IETE 46th Mid Term Symposium "Impact of Technology on Skill Development" MTS- 2015
Special Issue of International Journal of Electronics, Communication & Soft Computing Science and Engineering, ISSN: 2277-9477

Large Mode Area Solid Core Bragg Fiber

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***Abstract* — We numerically study the possibilities for very large mode area endlessly single mode solid core micro structured Bragg Fibers for high power delivery applications. The fiber design consists of solid core and ring of air holes concentric with the core, which form the low-index layers of the Bragg reflector in the cladding. The influence of geometrical parameters on dispersion is also investigated. Finally, the Bending loss characteristics have been discussed.**

***Index Terms*—Bragg Fiber, Dispersion, Photonic Crystal Fiber, Sellmeier's formula**

I. INTRODUCTION

There has been significant interest in Photonic crystal fibers (PCFs) in recent years. PCFs are fibers with a cladding composed of micro structural inclusions running parallel with the propagation axis, with a scale of the micro structuring being comparable to the wavelength of the electromagnetic radiation guided by the fibers [1-3]. An essential effect of the transverse periodic structure is to alter the effective refractive index for propagation along the direction of the fiber leading to new dispersive properties [4-8].

Applications requiring high-power delivery call for single mode area optical fibers. Although standard fiber technology has difficulties in meeting these requirements, the photonic crystal fibers has a large potential in this area because of their endlessly single mode properties combined with unlimited large effective areas[10].

Bragg fibers use a one dimensional photonic band gap formed by layers of alternating high-low refractive index surrounding the core. Ring structured Bragg fibers have been proposed [11] in which ring of air holes form the low index layers of the Bragg reflector in the cladding. Such fibers, with a hollow core have been demonstrated recently using silica [12].

The ring structured fiber with the single mode property consists of a hollow core surrounded by circular ring of air holes concentric with the core, embedded in a host material of homogeneous refractive index.

It has been shown that [11] increasing the number of rings of air holes in such a structure resulted in a dramatic decrease in the confinement loss of the fundamental mode , whilst the remaining modes remained largely unaffected with very high confinement loss. This would effectively render these modes unguided, isolating the HE_{11} mode as the only guided mode.

II. FIBER STRUCTURE

The fiber design analyzed here consists of a solid core of radius 15 μm, surrounded by ring of air holes with Λ_e=9 μm signifying the external pitch, i.e. the spacing between the centers of holes in adjacent rings. Six rings of air holes have been considered and the overall diameter of the fiber has been considered as 125 μm. The diameter of the holes is considered to be 0.5 μm. The air fraction f of each ring is given by [12]

$$f = \frac{\pi d}{4\Lambda_i} \quad (1)$$

where d is the diameter of the air hole and Λi is the internal pitch, i.e. the spacing between centers of adjacent holes in the same ring. The number of air holes in the first ring was 8 and in the successive rings 24 air holes have been placed .So all the air holes have been placed radially at the same location which make the design easy for the manufacturer. The effective refractive index of each ring varies drastically since the air fraction ratio varies in each ring of air holes. The refractive index of the air holes is considered to be one and the refractive index of the host material silica is calculated using the Sellmeier's formula as given below.

$$n_1(\lambda) = C_0 + C_1\lambda^2 + C_2\lambda^4 + \frac{C_3}{(\lambda^2 - 0.035)} + \frac{C_4}{(\lambda^2 - 0.035)^2} + \frac{C_5}{(\lambda^2 - 0.035)^3} \quad (2)$$

where C_0 = 1.4508554, C_1 = -0.0031268, C_2 = -0.0000381, C_3 = -0.0030270, C_4 -0.0000779 and C_5 = -0.0000018.

To find out the average refractive index of the cladding, each ring of holes was replaced by a homogeneous layer of constant refractive index nav given using equation (1) as

$$n_{av} = f + (1 - f)n_1 \quad (3)$$

which is simply the arithmetic mean of the silica refractive index n_1 and the hole refractive index, weighted by the air fraction of the ring of holes.

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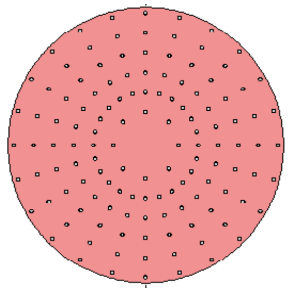

Fig 1. Solid Core Bragg Fiber

III. Effective Area Calculations

To investigate the properties of newly designed Bragg fiber, the commercial software FEMLAB is used. This software is an implementation of the finite element method which is very efficient for Eigen value calculations on fibers. The distribution of the magnetic field of the fundamental mode of this PCF at λ=1.55µm is shown in fig.2.

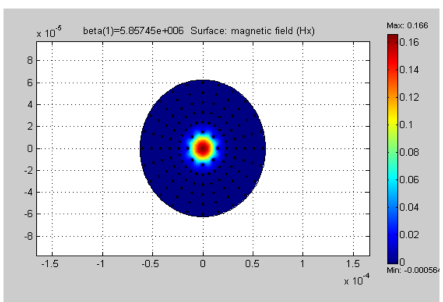

Fig .2. Surface magnetic field at λ=1.55µm

The single mode behaviour of the fiber has been verified in the wavelength region 1.2 µm to 1.6 µm. The fiber becomes multi moded when the inner ring of air hole has been removed as shown in fig.3.

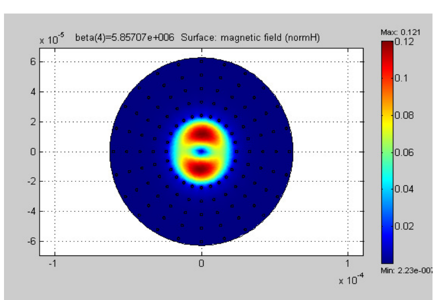

Fig .3. Higher order mode in Bragg Fiber

The effective area of the is calculated for different values of the hole diameter using the formula [13]

$$A_{eff} = \frac{\left[\int\limits_{-\infty}^{\infty} \int\limits_{-\infty}^{\infty} | F(x,y) |^2 dxdy \right]^2}{\int\limits_{-\infty}^{\infty} \int\limits_{-\infty}^{\infty} |F(x,y)|^4 dxdy}$$

(4)

where F(x, y) is the modal field distribution inside the fiber. The effective area variation for different wavelengths is shown in Fig.4. The effective area is found to be 550 µm^2 when the hole radius is fixed at 0.5 µm at λ=1.55µm. The effective area reduces when the hole radius increases and the area increases when wave length increases. Since the effective area is very high, LED sources can be used to launch power inside the fiber instead of LASER sources which will reduce the total cost of the system also the fiber can be used for very high power applications.

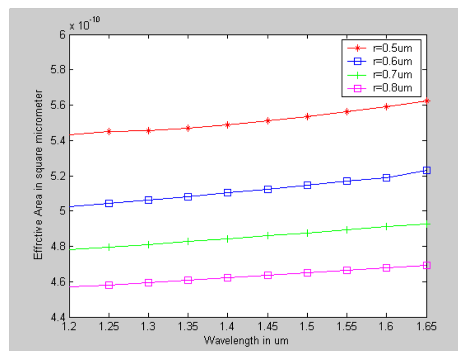

Fig .4. Effective Area Characteristics of Brag Fiber

IV. Dispersion Properties of Bragg Fiber

The FEMLAB software can accurately calculate chromatic dispersion by the following procedure. The effective refractive index of the fundamental mode is given by n_{eff} = ß/k_0, where ß is the propagation constant and k_0=2Π/λ, is the free space wave number. Once the modal effective indices are solved, the dispersion parameter D is calculated using the formula

$$D = -\frac{\lambda}{c}\frac{d^2 n_{eff}}{d\lambda^2} \qquad (5)$$

where c is the velocity of light in vacuum. The values of n_{eff} are computed with a wavelength step of 0.05 um. The 2nd order derivative has been calculated using the finite difference

$$D = -\frac{\lambda}{c}\frac{n(\lambda+\Delta) - 2n(\lambda) + n(\lambda-\Delta)}{\Delta^2} \qquad (6)$$

The dispersion parameter values are calculated for various hole radius and we found out these values are very well comparable with conventional fibers. The dispersion characteristics are plotted as shown in fig.5. The dispersions in Bragg fiber with large diameter are very small. With the large diameter, the effective indices of the fundamental mode at different wavelengths approach n1, the silica refractive index and change slowly, making the second derivative of effective refractive index with respect to wavelength small. In addition, by varying the core radius and air hole radius, the dispersion can be made small. This fiber is found to have dispersion of 5ps/nm.km at the wavelength 1.55 µm.

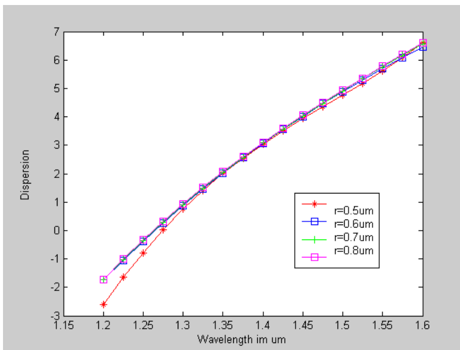

Fig .5. Dispersion Characteristics of Brag Fiber

V. MACRO BENDING LOSS IN BRAGG FIBER

The investigation of macro-bending losses of Bragg fiber is very important from a practical handling point of view. Predictions of macro-bending losses have been made using the antenna theory of Sakai and Kimura [14, 15], but we use a full transformation of standard fiber parameters such as Δ, W and V [16] to fiber parameters appropriate to high index contrast Bragg fiber. Thus the bending loss formula for the power attenuation coefficient of conventional step index fiber is transformed into the following expression [16]

$$\alpha(\frac{db}{m}) = 4.343\frac{\sqrt{\pi}}{4}\frac{1}{A_{eff}W}\frac{\rho\exp(-\frac{4\Delta W^3}{3\rho V^2}R)}{\sqrt{\frac{WR}{\rho}+\frac{V^2}{2\Delta W}}} \quad (7)$$

where A_{eff} is the effective core area, R is the radius of the curvature in the bend , ρ is the effective core radius , Δ is the relative difference between the core and the cladding, V is the normalized frequency and W is the normalized decay parameter. The values of V and W are calculated using the formulas [17]

$$V = \frac{2\pi}{\lambda}\rho\sqrt{n_s^2 - n_{cleff}^2} \quad (8)$$

$$W = \frac{2\pi}{\lambda}\rho\sqrt{n_{eff}^2 - n_{cleff}^2} \quad (8)$$

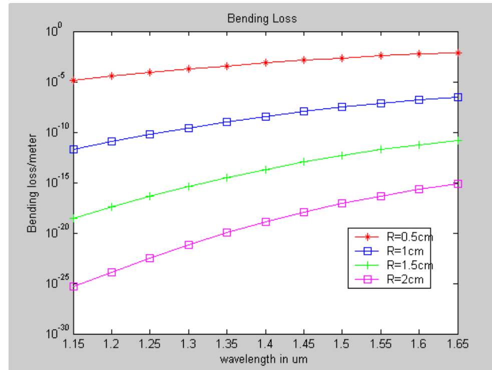

Fig .6. Bending loss characteristics of Bragg Fiber

The bend radius has been varied from 0.5 cm to 2 cm and the bending loss characteristics have been plotted as shown in fig. 6. It is observed that the bend loss increases when the bend radius decreases and the loss increases when the wavelength increases.

VI. CONCLUSION

In this paper we present a new design for large mode area fiber. This fiber supports only a single mode in the wavelength region 1.2 µm to 1.6 µm. The effective area is found to be 550 μm^2 when the hole radius is fixed at 0.5 µm at λ=1.55µm. The Chromatic dispersion value is found to be 5ps/nm.km at the wavelength 1.55 µm. The Bending loss characteristics also have been calculated and found out to be very small in the interested wavelength. In our entire design, we have considered equal spacing between the centers of holes in adjacent rings as Λ_e =9 µm. By varying the spacing between every ring, a chirp profile can be created and the effect in dispersion characteristics can be analyzed.

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Mani Roja was born in Tirunelveli (T.N.) in India on June 19, 1969. She has received B.E. in Electronics & Communication Engineering from GCE Tirunelveli, Madurai Kamraj University in 1990, and M.E. in Electronics from Mumbai University in 2002. Her employment experience includes 25 years as an educationist at Thadomal Shahani Engineering College (TSEC), Mumbai University. She holds the post of an Associate Professor in TSEC. Her special fields of interest include Image Processing and Data Encryption. Currently, she is pursuing her PhD from Sant Gadge Baba Amravati University. She has over 30 papers in National / International Conferences and Journals to her credit. Ms. M.Mani Roja is a life member of IETE and, ISTE.

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