ldots\ldots(1)$$

Where Δx, Δy, Δz are the space steps in three different direction respectively. Δt is the time steps and υ is the speed of light.[10]

III. Design of the PCF

In Fig1 shows that the fiber is composed of 6 rings of air holes in the cladding region which are arranged in rectangular lattice formation. The innermost ring made of ring waveguide with high refractive index (1.5) and all outermost rings has lower refractive index (1.45). The centre air hole is missing which act as a fiber core. The refractive index of the background region and the centre is 1.45 whereas refractive index of air hole is 1. Hole pitch= 2.3μm, diameter of air hole d=0.5175 μm.

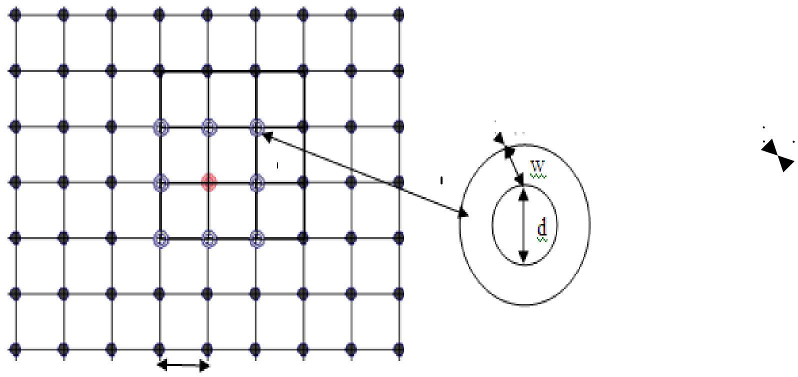

Fig.1 Index –guiding PCF, d=0.5175 μm, Λ=2.3 μm, w=0.14 μm

Because periodicity in cladding holes is not important in index guiding PCF to confine light in a core region. Thus we have preferred to have holes with different width.

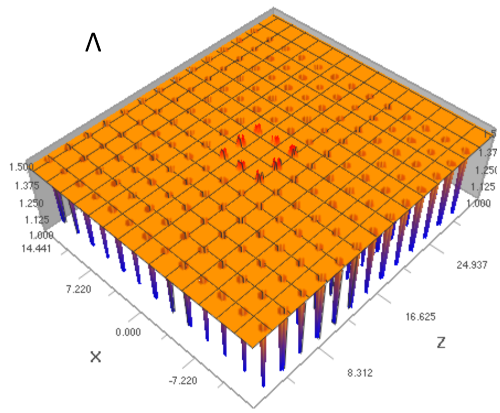

Fig 2: 2D refractive index profile for rectangular layout for w=0.14 μm (Number of rings= 6, air hole diameter (d) = 0.5175 μm

The waveguide dispersion is given as:[11]

$$D = \left(\frac{-\lambda}{c}\right)\left(\frac{d2Re[n_{eff}]}{d\lambda^2}\right)\ldots\ldots\ldots\ldots\ldots..(2)$$

Where λ is wavelength in μm, c is the velocity of light.

A normalized frequency parameter, which determines the no. of modes of a step index fiber, is known as V-number. The V no. is a parameter which is often used in the context of step index fiber. It is defined as:[12]

$$V = \frac{2\pi}{\lambda} a\sqrt{\eta_{core}^2 - \eta_{cladding}^2} \ldots\ldots\ldots\ldots\ldots..(3)$$

Where λ is the vacuum wavelength and a is the radius of the fiber. η_{core} is the core refractive index. $\eta_{cladding}$ is the cladding refractive index. For V values below 2.405, a fiber supports only single mode per polarization direction. [11-12]

. The effective area can be explained in terms of the spot-size by using below mentioned equation:[13-14]

$$A_{eff=\pi W^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..[4]$$

For step index and graded index single mode fiber operating near the cutoff wavelengthλ_c, the field distribution of the fundamental mode is approximately Gaussian[15-16].

IV. Numerical Results

Our proposed PCF design shows a ultra-flattened negative dispersion at 1.3 μm -2.0 μm. Due to the high refractive index in the ring waveguide the modes are confined around the outer region The fabrication of our structure is possible by standard stack and draw technique. The influence of changing width on dispersion, V-Parameter, mode field diameter and effective area are as shown in graphs.

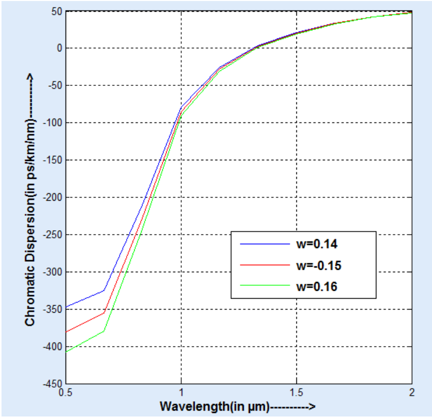

Fig.3 Calculated dispersion with respect to excitation wavelength for different width

From Fig.3 it is depicted that the min negative dispersion obtained is -408(ps $nm^{-1}km^{-1}$) at 0.5µm when w=0.16µm, as the width increased the dispersion value tends towards more negative values. The min. dispersion obtained at 1.55µm is 22.368017(ps $nm^{-1}km^{-1}$) at w=0.16µm.we get zero dispersion at entire E-bands.

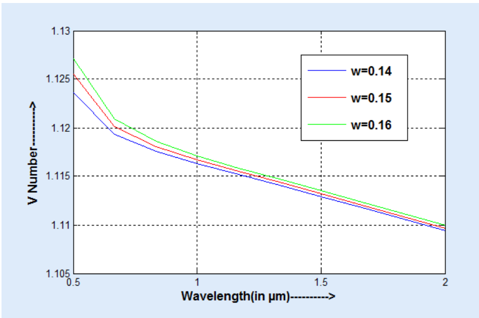

Fig.4 Calculated V-parameter with respect to excitation wavelength for different width

Fig.4 shows that the max. value of V parameter is 1.127099 with width = 0.16µm at 0,5µm. When width = 0.14µm, the value of V parameter is 1.123646. With width=0.15µm, the V parameter is 1.12548. As the width increased, the V parameter also increased with low dispersion

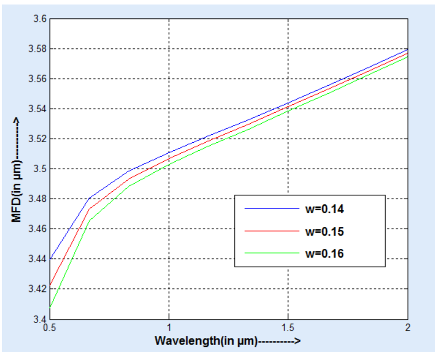

Fig.5: Calculated Mode field diameter with respect to excitation wavelength for different width

Fig.5 shows that the max. value of Mode field diameter is 3.579383 µm with width = 0.14µm at 2.0µm. When width = 0.16µm, the min value of mode field diameter is 3.407353172 µm at 0.5 µm. As the wavelength increases, the mode field diameter also increases. But as the width increased, the mode field diameter decreased.

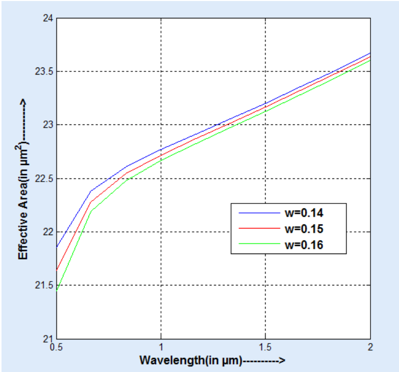

Fig.6 Calculated Effective Area with respect to excitation wavelength for different width

Fig.6 shows that the max. value of Effective area is 23.66760157 μm^2 with width = 0.14μm at 2.0μm. When width = 0.16μm, the min value of Effective area is 21.44727421 μm^2 at 0.5 μm. As the wavelength increases, the Effective area also increases. But as the width increased, the Effective area decreased.

V. Conclusion

With this work, we have demonstrated PCF with higher refractive index at the innermost ring, which is made of ring waveguide. For PCF, with circularly shaped air holes, the highest value of V parameter is 1.127099 with width = 0.16μm. The min. value of dispersion is -408($ps\,nm^{-1}km^{-1}$) at 0.5μm with d = 0.5175μm, Λ = 2.3μm. Due to V parameter less than 2.405 the proposed PCF are suitable for single mode fiber application. The other properties of PCF like mode field diameter and effective area also calculated and compared for different width. Due to zero dispersion in the optical E-band, the PCF find important applications in communication.

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