ISSN 2348 – 8034
Impact Factor- 5.070

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES

AN OVERVIEW OF MULTI LAYERED COAXIAL STEP INDEX CYLINDRICAL DIELECTRIC WAVEGUIDES

Ganga Prasad Gupta[1], Nilanjan Sil[2], Achint Kapoor*[3] and Sanjay Kumar Dey[3]
[1]Department of Physics, BSK College, Maithon-828207, India
[2]Department of Physics, Silli Polytechnic, Ranchi-835102, India
[3]University Department of Physics, Ranchi University, Ranchi-834008, India

ABSTRACT
We present an in-depth study of the multi layered step index fibre. For this purpose, we have presented the abstracts and conclusions drawn by different workers in tabular form. We analyze the result from our perspective and suggest further improvement in the study of multi layered co-axial step index fiber from the practical application point of view for optimum utilization.

Keywords: *Optical fibre, Multi layered structure, Dielectric waveguide*

I. INTRODUCTION

Optical fibres provide the means of transmitting large amount of data from one place to another. However transmission of data requires proper geometry of the dielectric material waveguide and width of the core and the cladding. Several workers have studied optical waveguides with various forms of cross-sections yielding important and useful results [1-9] from practical stand point. We have analyzed the work done in multi clad fibres by the workers [10-16]. Different workers have analyzed the multi clad fibres for obtaining classification of modes, cutoff conditions, normalized propagation constant, normalized frequency parameter, power flow, dispersion curve etc. by employing analytical methods or by different numerical techniques. Although the techniques used for obtaining results are different but the main feature of all the workers was how to provide better values of different parameters in order to improve these fibres having immense technological importance. Our main thrust in this paper is to analyze and compare the works of different authors and to suggest our view point for further improvement in the performance of multi clad dielectric cylindrical optical waveguide.

II. FORMULATION OF PROBLEM

The geometrical configuration of the cylindrical dielectric multi clad fiber under consideration is shown in figure 1. We are presenting the expression of cutoff condition for three layered structure. Consider dielectric constant and permeability for the different regions as respectively (ε_1, μ_1), (ε_2, μ_2) and (ε_3, μ_3). Let the radius of inner circular dielectric boundary be 'a', that of outer one be 'b', while the region III extends up to infinity in our mathematical formulation.

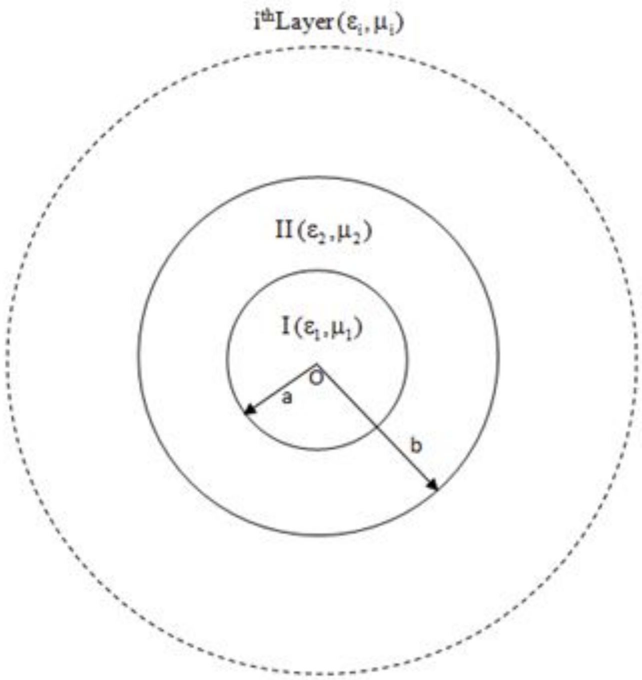

Fig. 1 Concentric multi layered dielectric waveguide

The fields satisfy the scalar wave equation and we obtain the following expressions for three regions as:

$$\psi_m^1 = A_m^1 J_m(\alpha_1 r) \tag{1}$$

$$\psi_m^2 = A_m^2 I_m(\alpha_2 r) + C_m^2 K_m(\alpha_2 r) \tag{2}$$

$$\psi_m^3 = C_m^3 K_m(\alpha_3 r) \tag{3}$$

$$\phi_m^1 = B_m^1 J_m(\alpha_1 r) \tag{4}$$

$$\phi_m^2 = B_m^2 I_m(\alpha_2 r) + D_m^2 K_m(\alpha_2 r) \tag{5}$$

$$\phi_m^3 = D_m^3 K_m(\alpha_3 r) \tag{6}$$

Here $\psi_m^1 s$ & $\phi_m^1 s$ corresponds to electric field and magnetic fields respectively. $\alpha's$ are mode characteristics parameters and expressed as

$$\alpha_i^2 = \omega^2 \mu_i \varepsilon_i - \beta^2 \tag{7}$$

where $i = 1, 2 \& 3$ for three regions where mode characteristics parameters for the region I is positive and negative for region II and III. We then employ the boundary conditions of continuity of electric and magnetic fields at the interface and then by mathematical manipulations, we obtain the cutoff condition, which is known as characteristics equation and is expressed as

$$\begin{vmatrix} P_{mm} & Q_{mm} \\ R_{mm} & S_{mm} \end{vmatrix} = 0 \tag{8}$$

Where symbols are expressed as

$$\left.\begin{aligned} P_{mm} &= U_m P^3_{mm} + Q^3_{mm} + \varepsilon_2 V_m R^3_{mm} \\ Q_{mm} &= \mu_2 V_m P^3_{mm} + W_m R^3_{mm} + S^3_{mm} \\ R_{mm} &= V_m P^4_{mm} + Q^4_{mm} + \varepsilon_2 V_m R^4_{mm} \\ S_{mm} &= \mu_2 V_m P^3_{mm} + W_m R^4_{mm} + S^4_{mm} \end{aligned}\right\} \quad (9)$$

Also

$$\left.\begin{aligned} U_m &= \frac{\left[p_m q_m - \Delta_m(\varepsilon_1,\varepsilon_2)\,\eta_m(\mu_1,\mu_2)\right]}{\left[\eta_m(\varepsilon_1,\varepsilon_2)\,\eta_m(\mu_1,\mu_2) - p_m^2\right]} \\ \mu_2 V_m &= \frac{\left[p_m \Delta_m(\mu_1,\mu_2) - q_m \eta_m(\mu_1,\mu_2)\right]}{\left[\eta_m(\varepsilon_1,\varepsilon_2)\,\eta_m(\mu_1,\mu_2) - p_m^2\right]} \\ W_m &= \frac{\left[p_m q_m - \Delta_m(\varepsilon_1,\varepsilon_2)\,\eta_m(\mu_1,\mu_2)\right]}{\left[\eta_m(\varepsilon_1,\varepsilon_2)\,\eta_m(\mu_1,\mu_2) - p_m^2\right]} \end{aligned}\right\} \quad (10)$$

Further

$$\left.\begin{aligned} &\left.\begin{aligned} P^3_{mm} &= \left(\frac{m\beta}{b\omega}\right)\left[\frac{1}{\alpha_2^2} - \frac{1}{\alpha_3^2}\right] I_m(\alpha_2 b) K_m(\alpha_3 b) \\ Q^3_{mm} &= \left(\frac{m\beta}{b\omega}\right)\left[\frac{1}{\alpha_2^2} - \frac{1}{\alpha_3^2}\right] K_m(\alpha_2 b) K_m(\alpha_3 b) \end{aligned}\right\} \quad (A) \\ &\left.\begin{aligned} R^3_{mm} &= \left[\left(\frac{\mu_2}{\alpha_2}\right) I'_m(\alpha_2 b) K_m(\alpha_3 b) - \left(\frac{\mu_3}{\alpha_3}\right) I_m(\alpha_2 b) K'_m(\alpha_3 b)\right] \\ S^3_{mm} &= \left[\left(\frac{\mu_2}{\alpha_2}\right) K'_m(\alpha_2 b) K_m(\alpha_3 b) - \left(\frac{\mu_3}{\alpha_3}\right) K_m(\alpha_2 b) K'_m(\alpha_3 b)\right] \end{aligned}\right\} \quad (B) \end{aligned}\right\} \quad (11)$$

Also P^4_{mm} and Q^4_{mm} will be same as set B of eq^n (11) with (μ_2, μ_3) being replaced by $(\varepsilon_2, \varepsilon_3)$ and R^4_{mm} and S^4_{mm} are same as set A of the same equation.

Also have

$$\left.\begin{aligned} p_m &= \left(\frac{m\beta}{a\,\omega}\right)\left[\frac{1}{\alpha_1^2}+\frac{1}{\alpha_2^2}\right] J_m(\alpha_1 a)\, I_m(\alpha_2 a) \\ q_m &= \left(\frac{m\beta}{a\,\omega}\right)\left[\frac{1}{\alpha_1^2}+\frac{1}{\alpha_2^2}\right] J_m(\alpha_1 a)\, K_m(\alpha_2 a) \end{aligned}\right\} \quad (A')$$

$$\left.\begin{aligned} \eta_m(x,y) &= \left(\frac{x}{\alpha_1}\right) J'_m(\alpha_1 a)\, I_m(\alpha_2 a) + \left(\frac{y}{\alpha_2}\right) J_m(\alpha_1 a)\, I'_m(\alpha_2 a) \\ \Delta_m(x,y) &= \left(\frac{x}{\alpha_1}\right) J'_m(\alpha_1 a)\, K_m(\alpha_2 a) + \left(\frac{y}{\alpha_2}\right) J_m(\alpha_1 a)\, K'_m(\alpha_2 a) \end{aligned}\right\} \quad (B')$$

$$(12)$$

Same mathematical concept can be utilized for four, five, six layers respectively and so on. Based on the above characteristic equation different authors obtained values for different parameters by employing different analytical method and numerical techniques. Values so obtained by different workers are of immense technological importance having far reaching consequences in the advancement of large data transmission through multi clad dielectric waveguide.

III. OUTCOME OF DIFFERENT REFERENCES IN TABULAR FORM

Ref. No	Paper's Title	Abstract	Conclusion
10.	Classification of hybrid modes in cylindrical dielectric optical waveguides	The classification of hybrid modes in cylindrical dielectric waveguides consisting of two or three layers is studied. A new mode designation based upon the separation of the characteristic equation is introduced. That is, separate characteristic equations for HEnm and EHnm modes are derived. This new scheme covers dielectric rods, dielectric tubes, cladded optical fibers and any three-layer structure in general. It is analytically shown that no crossover exists between HE and EH modes with the same order of azimuthal variation (n).	A new scheme for the classification of hybrid modes in cylindrical dielectric waveguides has been proposed. Two separate equations, one representing EH and the other HE modes, have been derived. This new scheme is precise, well defined, universal, and yields a unique classification. It has been shown that no crossovers exist between HE and EH modes of the same order of azimuthal variation. It has also been shown that the amplitude coefficient ratio cannot be used for hybrid mode designations in three-layer structures. Dispersion curves of several lower-order modes for a rod, a cladded fiber and a tube with some specified parameters have been presented.
11.	Modal characteristics of three-layered optical fiber waveguides: a modified approach	By invoking Debye potentials, we formulate exact eigenvalue equations and the corresponding field distributions for general, three-layered, radially stratified, dielectric, and nonferromagnetic metal, optical fibers. By using cross	The exact EVE's have been formulated for a general three layered, all-dielectric or non ferromagnetic metallic, fiber waveguide. The simple formalism presented here involves only the Bessel functions and their cross products. As a result, the EVE's can be solved graphically. The method can be applied

ISSN 2348 – 8034
Impact Factor- 5.070

		products of Bessel functions, which may be regarded as the basic functional elements of the eigenvalue equations, a comparison is made between the properties of a three-layer structure and a simple step-index profile, and a simple graphical solution is obtained. The technique is applied to several practical structures, including two-layer fibers having a central index depression in the core, ring-core fibers, W fibers, and progressively stepped three-layered structures. The mathematical procedure is simple, and the results are of interest to optical fiber designers.	easily to many practical waveguide structures, such as single-mode fibers showing a central index dip, large-diameter ring-core fibers, W fibers, and progressively stepped three-layer fibers.
12.	Modal characteristics of a doubly clad step-index optical fibre: a general analytical approach	Using a fairly rigorous approach, a general characteristic equation for a doubly clad step-index fibre has been derived under the assumption that the refractive-index difference between the inner and outer cladding is small. Two different profiles, i.e., the W profile and the staircase profile, have been treated together and a discussion of their common characteristics has been made. Cutoff conditions for low-order modes have been obtained. For a certain range of values of the transverse-phase parameter ratio, the singly-clad fibre has greater mode cutoff V numbers than those of a doubly clad fibre. The analysis anticipates the possibility of obtaining greater cutoff V numbers for W-profile fibres.	The foregoing analysis and discussion show the cutoff properties for all doubly clad fibres for which refractive-index differences between the inner and outer claddings are small irrespective of the nature of the profile. Although, as is well known, the mode-suppression property of a singly clad fibre generally deteriorates with the addition of more cladding, the interesting result emerges that there are special situations when the mode suppression property is improved. One of the conditions for the cutoff of the TE01 mode is identical to the corresponding cutoff for W fibres as obtained by Kawakami and Nishida. This means that the behaviour of W-clad fibres is "pre-indicated" in the present analysis, which can be developed further for both W fibres $(\delta>0)$ and staircase $(\delta<0)$ fibres with small and large values of δ .
13.	Mode Classification in Cylindrical Dielectric Waveguides	We discuss an analytical approach which leads to a global scheme for mode classification in two- and three-layers step-profile cylindrical dielectric waveguides, based on the requirements of analytical continuity HE → TE and EH → TM in the limit such that the system under	We have presented an approach which has resulted into a global scheme for classification of hybrid modes in all types of three-layers dielectric waveguides, like step-index fibers, W -type fibers and dielectric tubes together with that in dielectric rods. In this scheme, the characteristic equation with the positive (negative) sign

		consideration becomes a circular metallic wave-guide. Technically, HE and EH hybrid modes correspond to the two roots of the problem's quadratic characteristic equation. It turns out that the mode designation has the universality in the sense that the equation obtainable from the root involving positive (negative) sign always describes HE (EH) mode.	corresponding to two roots of a quadratic equation always yields TE (TM) mode condition in the limiting case of a circular metallic waveguide and corresponds to HE (EH) mode equation due to dominance of the magnetic (electric) field. The beauty of our approach lies in the fact that there is uniqueness in the mode designation related to the sign convention for various types of waveguides while analytical continuity is preserved throughout the process of mode designation. Moreover, it has its physical basis and is not merely based on mathematical nicety.
14.	ON THE ANALYSIS OF A WEAKLY GUIDING DOUBLY CLAD DIELECTRIC OPTICAL FIBER WITH AN ANNULAR CORE	A fairly rigorous analytical treatment of an annular core dielectric optical fiber is presented, the core of the fiber lying between two concentric claddings with the outer cladding extended infinitely. For the theoretical approach, the approximation of the vanishing refractive index difference between the core and the cladding sections is implemented. The investigation is on the preliminary ground, and a numerical estimation of the modal cutoffs is presented for the said fiber. The effects of the core width as well as the inner core diameter on the propagation constants β_c at field cutoffs are presented. Plots are also shown of the variation of β_c with the change in the refractive index values	From the foregoing analysis and discussion, the inference can be drawn that dielectric ACFs present higher cutoffs for the LP_{11}-modes than the conventional single-clad optical fibers. Further, LP_{01}-modes have a nonzero cutoff in the case of ACFs. The inner clad diameter has an effect on the cutoff propagation constants β_c in such a way that, with its increase, there occurs a slower decrease in β_c with the increase in the core thickness d. Also, with the increase in Δ, β_c also shows an increase, and this tendency becomes more prominent for higher values of the inner clad radius r_1. In this communication, the only approximation used is that the RI difference between the guiding and nonguiding regions is small. However, the fields are taken in their exact forms. It is presumed that ACFs can be useful, particularly in the area of fiber-optic sensors where the study of evanescent wave spectroscopy plays a vital role. Such ACFs filled with different kinds of materials (affecting the nature of evanescent waves) would be useful for sensor applications. Their use in all-fiber narrowband spectral filtering may also be expected. Moreover, optical fiber structures with periodicity in materials are already in use in photonic bandgap guidance

ISSN 2348 – 8034
Impact Factor- 5.070

15.	Effect of cladding layers on the mode of circular optical waveguides	In this paper, the analytical study of the modal characteristics, cutoff condition and dispersion curves of circular optical waveguide having various cladding layers are presented. The proposed three structures of waveguide have three parts namely core with highest refractive index dielectric material, inner claddings and outer cladding. The guided modes and propagation wave vectors can be evaluated by using a determinant which is constructed by the boundary matched method under the weakly guiding condi- tion. The cutoff conditions of modes for varying number of inner claddings are compared. The analysis shows that one can control the propagation property of optical waveguide by increasing the number of inner claddings. These claddings provide additional degree of freedom to control the modes.	We can conclude that on increasing the number of layers the cut-off V value of each mode increases. It means the optical fiber waveguide can be operating on longer range of normalized frequency for single mode. We also found that when on increasing the width of first inner cladding to higher value the mode cut-off value will not increase longer i.e.it remains constant.
16.	Modal characteristics analysis of a doubly clad optical fiber with semi-weakly guiding approximation	Modified characteristic equations for doubly clad multimode fibers were rigorously derived under semi-weakly guiding approximation in this article. The analytical expressions of the power flows distributed in the three regions of fiber cross section are also given. Different from previous works, results in this paper elucidate that, other than the inner cladding, the refractive indices also hold a non-ignorable influence on the modal power distribution and mode behaviors. By comparing the results of two models, this article demonstrates that the singly clad fiber model may not be suitable for analyses of common doubly clad fibers.	The formulas we derived for DCFs clearly prove that the modal features of DCF model are much more complex than those of SCF model, and the inner cladding plays a significant role in the results. By comparing the results of the SCF model and the DCF model when targeting the same DCF, it shows that the SCF model may not fit for the analyses of DCF although it is now widely used in articles focusing on DCF. More importantly, we find that, other than the thickness of the inner cladding, modal characteristics can also be influenced by the ratio of the refractive indices of inner and outer claddings. This trait is overlooked in previous literature while using WGA at both of the cladding interfaces. In fact, the refractive index differences between the inner and outer claddings are always too large to use WGA. Therefore, the characteristic equations obtained for DCFs in this article are much closer to the practical situations, because semi-

			WGA is used. The results in this article are of interest to optical fiber design works and mode control in high power fiber lasers and amplifiers. The analytical and mathematical methods in this article are also available for other types of DCFs.

IV. DISCUSSION

We have purposely chosen different papers authored by different workers spanning a period of four decades having far reaching consequences on the technology of waveguide system. Many authors [10,13] have formulated analytical scheme for mode classification for multi layered co-axial dielectric optical waveguide. Reference number [10] have formulated separate characteristic equation for H E & E H mode and further suggested that there is no cross-over between the two types hybrid modes which was further improved later on by reference [13] by developing a quadratic characteristic equation for multi layered structure with two roots of the quadratic equation being assigned for H E (+ve root) and E H (-ve root) which turns out to be universal scheme of mode classification. Besides these analytical scheme many workers [11,12,14-16] have applied different numerical techniques for obtaining different physical parameters of multi layered structure by assigning different values of dielectric constant and geometrical configuration. The values of different physical parameters suggested by different authors are proving to be a milestone in the workshop of multilayered structure. It was further suggested by an author [15] that by increasing the number of layers one can control the number of sustained modes.

In addition to above references other workers have also contributed for obtaining various parameters related to co-axial multilayered dielectric waveguide and their results are akin to the results obtained by the workers under consideration. Thus we notice that by varying geometrical configuration and dielectric constant one can improve the performance of multilayered co-axial optical waveguide.

V. SUGGESTION

Based on the above facts we wish to suggest that one can obtain the above parameters by assigning such values to geometrical configuration and dielectric constant which have not been considered in numerical calculation till date as their influence is non ignorable and that may lead to further enhancement in the performance of data transmission technology. Fabricators may then be asked to prepare such materials with those values of dielectric constant and geometrical configuration, so that data transmission technology may get further boost.

VI. CONLUSION

We have studied and tabulated the results obtained by different workers in multi layered co-axial optical waveguide. The main purpose of our study is to correlate the works done by different workers and on the basis of that we present our suggestion which may bear far reaching impact on the data transmission technology

REFERENCES

1. *R. B. Dyott, Cutoff of the first order modes in elliptical dielectric waveguide :An experimental approach, Electron. Lett. 26(1990), pp.1721-1723.*
2. *A. Kumar and R. K. Varshaney, Propagation characteristics of higly elliptical core optical waveguides: A perturbation approach, Opt. Quantum . Electron. 16(1984), pp.349-354.*
3. *A. Kumar, K. Thyagrajan and A. K. Ghatak, Analysis of rectangular core dielectric waveguides: An accurate perturbation approach, Opt. Lett. 8(1983), pp. 63-65.*

4. P. K. Sukla, P. K. Choudhary, P. Khastgir and S.P. Ojha, Comparative aspects of a metal- loaded traingular waveguide with uniform and non uniform distribution of Goell's matching points. J. Inst. Electron telecommun. engg. 41(1995), pp. 217-220.
5. J. R. James and I. N. L. Gallett, Modal analysis of triangular- cored glass- fibre waveguides, Proc. Inst. Elect. Engg.120(1973), pp. 1362-1370.
6. . P. K. Choudhary, P. Khastgir and S. P. Ojha, A mathematically rigorous cutoff analysis of parabolic cylindrical wave guides, J. Phys Soc. Jpn. 61(1992), pp. 3874-3877.
7. P. K. Choudhary, P. Khastgir, S. P. Ojha and K.S. Ramesh, An exact analytical treatment of parabolically deformed planar waveguide near cut off, Optik 95(1994), pp. 147-151.
8. P. K. Choudhary, On the preliminary study of a dielectic guide having a Piet Hein geometry, Ind J. Phys. 71B (1997), pp. 191-196.
9. V. Mishra, P. K. Choudhary, P. Khastgir and S. P. Ojha, Electromagnetic wave propagation through a dielectric guide having Piet Hein cross section geometry, Microwave. Opt. Technol. Lett. 12 (1996), pp. 250-254.
10. A.Safaai-Jazi and G. L. Yip, Classification of hybrid modes in cylindrical dielectric optical waveguides, Radio Sci. 12, 4(1977), pp. 603-609.
11. Charles Y. H. Tsao, David N. Payne, and W. Alec Gambling, Modal characteristics of three-layered optical fiber waveguides: a modified approach, J.Opt.Soc. Am.A, 6, 4(1989), pp. 555-563.
12. V. K. Chaubey, K. K. Dey, S.P. Ojha and P. Khastgir , Modal characteristics of a doubly clad step-index optical fibre: a general analytical approach, Can. J. Phys. 66,(1988), pp. 796-802.
13. A. Kapoor and G. S. Singh, Mode Classification in Cylindrical Dielectric Waveguides, J. Lightwave Technol. 18, 5(2000), pp. 849-852.
14. B.C. Sarkar, P. K. Choudhury and T. Yoshino, ON THE ANALYSIS OF A WEAKLY GUIDING DOUBLY CLAD DIELECTRIC OPTICAL FIBER WITH AN ANNULAR CORE, Microwave and optical technol. Lett.31, 6(2001), pp. 435-439.
15. J. B. Maurya, Y.K. Prajapati, V. Singh & J.P. Saini, Effect of cladding layers on the mode of circular optical waveguides, Optik 124,(2013), pp.106-1069.
16. X. Tan, X. Liu, W. Zhao, C. Li, Y. Wang and J. Li, Modal characteristics analysis of a doubly clad optical fiber with semi-weakly guiding approximation, Optics Comm. 294 (2013),pp. 148-155