Design, Fabrication, and Analysis of a Mach-Zehnder Interferometer on a Silicon-on-Insulator Platform

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***Abstract*—This paper presents the design, modeling, fabrication, and data analysis of a Mach-Zehnder interferometer (MZIs) on a silicon photonic platform. The design objective is to observe the effect of the path length variation on the spectral response of an interferometer circuit. Different MZI configurations are designed using KLayout which is then sent for fabrication using electronic beam lithography. The optical transmission results would be then compared with the simulations on Lumerical INTERCONNECT to verify the validity of the fabricated design.**

***Index Terms*—Mach-Zehnder interferometer, fabrication, silicon-on-insulator, electronic beam lithography**

I. Introduction

The growing field of photonic integrated circuits (PICs) has gained attention to address the limitations of electronics in terms of scalability and computational power. By using light as the carrier of information, different properties of light such as wavelength, polarization, and mode, can be manipulated for signal processing.

One of the simplest circuit topologies in silicon photonics is the Mach–Zehnder interferometer (MZI). An MZI consists of a beam splitter at the input port and a beam combiner at the output port, connected by two optical waveguide arms. Depending on the relative phase difference between these two paths, the optical signals interfere either constructively or destructively at the output. Variations in the path length of one arm introduce a phase shift, which directly influences the interference condition and, consequently, the output intensity of the device.

II. Theory of Operation

A typical beam splitter on an MZI has a splitting ratio of 50:50, in which light travels in two different waveguide arms. If there is a difference in the path length which would induce a phase difference, then there would be a noticeable shift of interference pattern at the output. This is governed by equation (1):

$$I_{out} = I_0 \cos^2(\frac{\Delta\theta}{2}) \tag{1}$$

This phase difference $\Delta\theta$ is related to the path length difference ΔL and the effective index n_{eff} using equation (2)

$$\Delta\theta = (\frac{2\pi n_{eff}\Delta L}{\lambda}) \tag{2}$$

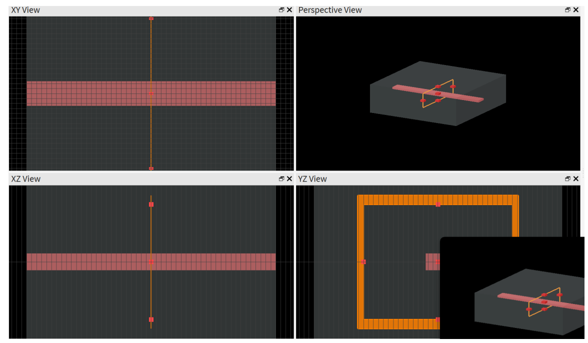

Fig. 1. Simulation setup for Lumerical MODE.

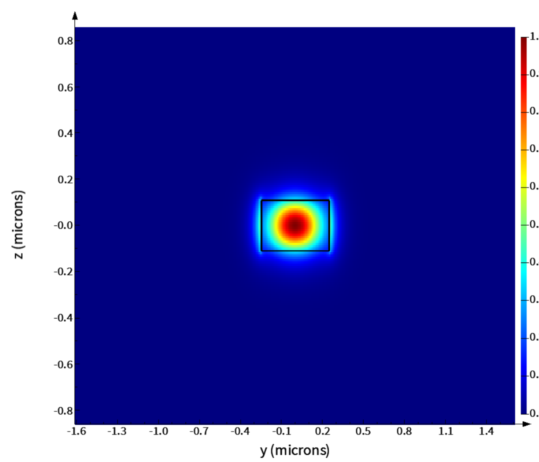

Fig. 2. Mode profile of the waveguide.

III. Modeling and Simulation

This design uses a silicon-on-insulator platform, with silicon dioxide (SiO_2) as the cladding and silicon as the waveguide material. In order to confirm the behavior of the light in a waveguide, simulations are performed using Lumerical MODE, with the setup illustrated in Figure 1. For a given width of $0.5\mu m$ and a thickness of $0.22nm$, the mode profiles for the fundamental TE mode is shown in Figure **??**.

Using a script in Lumerical MODE, the compact model of this waveguide at a wavelength of $1.55\mu m$is given by equation (3).

$$n_{eff}(\lambda) = 2.445 - 1.143 * (\lambda - 1.55) - 0.4370 * (\lambda - 1.55)^2 \tag{3}$$

Moving forward, the MZI is simulated in Lumerical INTERCONNECT to visualize the transmission spectrum. Figure 3 shows the schematic set-up of the MZI simulation, consisting

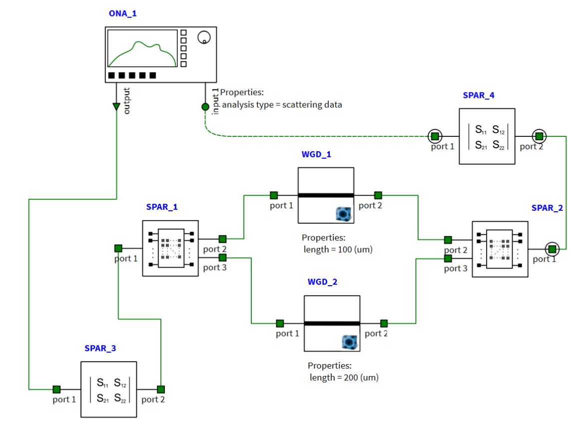

Fig. 3. Mach-Zehnder interferometer in Lumerical INTERCONNECT

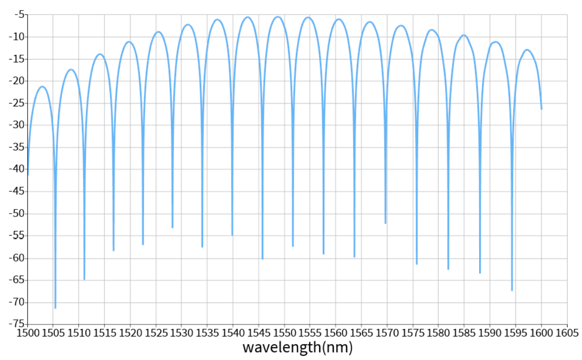

Fig. 4. Transmission in dB vs Wavelength of an MZI with $\Delta L = 100\mu m$

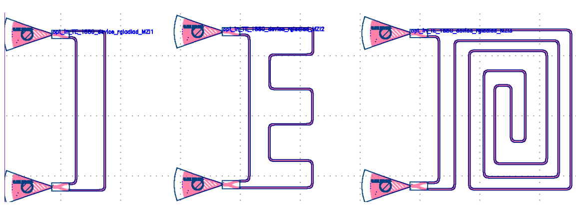

Fig. 5. MZI schematic created in KLayout with three different ΔL.

of an optical network analyzer as the visualizer, connected to a grating coupler modeled using its S-parameters.

In this simulation, Y-branch was used as the beam splitters, and a waveguide of two different lengths (100 μm and 200 μm) are connected in between them. After running, the transmission spectrum is generated by the optical network analyzer, as presented in Figure 4.

Finally, this simple interferometer is created using KLayout to generate the GDS file to be sent to the fabrication facility. Figure 5 illustrates the mask created in KLayout. This consists of three MZIs with different path lengths.

IV. Fabrication

The fabrication of the chip is to be performed at the University of British Columbia's 100keV electron beam lithography by Applied Nanotools Inc., Canada.

V. Experiment Data

This section will contain the experimental data obtained from the fabricated chips.

VI. Analysis

This section will be completed once the results from the automated optical probe station is obtained.

VII. Conclusion

Designing a photonic integrated circuit has a lot of important details to consider, starting from the analytical model, circuit simulations, and most importantly, the layout and fabrication of the physical device up until the measurement and data analysis.

References

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