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Design of Spectral Filters Based on Linear Polarized Mode Coupling of Optical Fibers

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Abstract*: Design of optical spectral filters based on mode coupling of optical fibers is presented. The finite difference method is applied to evaluate the dispersion characteristics of optical fiber coupler which is constructed from two fibers as a composite multi-dielectric waveguide with different cores but the same cladding. Also, power and field distributions for both fibers as a separate and as a composite waveguide are investigated. The spectral characteristics of the filters are computed depending on the coupling of two linear polarized modes LP01 and LP11. The dependence of the transmission coefficient on operating wavelengths is illustrated. Finally, the spectral bandwidth of filter as a function of the distance between the two cores is addressed.

Keywords: About four key words or phrases in alphabetical order, separated by commas.

I. INTRODUCTION

The rapid increasing demanding for optical communication systems and signal processing pouches to the improvement of all optical fiber spectral filter characteristics. It is one of the most important passive elements for optical communications and passive networks which mostly use wavelength division multiplexing and demultiplexing techniques. It has the advantage to integrate easily with the optical fiber networks. It also provides a low loss coupling due to its fabrication from optical fibers.

Many types of spectral filters are designed and analyzed such as: diffraction grating filters [1-3], Fabry-Perot filters [4-6], Mach-Zehnder interferometer filters [7-9], all fiber filters [9-11] and others. Most of all fiber wavelength selective filters which have been drawn in the published papers consist of similar or dissimilar fibers with different shaping of refractive indices [12-20]. These filters depend on single mode fibers supporting LP01 in their coupling operation at a range of interesting wavelengths.

In this paper, the finite difference method (FDM) is used to find the optical properties of a directional coupler proposed by [21]. The coupler consists of two dissimilar fibers, one fiber has single mode LP01 and the other supports two modes LP01 and LP11. Dispersion characteristics, power and field distributions for both separate fibers are evaluated and, they are also computed for composite modes of multi-dielectric waveguide by applying the FDM of Opti-fiber Software.

Spectral characteristics of the coupler are investigated by using the coupled mode theory of parallel dielectric waveguides.

The paper is organized as: section 2 deals with geometry and method of analysis. Discussion and numerical results are illustrated in section 3. Conclusions of the article are drawn in section 4.

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II. GEOMETRY AND METHOD OF ANALYSIS

A. Geometry

The geometry of the coupler is shown in Figure.1. The geometry consists of two fibers, one supports single mode LP01 called fiber1 and the other has two modes LP01 and LP11 called fiber2 with cladding contains the two cores.

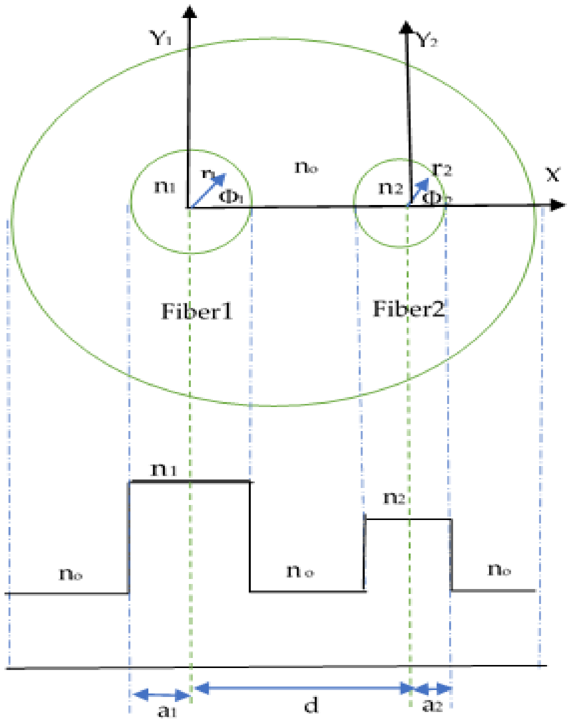

Figure 1: Geometry of the spectral filter.

Where a_1, a_2, and d is core radius of fiber1, core radius of fiber2 and the distance between the two centers of fibers, respectively. The refractive indices n_1 and n_2 represent cores indices of fiber1 and fiber2, respectively. The refractive index of the cladding is represented by n_0.

B. Dispersion Characteristics and Field Distributions

For weakly guiding approxi -mation of optical fiber, the scalar wave analysis can be applied. The scalar wave equation can be defined as [18]:

$$\frac{1}{r}\frac{d}{dr}\left(r\frac{d\varphi}{dr}\right)+\left(k_0^2 n^2-\beta^2-\frac{l^2}{r^2}\right)\varphi=0.0 \qquad (1)$$

where ko is the free-space wave, β is the propagation constants, n is the refractive-index, φ is the transverse field function, and l is the azimuthal mode number for LP_{ln} modes.

FDM of Opti-Fiber Software is used to solve the above equation taking into consideration the boundary conditions of the fields between core and cladding. The solution gives the dispersion characteristics of linear polarized modes LP_{01} and LP_{11} of fiber1 and LP_{01} for fiber2. power distributions of each separate fiber modes LP_{11} for fiber1 and LP_{01} for fiber2 are calculated. Also, power distributions of composite modes for multi-dielectric waveguide are determined.

C. Spectral Characteristics of Optical Filter

The coupling mode equations of the parallel dielectric waveguides are applied to define the coupling coefficients as:

$$k_{12}=\sqrt{\frac{2(n_2^2-n_0^2)}{n_1 n_2}}\,\frac{K_1(w_1 d)}{K_1(W_2)\sqrt{K_0(W_1)K_2(W_1)}}\,.$$

$$\frac{U_1 U_2}{a_1 V_1}\,\frac{1}{U_2^2+w_1^2 a_2^2}\{w_1 a_2 K_0(W_2)I_0(w_1 a_2)+$$

$$W_2 K_1(W_2)I_0(w_1 a_2)\} \qquad (2)$$

$$k_{21}=\sqrt{\frac{2(n_1^2-n_0^2)}{n_1 n_2}}\,\frac{K_1(w_2 d)}{K_1(W_2)\sqrt{K_0(W_1)K_2(W_1)}}\,.$$

$$\frac{U_1 U_2}{a_2 V_2}\,\frac{1}{U_1^2+w_2^2 a_1^2}\{W_1 K_0(W_1)I_1(w_2 a_1)+$$

$$w_2 a_1 K_1(W_1)I_0(w_2 a_1)\} \qquad (3)$$

where:

$$U_1=u_1 a_1=k_0 a_1\sqrt{n_1^2-\frac{\beta_{11}^2}{k_0^2}}$$

$$U_2=u_2 a_2=k_0 a_2\sqrt{n_2^2-\frac{\beta_{01}^2}{k_0^2}}$$

$$W_1=w_1 a_1=k_0 a_1\sqrt{\frac{\beta_{11}^2}{k_0^2}-n_0^2}$$

$$W_2=w_2 a_2=k_0 a_2\sqrt{\frac{\beta_{01}^2}{k_0^2}-n_0^2}$$

$$V_1^2=U_1^2+W_1^2 \text{ and } V_2^2=U_2^2+W_2^2$$

and $k_0=2\pi/\lambda$ is the wavenumber of free space. It can be noted from Eqns.1 and 2 that k_{12} and k_{21} are equal when $n_1 = n_2$ and $a_1 = a_2$. The transmission coefficient T(λ) is defined as the ratio between the power from fiber1 at z=L and the power into fiber2 at z=0.

$$T(\lambda)=\frac{|k_{12}|^2}{|S|^2}\sin^2(SL) \qquad (4)$$

where

$$S=\left[\left\{\frac{\beta_{11}-\beta_{01}}{2}\right\}^2+k_{12}k_{21}\right]^{\frac{1}{2}},$$

The transmission coefficient T(λ) is depend on the wavelength through S. So, the transmission coefficient can be determined for a specific range of wavelengths and parameters of the fiber. Therefore, narrowband and broadband spectral filters can be design by a reasonable selection of these parameters. Also, the coupling length L_c can be defined as:

$$L_c=\frac{\pi}{2S}\bigg|_{\beta_{11}=\beta_{01}}=\frac{\pi}{2\sqrt{k_{12}k_{21}}}, \qquad (5)$$

where β_{11} and β_{01} are propagation constants of LP_{11} and LP_{01} modes, respectively.

III. NUMERICAL RESULTS AND DISCUSSION

The performance of the proposed LP_{01} – LP_{11} fiber coupler for applications in wavelength filtering can be tested through numerical results based on the above formulations. To determine the transmission characteristics, dispersion characteristics of LP_{01} mode for fiber2 and LP_{11} mode for fiber1 are calculated using FDM of Opti-Fiber software. The parameters and material compositions of the used fibers at λ =1.33µm is summarized in Table-I.

Table- I: Parameters and material compositions of optical fibers

Fiber NO.	Core radius(µm)	Δ at λ= 1.33µm	Core material	Cladding material
1	3.4	0.8%	13.5m/o GeO2 86.5m/o SiO2	5.8 m/o GeO2 94.2 m/o SiO2
2	3.1	0.4%	9.1 m/o GeO2 90.9 m/o SiO2	

Fig.2 illustrates the dependence of effective index (β/ko) on wavelength of LP_{01}, LP_{11} for fiber1 and LP_{01} for fiber2.

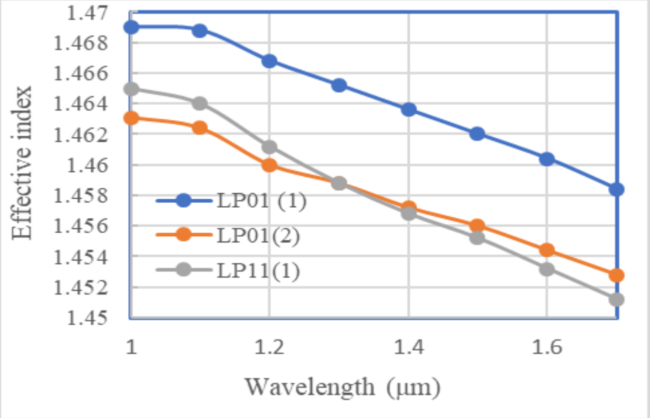

Fig.2. Illustrates the dependence of effective index (β/ko)

on wavelength of LP_{01}, LP_{11} for fiber1 and LP_{01} for fiber2.

Fig..2 shows that, the effective index of LP_{01} mode for fiber2 equals the effective index of LP_{11} modes of fiber1 at λ=1.33µm. This means, the two modes have equal propagation constant and phase matched at λ=1.33µm. It can be shown that, the dispersion characteristic for LP_{01} mode for fiber1 is satisfied fact that LP_{01} mode of the two fibers produce different effective indices and thus do not exchange power.

Distributions of power and field across the cross section of each fiber separately and across the cross section of the filter structure at λ =1.33µm is calculated using FDM of Opti-Fiber Software as in Figs..3, 4, 5, 6 and 7.

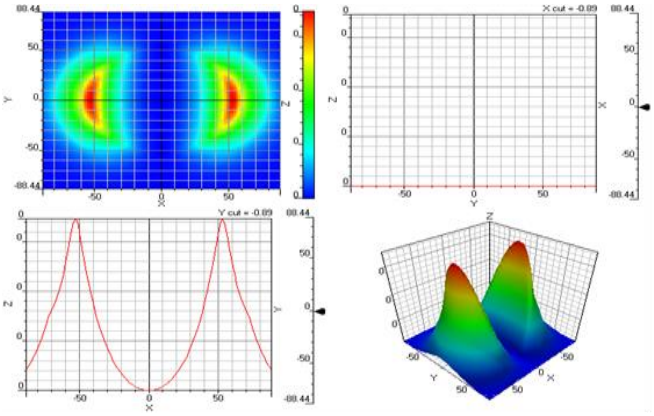

Fig.3 Iillustrates the the power distribution of LP_{11} for fiber1 at λ=1.33µm.

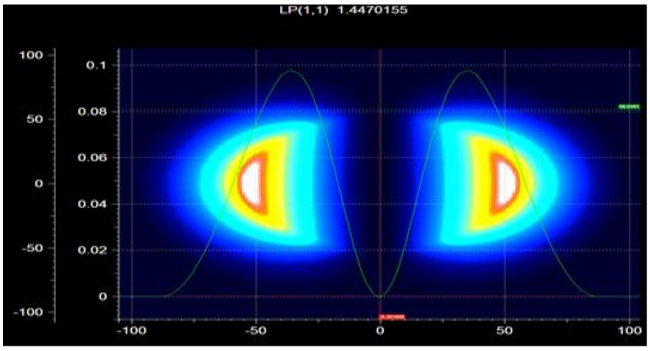

Fig.4 Illustrates the field distribution of LP_{11} for fiber1 at λ =1.33µm.

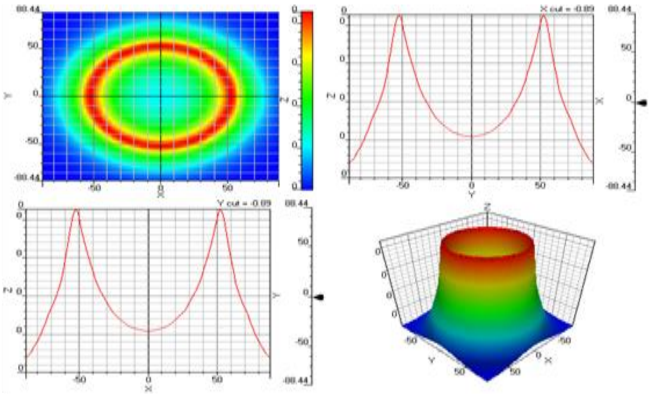

Fig.5 Illustrates the power distribution of LP01 for fiber2 at λ=1.33µm.

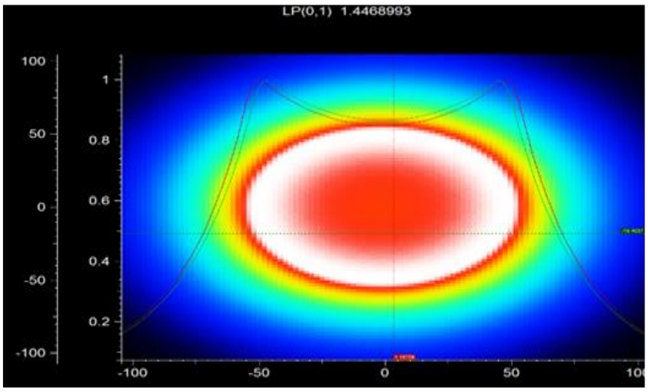

Figure.6 illustrates the field distribution of LP_{01} for fiber2 at λ=1.33µm.

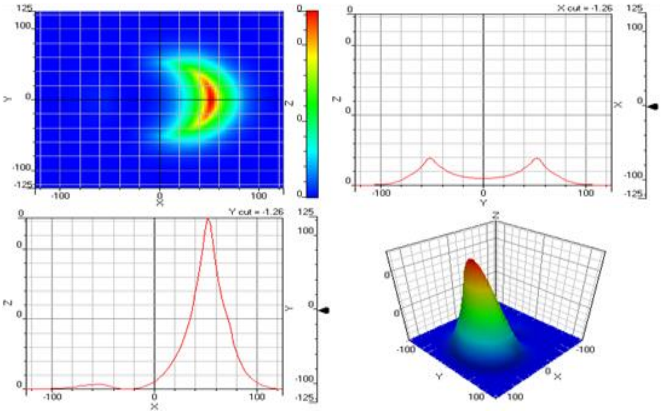

Figure.7 illustrates the power distribution of composite LP_{01} and LP_{11} across filter cross section at λ =1.33µm.

Fig.8 illustrate the dependence of the spectral width of 1.33 µm spectral filter on the separation distance d between the centers of each core centers. The spectral width of the filter is defined as the difference in slop between the dispersion characteristics of the interaction modes as well as the core separation d. When the slope difference is increased the spectral width is decreased. Also, increasing in the separation distance d, produces a decreasing in spectral width.

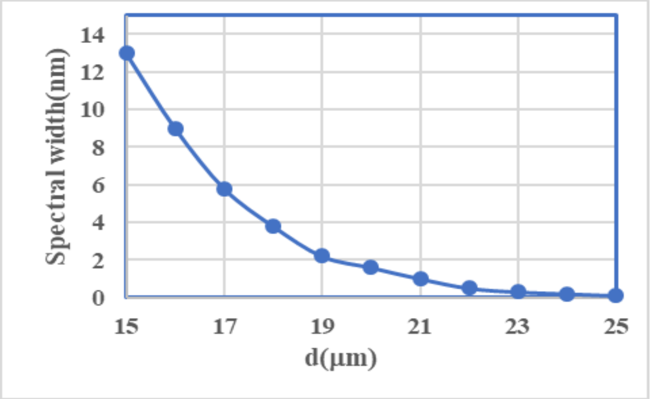

Fig.8 Illustrates the dependence of the spectral width on the separation distance d.

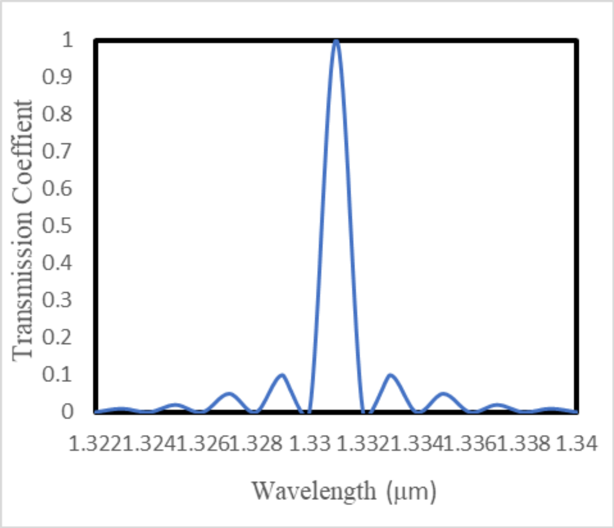

Fig.9 illustrates the dependence of the transmission coefficient on the wavelength

IV. CONCLUSION

The coupled mode theory is applied to investigate the coupling properties of the two-fiber coupler based on the coupling between LP01 and LP11 modes. The coupler cross section is considered as a multi-dielectric waveguide for evaluating the dispersion characteristics, power and field distributions. The FDM of Opti-Fiber Software is applied for solving the scalar wave equation. With selection of appropriate parameters, the coupler can be designed to either narrowband or broadband spectral filter. Design information and transmission characteristics for filter with maximum matching at λ=1.33µm which is widely used in optical fiber communications were calculated. This type of spectral filter has the advantage that it can be easily fabricated, and the loss of connections is very low.

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