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NOVEL HYBRID PHOTONIC CRYSTAL FIBER WITH DEFECTED CORE FOR DISPERSION COMPENSATION OVER E TO U BAND TELECOMMUNICATION

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ABSTRACT

A Hybrid photonic crystal fiber with defected core is proposed for dispersion compensation over E to U band telecommunication and simulated by finite element method with perfectly matched layers (PML). The numerical results shows a high negative chromatic dispersion of about -389 ps/nm/km and the relative dispersion slope the same as the single mode fiber SMF-28 of about 0.0036nm^{-1} at wavelength λ=1.55 μm. these properties make our proposed design usable for several applications such as compensation dispersion and so.

Keywords: hybrid photonic crystal fiber, finite element method, relative dispersion slope, chromatic dispersion.

1. INTRODUCTION

To control chromatic dispersion caused by single mode fiber (SMF-28), Photonic crystal fiber [1] also called holey fiber [2] is used due to many particular properties such as single mode operation [3], tuning dispersion [4] and birefringence [5], which are not achieved by the conventional fibers [6]. Up to now, many models of photonic crystal fiber with a high negative chromatic dispersion have been reported. For example a conventional dispersion compensating fiber present a coefficient of chromatic dispersion approximately of about -100 to -250 ps /nm/km [7]. Another design shows a negative dispersion of about -390ps/nm/km is presented by Md.Aminul Islam et al [8]. Marcos et al presented a dual concentric photonic crystal fiber with a high chromatic dispersion of about -1800 ps/nm/km [9]. in this paper, a hybrid photonic crystal fiber with defected core is proposed and calculated by the finite element method with perfectly matched layers, a high negative chromatic dispersion of about -389 ps/nm/km and the relative dispersion slope of about 0.0036nm^{-1} identical to the single mode fiber SMF-28 are obtained .this properties makes our proposed hybrid photonic crystal fiber usable in the high transmission systems.

2. DESIGN METHODOLOGY

Figure-1 indicate the cross section of the proposed hybrid photonic crystal fiber, which is composed for seven rings air hole in the cladding where (Λ) is the pitch, (d) is the diameter of the first rings, (d_p) is the diameter of the small air holes which are added in the core and the first rings in order to obtain a relative dispersion slope the same as the single-mode fiber SMF-28 and (d_1) is the diameter of rest rings. The substrate is made to be silica.

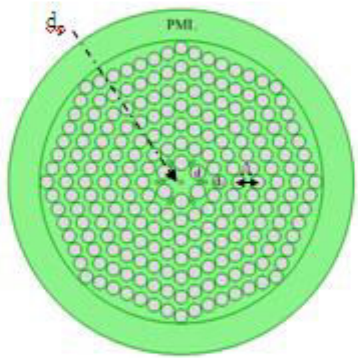

Figure-1. Cross section of the proposed design.

To determine the chromatic dispersion, effective area and confinement loss, Comsol Multiphysics based on finite element method with perfectly matched layers (PML) is used for solving the Maxwell equation following [10].

$$\nabla \times ([s]^{-1}\nabla \times \overrightarrow{E}) - K_0^2 n^2 [s]\vec{E} = 0 \quad (1)$$

Here $\vec{E}$ is the electric field vector, k_0 free space wave number, n refractive index of the effective medium, [s] the matrix of the PML layers, $[s]^{-1}$ is the matrix inverse of [s].

Chromatic dispersion is one most important parameters to reduce transmission in optical fibers, once the effective index of the hybrid photonic crystal fiber is calculated, the chromatic dispersion is given by [11]

$$D = -\frac{\lambda}{c}\frac{d^2 Re(n_{eff})}{d\lambda^2} \quad (2)$$

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Where Re (n_{eff}) is the real part of the effective index , λ the wavelength, c the velocity of light in a vacuum,

To compensate the positive chromatic dispersion caused by the single mode fiber (SMF-28) the following condition must be satisfied [12].

$$RDS = \frac{S_{SMF}(\lambda)}{D_{SMF}(\lambda)} = \frac{S_{DCF}(\lambda)}{D_{DCF}(\lambda)} \quad (3)$$

Where $S_{SMF}(\lambda)$, $S_{DCF}(\lambda)$ are the dispersion slopes for the single mode fiber SMF and DCF respectively. The RDS value of the single mode fiber is about 0.0036nm^{-1} at wavelength λ =1.55µm.

After compensation, the residual dispersion can be written as suite [13]:

$$D_r(\lambda) = D_{SMF}(\lambda)L_{SMF} + D_{DCF}(\lambda)L_{DCF} \quad (4)$$

Here L_{SMF}, L_{DCF} are the length for the single mode fiber (SMF) and dispersion compensating fiber (DCF), respectively.

Once that the imaginary part of the effective index obtained, the confinement loss is calculated by the following relationship [14]:

$$L_c = \frac{2\pi}{\lambda} \times 8.686 \times Im(n_{eff}) \quad (5)$$

In dB/m, Im(n_{eff}) is the imaginary part of effective index.

3. SIMULATION RESULTS

Figure-2 illustrate the electric field distribution at wavelength λ =1.55µm, from Figure, it clear that the power is confined in the core.

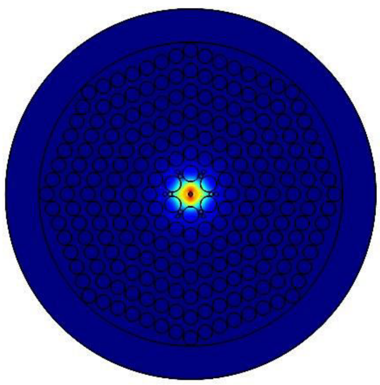

Figure-2. The electric field distribution at λ =1.55µm.

For several calculations, the optimum design parameters are (Λ=1µm, d=0.78µm, d_l=0.7µm, d_P=0.2µm), the dispersion characteristics of hybrid photonic crystal fiber are shown in Figure-3, from the figure it is clear that this proposed fiber present a negative chromatic dispersion of about -389 ps/nm/km at wavelength λ =1.55µm. this high negative chromatic dispersion makes our proposed hybrid photonic crystal fiber with defected core usable in high transmission systems, and so.

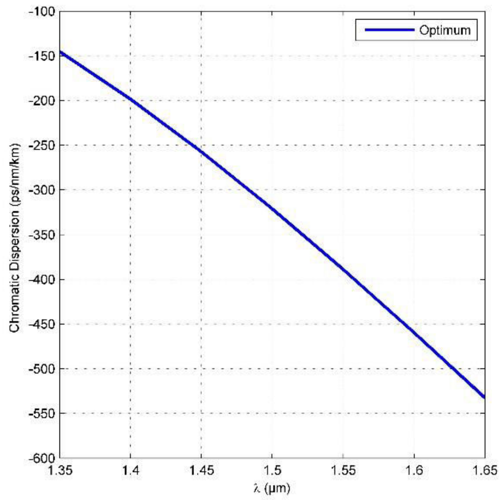

Figure-3. Chromatic dispersion as wavelength for optimum design parameters

Figure-4 exhibit the effect of the air hole diameter (d) on the chromatic dispersion. As the diameter (d) is varied as 0.76 to 0.8µm, .we can see that the chromatic dispersion value increases when the diameters of the air hole (d) increase. Also at wavelength λ =1.55µm the chromatic dispersion value are -360, -389 and -422ps/nm/km respectively for d=0.76, 0.78and 0.8µm.

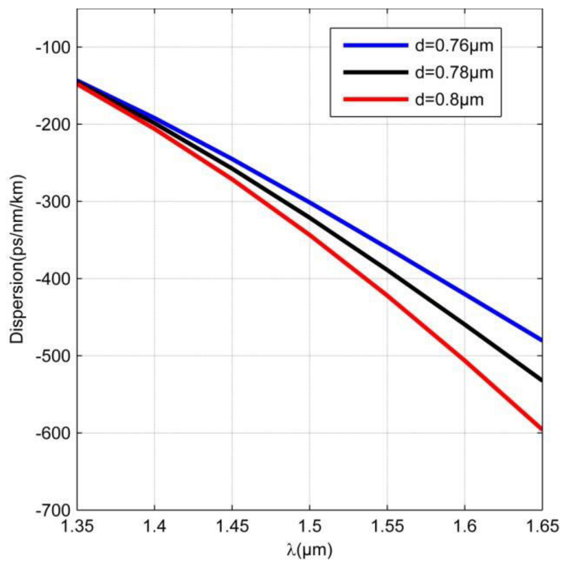

Figure-4. The effect of (d) on chromatic dispersion.

From Figure-5, present the variation in the small air hole diameter. From the Figure, we can see that the value of chromatic dispersion is increased when the small air hole diameter increased or vice versa.

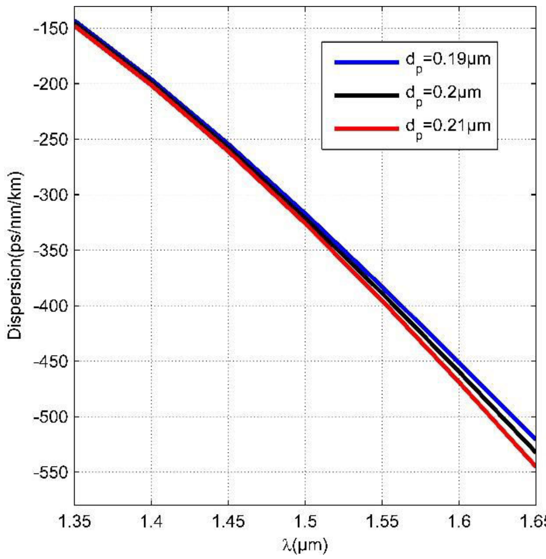

Figure-5. The effect of (d_p) on chromatic dispersion.

Figure-6 reveals the effect of the rest ring diameter (d_1) on chromatic dispersion while we kept (Λ =1μm, d=0.78μm, d_1=0.7μm, d_P=0.2μm).

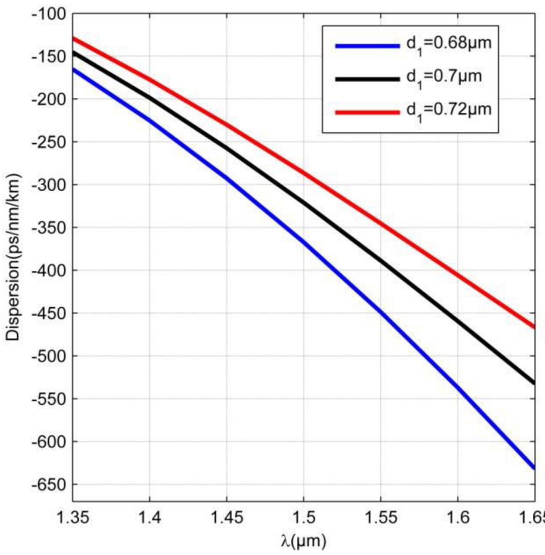

Figure-6. The effect of (d_1) on chromatic dispersion.

It is clear that the chromatic dispersion is decreased as wavelength increases and decrease as air hole diameters (d_1) of the rest ring increases.

Figure-7, shown the pitch dependence on chromatic dispersion .The results shows that the value of chromatic dispersion decreases as the pitch increase. For example, at wavelength λ =1.55μm, the values of chromatic dispersion are about - 411,-389 and -233ps/nm/km for

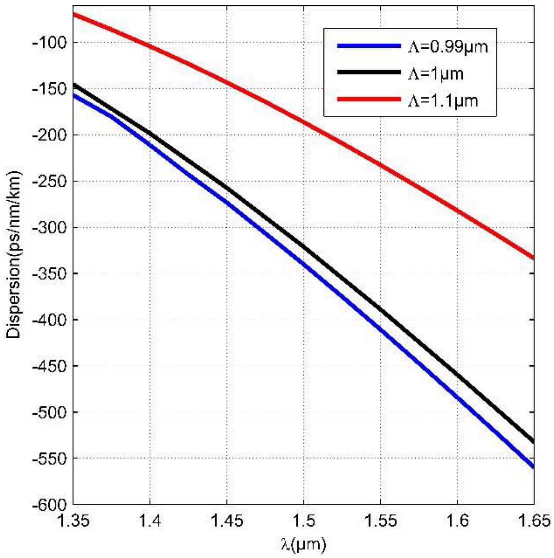

Figure-7. The effect of (Λ) on chromatic dispersion.

While Figure-8 shows the residual dispersion as wavelength. It is clear that the residual dispersion is lower than ±64ps/nm in the wavelength range of 1.38 to 1.675 μm, which make our proposed design an excellent device for high transmission system over E to U wavelength band telecommunication.

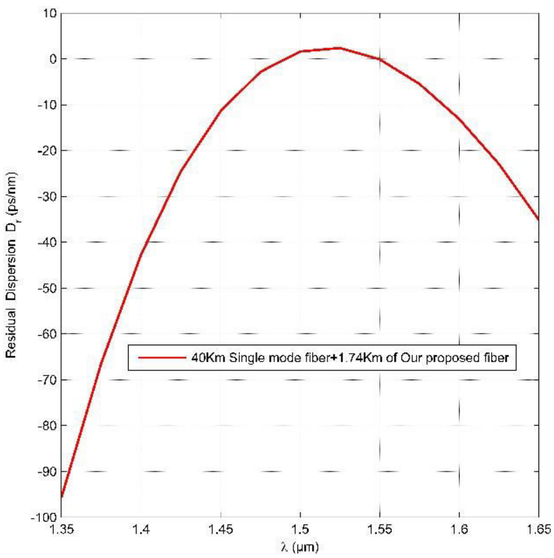

Figure-8. Residual dispersion as function of wavelength for the optimum design parameters.

Figure-9 shows the variation of effective area as wavelength for optimum design, from Figure we can see that the effective area increased with wavelength and the value of effective area is about of 1.77μm² at wavelength λ =1.55μm.

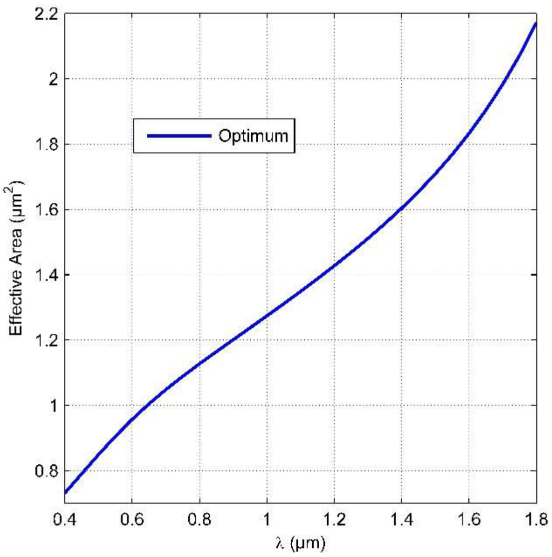

Figure-9. Effective area as wavelength for optimum design.

Figure-10 plot the confinement loss as a function of wavelength. For the optimum design parameters (Λ =1μm, d=0.78μm, d_1=0.7μm,d_P=0.2μm).

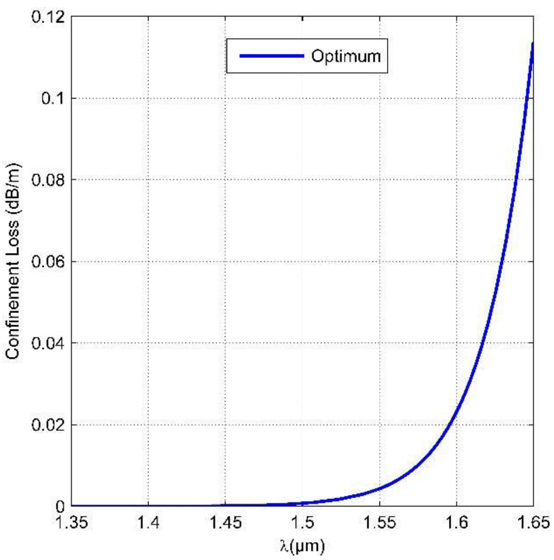

Figure-10. Confinement loss as function of wavelength for the optimum design parameters.

From the figure, we can see that the confinement loss of about 0.0043dB/m at wavelength λ=1.55μm. after the operating wavelength the confinement loss increases when the wavelength increase.

Table-1. Presents a comparison between properties of the proposed design and other design at wavelength λ =1.55μm.

DCF	Chromatic dispersion (ps/nm/km)
[15]	-138
[8]	-390
[16]	-294
Our proposed design	-389

4. CONCLUSIONS

In summary, a hybrid photonic crystal fiber with defected core is proposed and simulated by finite element method with perfectly matched layer (PML).this proposed design offers a negative chromatic dispersion of about -389 ps/nm/km at wavelength λ =1.55μm and a relative dispersion slope of about 0.0036nm^{-1} identical to the single mode fiber .which could be a suitable candidate for dispersion compensation in high transmission system and so.

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