Impact of Elliptical Holes Filled with Ethanol on Confinement Loss and Dispersion in Photonic Crystal Fibers

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***Abstract*—To get a confinement loss value, the weakest possible We have interest to optimize an optical fiber our structure has a cladding which is formed by holes in silica. The geometry of the holes is special because they have an elliptical shape and oriented with some angle. The introduction of ethanol in the holes, the omission of some rings allows us to have values very close to zero for the confinement loss. In this paper, we have designed an ultraflat dispersion PCF. We notice that the zero dispersion can be in the range from 1000 nm to 1650 nm and has the value of 0±0.14ps/nm/km.**

***Keywords*—confinement loss; dispersion; doped Photonic Crystal Fiber; ethanol-filled holes; elliptical holes; FDTD**

I. INTRODUCTION

The request for high bit rate is increasing in recent years. To meet this spectacular rise, optical fiber was used as a transmission medium. These fibers have a wide bandwidth and can carry high bit rates.

Despite this characteristic, these fibers have their limits due to the modal or chromatic dispersion. This makes then research to have not ceased and the researchers arrived in recent years to put on the telecommunications market the most reliable support that's the photonic crystal fiber [1-2] that meets a requirement in adjustable dispersion, unimodal character and high bit rate

PCF fiber presents a clear example of these media.The properties of these fibers such as dispersion who can be adjusted by the parameters of the fiber.

We are interested to fibers formed by a doped silica core which present a difference Δn between the core and the cladding [3-4]. This photonic cladding it is composed of holes filled with ethanol in the silica. These past years the research highlighted in this field and many researchers has touch in this axis [5-6] such as the study of photonics sensors [7-8]. With some arrangement this structure may be used for telecom applications.

Many parameters can influence the optical properties of such fibers as to know the number of rings surrounding the core, the core diameter and that of the holes denoted d, the distance between the centers of two adjacent holes noted (pitch). We can also reduce losses of guide by increasing the number of rings of holes [9]. The guiding of the light within these fibers is made by total internal reflection [10].

In previous work the effects of geometric deformations and arrangements of holes around the doped silica core on the confinement losses was stadied [11-12]. These geometric distortions can be introduced during the manufacturing. Although the fiber manufacturing techniques are very well controlled, geometric distortion effects and the arrangement of the holes around the core of the PCF on the confinement loss still remained to explore and to study.

Unlike conventional photonics fibers which are formed of air holes in silica our design structure is formed by a cladding which consists of ethanol-filled holes with some elliptical holes. Each ellipse possesses a major and a minor radius; we are interested on the effect of of the orientation angle and the omission of some rings on the confinement loss and dispersion and the effect of temperature after the introduction of ethanol into the holes.

An important characteristic of fiber is the dispersion .The Chromatic dispersion determines the transmission capacity of an optical communication system. This is an extension in the time limit the transmission rate as it forces to increase the time between two pulses. We stady the dispersion of our structure in a range of 800 nm to 1850 nm

II. THEORY

Since our design structure is in an XZ plane and since our numerical method is based on a temporal and spatial discretization of Maxwell equations [13-14]. The Y direction is laid as infinite and The propagation is along Z . All these hypotheses allow us to remove all derivatives from Maxwell's equations and divided them into two independent sets of equations which are The Transverse Magnetic (TM) and Transverse Electric (TE)

$$\min imum(\Delta x, \Delta y, \Delta z) \le \frac{\lambda_{\min}}{10 n_{\max}} \tag{1}$$

$$\Delta t \le \frac{1}{\gamma \sqrt{\frac{1}{(\Delta x)^2} + \frac{1}{(\Delta z)^2}}} \tag{2}$$

the maximum value of the refractive index of the calculation area is represented by n_{max}.

A mode is an adaptation of the light to the guide, a guided mode has its own velocity and an effective index. The modes represent a solution of Maxwell's equations. For some modes, light is well confined in the core. The determination of the imaginary part of the complex effective index allows us to calculate the confinement losses [15].

$$CL(dB/m) = \frac{2\times\pi\times 20\times \mathrm{Im}(n_{eff})}{\lambda\times\ln(10)} \tag{3}$$

Chromatic dispersion is obtained from the effective index calculated on a spectral band, it is expressed by the following relationship [16]:

$$D_c = -\frac{\lambda}{c}\frac{d^2 n_{eff}}{d\lambda^2} \tag{4}$$

Where λ is the operating wavelength and c is the the velocity of light in vacuum

To calculate chromatic dispersion we can use Taylor expansion:

$$\begin{aligned}\frac{d^2 n_{eff}}{d\lambda^2}\Big|_{\lambda=\lambda_0} \approx \frac{1}{24(\Delta\lambda)^2}&(-2n_{eff}(\lambda_0+2\Delta\lambda)\\ &+32n_{eff}(\lambda_0+\Delta\lambda)-60n_{eff}(\lambda_0)\\ &+32n_{eff}(\lambda_0-\Delta\lambda)-2n_{eff}(\lambda_0-2\Delta\lambda))\end{aligned} \tag{5}$$

Δλ is equal to 20 nm

III. MODELING AND ANALYSIS

We took a conventional structure formed by a doped silica core ($\Delta n = 2\ 10^{-2}$) and surrounded by five rings of holes in silica index n = 1.45. The holes are filled with ethanol whose index is a function of the location temperature [7].

The introduction of ethanol into the holes instead of air is specially designed for photonic fiber sensor [17]. In our article we will try to see the impact of the temperature of the places where is fibers installed on the confinement loss and dispersion for a telecom application λ=1,55μm

The ethanol index varies according to

$$n = n_0 - \alpha(T - T_0) \tag{6}$$

n_0 refractive index of ethanol at T_0. For T_0 = 20°, n_0 = 1.36048 and $\alpha = 3.94\times10^{-4}$

The core of our structure has 3 μm for radius, the pitch Λ= 4.5 μm. Holes filled with ethanol have an index value n = 1.358 (T = 25 °)

The structures is studied using the OPTIFDTD 8 software It is based on Finite Difference Time Domain method (FDTD). From the simulation we can see the profiles of the calculated mode; the result is shown in Figure 1.

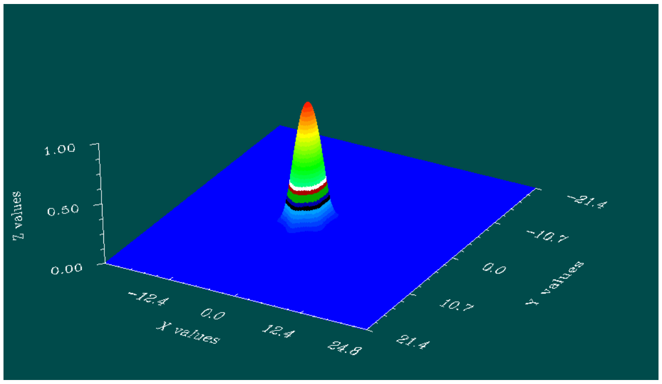

Fig. 1. 3D distribution of the fundamental mode of structure

We stady too structure designed (e) and (f) shown in fig.2.

(e): the core radius 3μm holes index 1.358; first rings of holes with 1.5μm radius; the second ring with q ratio = q_1=0.75 oriented 135 °with omission of the third rings.

(f): the core radius 3μm holes index 1.358; first rings of holes with 1.5μm radius; the second ring with q ratio = q_2= 0.75 oriented 135 ° with omission of the third rings.

with q_1= r /R and q_2= 2r /2R; R=0.6μm and r = 0.45 μm

The elliptical air holes have a major radius (R) and a minor radius (r) like is shown in Figure 3.

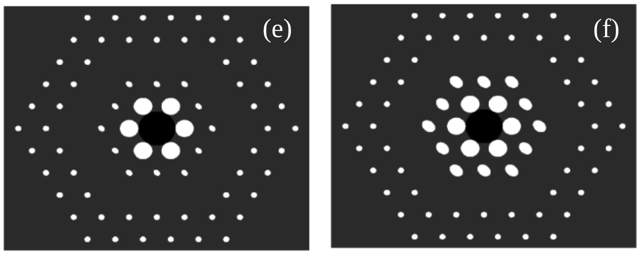

Fig. 2. cross section view of studied structure

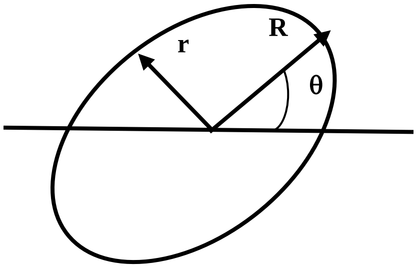

Fig. 3. Major radius, minor radius, and orientation angle

We can also see the behaviour of the effective refractive index in Figure 4.

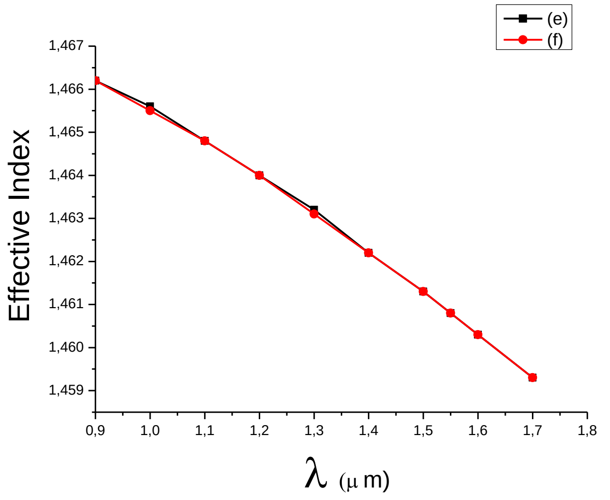

Fig. 4. variation of effective index with the wavelength λ for the studied structures

For the confinement loss we can see clearly in Figure 5 that the structure (f) in very close values in 0 from the value of λ = 1,4μm. It is a very interesting result which proves that such structure can be used for telecom applications in wavelengths λ = 1,55μm. although the number of ring of holes is reduced around the doped core. This represents a great technological interest in the manufacture of such a fiber.

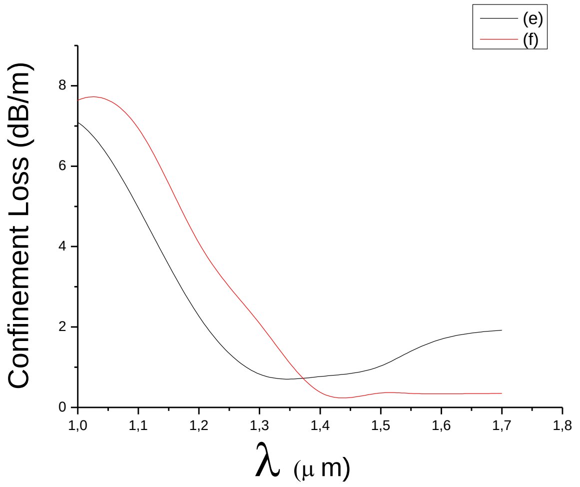

Fig. 5. Confinement loss plot according to wavelength

Generally optical fibers are put in places where there is a medium temperature variation principally made in military and the industrial machining.

We wanted to see the impact of the temperature on the value of the confinement loss of our held structure.

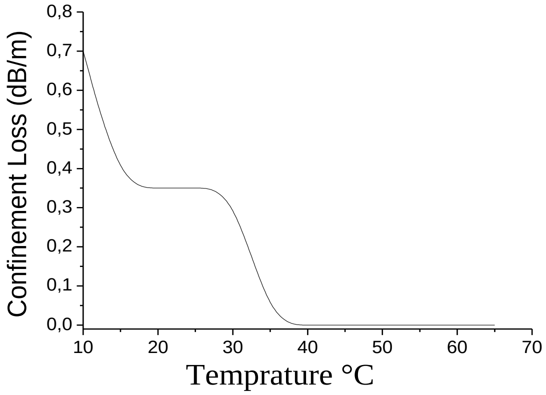

Fig. 6. Confinement loss of structure (f) as a function of temperature

We were able to notice that the value of the confinement loss is zero from 40°, as we shown in Figure 6.Thereafter we were interested in the value of the dispersion.

Realizing near-zero ultra-flat dispersion for a wide band wavelength is a major realisation of the PCFs engineering. For dispersion management Ultra-flat near-zero dispersion profile is helpful but also for achieving novel applications like high gain,broadband parametric amplification.

To realize the ultra-flat near-zero dispersion we fill holes with a liquide in this work we use ethanol

The simulation allowed us to determine the behavior of the dispersion as a function of wavelength, as we shown in Figure 7. We can notice that for the value of 1000 nm to 1650 nm dispersion value is 0±0.14ps / nm / km. This result is very important for transmissions.

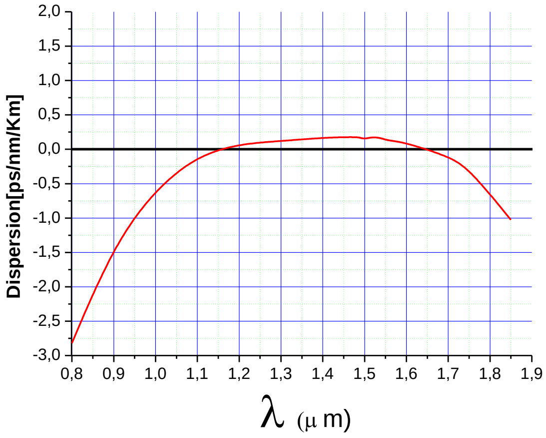

Fig. 7. Chromatic dispersion of structure (f) as a function of wavelength

IV. CONCLUSION

FDTD is used to simulate and analyse confinement loss and dispersion of a doped Photonic Crystal Fiber. A new structure is introduced, in our study we took a structure which has a cladding which is formed of holes in silica. The geometry of the holes is special because they have the elliptical shape and oriented with an angle of 135 °. The orientation of the holes of the first ring has a great effect on the value of the confinement loss in a manner that reduces the confinement loss values. The introduction of liquid such as ethanol in the holes, the omission of some rings allows us to have values very close to zero for the confinement loss.

The Chromatic dispersion determines the transmission capacity of an optical communication system.

We notice an ultraflat dispersion that has a value of D= 0±0.14ps/nm/km which can be in the range from 1000 nm to 1650 nm.

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