Available online at http://www.ijirr.com

ISSN: 2349-9141

International Journal of Information Research and Review
Vol. 2, Issue, 08, pp. 992-998, August, 2015

OPEN ACCESS JOURNAL

Full Length Research paper

EFFECTIVE REFRACTIVE INDEX STUDY OF THE ELLIPTICAL M-TYPE OPTICAL FIBER

[1]Seyed Meysam Arabzadeh and [2,*]Somayeh Makouei

[1]Department of Electrical Engineering, Ahar Branch, Islamic Azad University, Ahar, Iran
[2] Department of Electrical and Computer Engineering, University of Tabriz, Tabriz 51664, Iran

***Corresponding Author**

Received 27th July 2015; Published 31st August 2015

Abstract

In this paper, the effective refractive index of the M-type triple clad single-mode elliptical optical fiber was investigated. These kinds of multilayer optical fibers are useful for zero dispersion wavelength shifted applications. The effects of the optical and geometrical parameters on the effective refractive index were examined. The finite element method (FEM) was used for modal analysis. The simulation results indicated that by increasing the elliptical factor the effective refractive index was reduced and made the electrical field distribution to be smoother in the core and cladding layers. Also, by the growth of the core radius and Δ, the effective refractive index was raised. Furthermore with increase of the P, Q, R_1 and R_2 amplitude, the effective refractive index reduces. The concept to consider is that the effective refractive index sensitivity to wavelength was reduced by higher values of P.

Keywords: Effective Refractive Index, Elliptical Core Fibers, Single-Mode Fibers.

To cite this paper: Seyed Meysam Arabzadeh and Somayeh Makouei *2015.* Effective refractive index study of the elliptical m-type optical fiber*, International Journal of Information Research and Review.* Vol. 2, Issue, 08, pp. 992-998. August, 2015.

INTRODUCTION

Light has an enormous potential for data transmission with very high data rates. In most cases, optical data transmission uses optical fibers as the transmission medium, because light can be guided in fibers over very long distances with very low losses, also avoiding alignment issues, atmospheric influences, and the like (Agrawal, 2002; Ghatak and Thyagarajan, 1997; Hattori and Safaai-Jazi,1998; Palodiyaa and Raghuwanshib, 2015). One of the key parameters managing long haul communication is fiber dispersion. Zero-dispersion wavelength communication is the first alternative in this consideration. In the fiber design shifting the zero-dispersion wavelength to a wavelength in which the fiber has minimum attenuation is preferred. Recently, high bandwidth applications are requested in optical system. So, design of optical fibers including high bandwidth as well as low and uniform dispersion profile is interesting for researchers and applied engineers (Yin et al., 2000, Rostami and Savadi-Oskouei, 2007; Savadi-Oskouei et al., 2007; Makouei, 2013; Prajapati et al., 2013; Ghafoori Fard et al., 2008). Standard telecom fibers exhibit zero chromatic dispersion in the 1.3 μm wavelength region. This was convenient for early optical fiber communications systems, which often operated around 1310 nm. However, the 1.55 μm region later became more important, because the fiber losses are lower there, and erbium-doped fiber amplifiers (EDFAs) are available for this region (whereas 1.3 μm amplifiers do not reach comparable performance).

In this wavelength region, however, standard single-mode fibers exhibit significant anomalous dispersion (Wandel and Kristensen, 2005). For linear transmission, this can be a problem, because it leads to significant dispersive pulse broadening, limiting the achievable transmission rates or distances. Therefore, zero dispersion wavelength shifted fibers have been developed, which have modified waveguide dispersion so as to shift the zero dispersion wavelength into the 1.55 μm region (Ghafoori Fard et al., 2008; Wandel and Kristensen, 2005). This is achieved by modifying the refractive index profile of the core. A small pulse broadening factor (small dispersion and dispersion slope), as well as small nonlinearity (large effective area) and low bending loss (small mode field diameter) are required for long distance transmission. The performance of a design may be assessed in terms of the quality factor. This dimensionless factor determines the trade-off between mode field diameter, which is an indicator of bending loss and effective area, which provides a measure of signal distortion owing to nonlinearity (Rostami and Savadi-Oskouei, 2007; Savadi-Oskouei et al., 2007).

Polarization mode dispersion results from polarization dependent propagation characteristics. It can be relevant in high data rate fiber optic links based on single mode fibers. Polarization mode dispersion can have adverse effects on optical data transmission in fiber optic links over long distances at very high data rates especially for large channels dense wavelength division multiplexing (DWDM) systems, because portions of the transmitted signals in different polarization modes will arrive at slightly different times(Baghdadi et al., 2001; Kumar and Varshney, 1984) . Effectively, this can cause some level of pulse broadening, leading to inter symbol interference, and thus a degradation of the received signal, leading to an increased bit error rate. In principle, the problem could be solved by using well defined polarization states in polarization maintaining fibers, which is not a fiber without birefringence, but on the contrary a specialty fiber with a strong built-in birefringence **(**high-birefringence fiber or HIBI fiber**,** PM fiber**)**. This polarization state will be preserved even if the fiber is bent (Islam et al., 2009; Xuan et al., 2010). To introduce optical fibers for long haul communications, some fiber structures have been scrutinized. But certain types of optical fibers are known according to the refractive index characteristics as the R, W and M type (Makouei et al., 2007), which have some desired properties and characteristics which are in standard fibers (Yeh et al., 1979). In this paper, the effect of system geometrical and optical parameters on the effective refractive index (n_{eff}) of the M-type triple clad single-mode elliptical optical fiber is investigated. For the analysis, the finite element method will be used.

The organization of the paper is as follows

In Section 2, mathematical formulation and modal analysis is presented and the finite element method will be mentioned. In section 3, simulation results are presented and discussed. Finally, the paper ends with a short conclusion.

Mathematical Formulation

In this section, the mathematical equations of optical and geometrical parameters will be presented and the fiber structure completely will be introduced. Figure 1, shows the refractive index profile of the layers. The corresponding refractive index distribution function is defined as follows:

$$n(r) = \begin{cases} n_1, & 0 < r < a \\ n_2, & a < r < b \\ n_3, & b < r < c \\ n_4, & c < r \end{cases} \quad \text{......} \quad (1)$$

where r is the radius position of optical fiber. The effective refractive index is given by $n_{eff} = \frac{\beta}{k_0}$ where β is the propagation wave vector of guided modes and *k0* is the wave number in vacuum.

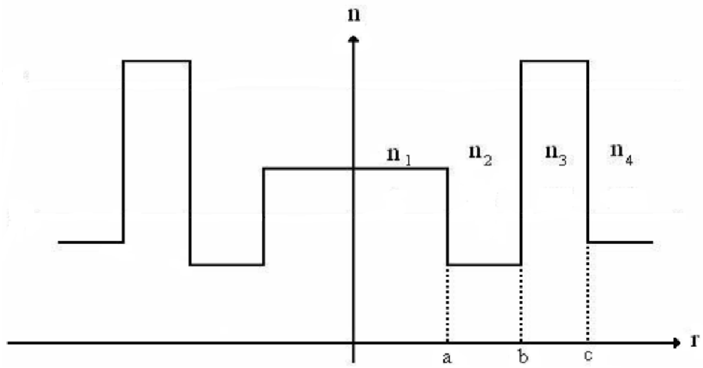

Figure 1. The refractive index profile of the M-type fiber

Geometrical parameters are defined as follows:

$$Q = \frac{a}{c}, P = \frac{b}{c}, L = \frac{a}{a'} = \frac{b}{b'} = \frac{c}{c'} \quad \text{......} \quad (2)$$

Also, the optical parameters are defined as:

$$\Delta = \frac{n_3^2 - n_4^2}{2n_4^2} \approx \frac{n_3 - n_4}{n_4}, R_2 = \frac{n_2 - n_4}{n_3 - n_2}, R_1 = \frac{n_3 - n_1}{n_3 - n_2} \quad \text{......} \quad (3)$$

Where a', $b'$and c', respectively are the minor radius of the core and claddings, and geometrical parameter, L, shows the ellipticity of fiber cross-section.

A perfect dielectric environment is an environment where σ = 0. Because for making optical devices, such as optical fiber, glass is used, so σ = 0. Therefore, Maxwell's equations would be simplified as follows:

$$\nabla^2 \vec{E} = \mu\varepsilon \frac{\partial^2 \vec{E}}{\partial t^2} \quad \text{(4)}$$

$$\nabla^2 \vec{H} = \mu\varepsilon \frac{\partial^2 \vec{H}}{\partial t^2} \quad \text{(5)}$$

For an environment with electrical permittivity ε_r, the wave equation for the electric field will be as follows:

$$\nabla^2 \vec{E} + \nabla\left(\frac{\nabla\varepsilon_r}{\varepsilon_r} \cdot \vec{E}\right) + k_0^2 \varepsilon_r \vec{E} = 0 \quad \text{(6)}$$

Where k_0 is the wave number in vacuum and is expressed as below:

$$k_0 = \omega\sqrt{\varepsilon_0 \mu_0} \quad \text{(7)}$$

When the electrical permittivity ε_r is constant in the environment, wave equation is reduced to the Helmholtz equation:

$$\nabla^2 \vec{E} + k_0^2 \varepsilon_r \vec{E} = 0 \quad \text{(8)}$$

According to the refractive index equation in the dielectric, the wave equation for the electric field is rewritten as follows:

$$\nabla^2 \vec{E} + k^2 \vec{E} = 0 \quad \text{(9)}$$

The need to calculate some important characteristics, such as the number of modes and their corresponding propagation constants of the waveguides was necessary and both analytical and numerical methods have been proposed (Kawano and Kitoh, 2001; Rahman, 1995). Finite Element Method constitutes one of the most powerful numerical methods when there is need for approximate solutions of a problem and In this paper, modal analysis is done by using the finite element method. In the execution of the finite element method, the cross-section Ω of the optical waveguide concerned is first suitably divided into a number of sub domains or elements and then analytical functions are applied to every element. The results are summed up to global matrixes and an eigenvalue matrix equation is produced. The final step is to solve the eigenvalue matrix equation and retrieve the propagation modes and the corresponding propagation constants. The meshing of the area is performed in many small elements. Elements are classified as one-, two-, and three-dimensional. An element consists of nodes. An element can be either a triangle with tree nodes (first order element) or six nodes (second order element), or a rectangle with four nodes (first order element) or eight nodes (second order element) and similarly any other shape (Waynant and Marwood, 2000). Different element shapes are shown in the Figure 2.

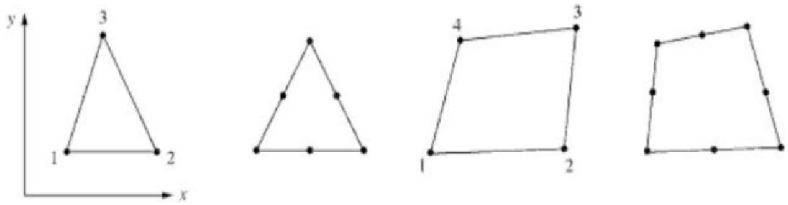

Figure 2. Different element shapes

The simplest example in one dimension would be a piecewise continuous linear function or, but for a more elaborate element it can be piecewise quadratic function. In two dimensions the elements are often triangles or rectangles. The simplest triangular element assumes a linear interpolation between the field values at the corner points (vertices) of the triangle. The interpolation functions are chosen and applied to the nodes of the elements. Usually, polynomial functions are used because they can be easily differentiated. Also, the degree of the polynomial is correlated with the order of the element used. The parameters of the elements are calculated and expressed in a matrix form. For the calculation of the parameters we used the variational approach. The matrixes of the elements are combined in order to generate an eigenvalue matrix equation which describes the global system. The necessary boundary conditions are introduced in the system. The boundary conditions which are used are the Neumann and Dirichlet conditions. Finally, the eigenvalue matrix system is solved using a suitable method according to the problem at hand. The most common algorithms which can be used are the Jacobi's and Householder's methods. By solving the equation, the propagation constants of the modes and the corresponding field distributions are produced (Okamoto, 2006; Huebner et al., 2001). In the following figure, meshing of the fiber cross-section is shown.

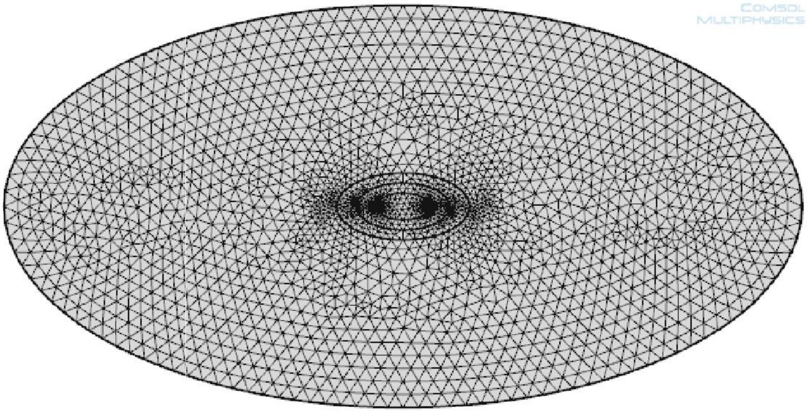

Figure 3. Meshing of the fiber cross-section

RESULTS AND DISCUSSION

In this section, simulation results are illustrated and the effects of geometrical and optical parameters on n_{eff} of the considered M-type optical fiber are investigated. Presented simulations have been done according to a=2.4 µm, Q = 0.4, Δ = 4e-3, P = 0.7, R_1 = 0.5, R_2 = - 0.3 and L = 2 which the L shows the ellipticity of fiber cross-section. The wavelength duration is considered between 1.2µm to 1.8µm. In order to study the effects of these parameters on the effective refractive index, each parameter is varied one at a time while the others kept constant.

Figure 4 illustrates that by increasing the L, n_{eff} reduces and the rate of decrement is more at the shorter wavelengths. In other words, by raising the ellipticity of cross-section, the effective refractive index decreases, also the n_{eff} is more sensitive to the smaller values of the L. According to Figures 5, it is clear that by the L raising, the fiber capability to confine the light in the core region increases and the electrical field spreads more in the cladding region. Also the field main peak which is localized in the second cladding layer will be shifted to the boundary between the second and third cladding layers.

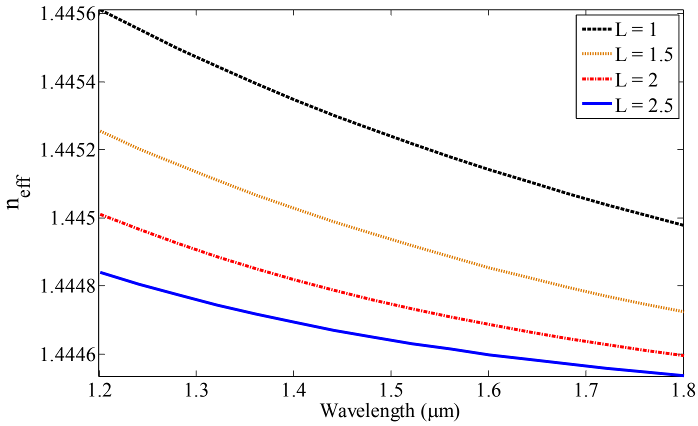

Figure 4. n_{eff} vs. wavelength (µm) for the L as a parameter

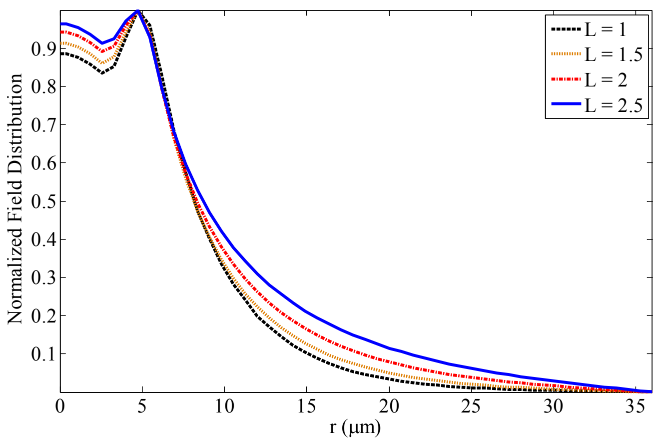

Figure 5. Normalized field distribution vs. radius (µm) for the L as a parameter at 1.55µm

Effect of the core radius "*a*" on the n_{eff} is shown in Figure 6. According to the *P* and *Q* definitions, it can be found out that by raising the core radius, duo to the *P* and *Q* are kept constant, the width of the first and second cladding layers are increased, but this increment in the second cladding layer is more, therefore the n_{eff} raises and the increment rate is the same at the short and long wavelengths approximately.

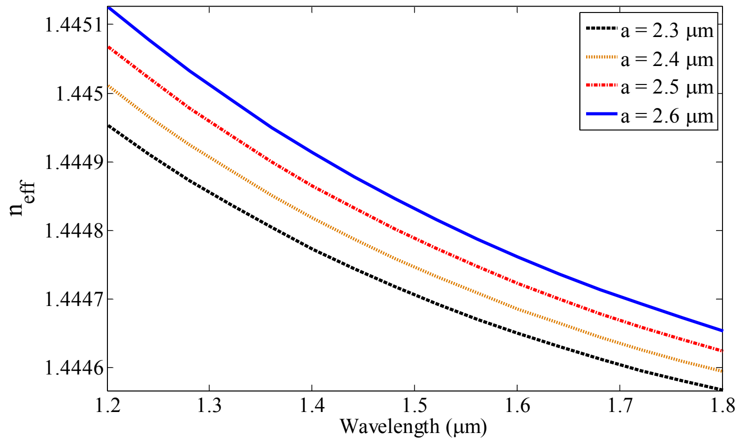

Figure 6. n_{eff} vs. wavelength (μm) for the core radius as *a* parameter

Figure 7 illustrates the influence of the *P* parameter on the n_{eff}. It is observed that by increasing the *P*, just the first cladding layer thickness raises and duo to the *Q* is kept constant, makes the second cladding layer radius to remain unchanged whereas its thickness decreases. So n_{eff} reduces and rate of reduction is more at the short wavelengths. Increase of the *P* causes the electric field spreads more in the cladding region.

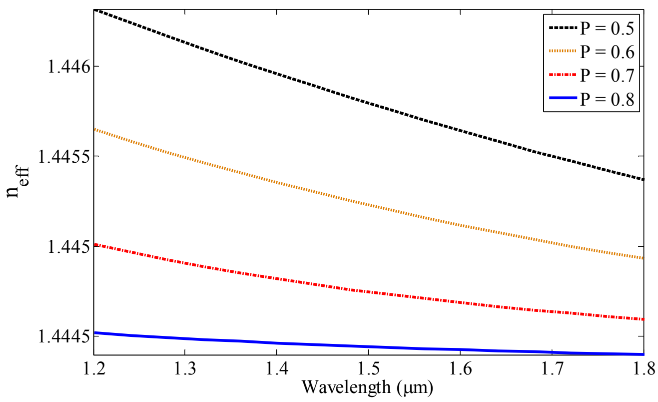

Figure 7. n_{eff} vs. wavelength (μm) for the *P* as a parameter

Figure 8 shows the effect of the *Q* on n_{eff}. It is found out that the by raising the *Q*, n_{eff} reduces and the rate of reduction at the shorter wavelengths is slightly more. In fact by increase of the *Q,* the radius of the first and second cladding layers reduces while the core radius stay unchanged. Consequently, the n_{eff} decreases. Moreover the n_{eff} is much sensitive to smaller values of the *Q*.

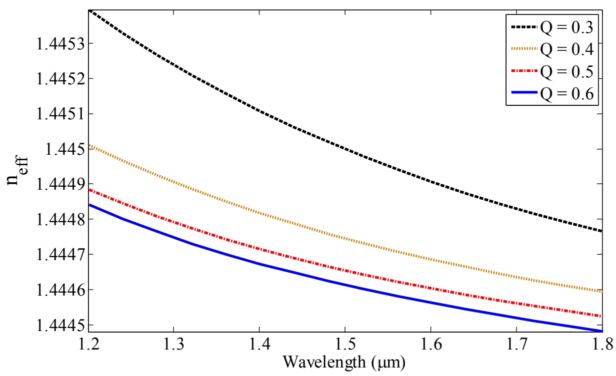

Figure 8. n_{eff} vs. wavelength (μm) for the *Q* as a parameter

The Δ influence is demonstrated in Figure 9. With increase of the Δ, first cladding layer refractive index (n_2) is decreased whereas the core and second cladding layer refractive indices (n_1 and n_3) are raised. The Δ has a strong impact on n_3 which can be expected according to the relation between Δ and n_3 . Thus according to the following figure, it is shown that by increasing the Δ, n_{eff} increases and this increment is a bit more at the shorter wavelengths.

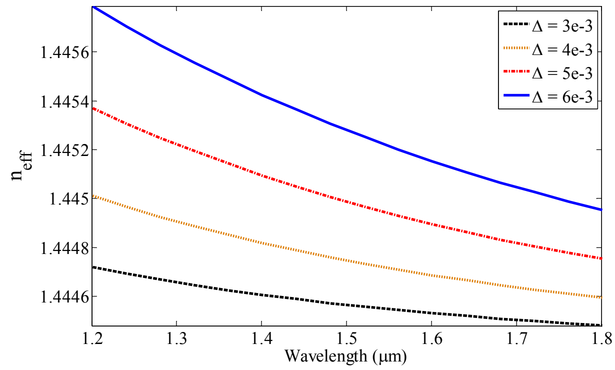

Figure 9. n_{eff} vs. wavelength (µm) for the Δ as a parameter

Figure 10 is illustrated to demonstrate the R_1 effect on n_{eff}. When the R_1 changes as the Δ and R_2 are kept constant, n_2 and n_3 stay unchanged and just the core refractive index (n_1) varies. However by increasing the R_1, n_1 decreases. Therefore it is obvious that the n_{eff} reduces by the R_1 increasing. As another result, the rate of decline is the same at the short and long wavelengths approximately.

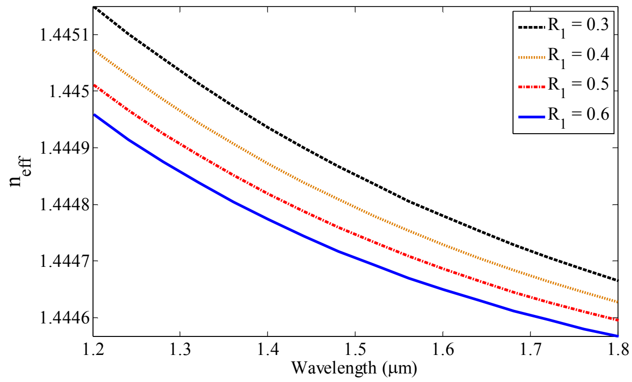

Figure 10. n_{eff} vs. wavelength (µm) for the R_1 as a parameter

The last simulation has been done to examine the R_2 impact. The R_2 influence on n_{eff} is shown in Figure 11. According to this figure, the n_{eff} increases by the amplitude of R_2 reduction. It can be said by decrease of the R_2 amplitude, n_2 increases, but the R_1 and Δ are kept constant, thus n_3 remains unchanged whereas n_1 raises, so it makes the n_{eff} to increase.

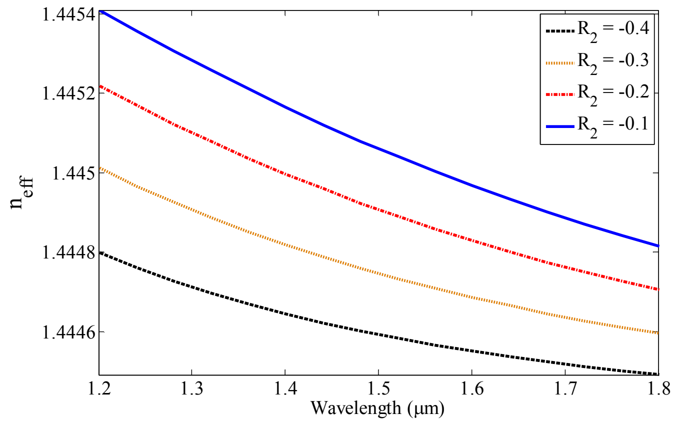

Figure 11. n_{eff} vs. wavelength (µm) for the R_2 as a parameter

Conclusion

The influence of the optical and geometrical parameters on the effective refractive index of the M-type triple clad single mode elliptical optical fiber were studied. The simulation results indicate that by increasing the core radius and also with increase of the Δ, the effective refractive index raises. Furthermore with increase of the L, P, Q , R_1 and R_2 amplitude, the effective refractive index reduces. The n_{eff} is more sensitive to the smaller values of the Q and L which indicates the ellipticity of the fiber. In addition, among the optical and geometrical parameters, the n_{eff} is the most sensitive to changes in the Δ and P. In the meantime, cladding layers thickness which is affected by changes in the geometrical parameters, have a significant impact on the effective refractive index.

REFERENCES

Agrawal, G.P. 2002. Fiber-Optics Communication Systems third edition. John Wiley and Sons. NewYork.

Baghdadi, J.A., Safaai-Jazi, A. and Hattori, H.T. 2001. Optical fibers with low nonlinearity and low polarization-mode dispersion for terabit communications. Optics and Laser Technology. 33, 285-291.

Ghafoori Fard, H., Dehesht, A., Rostami, A. and Nejati, S. 2008. A novel dispersion-shifted single mode optical fiber design with ultra-high-bit-rate and very low loss for long-haul communications. Optics Communications. 281, 5779–5787.

Ghatak, A. and Thyagarajan, K. 1997. Introduction To Fiber Optics. University Press. Cambridge.

Hattori, H.T. and Safaai-Jazi, A. 1998. Fiber designs with significantly reduced nonlinearity for very long distance transmission. Applied Optics. 37(15): 3190- 3197.

Huebner, K.H., Dewhirst, D.L., Smith, D.E. and G.Byrom, T. 2001. The Finite Element Method for Engineers. Wiley Interscience.

Islam, M.M., Zahid, M.A., Jamal, N.B., Parvez, M.R. and Alam, M.S. 2009. Wavelength Dependence of Guiding Properties in Highly Birefringent Elliptical Ring Core Optical Fiber. Journal of electrical engineering. 36, 10-15.

Kawano, K. and Kitoh, T. 2001. Introduction to Optical Waveguide Analysis: Solving Maxwell's Equations. John Wiley and Sons.

Kumar, A. and Varshney, R.K. 1984. Effect of depressed inner cladding on the polarization characteristics of elliptical-core fibers. Optics Letters. 9, 522-524.

Makouei, S. 2013. Characteristics comparison of the ZDSFs based on the triangular graded index and step index single-mode optical fiber. OPTICS COMMUNICATIONS. 291, 202-206.

Makouei, S., Savadi-Oskouei, M. and Rostami, A. 2007. Study of bending loss and mode field diameter in depressed inner core triple-clad single-mode optical fiber. Optics Communications. 280, 58-67.

Okamoto, K. 2006. Fundamentals of Optical Waveguides. Academic Press.

Palodiyaa, V. and K.Raghuwanshib, S. 2015. Design and Parametric Study of Depressed Core Optical Fiber. Procedia Computer Science. 46, 1385–1392.

Prajapatia Y., Jitendra, B.M., Vivek, S., and Sainic, J.P. 2015. Modal Analysis and Dispersion Curves of an Elliptical W-type Single Mode Fiber. Optics and Spectroscopy. 118(5): 821–828.

Prajapatia, Y., Singh, V. and Saini, J.P. 2013. Analysis of dispersion relation of the elliptical dielectric waveguides having M-type refractive index profile. Optik. 124, 1736–1740.

Rahman, B.M.A. 1995. Finite Element Analysis Of Optical Waveguides. Progress in Electromagnetics Research. 10, 187-216.

Rostami, A. and Savadi-Oskouei, M. 2007. Investigation of dispersion characteristic in MI- and MII-type single mode optical fibers. Optics Communications. 271, 413–420.

Savadi Oskouei, M., Makouei, S., Rostami, A. and Koozeh Kanani, Z.D. 2007. Proposal for optical fiber designs with ultrahigh effective area and small bending loss applicable to long haul communications. Optical Society of America. 46(25): 6330-6339.

Wandel, M. and Kristensen, P. 2005. Fiber designs for high figure of merit and high slope dispersion compensating fibers. Opt. Fiber Commun. Rep. 3, 25–60.

Waynant, R.W. and Marwood, N. 2000. Electro-Optics Handbook. McGraw-Hill.

Xuan, H., Ju, J. and Jin, W. 2010. Highly Birefringence Optical Microfibers. Optics Express. 4, 3828-3839.

Yeh, C., Ha, K., Dong, S.B. and Brown, W.P. 1979. Single-mode optical waveguides. Applied Optics. 18, 1490-1504.

Yin, S., Chung, K.W., Liu, H., Kurtz, P. and Reichard, K. 2000. A new design for non-zero dispersion-shifted fiber (NZ-DSF) with a large effective area over 100 mm2 and low bending and splice. Optics Communications. 177, 225–232.

****