IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.Volume 17, Issue 6, Ser. I (Nov. – Dec. 2022), PP 09-12
www.iosrjournals.org

Reduction of Mode Coupling in Multi-Cladding Optical Fiber

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Abstract: *A multi-layer multi-mode optical fiber of silica glass with differences in refractive indices between cladding layers is proposed. It is found that the amount of coupling between various modes will be minimized due to differences in the effective refractive indices among the adjacent modes. It would provide higher transmission capability at the time of signal transmission in the optical fiber communication system.*

Key Word*: Ring core optical fiber, refractive indices, multimode, mode coupling*

Date of Submission: 05-11-2022 Date of Acceptance: 20-11-2022

I. Introduction

In recent times, fast data communication has become possible mainly due to fiber optic communication. Multimode fibers are used for high bit rates as these fibers can support multiple modes through a single core. Mode coupling occurs due to a large number of modes passing through the single core which can suppress bit rate [1]. The mode coupling effect can be minimized by increasing the propagation constant difference between consecutive modes by increasing the difference in refractive indices between adjacent layers [2]. In tapered fibers, light is guided through the cladding-surrounding interface instead of the core-cladding interface [3]. It has been reported that ring core multi-cladding multimode fiber is suitable for such tapered shapes also. Mode Division Multiplexing(MDM) has attracted much research interest as a means to increase the transmission capability of a single fiber which utilizes space as an additional degree of freedom[4],[5]. Mutual coupling between modes is found to be a problem that limits the performance of MDM transmission, but the resultant mixed and scrambled signals can be recovered by utilizing multiple input multiple outputs based signal processing [4]. Few-mode optical fiber having large differences in effective refractive index between two adjacent modes can suppress coupling between modes[6], and it removes the necessity of using Multi input multi output signal processing. Ring core optical fiber has been found to reduce the dispersion and optimize bandwidth [7]

In the present paper, a five-layer optical fiber has been proposed. The design of the fiber has been made in such a manner that the amount of coupling between the modes and subsequent effects would be suppressed due to changes in refractive indices in different modes present in the fiber.(10)

II. Optical Fiber Structure:

A five-layer multi-mode fiber. Here n_0, n_1 to n_5 are the refractive indices of centre, ring core, second, third, fourth and fifth layers, respectively. Here r_0 to r_5 are the radius of centre, core, second, third, fourth and fifth layers, respectively.

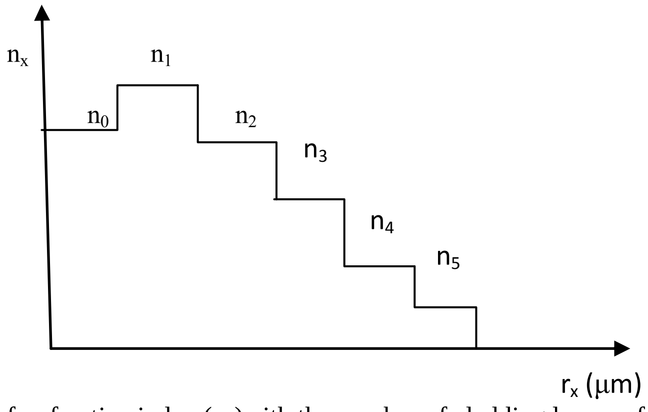

Figure 1: Variation of refractive index (n_x)with the number of cladding layers of optical fiber.

Calculation of refractive index of each layer using Sellmeier equation [8] for the free space wavelength is 1.55µm: n_0=1.485,n_1=1.505,n_2=1.465,n_3=1.445,n_4=1.425,n_5=1.405.
Radius of each layer :r_0=20µm,r_1=25µm,r_2=30µm,r_3=35µm,r_4=40µm,r_5=45µm

III. Signal Propagation Characteristics of the Fiber:

Normalized Transverse Propagation Constants:

The normalized transverse propagation constants in a fiber vary with effective refractive index (n_{eff}) for a given frequency along the propagation direction *z*. The governing equation is as follow [7]:

$$w_x = k_0 r_1 \sqrt{(n_{eff}^2 - n_x^2)} \qquad n_{eff}>n_0 \qquad (1)$$

$$u_x = k_0 r_1 \sqrt{(n_x^2 - n_{eff}^2)} \qquad n_{eff}<n_1$$

In the fiber w_x and u_x are the normalized transverse propagation constants of layers 0,1,2,..,5

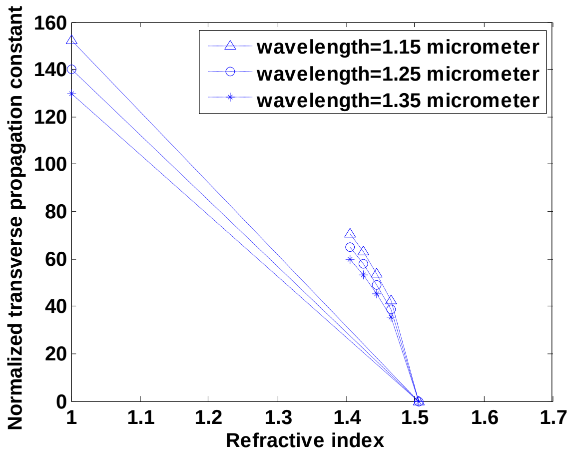

Figure 2: Variation of normalized transverse propagation constant with n of each layer.

The difference in the propagation constants between two modes m and m' (Δβ) is given by [9] the following formula:

$$\Delta\beta = \beta_m - \beta_{m'} = k.\Delta n_{eff} \qquad (2)$$

Where, $\Delta n_{eff} = (n_{eff,m} - n_{eff,m'})$

Here, $n_{eff,m}$ and $n_{eff,m'}$ are the effective refractive indices of mode m and m', respectively.

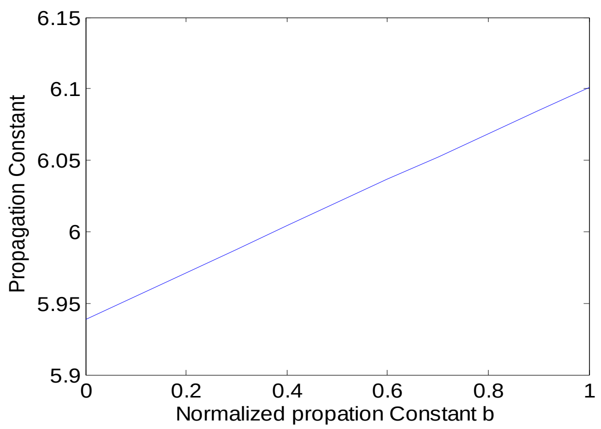

Figure 3. Variation of propagation constant (β) with b

Power Density at the Core Cladding Interface:

The power density at the core cladding interface ($P_{interface}$) in dB in the fiber is given by [10]:

$$P_{interface} = P\ v / (\ \pi N\ r_1^2) \qquad (3)$$

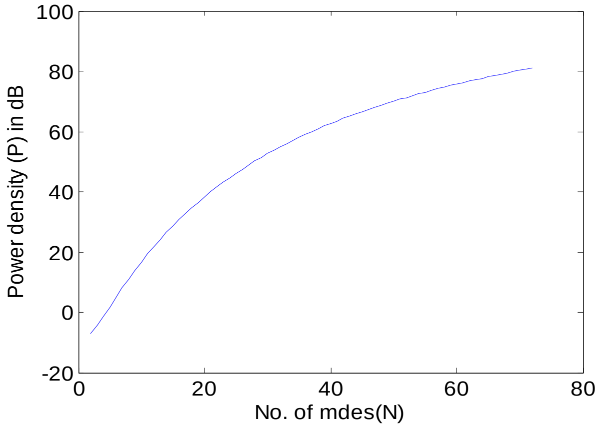

Figure 4. Variation of Power density (P_{dB}) with number of modes

Power distribution in the fiber is obtained by averaging over all modes treating mode index v as continuous variable is given by [10]:

$$\frac{P_{interface}}{P} = \frac{1}{\pi N r_1^2} \int_0^N \left(\frac{v}{N}\right) dv \qquad (4)$$

Average cladding power (P_c) :

$$\frac{P_{cladding}}{P} = \frac{1}{N} \int_0^N \left(\frac{v}{N\sqrt{(2N - 2v)}}\right) dv \qquad (5)$$

Where, N is total number of modes in the fiber and P is total power in the fiber.

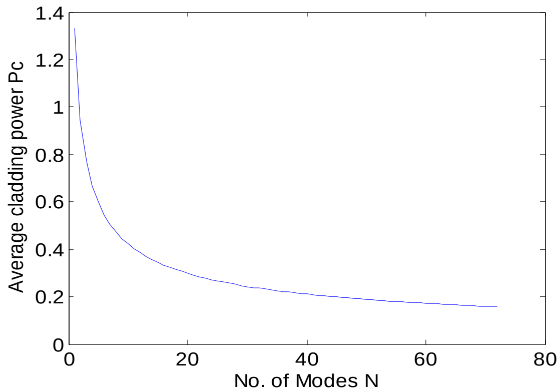

Figure 5. Variation of average cladding power (P_c) with number of modes (N)

Normalized Frequency (V):

The normalized frequency (V) in the fiber is given by [11]:

$$V = \frac{2\pi r_1}{\lambda} (n_1^2 - n_2^2) \qquad (6)$$

With radius of core r_1=25 µm and free space wavelength λ=1.55 µm normalised frequency (V) in the fiber can be calculated to be 12. If V≤2.404, the fiber is multi-mode step index fiber.

IV. Result

It is observed from the study that when difference of propagation constant between mode increases, the mode coupling coefficient will decrease. The rate of decrease becomes very low after around 40 number of modes. The decrease in mode coupling will imply in lowering the dispersion losses arising out of the presence of different modes in the core cladding interface, the internal coupling losses among various modes and this will give better spectral efficiency related to coupling of optical power into the fiber.

V. Conclusion

The results of the current study have demonstrated that increasing the propagation constant and effective refractive index differences between neighboring modes will result in a reduction in mode coupling loss in the fiber. The fiber's multi-modal dispersion loss will be minimized by the lower power coupling. Better spectral efficiency and less cross-talk between guided modes in the optical fiber communication network will result in a reduction in multi-modal dispersion loss.

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