A Proposal of Mach-Zehnder Interferometer

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Abstract: This report describes the design of a Mach-Zehnder interferometer for silicon-on-insulator. Including the waveguide simulations, and Mach-Zehnder network simulation.

1. INTRODUCTION

the Mach–Zehnder interferometer is a device used to determine the relative phase shift variations between two collimated beams derived by splitting light from a single source. The interferometer has been used, among other things, to measure phase shifts between the two beams caused by a sample or a change in length of one of the paths. The apparatus is named after the physicists Ludwig Mach (the son of Ernst Mach) and Ludwig Zehnder. Nowadays, Mach-Zehnder interferometer has widely used in optical switches and optical modulators. In this article, we proposed a Mach-Zehnder interferometer and gave its design process and simulations.

2. THEORY

Mach Zehnder interferometer is a two-port network, constructed by two Y branch splitter, and two strip wave guides with different path length. Also, for measurement purpose, we will add two grating couplers on each side of Y branch. So, let us discuss y-branch splitter first. We begin with the Electric field intensity, the input light will split into two branches equally, which means each output has an intensity of $I_1 = I_2 = I_i$. For electric field $E_1 = E_2 = \frac{E_2}{\sqrt{2}}$. For the combiner, the light combines, the output will be the vector summation of the two input fields, divide by $\sqrt{2}$. The equation is $E_o = \frac{E_1+E_2}{\sqrt{2}}$. For ideal case,

$$E_{o1} = E_{i1} = E_{i1} * e^{-i\beta L1} \qquad (1)$$

$$E_{o2} = E_{i2} = E_{i2} * e^{-i\beta L2} \qquad (2)$$

We got the electric field of y-branch.

$$E_{o2} = \frac{E_{o1}+E_{o2}}{\sqrt{2}} = \frac{E_i}{\sqrt{2}} \times (e^{-i\beta L2} + e^{-i\beta L1}) \qquad (3)$$

So, the intensity will be.

$$I_o = \frac{I_i}{4} \times |e^{-i\beta L2} + e^{-i\beta L1}|^2 = \frac{I_i}{2} \times [1 + \cos(\beta \triangle \mathrm{L})] \qquad (4)$$

3. MODELLING AND SIMULATATION

In this design, we use the strip waveguide with 500nm width and 220nm height, the simulation results and profiles are presented here.

By using the Lumerical MODE, we were able to simulate the wave guide Electric filed intensity of TE and TM mode, results shown in Fig.1 and Fig.2.

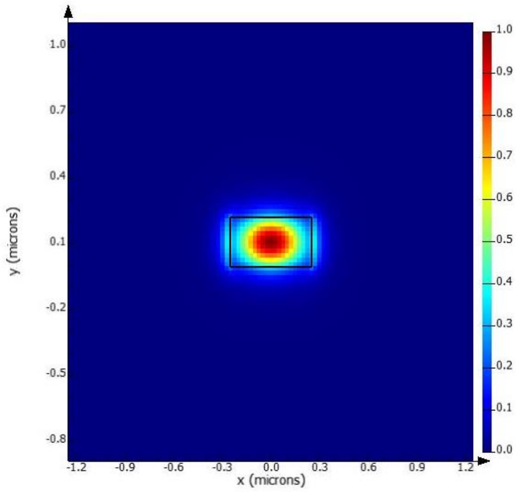

Figure 1 Electric field of TE mode

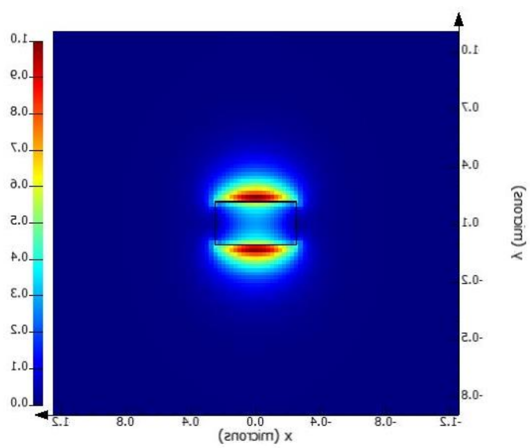

Figure 2Electric field of TM mode

Using script [1] in Lumerical MODE, we were able to extract the waveguide parameters.

$$n_{eff}(\lambda) = 2.45079 - 1.13117 \times (\lambda - 1.55) - 0.0441242 \times (\lambda - 1.55)^2 \qquad (5)$$

Also, we can simulate the effective index and group index versus wavelength. Results shown in Fig.3 and Fig.4. We can see that we can see that the effective index decreases with the wavelength, while the group index increases with the wavelength.

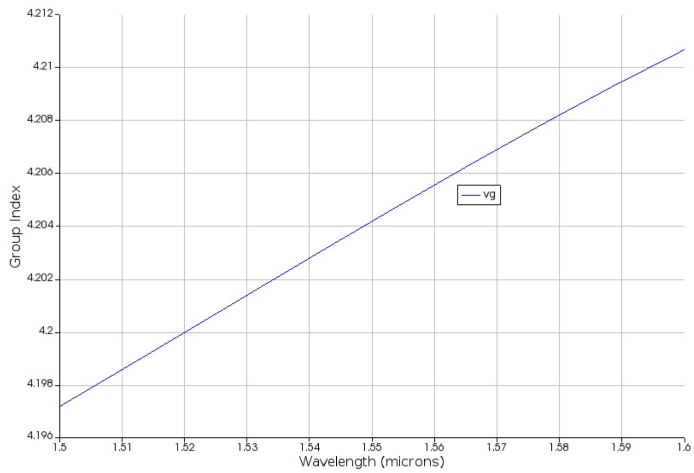

Figure 3group index VS wavelength

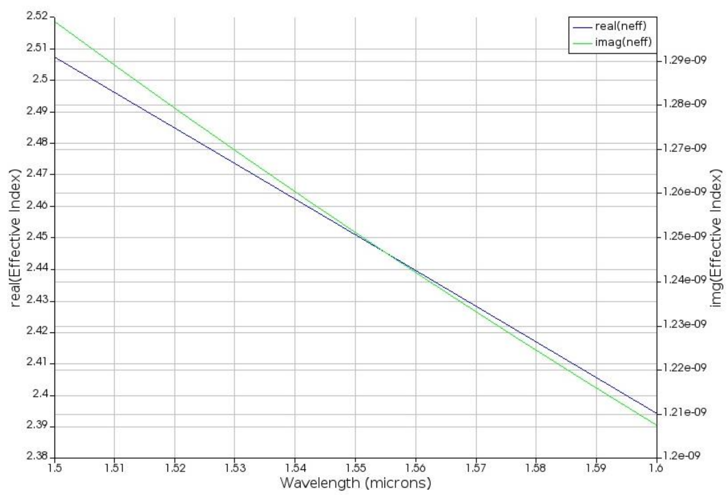

Figure 4effective index VS wavelength

Next, we simulate the MZI using Lumerical INTERCONNECT. First, we characterize the insertion loss of grating coupler, shown in Fig. 5.

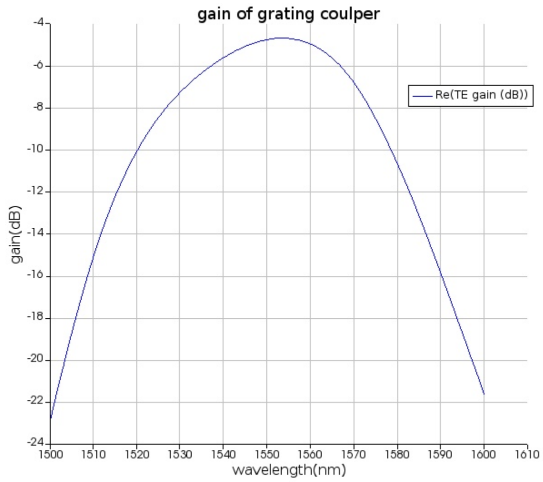

Figure 5gain VS wavelength.

Then we simulate the MZI. From the transfer function we can get.

$$T_{MZI} = \frac{1}{2} \times [1 + \cos(\beta \bigtriangleup \mathrm{L})] \qquad (6)$$

From FSR equation we can know that.

$$FSR = \lambda/[\bigtriangleup \mathrm{L} \times N_g] \qquad (7)$$

After calculation we can get the relation between △ L and λ, shown in table1.

△ L(um)	FSR(nm)
28.5726	20
38.0968	15
57.1452	10
114.2905	5

Table 1FSR VS △λ

For easier calculation we round △ L to be 50 um. In this article, we simulate MZI with path length difference is 50 um. Due to the measurement bandwidth limited by grating coupler, we limit the FSR to be short than 50 nm.

First, we simulate MZI network without grating coupler, and then we can add the grating coupler. We can compare the difference of insertion loss of these two networks. Schematic shown in Fig.6. results shown in Fig.7 and Fig.8.

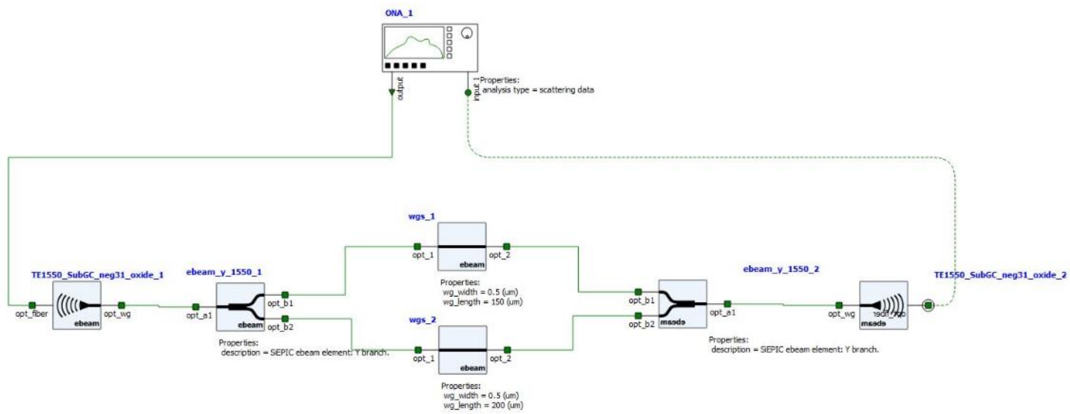

Figure 6MZI schematic

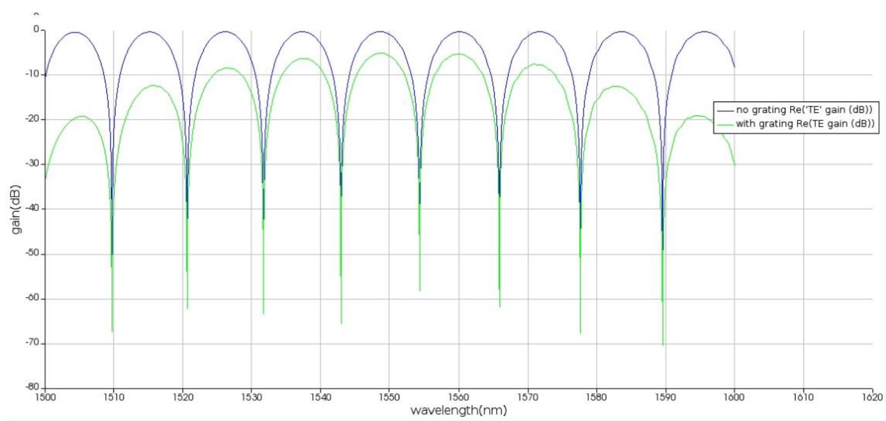

Figure 7insertion loss of MZI network with △ L= 50um.

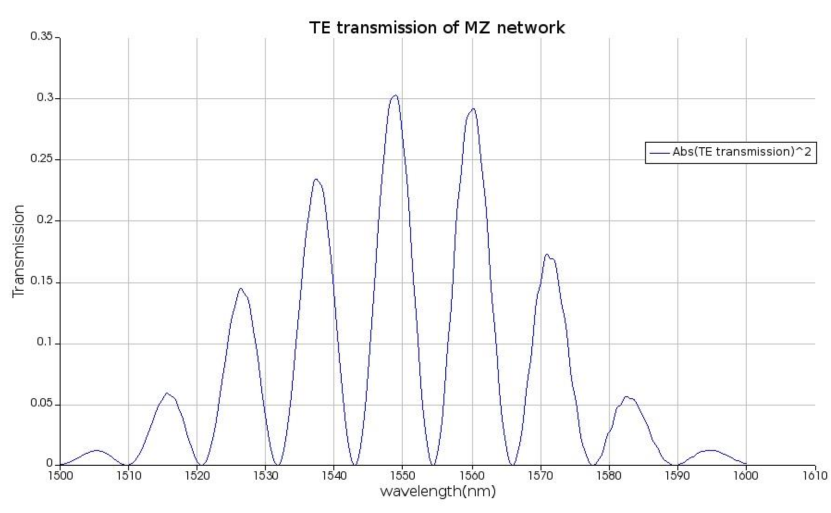

Figure 8transmission VS wavelength

4. CONCLUSION

In this article, we propose design of a MZI with different $\triangle$ L. The design process and simulations have been given in article, and the simulation result is close to the mathematical calculation result. We will compare the simulation results and fabrication results, in next couple weeks.

5. REFERENCE

[1] Chrostowski, L., & Hochberg, M. (2015). *Silicon Photonics Design: From Devices to Systems*. Cambridge: Cambridge University Press. doi:10.1017/CBO9781316084168