Simulation of Mach Zehnder Interleaver Based Thermo-Optic Effect in L-Band Range

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***Abstract*—Optical device based on Mach Zehnder Interferometer (MZI) is usually used as the optical switching, modulator and many applications in telecommunication networks. This paper discuss the Temperature Effect of Wavelength Division Multiplexing (WDM) Interleaver by using single and cascaded MZI. The Sellmeier equation is used to calculate the refractive index changing caused by the temperature changing. The output power of MZI is obtained by using matrix equation. The characteristic of output power varied with several temperatures between 28 and 300 degree Celsius. The wavelength used in this simulation is in L-Band region which is about 1570-1610nm. Temperature changing cause the changing of refractive index of material. The temperature changing leads to the shifting of wavelength channel which describe the characteristic of thermo optic effect on single and cascaded MZI.**

Keywords—single and cascaded Mach Zehnder Interferometer; Thermo-optic effect; Sellmeier Equation; transfer matrix method; wavelength shift.

I. INTRODUCTION

Dense Wavelength Division Multiplexing (DWDM) is one of critical technology to enabling the capacity expansion of fiber optic which can exponentially increase the bandwidth of optical communication. One of optical device that can be classified as optical wavelength circuit for WDM communication is the Mach Zehnder Interferometer (MZI). The MZI can be designed as optical passive component such as switches[1], interleaver[2][3], add-drop filters[4], modulator and demodulator[5] etc.

One popular technological issue is related with the capability to perform optical modulation and one of the interesting way to modulate the refractive index in silica waveguide is by using the thermo-optic effect. This effect is allowing low transmission loss, low cost, high stability, low power consumption, and very large scale of integration[6].

The thermo-optic effect on Cascaded Mach Zehnder Interleaver is explained by using sellmeier coefficient to obtain the changing of refractive index of silica which will discussed in part II, and the matrix equation is needed to calculate the output power of MZI and Comparation result of the thermo-optic effect on single and cascaded MZI is the important part to be discussed.

II. TEMPERATURE EFFECT IN REFRACTIVE INDEX OF SILICA

Silica waveguides is one of the material that usually used in optical device because this material has several advantages, including: low propagation loss, low coupling loss and reflection, excellent physical and chemical stability, low cost and large scale and also it is easy to control the phase by using thermo-optic effect.

The thermo-optic effect is a phenomenon by which the refractive index of a substance changes with temperature [9]. In silica glass, this effect is characterized by an increase in the refractive index as the temperature rises.

The sellmeier equation is an equation to characterize the heating effect in material. The sellmeier coefficients at any temperature *T* are computed from the room temperature and the thermo optic-coefficient (dn/dT) of material, where the thermo-optic coefficient for silica is 10^{-5}($^{0}C^{-1}$) [7]. The new effective refractive index due to temperature can be calculated by using the equation below[7].

$$n_T = n_R + (T - R)\,(dn/dT) \qquad (1)$$

By using Eq.(1) the relation of refractive index as a function of temperature can be simulated in Fig.1. The refractive index is increased linearly with the increasing of temperature. It is because the rising temperature cause the electrons of material move faster, so that the refractive index of material is increased.

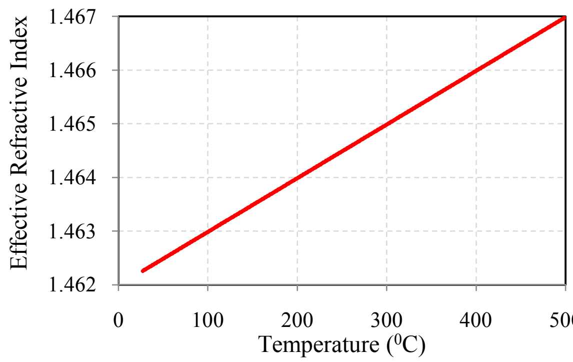

Fig 1. Effective refractive index as a function of temperature

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III. MACH ZEHNDER INTERLEAVER

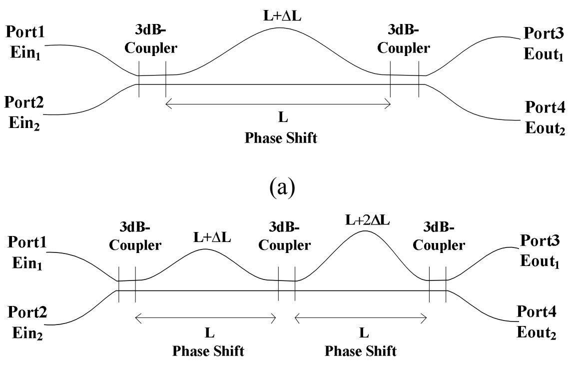

Fig. 2. MZI Structure (a) Single MZI, (b) Cascaded MZI

The MZI modulator has been extensively investigated and reported in the literature since 1980's as a potential electro-optic modulator for high digital bit-rate and RF transmission over optical fiber communication systems[8].

A. Single Mach Zehnder Interferometer(MZI)

The single MZI structure is consist of two 3dB silica directional coupler connected by two guide arms. The first coupler has function as a splitter and the second coupler as a combiner.

The transmission characteristic of MZI can be described using matrix method. The propagation matrix $M_{coupler}$ is described by [9]:

$$M_{coupler}=\begin{bmatrix} \cos\theta & j\sin\theta \\ j\sin\theta & \cos\theta \end{bmatrix} \qquad (2)$$

Where θ=Kd and K is coupling coefficient and d is coupling length, since the 3dB couplers MZI divide the power in equal rate, therefore $2Kd=\pi/4$.

In the central region the signals which entering the arms is coming from the same light source, the output from this two guides have a phase difference$\Delta\phi$, the propagation matrix $M_{\Delta\phi}$ for the phase shifter is:

$$M_{\Delta\square}=\begin{bmatrix} e^{j\beta\Delta L} & 0 \\ 0 & e^{-j\beta\Delta L} \end{bmatrix} \qquad (3)$$

$\beta=2\pi . n_{eff}/\lambda$ is the propagation constant, n_{eff} is effective refractive index dan ΔL is the arm's length difference. The relation between the output optical fields $Eout_1$ and $Eout_2$ with the input fields Ein_1 and Ein_2 is:

$$\begin{bmatrix} E_{out,1} \\ E_{out,2} \end{bmatrix}=M\begin{bmatrix} E_{in,1} \\ E_{in,2} \end{bmatrix} \qquad (4)$$

Where: $M=M_{coupler1}\cdot M_{\Delta\square}\cdot M_{coupler2}$ (5)

The propagation power of MZI is shown in Fig.3, and the parameters used in this calculation are: n_1=1.464, n_2=1.458 (n_1, n_2 are the refractive index material in core and cladding, respectively), waveguide core width h=7µm, λ=1.570µm-1.6µm.

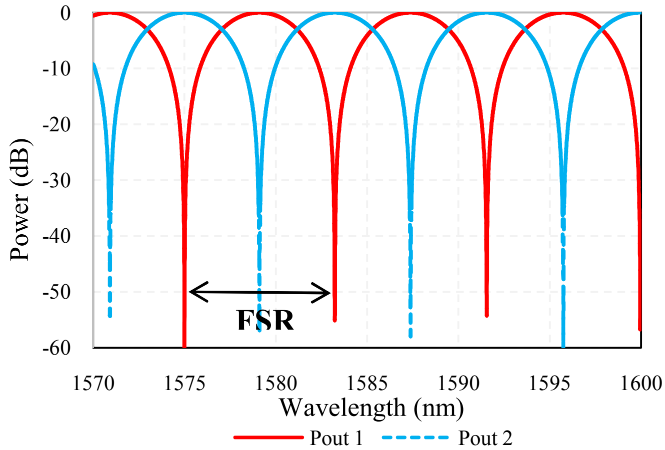

Fig. 3 Spectral response of single MZI

Fig. 3 shows that the MZI is a scalable device. This means that its spectral properties are periodic and these periodicities is called Free Spectral Range (FSR) [2]. This simulation shows the value of FSR is about 8,2 nm with the channel isolation power is less than -50dB in all wavelength range and the channel spacing between port1 and port2 is 4,08 nm.

B. Two-Stage Cascaded Mach Zehnder Interferometer

The following discussion observes the characteristic of Two-stage Cascaded Mach Zehnder Interferometer which consist of three 3-dB couplers and two phase shifter where ΔL_2=$2\Delta L_1$, The Cascaded MZI shown in Fig.2 (b) has a spectral response with a wider bandwidth than a single MZI [11].

Using the same method derivation in Eqs.(2) to (5), The spectral response of cascaded MZI is simulated using the following parameters : $n_1=1.464$, $n_2=1.458$ (refractive index in core and cladding), $\lambda_0=1575nm$ (central wavelength), $h=7\mu m$ (core width), $\Delta L=103.4\mu m$ (arm's length different) and L-Band wavelength range (1575-1600nm).

The spectral response of cascaded MZI is shown in Fig.4. The isolation power, crosstalk power, and FSR value from Fig.4 is summarized in Table 1.

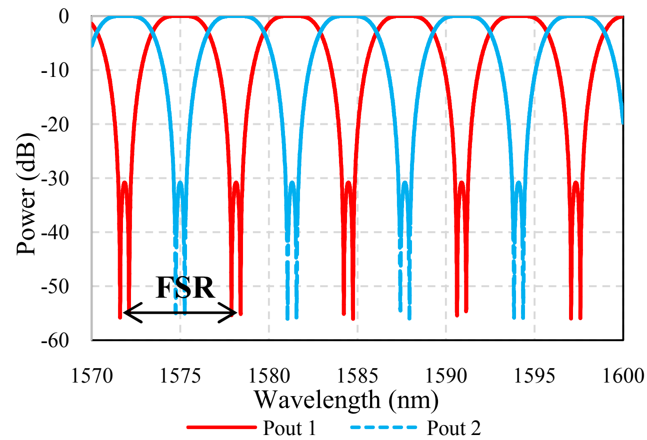

Fig. 4. Spectral response of cascaded MZI

TABLE I

CHARACTERISTIC OF CASCADED MACH ZEHNDER INTERFEROMETER

NO	Result	Value
1.	Isolation Power	-55dB
2.	Crosstalk	-30dB
3.	Channel Spacing	0,0082µm
4.	Space between Port1 and Port2	4,13nm

From simulation in Fig. 3 and 4, and Table1 shows the channel spacing of single and cascaded MZI is matching to the channel spacing of 100GHz L-Band ITU grid DWDM specification which is possible to all WDM channel.

IV. THERMO-OPTIC EFFECT ON MACH ZEHNDER INTERLEAVER

By using sellmeier equation, the changed of effective refractive index due to temperature had been explained in Fig.1. Since temperature is affecting to refractive index, then the propagation constants β is also depend on temperature. It is mean that the transmission power of MZI is influenced by the temperature change.

A. Temperature Effect on Single MZI

The spectral response of single MZI is shown in Fig.5, The parameters used in this simulation are: n_1=1.464, n_2=1.458, λ=1570nm-1600nm, h = 7µm and ΔL = 103.4µm.

The spectral responses are simulated in several temperatures with $\Delta T=100^0$C. The characteristic of single MZI which is shown in Fig.5 are summarized in Table 2.

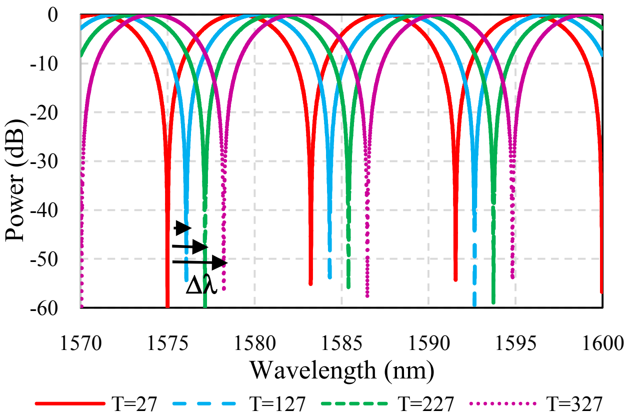

Fig. 5 Spectral response of single MZI in several temperature

TABLE 2

CHARACTERISTIC OF SINGLE MACH ZEHNDER INTERFEROMETER IN SEVERAL TEMPERATURE

No	Result	T_R	T_1=127	T_2=227	T_3=327
1.	Power	<-55dB	<-55dB	<-55dB	<-55dB
2.	FSR	8,2nm	8,2nm	8,2nm	8,2nm
3.	Wavelength Shift (Δλ)		1,08nm	2,15nm	3,23nm

B. Temperature Effect on Cascaded MZI

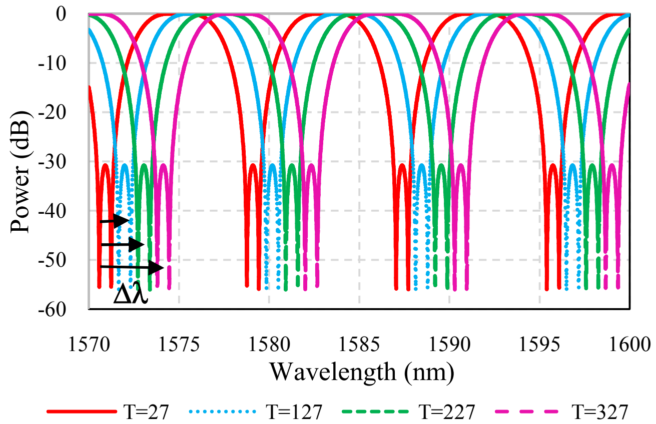

Fig.6 Spectral response of cascaded MZI in several temperature

Fig.6 shows the spectral response of cascaded MZI in temperature $T=27^0$C, 127, 227^0C, 327^0C. For simplicity, the temperature is notated as T_R, T_1, T_2, and T_3 respectively. The result of Fig.6 are summarized in Table 3.

A. Wavelength Shifting caused by Temperature Changing

Figs. 5, 6 and Tables 2, 3 shows that the heating in single and cascaded MZI is affecting to the wavelength shift. Simulation result from Table 2 and Table 3 shows that the wavelength shift in single and cascaded MZI has the same value. The relation of wavelength shift as a function of temperature changing is shown in Fig.7.

TABLE 3

CHARACTERISTIC OF CASCADED MACH ZEHNDER INTERFEROMETER IN SEVERAL TEMPERATURE

No	Result	T_R	T_1	T_2	T_3
1.	Isolation Power	-55dB	-55dB	-55dB	-55dB
2.	Crosstalk	-30dB	-30dB	-30dB	-30dB
3.	Channel Spacing/FSR	8,2nm	8,2nm	8,2nm	8,2nm
4.	Wavelength Shift (Δλ)		1,08nm	2,15nm	3,23nm

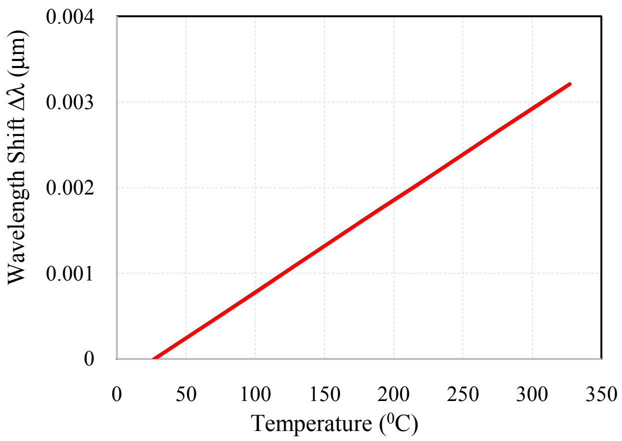

Fig. 7 Wavelength shift as a Function of Temperature

Fig.7 shows that the higher temperature produce the wider wavelength shifting. To describe the relation between wavelength shift and temperature changing, we use brute forces to fit a linear equation into λ shifting data caused by the temperature effects, which results in the following equation:

$$\lambda_T = \lambda_R + [1.08(T - T_R)](10^{-5}) \qquad (6)$$

Where λ_R and λ_T are wavelength at room, and T is temperature, respectively. Wavelength shift (Δλ) is $\Delta\lambda = \lambda_R - \Delta_T$ (μm), T and T_R are temperature at room and T (^{0}C) and 1.08 x 10^{-5} is constant. In designing an interleaver based thermo-optic, this equation can be used to immediately find out how many degrees the temperature should be heated to obtain a particular wavelength shift.

V. Conclusion

From simulation and discussion it can be concluded that the heating effect on single and cascaded MZI cause the wavelength shift. The value of wavelength shift due to temperature can be calculated by applying Eq.(6). This equation can be used as a basis for designing the MZI based thermo-optic, to obtain the degrees of temperature should be heated to produce a certain wavelength shift.

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