Ring Core Four-Clad Optical Fiber for Low Confinement Loss: Design and Analysis

Sunita Debbarma[1], Chinu Mog Choudhari[2]

[1,2]*Tripura Institute of Technology, Agartala,Tripura, India*

***Abstract*—In the present paper, a ring-core four-clad optical fiber of silica glass has been proposed. The fiber has been designed in such a way that a certain difference in refractive indices between consecutive layers can exist. The impact of changes in effective refractive index and difference in refractive index on the dispersion of the propagating signal, and phase constant is also investigated using the COMSOL 5.3a and Matlab 2018b software. It is discovered that this kind of structure provides a very less amount of multimodal loss.**

***Index Terms*—Ring core fiber, Mode coupling, dispersion, refractive index.**

I. INTRODUCTION

Multimode fibers are used for high bit rates as these fibers can support multiple modes through a single core. Mode coupling is the process of energy transfer between neighboring modes during their propagation [1]. The transmission of light along the micro structured optical fibers is influenced by differential mode coupling, and modal attenuation [2]. Mode coupling is mostly induced by intrinsic random perturbations of the fiber, such as refractive index variations, micro bends, and stresses [3]-[5]. Mutual coupling between spatial modes is discovered to be a significant issue that severely restricts the performance of Mode Division Multiplexing (MDM) transmission, although the mixed and scrambled signals that arise can be retrieved by using multiple input multiple output (MIMO) based signal processing [6]. Few-mode optical fiber can suppress coupling between modes and eliminate the need for MIMO signal processing by having considerable variances in effective refractive indices between two neighboring modes[6]. It has been discovered that ring-core optical fiber can increase bandwidth while minimizing dispersion [7].

It has been observed from the present study that the confinement loss and its subsequent effects would be minimized due to changes in effective refractive indices and phase constants in different modes present in the ring core and cladding layers of the ring core four clad fiber.

II. OPTICAL FIBER DESIGN

A four-clad, ring-core multimode fiber has been created. Here, the first, second, third, and fourth layers, as well as the center and ring core, have refractive indices of n_0 to n_5 respectively. Here, the first, second, third, and fourth layers' respective radii are r_0 to r_5, respectively.

According to the Sellmeier equation [8], the refractive indices of the layers are n_0=1 (air), n_1=1.505, n_2=1.465, n_3=1.445, n_4=1.425, and n_5=1.405 for a free space wavelength of =1.55 m. Each layer's radius is listed below as follows: r_0=2 m, r_1=25 m, r_2=30 m, r_3=35 m, r_4=40 m, and r_5=45 m.

III. THE PRINCIPLE PARAMETERS OF THE FIBER

The normalized transverse propagation constants in a fiber vary with effective refractive index (n_{eff}) for a given frequency along the propagation direction *z* and the governing equations are as follow [9]:

$$w_x = k_o\, r_1 \sqrt{(n_{eff}^2 - n_x^2)} \qquad n_{eff} > n_x \qquad (1)$$

$$u_x = k_o\, r_1 \sqrt{(n_x^2 - n_{eff}^2)} \qquad n_{eff} < n_x$$

In fiber u_x and $w_x$are the normalized transverse propagation constants of optical fiber.

Variation of effective refractive index n_{eff} between two adjacent modes for a changing wavelength (λ) is shown below.

Sl. No.	λ(μm)	n_{eff}
1	1	1.504469
2	1.1	1.504361
3	1.2	1.504244
4	1.3	1.504117
5	1.4	1.503981
6	1.5	1.503836
7	1.6	1.503682
8	1.7	1.50352

Table1: Variation of effective refractive index n_{eff} between two adjacent modes for a changing wavelength (λ).

Table 1 shows the variation of effective refractive index n_{eff} modes of fiber for the core radius r_1=25 μm with wavelength. It is seen from the graph that the value of n_{eff} modes decreases with an increase in the wavelength ofthe fiber.

The propagation constant (β) of a mode in a fiber determines how the amplitude and phase of that light signal varies with a given frequency along the propagation direction *z* and the governing equations are as follow [9]:

$$\beta^2=(k_0n_x)^2-(u_x/r_1)^2 n_{eff}<n_x,$$

$$\beta^2=(w_x/r_1)^2+(k_0n_x)^2 n_{eff}>n_x, \qquad (2)$$

Variation of Propagation constant with refractive index of fiber is shown below.

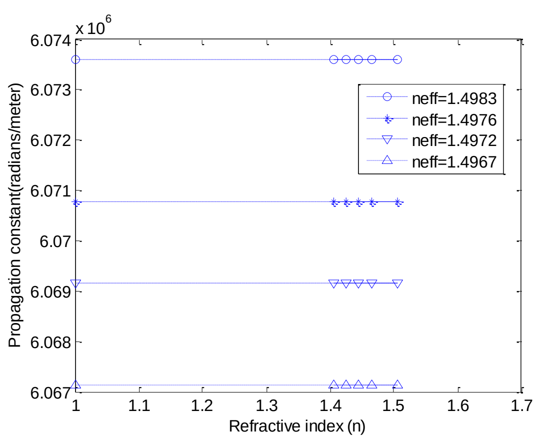

Fig.1. Variation of propagation constant (β) with refractive index (n_x) of LP_{01}, LP_{02}, LP_{03}, and LP_{04} mode.

Figure 1 shows variation of propagation constant (β) with refractive index (n_x) of core and cladding layers. The value of propagation constant (β) is found to remain constant for a linearly polarized mode, with the increase of refractive index of the fiber.

Variation of Birefringence for a changing wavelength (λ) is shown below.

Sl. No.	λ (μm)	Birefringence
1	1	$1.65\text{x } 10^{-08}$
2	1.1	$3.68 \text{ x } 10^{-08}$
3	1.2	$6.12 \text{ x } 10^{-08}$
4	1.3	$1.21 \text{ x } 10^{-08}$
5	1.4	$9.61 \text{ x } 10^{-08}$
6	1.5	$7.14 \text{ x } 10^{-08}$
7	1.6	$1.12 \text{ x } 10^{-07}$
8	1.7	$1.15 \text{ x } 10^{-07}$

Table2: Variation of Birefringence for a changing wavelength (λ).

The value of Birefringence is very low in the given fiber for a changing wavelength (λ) is shown in table 2.

Dispersion is of a wave depends on its frequency and the mathematical formulation of dispersion can be given by [10]-[12]:

$$D(\lambda) = - (\lambda/c)\,(d^2n/d\lambda^2) \qquad (7)$$

Where c is the speed of lightand D(λ) is the waveguide dispersion of light in the fiber.

Sl. No.	λ (μm)	Dispersion(ps/nm-km)
1	1	$-3.079\text{x}10^{11}$
2	1.1	$-3.430 \text{ x}10^{11}$
3	1.2	$-3.782 \text{ x}10^{11}$
4	1.3	$-4.140 \text{ x}10^{11}$
5	1.4	$-4.511 \text{ x}10^{11}$
6	1.5	$-4.876 \text{ x}10^{11}$
7	1.6	$-5.257 \text{ x}10^{11}$
8	1.7	$-640 \text{ x}10^{11}$

Table 3: Variation of Dispersion for a changing wavelength (λ).

Table 3 depicts the dispersion D change with wavelength for various air hole diameters of 0.5, 1, and

2 m. The graph shows that the dispersion initially drops relatively slowly as the wavelength increases, but after around 1.3 m, the dispersion rapidly decreases as the wavelength increases. For high speed fiber optic connection, it is desirable.

Sl. No.	λ (μm)	Confinement Loss(dB/km)
1	1.1	$-2.82671x10^{-08}$
2	1.2	$4.56228x10^{-09}$
3	1.3	$-5.08602x10^{-09}$
4	1.4	$3.37392x10^{-09}$
5	1.5	$5.10477x10^{-10}$
6	1.6	$-6.9851x10^{-10}$
7	1.7	$-4.69281x10^{-09}$

Table 4: Variation of Confinement Loss with a changing wavelength (λ).

Confinement Loss of fiber varies with a changing wavelength (λ) is shown in Table 4. From the above table it can be interpreted that the value of confinement loss very less in the given structure.

The mode coupling coefficient between mode m and m´ is given by [13,14,15] the following formula:

$$\Gamma_{ij} = R(\Delta\beta)\ |K_{ij}|^2 \quad (8)$$

With,

$$R(\Delta\beta) = C\ \sigma_{mdl}^2 / \ \{1+(\Delta\beta\ L_c)^{2p}\} \quad (9)$$

$$C=[\int_{-\infty}^{+\infty}\{1/(1+(\Delta\beta L_c)^{2p}\}d\Delta\beta\ ]^{-1} \quad (10)$$

$$K_{ij}= \ (\pi\omega e_0/2j\ )\int_0^{\infty} (\partial n_0/\partial r)A_i\ A_j r\ \partial r \quad (11)$$

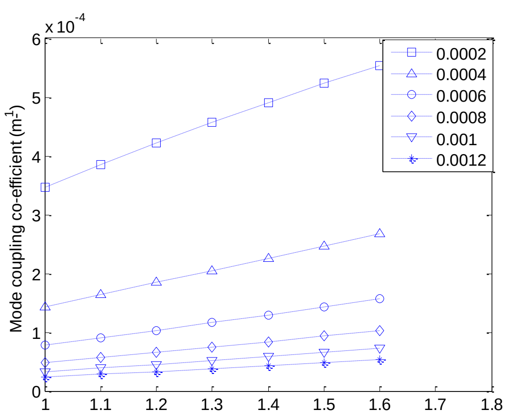

Fig.2: Variation of Mode coupling co-efficient in m^{-1} with Wavelength (λ)

It can be seen from the above figure that with a changing value of n_{eff}=0.0002, 0.0004, 0.0006, 0.0008 and 0.0012 the mode coupling co-efficient mm increases with the increase in wavelength.

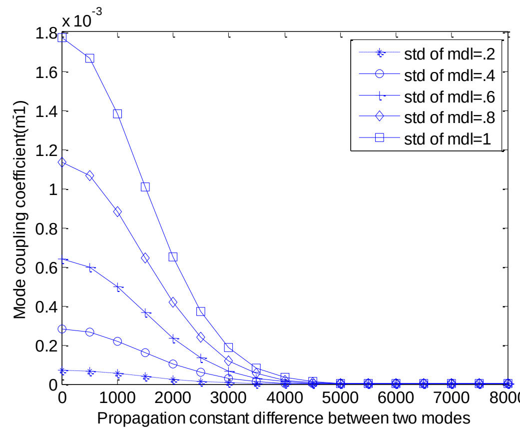

Fig. 3: Variation of Mode coupling co-efficientin m^{-1} with propagation constant difference Δβ between two modes.

Sl. No.	λ (μm)	Confinement Loss(dB/km)
1	1.1	$-2.82671x10^{-08}$
2	1.2	$4.56228x10^{-09}$
3	1.3	$-5.08602x10^{-09}$
4	1.4	$3.37392x10^{-09}$
5	1.5	$5.10477x10^{-10}$
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Table 4: Variation of Confinement Loss with a changing wavelength (λ).

IV.RESULT AND DISCUSSION

The variation of the mode coupling coefficient with respect to the propagation constant difference between adjacent two modes, for various values of the mode-dependent dispersion loss function's standard deviation, mdl=.2,.4,.6,.8, and 1 is depicted in Figure 3. The graph shows that the mode coupling coefficient will decrease as the difference in propagation constant between modes grows.

Confinement Loss of fiber varies with a changing wavelength (λ) is shown in Table 4. From the above table it can be interpreted that the value of confinement loss is very less in the given structure. This low amount of multimodal loss and confinement loss in the proposed study will result into lower value of fiber loss in fiber optic communication network.

V. CONCLUSION

The current work has demonstrated that increasing the propagation constant and effective refractive index differences between the adjacent modes will result in a reduction in multimodal loss and crosstalk in fiber. The fiber's multi-modal dispersion loss will be minimised by the lower power coupling between adjacent propagating modes.

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