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A New Design of Borosilicate Crown Glass Photonic Crystal Fiber to Minimize the Dispersion

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Abstract— In this design we present a defected core photonic crystal fiber using borosilicate crown glass .This paper shows that how the central defected air hole ,controls the dispersion of a photonic crystal fiber .For this purpose ,Finite difference time domain (FDTD) method with the perfectly matched layers (PML) boundary conditions has been used to investigate the result. It is possible to have high negative dispersion, by varying the size of defected core. It is also shown that borosilicate glass PCF provides much higher negative dispersion as compared to silica PCF of the same structure, so such PCF have high potential to be used as a dispersion compensating fiber in optical communication.

Index Terms—Borosilicate Crown glass, Dispersion, Photonic Crystal Fiber, Scalar Effective Index Method.

I. INTRODUCTION

Conventional optical fibers guide light by total internal reflection (TIR).Fig 1(a) depicts an all solid step index optical fiber with a higher index doped core surrounded by a lower index silica cladding and light is confined to the core by TIR at the core cladding interface. Fig 1(b) shows a photonic crystal fiber made from a single material with an array of air holes in the cladding [1].

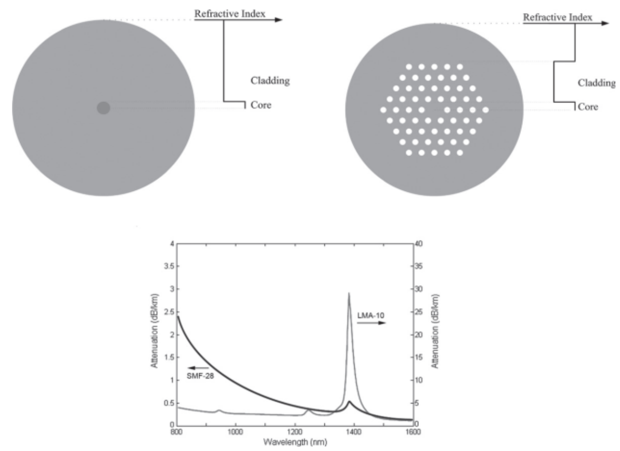

Figure 1. Index-guiding optical fibers. (*a*) A conventional step-index fiber; (*b*) a PCF; (*c*) attenuation spectra of a conventional fiber

These TIR fibers are also referred to as index-guiding fibers and have broadband transmission windows as shown in fig. 1(c) ;the loss edges at the short and long wavelengths are limited by Rayleigh scattering and infrared absorption of the fiber material respectively.

PCFs can be classified into two different types by their light guiding mechanism. They are index guiding photonic crystal fiber in which light is guided by total internal reflection and photonic band gap fibers in which light is guided by effect of band gap[2][3] .

Optical transmission systems require PCFs with large effect mode area(LMA) [4]. The LMA PCF is required not only to support broadband optical transmission but also to minimize the coupling losses to standard single mode fibers. Again in broadband communication systems, fiber dispersion and confinement loss play very important roles.

For example, in wavelength division multiplexing communication systems, it is essential to maintain a uniform response in different wavelength channels. This is strictly achieved by ensuring ultra -flattened dispersion characteristics of fibers [5]. There are so many reports [4]-[11] in the literature dealing with dispersion flattened PCFs, some of which event warrant low confinement loss[9].

Reducing dispersion and confinement loss are of the main concerns in designing PCFs. Today, exploiting multiple design parameters such as diameter and shape of the holes , using different materials(like As_2Se_3 ,borosilicate crown glass etc.) , the number of air hole rings and the spacing between these holes facilitates development of PCFs with improved properties. Several design for PCFs have been proposed to achieve the nearly zero ultra-flattened chromatic dispersion properties and low confinement loss [12].

In the present paper, a novel design for borosilicate crown glass PCF with defected core is put forth to compensate dispersion parameter. Also, the borosilicate crown glass PCF is compared to a silica PCF for the same structure.

II. DESIGNED MODEL

The proposed PCF is made up of borosilicate crown glass and has a array of air holes running along its length .The transverse cross section of PCF is shown in fig.

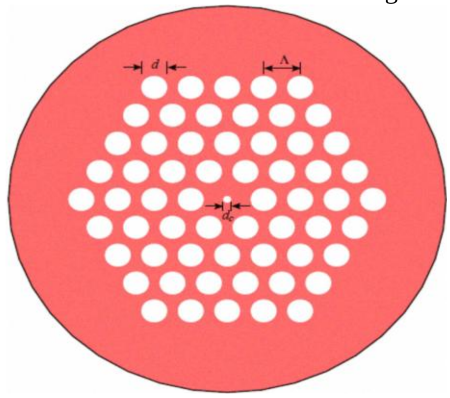

Fig 2 : Cross section of PCF with defected core

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Where , d_c is the defected core diameter

Λ is the pitch of lattice

And d is air hole diameter of other rings

The total number of air hole rings are four in order to solve as much as possible the structural composition of the PCF.

The physical mechanism of the proposed design procedure can be explained as follow :

The continuous enlargement of the defected air hole in central borosilicate crown glass region reduces the portion of the material in the core and as a result, there is a compensation of the inherent dispersion of the silica. The existence of the defected air hole in the core slightly reduces the effective core index and as a result the field lines penetrate the cladding more strongly in comparison with the non-defected core PCFs[13][14] .

III. THEORITICAL DISCUSSION

A. Effective Refractive Index

The refractive index of borosilicate crown glass is given by sellmeier formula[15] :

$$n^2 - 1 = \sum_i \left(\frac{A_i \lambda^2}{\lambda^2 - \lambda_i^2} \right) \quad (1)$$

In transparency region, the sellmeier formula can be reduced in Cauchy relation and it is given as below:

$$n^2 = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} \quad (2)$$

Here A = 7.56, B= 1.03μm^2 and C = 0.12 μm^2 are Cauchy coefficients.

B. Total Dispersion

The total dispersion is sum of material dispersion and waveguide dispersion. The chromatic dispersion, D (λ) of a PCF is easily calculated from the second derivative of the real part of effective refractive index.

$$D(\lambda) = -\frac{\lambda}{C} \frac{d^2 \mathrm{Re}[n_{eff}]}{d\lambda^2} \quad (3)$$

Where , $\mathrm{Re}[n_{eff}]$ is the real part of n_{eff} ,

λ is the wavelength in units of μm ,

C is the velocity of light in vaccum.

The material dispersion given by sellmeier formula is directly included in calculation.

Therefore, D in equation (3) corresponds to the total dispersion of PCF [16].

C. Confinement Loss

The confinement loss, L_c are due to the finite number of air holes which can be made in fiber cross section. As a consequence, all the PCF guided modes are leaky. In the solid core PCF for small values of d/Λ , the resulting loss can be large unless a sufficiently large number of periods is used [17]. The confinement loss can be calculated from the imaginary part of the mode index as :

$$L_c = 8.686 \; k_0 I_m[n_{eff}] \quad (4)$$

With the unit dB/m , where $I_m(n_{eff})$ is the imaginary part of the refractive index , $k_0 = 2\pi/\lambda$ is the wave number in free space.

IV. SIMULATION AND NUMERICAL RESULT

A small air hole is made in center of borosilicate crown glass PCF structure and the diameter (d) of cladding air holes are much higher than that of the diameter(d_c) of the defected core.

The simulation is done with parameter as below :

d= 1.35μm , Λ = 1.37μm and d_c / Λ = 0.4μm.

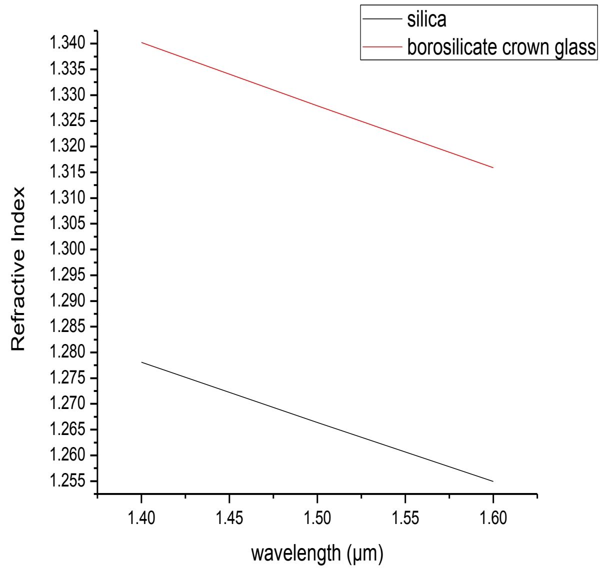

Fig 3(a) : Comparison of refractive index between silica and borosilicate glass PCF for the proposed structure.

To obtain wavelength dependent refractive index, sellmeier formula is used in both borosilicate crown glass PCF and silica PCF for the proposed structure.

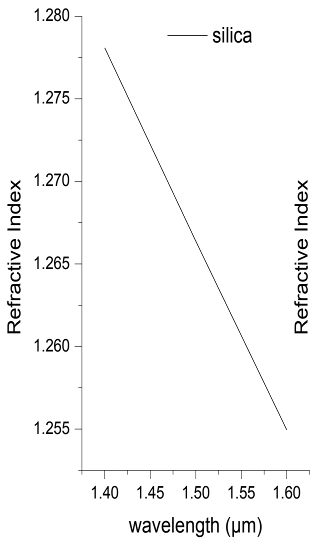

Fig:3(b)

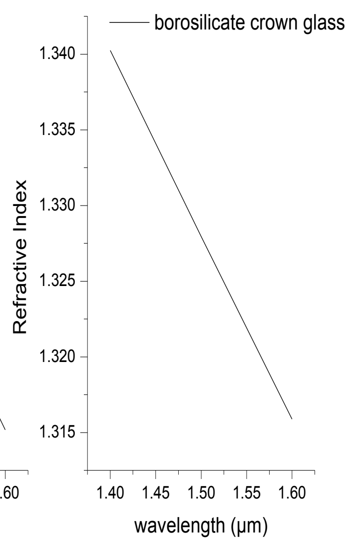

Fig:3(c)

Here fig 3(a) shows the comparison of effective refractive index for the proposed structure of PCF with defected core using silica and borosilicate crown glass as a core materials.

Fig 3(b) and 3(c) shows the effective index of silica and borosilicate crown glass PCF with defected core separately.

Now, the material dispersion of the borosilicate crown glass, which has been calculated by using sellmeier formula, can be represented as below curve:

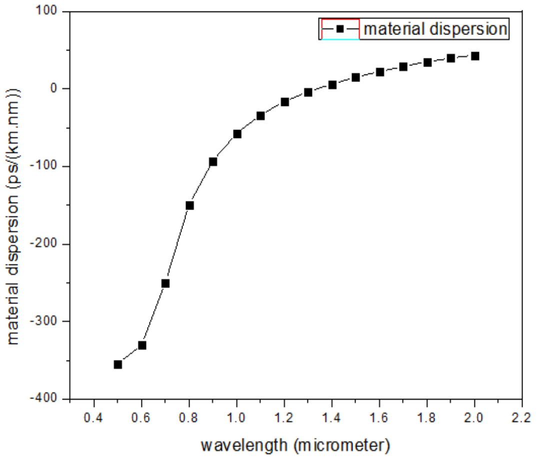

Fig 4: Materail dispersion of the borosilicate crown glass

Material dispersion is independent of structure parameter of fiber (like d, λ),so material dispersion remains constant for any lattice structure of Borosilicate Crown glass PCF.

Fig 5 shows the intensity profile of the borosilicate crown glass PCF with defected core at Λ= 1.37μm and air hole diameter d=1.35 μm at 1.6 μm wavelength and fig 6 shows the 3D mode field pattern of the proposed PCF at same wavelength i.e. 1.6 μm.

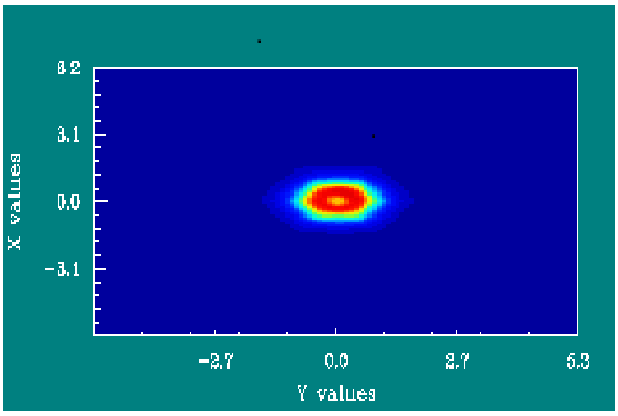

Fig 5: Intensity profile of proposed structure

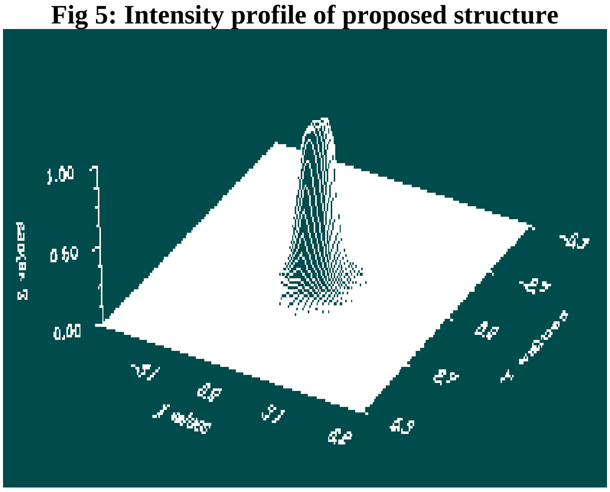

Fig 6: 3D mode field pattern of proposed PCF

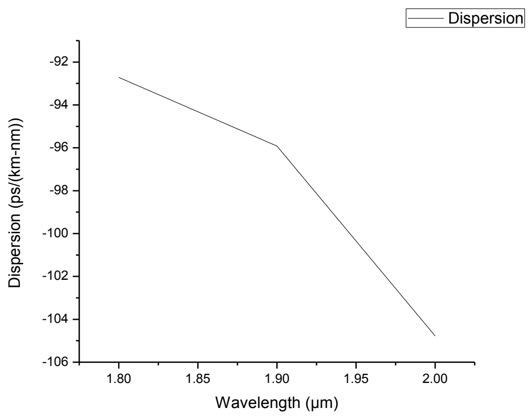

Fig 7: Dispersion curve of proposed PCF as a function of wavelength at d= 1.35 μm , d_c / Λ = 0.4μm and Λ = 1.37μm

Here, the fig 7 represents the chromatic dispersion of the defected core borosilicate crown glass PCF at different wavelength range. To become the PCF having defected core, a small air hole is introduced in center of PCF structure and the diameter d_c of defected core is taken much smaller than the diameters of cladding air holes. To reduce fabrication compexity , we set outer rings to have same air hole diameter. The parameter d_c is adjusted in such a way that in its influence the dispersion curve is investigated. To analyze the chromatic dispersion of proposed structure the parameter used in fig 7 are: d= 1.35 μm, d_c / Λ = 0.4μm and Λ = 1.37μm.

The scalar effective index method used for comparison of negative dispersion in silica and borosilicate crown glass PCF, in the given wavelength range. In this case it is found that borosilicate crown glass PCF provides higher negative dispersion than that of silica based PCF.

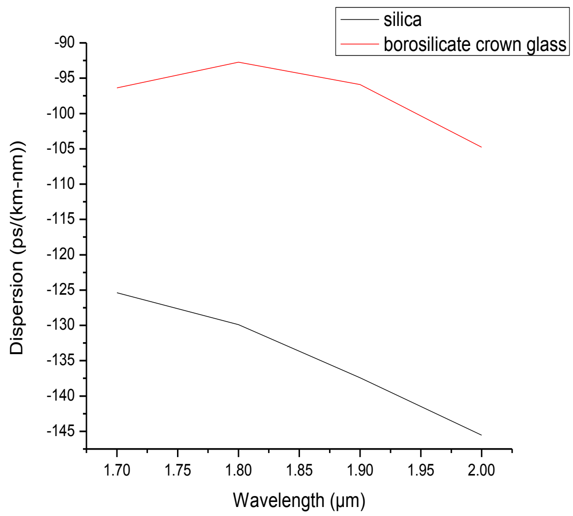

Fig 8: Comparision of chromatic dispersion of proposed structure using silica and borosilicate crown glass.

V. CONCLUSION

We have investigated the design for index guiding photonic crystal fiber with defected core based on borosilicate crown glass .The results shows that negative dispersion can be obtained.

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The design procedure for proposed structure is more easier and efficient i.e. relatively fewer geometrical parameters are needed.

The high linear refractive index and high non-linearity in borosilicate crown glass are more suitable for fiber based photonic wire devices. So, proposed PCF is useful in dispersion compensation ultra-broadband transmission application.

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