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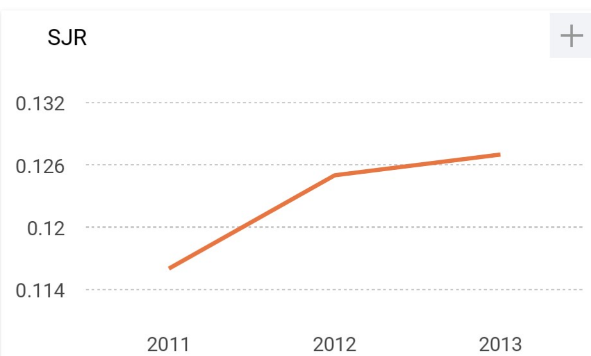

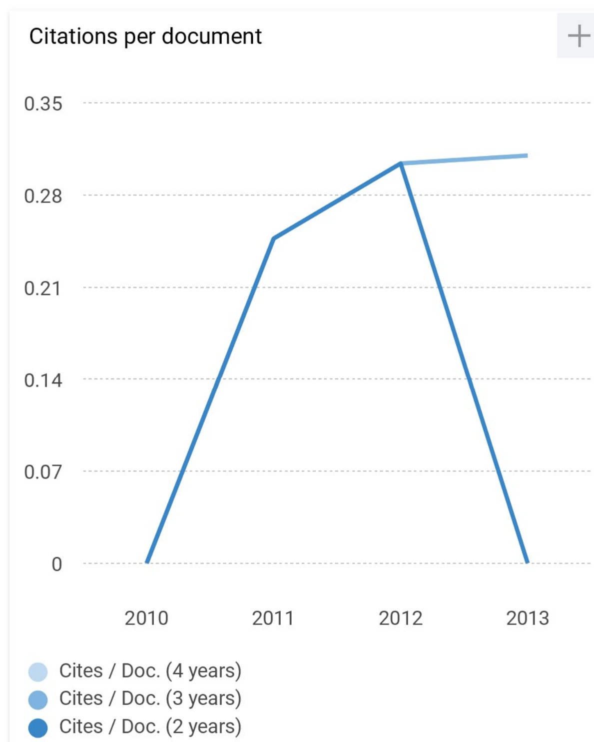

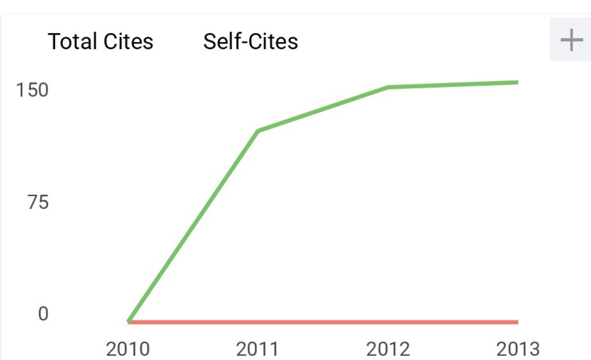

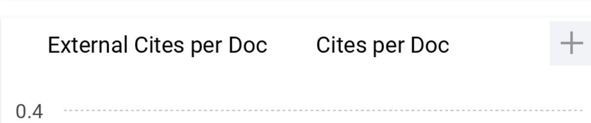

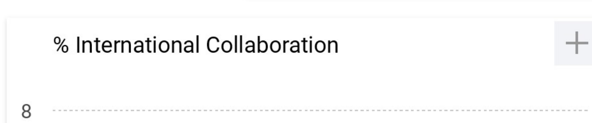

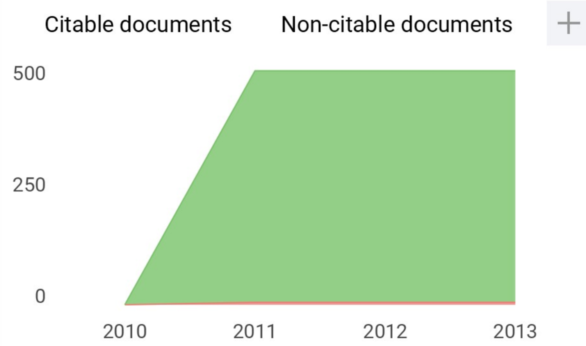

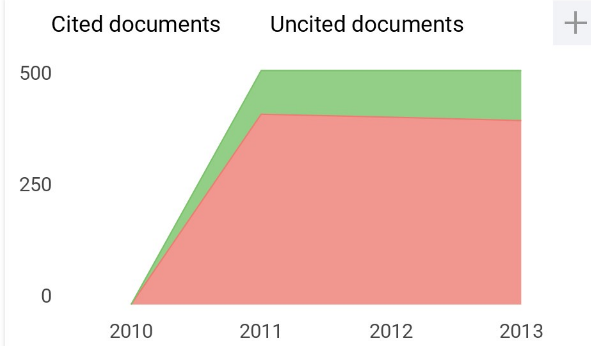

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CONTENTS

ICCAE 2010 Session 66 Electrical and Energy Systems

ICCAE 2010 Session 67 Electrical and Energy Systems

ICCAE 2010 Session 69 Industrial and Logistics Technology

ICCAE 2010 Session 70 Fluid Dynamics and Thermodynamics Technologies

ICCAE 2010 Session 71 Fluid Dynamics and Thermodynamics Technologies

ICCAE 2010 Session 72

ICCAE 2010 Session 73

ICCAE 2010 Session 74

ICCAE 2010 Session 75

ICCAE 2010 Session 77

ICCAE 2010 Session 78

ICCAE 2010 Session 79

ICCAE 2010 Session 80

ICCAE 2010 Session 81

Simulation of Optical Switching Based on Mach-Zender Interferometer Structure

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Abstract—**Optical switch plays an important roles in optical communication especially in Fiber to The Home networks. In this paper, we introduce a simple simulations to predict switch characteristic based on Thermo-Optic phase shifter on Mach-Zender Interferometer Structure. They are the comparison coupling coefficient as a function of separated two waveguides, interchange of modal power between the two guides as a function of propagation distance under phase matched conditions, and the switch characteristic of power as a function of temperature change. A Sellmeier equation is used to calculate refractive index change caused by temperature change.**

Keywords: Directional Coupler, Coupling Coefficient, Mach-Zender Interferometer, Switch Characteristic, Thermo-Optic Switch.

I. INTRODUCTION

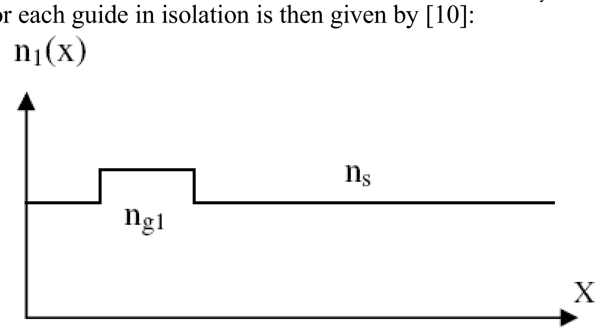
Optical waveguide switches play an important role in the construction of flexible and highly reliable optical communication networks. A practical switch should have certain characteristics, such as low insertion loss, small light reflection (high return loss), and low optical cross-talk. Stable switching operation with low driving power is also necessary. Switches with these characteristics can be realized using the electro-optic effect [1][2], the Thermo-Optic (TO) effect [3]-[5], or mechanical means [6]. Today, the leading technology for optical switching devices is Ti-diffusion in $LiNbO_3$, where switching is achieved using the electro-optic effect. For example, switched directional couplers based on $LiNbO_3$ devices are commercially available. These components can operate very fast, in the sub-nanosecond regime, but are generally polarization sensitive and expensive [2].

In some applications, polarisation insensitivity is more important than high switching speed (for example, by-pass switching in LAN's with ring topologies and circuit switching for video distribution [8]). In this case, optical waveguide switching using the polarisation independent TO effect, which gives switching times of the order of milliseconds, would be a good alternative.

The TO effect is the change in the optical index of refraction as a result of a temperature rise. Conventional TO phase shifters consist of a thin film heater deposited on the cladding of a buried channel guide. Since in a silica (SiO_2)-on-silicon optical waveguide, the glass conductivity is larger than air, heat will be conducted to the silicon substrate, which acts as a heat sink. In the steady-state, the result is a linear temperature gradient between the heater and the substrate, which increases the average temperature of the core. However, relatively high power consumption is involved and lateral heat diffusion in the glass can cause a thermal crosstalk between two adjacent guides [9][10]. These difficulties can be reduced by using a bridge-suspended waveguide structure, which lowers the required drive power and reduces the thermal crosstalk [7]. However, device switching times are lengthened proportionally. In this paper a simple simulation on thermo optic optical switch based on 2 directional couplers are analyzed. We provide a clear explanation on MZI based TO switch and its characteristics on temperature dependence.

II. COUPLED MODE THEORY

Parallel waveguides in directional coupler are oriented in z-direction and are described in isolation by refractive index distributions $n_1(x,y)$ and $n_2(x,y)$, respectively. Figure 1. shows how these index distributions might look for a pair of symmetric slab waveguides. Here the refractive index outside the guides in everywhere n_s, while the index in two guiding layers are n_{g1} and n_{g2} respectively. Assuming that the electric field is polarized in the y-direction, the scalar wave equation governing the variation of the electric field $E_{yi}(x,y,z)$ for each guide in isolation is then given by [10]:



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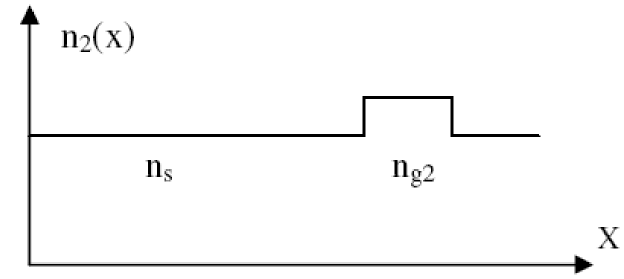

Fig. 1 Movement of Light From One Waveguide to Another Waveguide

To analyze the structure, we first construct a suitable theoretical model. In the geometry studied here, we shall consider a coupler consisting of two waveguides with constant separation. To describe the power transfer process, approximate coupled mode equations defining the change in the mode amplitudes for two guides can be written in compact matrix-vector form as [6.7] :

$$\frac{d\bar{A}}{dz} = -j\bar{\boldsymbol{M}}\,\bar{\boldsymbol{A}} \qquad (1)$$

where $\bar{\boldsymbol{A}} = \{A_1, A_2\}^T$ is a vector representing the amplitudes of the modes in the isolated guides 1 and 2, and $\bar{\boldsymbol{M}}$ is a 2x2 matrix defined by :

$$\bar{M} = \begin{bmatrix} \Delta\beta & K \\ K & -\Delta\beta \end{bmatrix} \qquad (2)$$

Here, $\Delta\beta$ is the mismatch between the propagation constant of each waveguide relative to a mean value β_0, and K is the coupling coefficient. Here K is the **coupling coefficient** [11] that can be defined:

$$K_{ij} = (K_o{}^2 / 2\beta_o)\frac{\langle (n_T{}^2 - n_i{}^2)E_i, E_j\rangle}{\langle E_i, E_j\rangle} \qquad (3)$$

Where $i,j = 1,2$ and $n_T(x,y) = n_T(x,y) + n_2(x,y) + n_s(x,y)$

For the symmetric structure with core width h and constant distance of two waveguides, the **coupling coefficient may be represented as**:

$$K = \frac{2K_o(n_1{}^2 - n_2{}^2)\gamma\cos^2(K\frac{h}{2})e^{-\gamma S}}{\beta\left(h + \frac{2}{\gamma}\right)(K^2 + \gamma^2)} \qquad (4)$$

Figure 2 shows the characteristic of Coupling Coefficient as a function of distance between two waveguides and wavelength. The parameters used in this calculation are as follows $n_1 = 1.464$, $n_2 = 1.458$, wavelength = 1550 nm, height (h) = 3 μm.

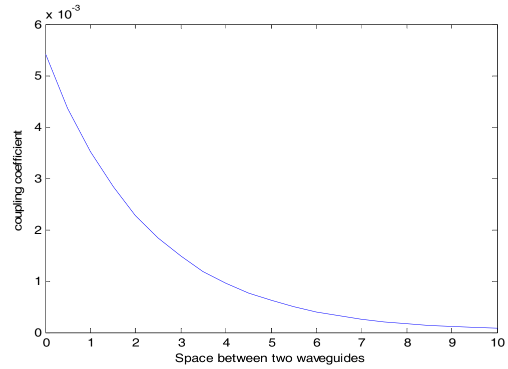

Fig. 2 Characteristic Coupling Coefficient As A Function of Separated Two Waveguides

Figure 3 demonstrates coupling coefficient as a function of wavelength. It is shown that the longer the wavelength is the bigger the coupling coefficients. This effect can be easily understood since longer wavelength give bigger evanescent field and shorter coupling length. As expected the characteristics take an exponential shape. This is typical for most of directional couplers devices.

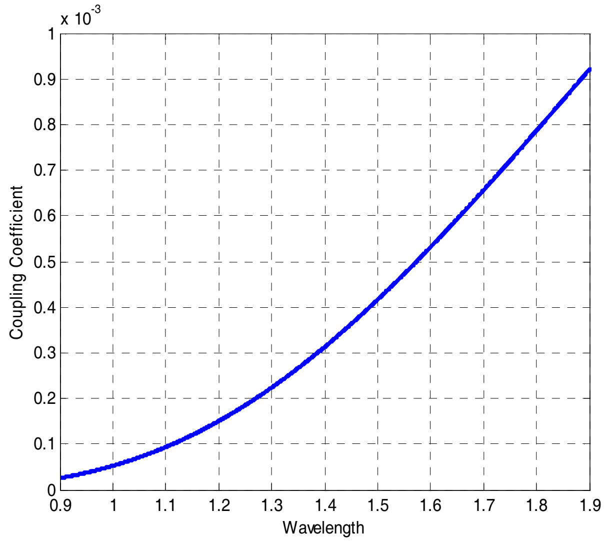

Fig. 3 Coupling Coefficient Characteristic A Function of Wavelength

III. Mach-Zender Thermo-Optic Switch

The Mach-Zehnder interferometer provides an elegant means of taking advantage of the Thermo-Optic effect. It consists of two back-to-back 3 dB silica directional couplers connected by two straight guide arms. The first directional coupler splits the input light into two components which travel along the straight guide and are recombined at the second directional couplers. Either or both the straight arms may have a heater to allow the relative phase of the recombining components to be altered. If the two are in phase, the guided output is high, and if they are out-of-phase, it is low.

Transmission characteristics of Mach-Zehnder interferometers can easily be described by coupled mode theory. In the simplest case, assuming no loss and perfect *y*-branches with a 3-dB splitting ratio, the output power is given by [17]:

$$P_1 = P_{in} cos^2(\Delta\Phi)$$
$$P_2 = P_{in} sin^2(\Delta\Phi) \quad (5)$$

where $P_{1,2}$ and P_{in} are the optical output and input powers respectively, and $\Delta\Phi$ is the phase difference between the two paths. $\Delta\Phi = \beta.L$, where L is distance between two Mach-Zender Interferometers arms and β is the propagation constant. A phase difference may be altered by changing the refractive index of one arm with respect to the other.

Thus, under phase-matched conditions, power transfer occurs periodically with z, as shown by Figure 4. The length z (in micrometers) required for total power transfer under the phase-matched condition is given from equation (5).

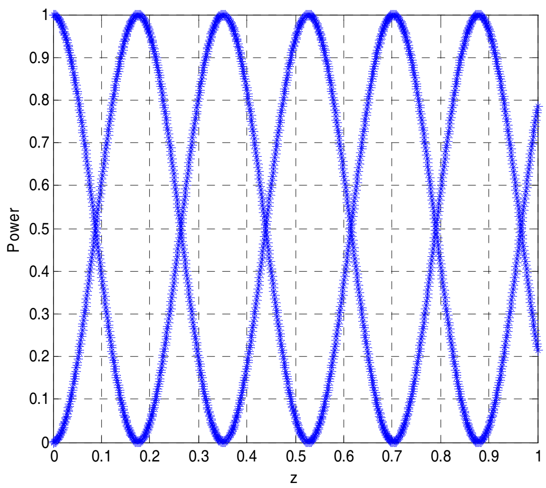

Fig. 4 Power Propagation along z-direction in Directional Coupler

IV. Temperature Effect in Refractive Index of Silica

The Thermo-Optic effect that originates from the temperature dependency of refractive index is useful for constructing integrated optical circuit such as Thermo-Optic switches. When the heater is on, the average waveguide temperature beneath the heater increases. As a result the effective optical path length increases by $\left(\frac{dn}{dT}\right)L\Delta T$, where $\frac{dn}{dT}$ is the Thermo-Optic constant of the silica waveguide, L is the heater length and ΔT is the temperature rise [12]. The typical value of $\frac{dn}{dT}$ for silica is 10^{-5} °C^{-1}. For example, heating a 10 mm long guide by 15.23°C will produce a $\pi/2$ radians phase shift at 1.523 μm wavelength [13]. The driving power and the response time are dependent on the cladding layer thickness, the thermal conductivity of the waveguide and the substrate material. For silica on silicon, the heat supplied by the heater mainly diffuses into the Si substrate through the SiO_2 cladding layer just below the heater and then through SiO_2 core layer. This is because the thermal conductivity of Si is much larger than that of SiO_2. Any lateral heat flow into the cladding glass is small, and all the glass reaches thermal equilibrium very quickly [12].

These Thermo-Optic coefficients *(dn/dT)* and their dispersion have been critically analyzed and smoothed by properly taking into account the band edge dispersion. The Sellmeier coefficients at any temperature *T* are computed from the room temperature Sellmeier equation and the smoothed *dn/dT* values by calculating refractive indexes from the relation [14]:

$$n_T = n_R + (T-R)(dn/dT) \quad (7)$$

where T is the temperature in °C, R is the room temperature, n_T and n_R are the refractive indexes at T and room temperature, respectively. Figure 5 demonstrates the temperature dependence on effective refractive index change on silica waveguide. In this calculation the value of n_1 = 1.464 and n_2 = 1.458.

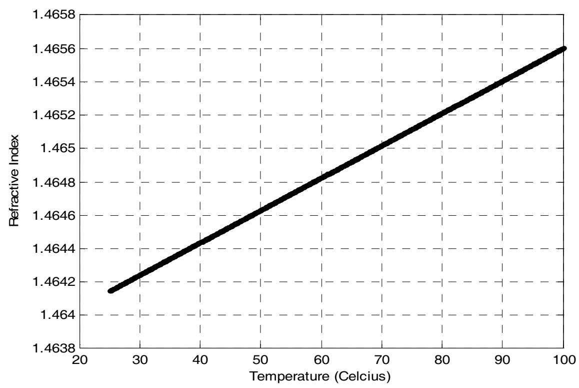

Fig. 5 Effective Refractive Index As A Switch of Temperature in Silica Waveguides

Based on Figure 5 calculation the switch characteristic of Mach-Zender Interferometer can be predicted. Figure 6 demonstrates switch characteristic of silica Mach-Zender Interferometers as a function of temperature. As predicted it follows sinusoidal shape and the swicth temperature occurs within 500° C.

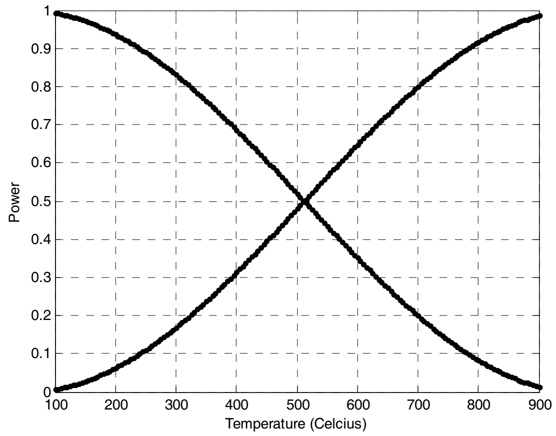

Fig. 6 Switch Characteristic between Two Waveguides in Certain Temperature

V. CONCLUSION

We have demonstrated a simple simulation to predict Thermo-Optic switch based on Mach-Zender Interferometer structures. Switch characteristic follows as sinusoidal shape as a function of temperature raise. However, power consumption is expectedly high due to high temperature needed to set switching characteristic.

The light can be switched when there is a change of propagation constant. If the refractive index change becoming higher, the propagation of the light also will change, then the light can switch to another waveguide. Refractive index can be changed by heating the silica that has certain Thermo-Optic coefficient.

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