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Effect of Temperature and Material Dispersion on the Performance of Single Mode Optical Fibers Directional Coupler

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Abstract- The performance of optical fiber directional coupler depends upon the material dispersion and the change of temperature. Usually, the directional coupler is designed by assuming that it is used with a specific temperature such as 300ºK and a specific wavelength such as 1.55µm. The directional coupler is used with different wavelengths and temperatures than that the specific values. Therefore, with neglect the effect of temperature and change of operating wavelength there are errors in the performance of directional coupler as a power divider (error of output powers), power combiner (error of output powers) and as a bandpass filter (error of passband wavelengths).

The propagation constants of the two fibers and the coupling coefficient between the two fibers are functions of the operating temperature and operating wavelength.

The errors for as a power divider (as a combiner) are greater than the error for as a bandpass filter.

As the germania ratio increases, the error value increases. Also as the absolute value of the difference between the wavelength and the reference wavelength increases, the error becomes more. Also, this occurs with the temperature. While as the coupler length (L) increases, the error of output power either increases or decreases.

These errors can be minimized at certain operating and structure parameters of the optical fiber directional coupler.

Key words: *Directional Coupler, coupled mode theory, power divider, bandpass filter, material dispersion*

I. INTRODUCTION

The directional coupler is one of the most important component in integrated optic devices [1-4] and their applications still in the new researches [1,3,5]. It consists of two adjacent fibers (waveguides) which separated by very small distance (Fig.1). It has several applications such as power divider , power combiner and bandpass filter.

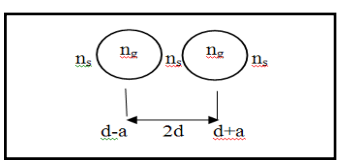


Fig.1 Cross section of two symmetrical optical fibers directional coupler

The refractive indices of the two fibers of the directional coupler are functions of wavelength (λ) , temperature (T) [6] and germania ratio ,x, (ratio of germania, GeO_2, doped to the silica in the core of fiber) [7]. As the temperature (T ºK) increases, both the core refractive index (silica doped germania, n_g) and clad refractive index (pure silica, n_s) are increased. While both n_g and n_s are lowered with wavelength (λ µm). As the germania ratio, x, increases, the refractive index of core increases.

The propagation constants of the two single mode fibers (β_1 and β_2) are determined by using the empirical equation with normalized frequency (V= 1.5 to 2.4) [8,9]. The values of β_1 and β_2 are functions of T and λ.

The coupling coefficient (C) is evaluated by using the coupled mode theory (CMT) [10-12]. In this method the two fibers directional coupler are treated as a two individual waveguides. A general formula for the coupling coefficient is done. The value of C depends strongly on both the wavelength (λ) and the refractive indices of the two fibers. So, C depends upon material dispersion (MD) [13] and temperature (T).

As the wavelength increases, the coupling coefficient (C) increases but the propagation constant (β) decreases, while vice versa with the effect of temperature.

The input optical power to the directional coupler (P_{i1}) transfers between the two fibers of the directional coupler (P_{o1} and P_{o2}). The values of P_{o1} and P_{o2} are functions of C and $\Delta\beta$ (where $\Delta\beta = \beta_1-\beta_2$), also on the length of coupler (L). Therefore, P_{o1} and P_{o2} are functions of λ and T. In case of $\beta_1=\beta_2$, the input power can be completely transferred from one fiber to another and the output power affects by C and L only.

The performance of optical directional coupler has an error, if the refractive indices of the fibers are considered constant value (which evaluated at reference wavelength, λ_r =1.55μm and reference temperature, T_r=300°K) without material dispersion and change of temperature.

The directional coupler can be used as multi windows bandpass filter or reject band filter according to the coupler length

In this study,
The effects of T, MD, x and L on the performance of directional coupler as a power divider and as a bandpass filter are studied with and without the effect of material dispersion and change of temperature.
With neglect the effect of material dispersion and change of temperature, there is a weak error in coupling coefficient (R_C). This error increases with large values of $|\lambda-\lambda_r|$ and $|T-T_r|$. But the error in propagation constant (R_β) is very weak.
The simulation results showed that negligence of the effect of both dispersion and temperature occur very little error at certaines values.
To confirm this concept, a numerical example of two single mode optical fibers directional coupler is studied. The coupler consists of, two symmetrical fibers with core radius (a = 4μm), central to central cores distance (d=10μm), the core material from silica doped germania (with germania ratio, x= 0.025), clad material from pure silica and the coupler length L= 500μm.

II. MATHEMATICAL ANALYSIS

II.1. Refractive index, normalized frequency , radius of fiber and coupling coefficient

II.1.1 Refractive indices (n_g and n_s), material dispersion (MD) and normalized frequency (V)
Effect of temperature (T), germania ratio (x) and wavelength (λ) on the refractive indices of core (silica doped germania, n_g) and clad (pure silica, n_s) of fiber are defined as [6];

$$n_g^2 = 1 + \frac{a_{1xt}\lambda^2}{(\lambda^2-b_{1xt}^2)} + \frac{a_{2xt}\lambda^2}{(\lambda^2-b_{2xt}^2)} + \frac{a_{3xt}\lambda^2}{(\lambda^2-b_{3xt}^2)} \tag{1.a}$$

$$n_s^2 = 1 + \frac{a_{1t}\lambda^2}{(\lambda^2-b_{1t}^2)} + \frac{a_{2t}\lambda^2}{(\lambda^2-b_{2t}^2)} + \frac{a_{3t}\lambda^2}{(\lambda^2-b_{3t}^2)} \tag{1.b}$$

where;
$a_{1xt} = (a_{10}+u_1x)\, f_{t1}$, $a_{2xt} = (a_{20}+u_2\, x)\, f_{t1}$, $a_{3xt} = (a_{30}+u_3\, x)\, f_{t1}$, $b_{1xt} = (b_{10}+v_1\, x)\, f_{t2}$,
$b_{2xt} = (b_{20}+v_2\, x)\, f_{t2}$, $b_{3xt} = (b_{30}+v_3\, x)\, f_{t2}$, a_{10}=0.6961663 , a_{20}=0.4079426 , a_{30}=0.8974794,
b_{10}=0.0684043 , b_{20}=0.1162414 , b_{30}=9.8961610 , u_1= 0.1107001 , u_2= 0.31021588,
u_3= -0.04331091 , v_1= 0.000568306 , v_2= 0.03772465 , v_3= 1.94577 , $f_{t1} = e_1+e_2T$,
$f_{t2} = T_0/T$, e_1=0.93721 , e_2=0.0002143 , T_0=293 °K,
a_{1t} , a_{2t} , a_{t3} , b_{1t} , b_{2t} and b_{3t} are defined by putting the value of x=0 through the parameters a_{1xt} , a_{2xt} , a_{3xt}, b_{1xt}, b_{2xt} and b_{3xt} respectively. wavelength (λ μm) and temperature (T °K).
Note that, the values of a_{1xt} , a_{2xt} , a_{3xt} , b_{1xt} , b_{2xt} and b_{3xt} (with x=0 and $f_{t1}=f_{t2}=1$) are defined at temperature T=293 °K [14] and so, the best reference temperature T_0=293 ^{0}K.

The refractive indices of core (n_g) and clad (n_s) materials are increase with both temperature (T) and germania ratio (x) while they are decrease with wavelength (λ μm) (Fig.2). Therefore, material dispersion {MD = $(-\lambda/v)(d^2n_{g,s}/d\lambda^2)$, v is the speed of light} must be taken at the design of directional coupler.
The normalized frequency (V) is defined in below (Eq.3). As λ increases , the value of V decreases, while vice versa for T and x (Fig.3).

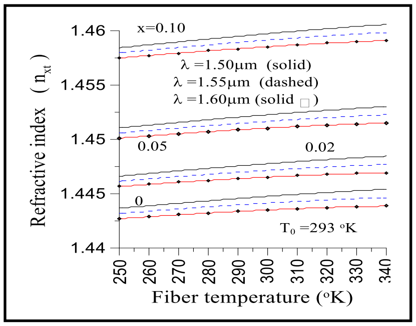


Fig.2 Effect of both T, x and λ on both n_g and n_s

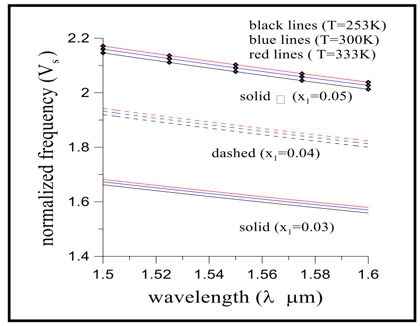


Fig.3 Effect of both T, x and λ on V (with a=3.5μm)

II.1.2 Limits of fiber core radius (a) and germania ratio (x) for single mode fiber.

For single mode optical fiber with normalized frequency (V ranges between 1.5 and 2.4) and with λ=1.5 to16μm, T= 253 to 333°K and the G_eO_2 ratio, x=2.5 to 4.0% , the corresponding value of core radius a= 3.69 to 4.37μm (We take a=4μm).

II.1.3 Coupling coefficient

The coupling coefficient (C) of two symmetric single mode fibers directional coupler is derived by using coupled mode theory (CMT) [10-12] as;

$$C = \lambda \frac{1-b}{2\pi a^2 N} \frac{K_0(V\sqrt{b}\ d_1)}{K_1^2(V\sqrt{b})} \tag{2}$$

Where,

d_1=d/a, a is the fiber core radius, d is the distance between two centers and V is the normalized frequency,

$$V = \frac{2\pi}{\lambda}\,(n_g^2 - n_s^2)^{0.5} \tag{3}$$

b is the normalized propagation constant,

$$b = (N^2 - n_s^2)/(n_g^2 - n_s^2) \tag{4}$$

N is the effective refractive index of fiber, propagation constant $\beta = 2\pi\, N/\lambda$ (5)

n_g is the core refractive index and n_s is the clad refractive index

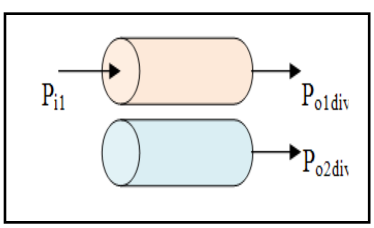
λ is the operating wavelength , K_o and K_1 are the Bessel functions.

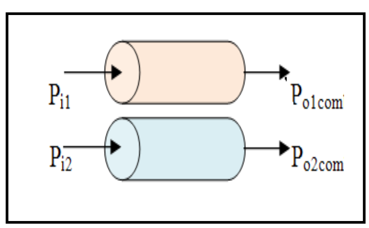
The coupling coefficient C has a peak value at main value of normalized frequency (V_{pc}) which affected by the values of T and λ. The value of C either increases or decreases with temperature T and λ according to the value of $V < V_{pc}$ or $V > V_{pc}$.

II.2 Applications of directional coupler

II.2.1 Directional coupler as a power divider

The input optical power (P_i) through fiber 1 is divided into output power from fiber 1 ($P_{o1\ div}$) and output power from fiber 2 ($P_{o2\ div}$) (Fig.4).





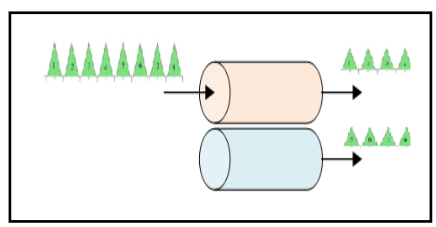


Fig.4 directional coupler as a divider Fig.5 directional coupler as a combiner Fig.6 directional coupler as a bandpass filter

And with lossless symmetric fibers ($\Delta\beta = \beta_1 - \beta_2 = 0$) $P_{o1\ div}$ and $P_{o2\ div}$ are defined as [15];

$$P_{o2\ div} = P_i\, sin^2(C\ \ L) \tag{6.a}$$

$$P_{o1\ div} = P_i\, cos^2(C\ \ L) \tag{6.b}$$

Where, L is the coupler length

The effect of both temperature (T) and material dispersion (MD) on the output powers ($P_{o1\ div}$ and $P_{o2\ div}$) is evident through C.

II.2.2 Directional coupler as a combiner

The two input optical powers, through fiber 1 (P_{i1}) and through fiber 2 (P_{i2}) are combined and the output power from fiber 1 ($P_{o1\ comb}$) or output power from fiber 2 ($P_{o2\ comb}$) (Fig.5).

And with lossless symmetric fibers ($\Delta\beta = \beta_1 - \beta_2 = 0$) $P_{o1\ comb}$ and $P_{o2\ comb}$ are defined by using coupled wave equations [10,16] as;

$$P_{01\ comb} = P_{i1}\ cos^2(C\ L) + P_{i2}\ sin^2(C\ L) \quad (7.a)$$

$$P_{02\ comb} = P_{i1}\ sin^2(C\ L) + P_{i2}\ cos^2(C\ L) \quad (7.b)$$

Where, L is the coupler length

Also, as in case of directional coupler as a divider, the effect of both T and MD on the output powers (P_{o1} and P_{o2}) is evident through C.

II.2.3 Directional coupler as a bandpass filter

The output powers (P_{o1} and P_{o2}) are functions of C, so they are functions of λ to degree it acts as a bandpass filter (Fig.6).

The value of bandpass wavelengths (Δλ) is defined as [17,18];

$$\Delta\lambda = 2.5 / \left\{ L \left| \frac{dC}{d\lambda} \right| \right\} \quad (8)$$

Where, L is the directional coupler length
The effect of both temperature and material dispersion on Δλ is evident through dC/dλ.

II.3 Errors due to neglect the effect of either T or MD or both T and MD

$\beta_{r\ MD}$, $C_{r\ MD}$, $P_{2div\ r\ MD}$, $P_{2comb\ r\ MD}$ and $\Delta\lambda_{r\ MD}$ are the values of β , C , $P_{o2\ div}$, $P_{o2\ comb}$ and Δλ with n_g and n_s at λ_r =1.55µn.
$\beta_{r\ T}$, $C_{r\ T}$, $P_{2div\ r\ T}$, $P_{2comb\ r\ T}$ and $\Delta\lambda_{r\ T}$ are the values of β , C , $P_{o2\ div}$, $P_{o2\ comb}$ and Δλ with n_g and n_s at T_r =300°K .
$\beta_{r\ T\ MD}$, $C_{r\ T\ MD}$, $P_{2div\ r\ T\ MD}$, $P_{2comb\ r\ T\ MD}$ and $\Delta\lambda_{r\ T\ MD}$ are the values of β , C , $P_{o2\ div}$, $P_{o2\ comb}$ and Δλ with n_g and n_s at λ_r =1.55µn and T_r =300°K .

II.3.1 Error due to neglect the material dispersion (i.e. refractive index evaluated at λ_r =1.55µm) are;

$$R_{\beta\ MD}\ \% = 100\ \frac{\beta \text{ at any } \lambda - \beta_{r\ MD}}{\beta \text{ at any } \lambda} \quad (9.a)$$

$$R_{C\ MD}\ \% = 100\ \frac{C \text{ at any } \lambda - C_{r\ MD}}{C \text{ at any } \lambda} \quad (9.b)$$

$$R_{P2\ div\ MD}\ \% = \frac{P_{2div \text{ at any } \lambda} - P_{2div\ rMD}}{P_{2div} \text{ at any } \lambda} \quad (9.c)$$

$$R_{P2comb\ MD}\ \% = 100\ \frac{P_{2comb} \text{ at any } \lambda - P_{2comb\ r\ MD}}{P_{2comb} \text{ at any } \lambda} \quad (9.d)$$

$$R_{\Delta\lambda\ MD}\ \% = 100\ \frac{\Delta\lambda \text{ at any } \lambda - \Delta\lambda_{r\ MD}}{\Delta\lambda \text{ at any } \lambda} \quad (9.e)$$

II.3.2 Error due to neglect the effect of varying temperature from (T_r=300°K) are;

$$R_{\beta\ T}\ \% = \frac{\beta \text{ at any } T - \beta_{r\ T}}{\beta \text{ at any } T} \quad (10.a)$$

$$R_{C\ T}\ \% = 100\ \frac{C \text{ at any } T - C_{r\ T}}{C \text{ at any } T} \quad (10.b)$$

$$R_{P2div\ T}\ \% = 100\ \frac{P_{2div} \text{ at any } T - P_{2div\ r\ T}}{P_{2div} \text{ at any } T} \quad (10.c)$$

$$R_{P2comb\ T}\ \%\ 100\ \frac{P_2 \text{ at any } T - P_{2comb\ r\ T}}{P_2 \text{ at any } T} \quad (10.d)$$

$$R_{\Delta\lambda\ T}\ \% = 100\ \frac{\Delta\lambda \text{ at any } T - \Delta\lambda_{r\ T}}{\Delta\lambda \text{ at any } T} \quad (10.e)$$

II.3.3 Error due to neglect both MD ($\lambda \neq \lambda_r$) and T ($T \neq T_r$) are;

$$R_{\beta\ T\ MD}\ \% = 100\ \frac{\beta \text{ at any } \lambda, T - \beta_{r\ T\ MD}}{\beta \text{ at any } \lambda, T} \quad (11.a)$$

$$R_{C\ T\ MD}\ \% = 100\ 100\ \frac{C \text{ at any } \lambda, T - C_{r\ T\ MD}}{C \text{ at any } \lambda, T} \quad (11.b)$$

$$R_{P2div\ T\ MD}\ \% = 100\ \frac{P_{2div} \text{ at any } \lambda, T - P_{2div\ r\ T\ MD}}{P_{2div} \text{ at any } \lambda, T} \quad (11.c)$$

$$R_{P2comb\ T\ MD}\ \% = 100\ \frac{P_{2comb} \text{ at any } \lambda, T - P_{2comb\ r\ T\ MD}}{P_{2comb} \text{ at any } \lambda, T} \quad (11.d)$$

$$R_{\Delta\lambda\ T\ MD}\ \% = 100\ \frac{\Delta\lambda \text{ at any } \lambda, T - \Delta\lambda_{r\ T\ MD}}{\Delta\lambda \text{ at any } \lambda, T} \quad (11.e)$$

III. SIMULATION RESULTS and DISCUSSIONS

From (Fig.7.a), as the temperature increases, C decreases with λ=1.50 and 1.55μm (where $V > V_{pc}$) while C increases with λ = 1.6μm (where $V < V_{pc}$). From (Fig.7.b), the percentage error of the coupling coefficient (R_C) due to varying temperature from 300ºK, increases with ΔT { ΔT_{300} = abs(T-300)} and maximum percentage error ($R_{C\ max}$) = 3.3459 at T=252ºK with λ=1.50μm.

For the two optical fiber directional coupler with $\beta_1 = \beta_2$, the output power ($P_{o2\ div}$) depends upon the value of C and the coupler length (L). P_{o2div} depends upon both T and λ (Fig.7.c). Maximum percentage error of $P_{o2\ div}$ ($R_{P2\ max}$) is 5.9328 occurs at T=252 and λ=1.50μm (Fig.7.d).

The passband wavelength (Δλ) decreases with λ and T (Fig.7.e) and the percentage error of passband wavelength ($R_{\Delta\lambda}$) increases with λ {maximum percentage error, for T=252 ºK, $R_{\Delta\lambda max}$ = 1.1254 (at λ= 1.50μm) , 0.2213 (at λ=1.55μm) and 0.2275 (at λ= 1.60μm) } (Fig.7.f).

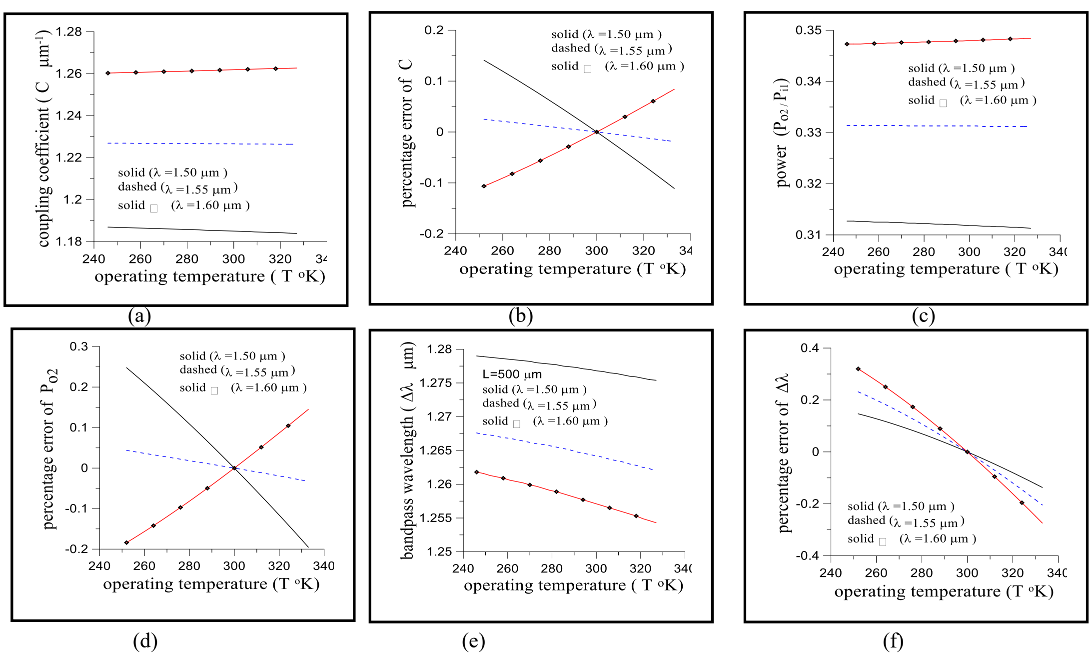


Fig.7 Effect of temperature (T) on the performance of directional coupler
(with L=500μm, a=4μm, d=10μm, x=0.025) with material dispersion

As expected, coupling coefficient increases with λ (Fig.8.a) where $V < V_p$, dependence of C on T weakly. The corresponding percentage error (R_C) due to neglect the material dispersion of core and clad materials of fiber ($R_{C\lambda 1.55}$) increases with the value of {abs(λ-1.55)} (Fig.8.a and Fig.8.b).

The error due to neglect the effect of temperature (T≠ Tr =300°K) and neglect the material dispersion (refractive index evaluated at $\lambda=\lambda_r$ = 1.55μm only) increases with λ for R_c , R_{P2} and $R_{\Delta\lambda}$ (Fig.8). The value of Δλ decreases with both λ and T (Fig.8.e)

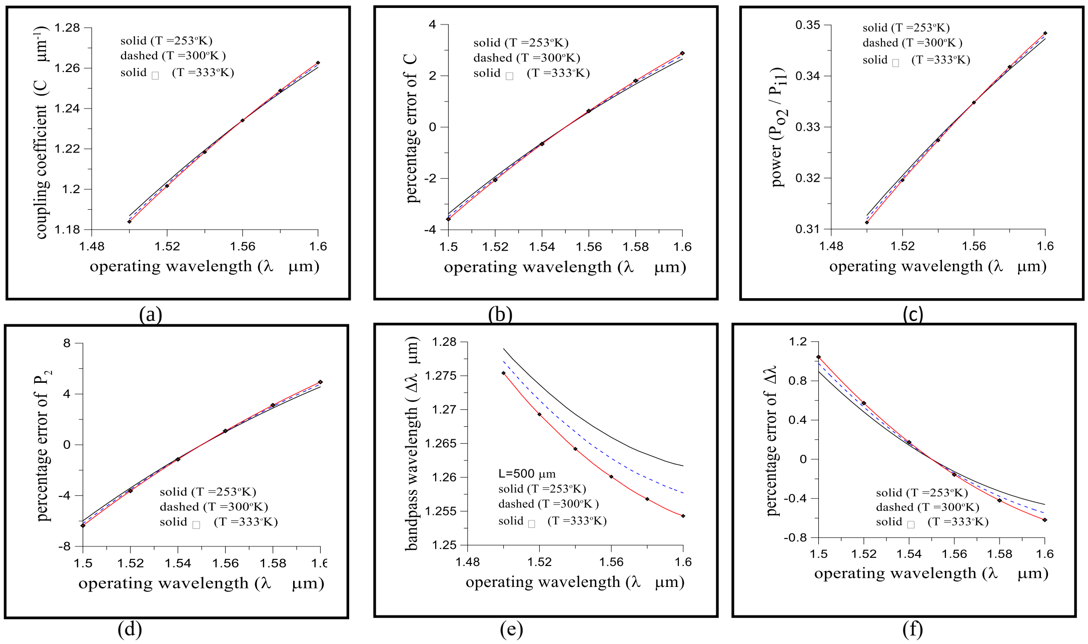


Fig.8 Effect of neglect material dispersion on the performance of directional coupler
(with L=500μm, a=4μm, d=10μm , x=0.025)

Coupling coefficient decreases with germania ratio (x) (Fig.9.a) (because core refractive index increases and so C decreases) the value of R_C increases with x (Fig.9.b). With directional coupler length L=0.5 mm, the output power $P_{o2\ div}$ decreases with x. Also Δλ decreases with x and λ (Fig.9.e)
The values of C , $P_{o2\ div}$ and Δλ are decreased with x and T (Figs.10.a, 10.c and 10.e) and vice versa for R_c and $R_{p2\ div}$ (Figs.10.b and 10.d).

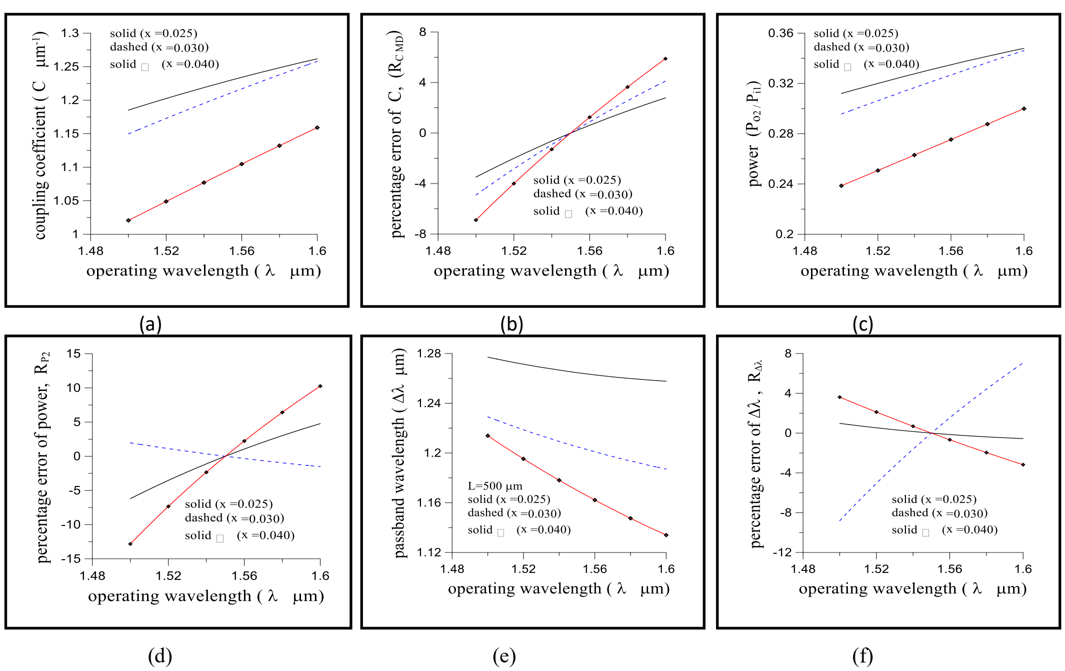


Fig.9: Effect of GeO_2 ratio (x) and λ on the performance of directional coupler
(with T=300 °K ,L=500μm, a=4μm, d=10μm)

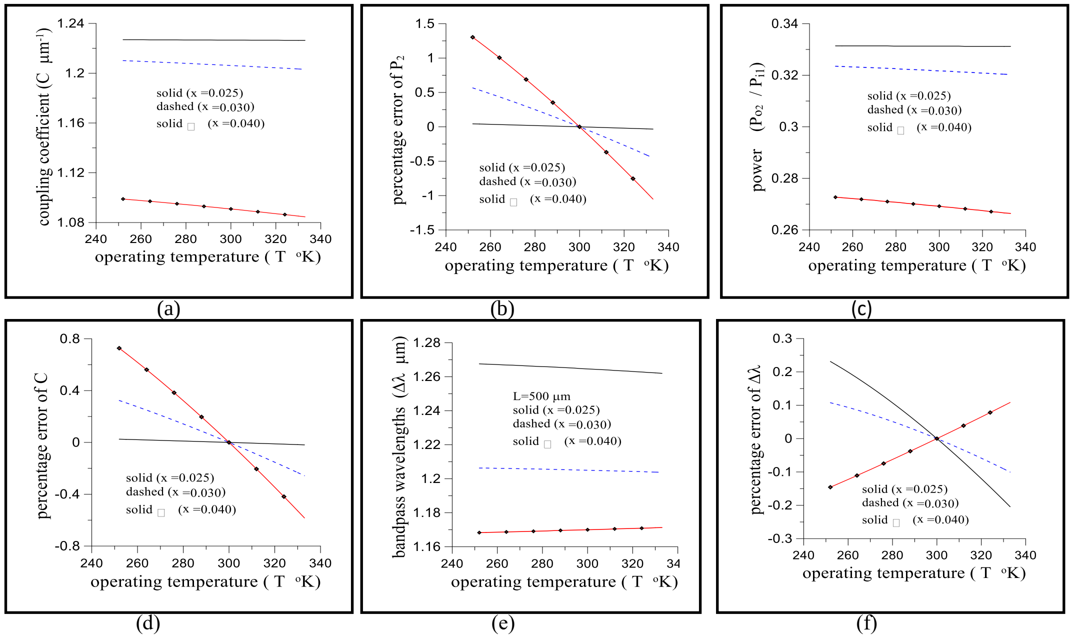


Fig.10: Effect of GeO_2 ratio (x) and temperature (T) on the performance of the directional coupler (with λ=1.55µm , L=500µm, a=4µm, d=10µm)

As the difference ($T-T_r$) increases, the percentage error of propagation constant ($R_{\beta\, T\lambda}$) becomes evident increases, while the error due to ignore the material dispersion is little (Fig.11.a).

Percentage error of C (R_C) increases with abs ($\lambda-\lambda_r$) with speed rate, while the effect of T very little (Fig.11.b). Percentage error of $P_{o2\ div}$ (R_{P2}, Fig.11.c) similar with error of C (Fig.11.b).

But the percentage error of Δλ (Fig.11.d) either increases or decreases with T and λ due to the Δλ in relation with dC/dλ.

As the germania ratio increases, the error increases (Figs.11 and 12). Such as percentage error of $P_{o2\ div}$ ($R_{P2\ div}$) increases from 4.6 (with x=0.025) to 11.32 (with x=0.04).

The percentage error of the output power ($R_{P2\ div}$) either increases or decreases with the coupler length (L) (Fig.13). The temperature dependence of R_{P2} very little, while the wavelength dependence of $R_{P2\ div}$ increases with absolute ($\lambda-\lambda_r$) increases with temperature

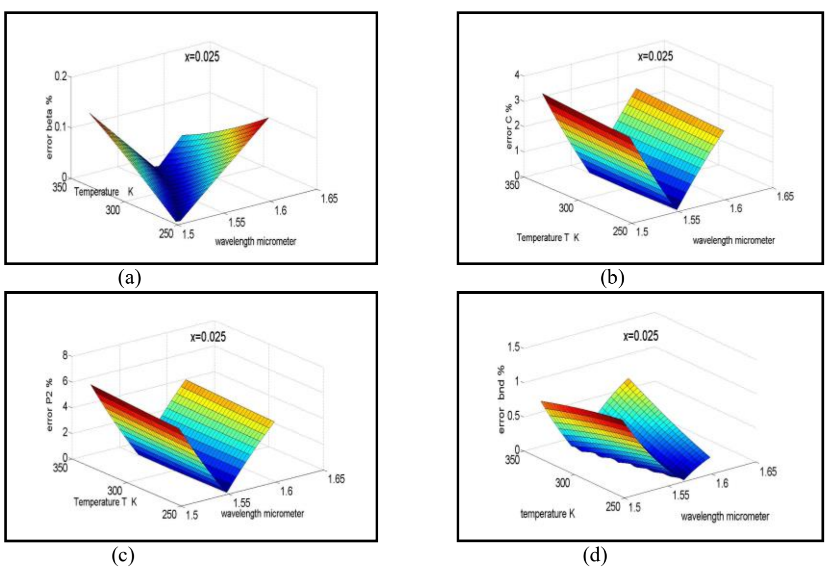
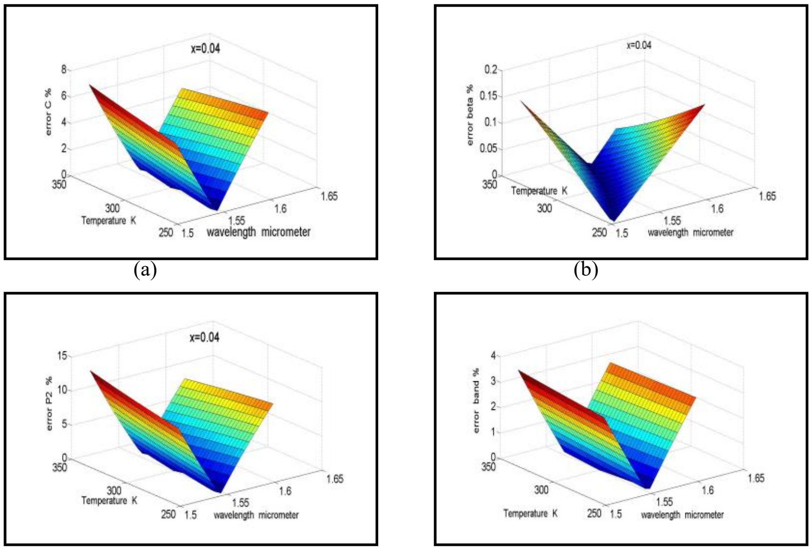


Fig.11: Percentage errors of propagation constant (R_β), coupling coefficient (R_C), output power (R_{P2div}) and bandwidth ($R_{\Delta\lambda}$) due to neglect both MD and T. With x=0.025, L=500µm, a=4µm, and d=10µm. (T_r=300°K and λ_r=1.55µm).



(a) (b)

(c) (d)

Fig.12: Percentage errors of propagation constant (R_β), coupling coefficient (R_C), output power ($R_{P2\ div}$) and bandwidth ($R_{\Delta\lambda}$) due to neglect both MD and T. With x=0.04 , L=500µm, a=4µm , and d=10µm (T_r =300°K and λr=1.55µm).

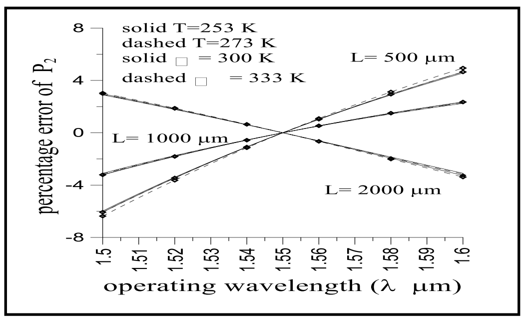
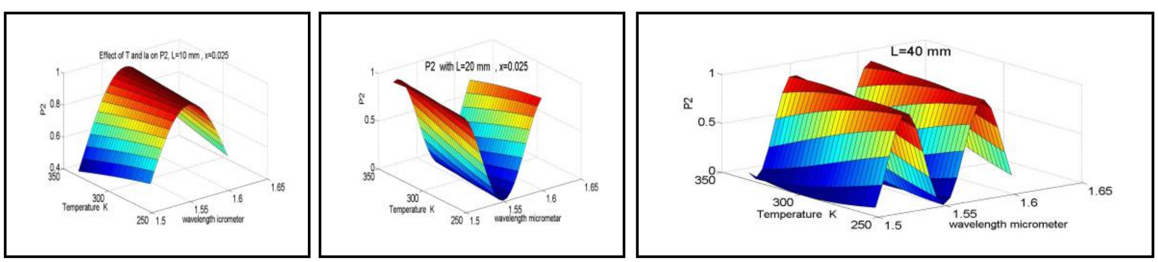


Fig.13 Effect of coupler length (L) on the percentage error of P_2 ($R_{P2\ div}$)

From Fig.14.a, the value of bandpass (Δλ) decreases with T, where the value of $P_{o2\ div}$ increases with T. With different L, the directional coupler can acts as band rejected (Fig.14.b) or multi passbands (Fig.14.c)

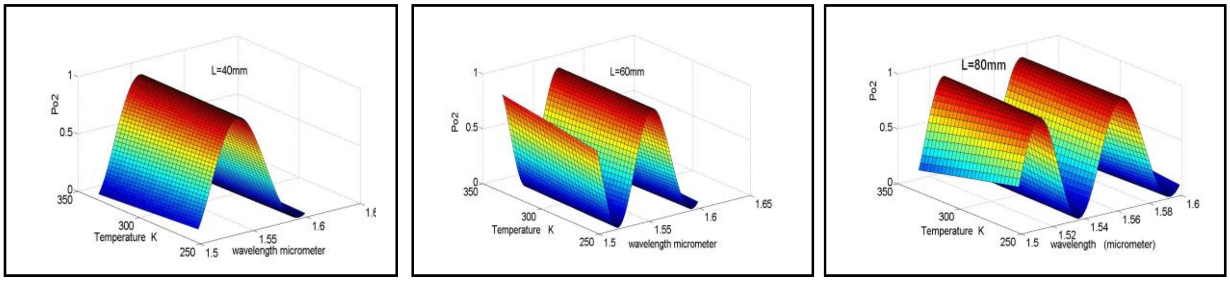


a) L=20 mm b) L=10 mm c) L=40 mm

Fig.14 Effect of T on the performance of directional coupler as a bandpass filter with different coupler length L (With x=0.025 , a=4µm , and d=10µm)

As expected the number of bandpass windows increases with the coupler length (Fig.15)

The passband (Δλ) decreases with T (Table.1). The peak of $P_{o2\ div}$ crawls toward the high wavelength Table (1). The number of passband windows and the rejected widow depend upon the coupler length (Figs.10 and 11). The values of passband ($\Delta\lambda_P$) and rejected band ($\Delta\lambda_R$) are decreased with increasing the operating temperature Table (2).



(a) L=20 mm b) L=40 mm c) L=80 mm

Fig.15 Effect of L on the performance of directional coupler as a bandpass filter with different coupler length L (With x=0.025 , a=4μm , and d=10μm)

Table 1: Effect of temperature on the band wavelengths of the directional coupler as a bandpass filter

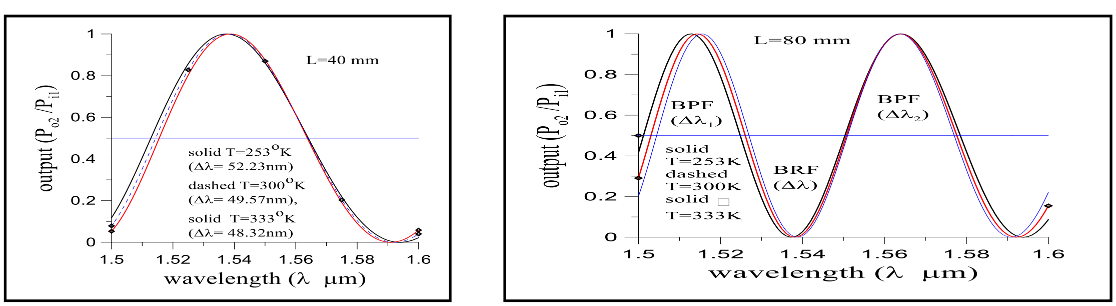
(a=4μm, d=10μm, L=40mm, x=2.5%) as shown in Fig.16.a

T °K	λ_{h1} (P=1/2 P_{max}) nm	λ_{h1} (P =P_{max}) nm	λ_{h1} (P=1/2P_{max}) nm	Δλ nm
253	1512.83	1537.30	1564.06	52.23
273	1513.44	1537.70	1563.99	50.55
300	1514.33	1538.20	1563.90	49.57
333	1515.53	1538.80	1563.84	48.31

Table 2: Effect of temperature on the band wavelengths of the directional coupler as a bandpass filter (a=4μm, d=10μm, L=80mm, x=2.5%) (Fig.10.b)

		T	253	273	300	333
		$\Delta\lambda_{F1}$	23.61	23.38	23.01	22.53
		$\Delta\lambda_{R}$	25.51	25.21	24.70	24.06
		$\Delta\lambda_{F2}$	28.18	27.63	26.90	26.00
BPF1 ($\Delta\lambda_{F1}$)		λ_{HL1}	1501.23	1501.96	1503.05	1504.44
		λ_{F1}	1512.85	1513.45	1514.35	1515.55
	BRF ($\Delta\lambda_{R}$)	λ_{HH1} , λ_{HLR}	1524.84	1525.34	1526.06	1526.97
		$\lambda_{R\ 1}$	1537.35	1527.65	1538.15	1538.75
BPF2 ($\Delta\lambda_{F2}$)		λ_{HHR}, λ_{HL2}	1550.35	1550.55	1550.76	1551.03
		λ_{F1}	1564.15	1564.05	1563.95	1563.75
		λ_{HH2}	1578.53	1578.18	1577.66	1577.03

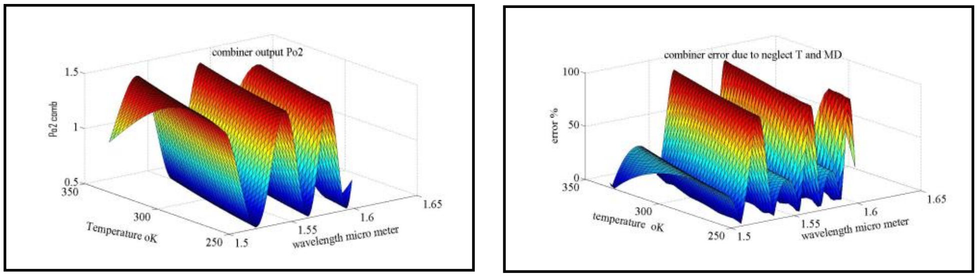
From (Fig.16.a), the value of bandpass (Δλ) decreases with T (Fig.8.a, Fig.11.a), where the value of P_2 increases with T. With different L, the directional coupler can acts as band rejected (Fig.16.b) or multi passbands (Fig.15.c, Fig.16.b).



a) bandpass wavelengths with L=40mm b) bandpass and band rejected wavelengths with L=80mm

Fig.16 Effect of temperature on the passband wavelengths and rejected wavelengths of the directional coupler as a bandpass filter

The combiner output is periodically with wavelength and increases with temperature (Fig.17.a)
The error due to neglect change of temperature increases with ΔT (Fig.17.b) but error increases or decreases with λ



a) combiner output b) error in combiner due to T and λ

Fig.17 Directional coupler as a combiner (P_{i1}=0.5 , P_{i2}=1.5) , L= 30mm

IV. CONCLUSION

The performance of optical directional coupler depends upon both the material dispersion (MD) of fiber and the change of temperature (ΔT). The error due to neglect MD increases with the absolute difference between the operating wavelength (λ) and the reference wavelength (λ_r = 1.55µm). Also the error due to neglect ΔT increases with the difference between the operating temperature (T) and the reference temperature (T_r =300^{o}K).

The error of propagation constant of the fiber (β) is very little. But the error of the coupling coefficient between two fibers (C) becomes evident. While the errors of output power for divider ($P_{o2\ div}$) and for combiner ($P_{o2\ comb}$) also the error of passband (Δλ) of the bandpass filter are varying periodically from small to large and vice versa according to the coupler length (L) and the wavelength (λ).

The error becomes more with the ratio of GeO_2 in the fiber core. At T=300^{o}K, the error of P_{o2} with x=4% becomes 30 times of error with x=2.5%. Also, at T=333^{o}K, the error of Δλ with x=4% becomes 14 times of error with x=2.5%.

The errors can be minimized by use certain operating and structure parameters of the directional coupler.

The effect of T and DM must be taken into account when using the directional coupler.

V. REFERENCES

[1] Rongqing Hui*," Fiber Directional Coupler,"* ScienceDirect , Copyright © 2022 Elsevier B.V. or its licensors or contributors. ScienceDirect ® is a registered trademark of Elsevier B.V. Copyright © (2022). https://www.sciencedirect.com/topics/engineering/fiber-directional-coupler (It was read on Monday, 23 May 2022 at 10 pm)

[2] Rongqing HuiMaurice O' Sullivan ," Fiber Optic Measurement Techniques : Chapter 3 - Characterization of Optical Devices,", (2009), pp.259-363. https://www.sciencedirect.com/science/article/pii/B9780123738653000033 (It was read on Monday, 24 Oct. 2021 at 10 pm)

[3] J. P. George, N. Dasgupta, and B. K. Das ," Compact Integrated Optical Directional Coupler with Large Cross Section Silicon Waveguides ," ResearchGate , Article *in* Proceedings of SPIE - The International Society for Optical Engineering · April (2010) ,
Downloaded From:
http://proceedings.spiedigitallibrary.org/ on 07/08/2015 Terms of Use: http://spiedl.org/terms, (2015).

[4] Chin-Lin Chen, "Optical Directional Couplers and their Applications," December (2005).

[5] XI Chen, Rui-Dan Wen, and Shuo-Yen Tseng,"Analysis of Optical Directional Couplers Using Shortcuts to Adiabaticity", Optics Express 18322, Vol. 24, No. 16, Aug (2016), pp.1:10.

[6] Mahmoud I. Abd-Alla and Fatma M. Aref M. Houssien," Improvement of the Performance of Advanced Local Area Optical Communication Networks by Reduction the Effects of the Propagation Problems", International Journal of Computer Science a nd Information Technologies (IJCSIT), USA, Vol. 1 , No.3, (2010), pp. 147-157.

[7] Volkmar Brückner, " To the Use of Sellmeier Formula," Article · May (2014). https://www.researchgate.net/publication/262294649

[8]https://www.fiberoptics4sale.com/blogs/archive-posts/95048070-basic-optics-for-optical-fiber (It was read on Monday, 23 May 2022 at 10 pm)

[9] Ajoy Chatak, "Optics," MC Graw Hill company Limited, 4th Edition.(2008), pp.25.6.

[10] DIETRICH Marcuse, " Theory of dielectric optical waveguides." AT&T New-York (1991).
[11] Ajoy Ghatak ,K. Thyagarajan," Introduction to fiber optics," Cambrdge university press (1998).
[12] Wei-Ping Huang, "Coupled-Mode Ttheory For Optical Wwaveguides: an Overview," Journal of the Optical Society of America A**,** Vol. 11, Issue 3, (1994), pp. 963-983.
[13] KIN SENG CHIANG , Theory of Pulse Propagation in Optical Directional Couplers," Journal of Nonlinear Optical Physics & MaterialsVol. 14, No. 02, pp. 133-147 (2005)
(It was read on sunday 24 Oct. 2021 at 10 pm)
[14] Ronald W. Waynant and Marwood N. Ediger**,** W. J. Tropf, T. J. Harris, and M. E. Thomas, " Electro-Ooptics Handbook" Chapter 11, Optical Materials: Visible and Infrared , McGRAW-HILL, INC. New York, 2ed Ed. (2000), pp11.57.
[15] Richard Syns and John Cozens, " Optical Guided Waves and Devices, "Mc -Graw -Hill Book Company , New York (1992).
[16] A. Zaghloul, "A Simple Analysis of a Multimode Three Optical Slab Waveguide Directional Coupler," 18th Radio Science Conference, Alexandria, March (2002), pp.544-552.
[17] Azeemuddin Shaik and Vinoy K.J, " Design of Bandpass Filter Using Branch-Line Directional Coupler," E8 242 Radio Frequency Integrated circuits and systems, Mini Project (Jan –Apr 2011).
[18] D. Marcuse, "Directional Coupler Filter Using Dissimilar Optical Fibers" Indexing terms: optical communications, Fibers, optics, optical filters, Elect. Lett. vol.21, (1985).