Design Proposal: Mach-Zehnder Interferometer

Mukund Jha (eez207535@iitd.ac.in)

Abstract— **This report details the design of a Mach-Zehnder interferometer (MZI) for fabrication on a silicon-on-insulator (SOI) platform, utilizing strip waveguides. We present simulated results and analytical evaluations that justify the design choices. A preliminary layout mask is included for future fabrication and automated testing.**

I. INTRODUCTION

THE Integrated photonics has profoundly advanced the optical communications industry by enabling high-speed, compact, and energy-efficient devices [1, 2]. Silicon photonics offers robust performance and scalability, making it a key technology for meeting the increasing bandwidth demands of optical networks [1, 5]. A crucial component in this domain is the Mach-Zehnder interferometer (MZI), which is essential for developing high-speed modulators, switches, and next-generation reconfigurable optical add-drop multiplexers (ROADMs) [3, 4]. This work presents the design and layout of MZI devices using strip waveguides on a silicon-on-insulator (SOI) wafer, with plans for subsequent fabrication. The design decisions are validated by analytical and simulated evaluations. Strip waveguides, known for their low propagation loss (typically under 3 dB/cm), are well-suited for on-chip routing purposes [5].

II. THEORY

A simple Mach-Zehnder interferometer (MZI) works by splitting a light beam and then putting it back together. Imagine a device with a single entrance and a single exit. Inside, a beam splitter divides the incoming light into two paths, which travel along identical guides and then meet again at a combiner. Because the paths are identical, the light waves meet perfectly in sync at the end, strengthening the signal.

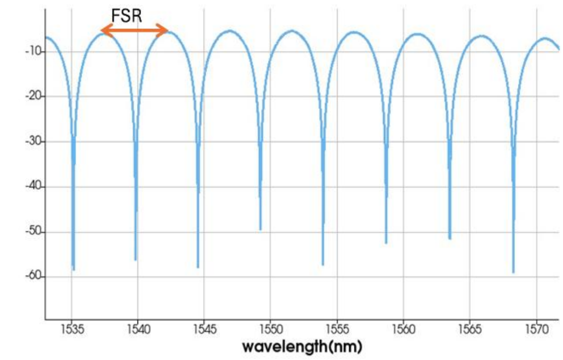


Figure 1 : MZI response with a FSR depending on path length difference

To create different effects, the two paths can be made unequal. By changing the length of one path, the light waves can arrive out of sync. This causes them to interfere with each other, creating a range of outcomes from maximum signal strength to complete cancellation, all dependent on the light's wavelength. Varying the properties of the waveguides, such as their material or thickness, can also achieve this effect. The MZI response with a FSR depending on the MZI path length diffrernce is shown in Figure 1.

III. MODELING AND SIMULATION

The waveguide geometry under consideration is a rectangular cross-section measuring 220 nm in height and 500 nm in width (Figure 1). The choice of 220 nm thickness reflects the de facto standard in contemporary silicon photonics foundries, where this dimension has been widely adopted due to its compatibility with mature fabrication processes and its ability to support single-mode guiding in the telecom C-band. The lateral dimension of 500 nm was selected primarily for two practical reasons. First, the 220 nm × 500 nm combination ensures that the fundamental TE mode propagates very close to the single-mode cutoff, thereby reducing the risk of higher-order mode excitation while maintaining strong confinement. Second, this width is consistent with existing experimental characterization: in particular, S-matrix data for key building blocks such as grating couplers and Y-branch splitters have already been obtained at this geometry. Leveraging these validated datasets facilitates accurate modeling, simulation, and circuit-level design, while also aligning the design with industry-tested component performance.

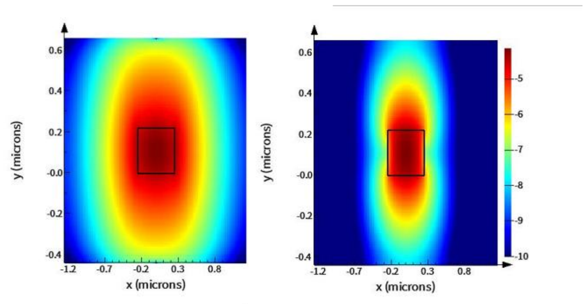


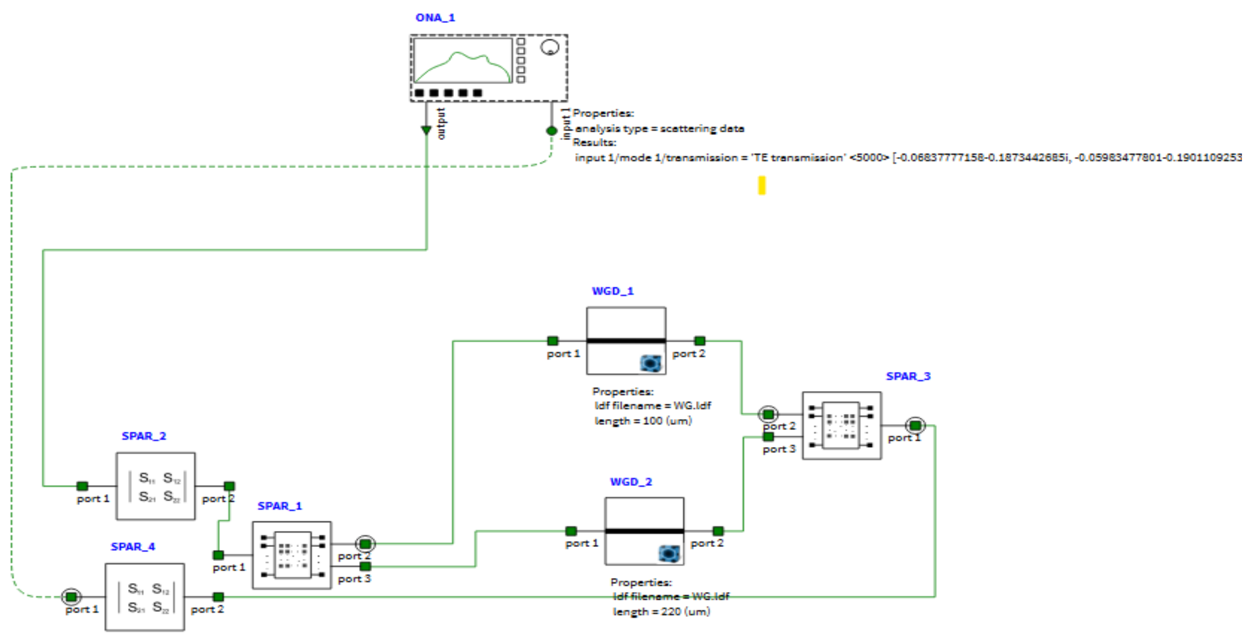
Figure 2(a) TE Mode, (b) TM Mode

For the selected waveguide geometry, a modal analysis was carried out using Lumerical MODE software [6] at a reference wavelength of 1550 nm. The simulation identified the guided modes supported by the structure, along with their corresponding effective indices. The variation of group index and effective index over wavelength are shown in Figure 3 (a) and Figure 3(b). After obtaining the modal analysis data, the effective index data fitted with respect to the wavelength as shown in figure 3(c).

Figure 3(d) shows the variation of effective index over the waveguide width.

Then, simulations for the complete MZI circuit were performed, for several values of length mismatches in the MZI branches. As expected, the number of oscillations in the transfer function is proportional to the ΔL parameter. Figure 4 shows the schematic of MZI used to simulate in Lumerical interconnect. Figure 5 shows the MZI response for path length diffrernce of 100um and 200um.

Figure 4 The Schematic of MZI with path length difference of 120um between two branches of MZI



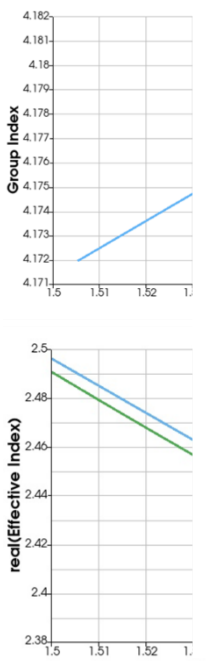
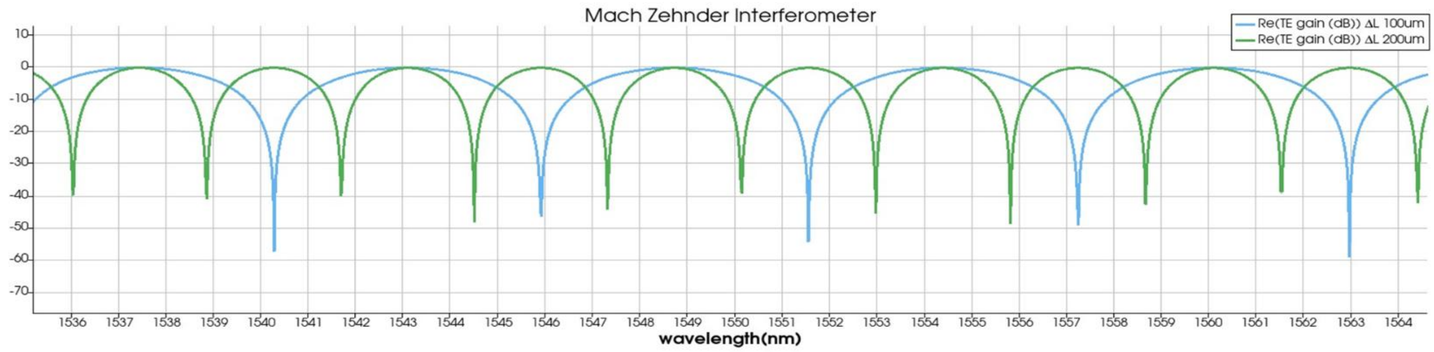


Figure 3 (a) Group index variation over wavelength , (b) effective index variaton over wavelengrh , (c) fitted effective index over wavelength , (d) effective index over waveguide width



The first draft proposal was developed in Klayout software. The layout mask for three different MZI path length difference is proposed in mask layout shown in Fig. TE gratings has been oriented along right side to meet the fabrication requirements. The separation between grating couplers are kept at 127um.

The bend radius of all waveguides has been kept at 5um.

The current draft design has only TE modes but in final design TM modes and MMI splitter may also be investigated.

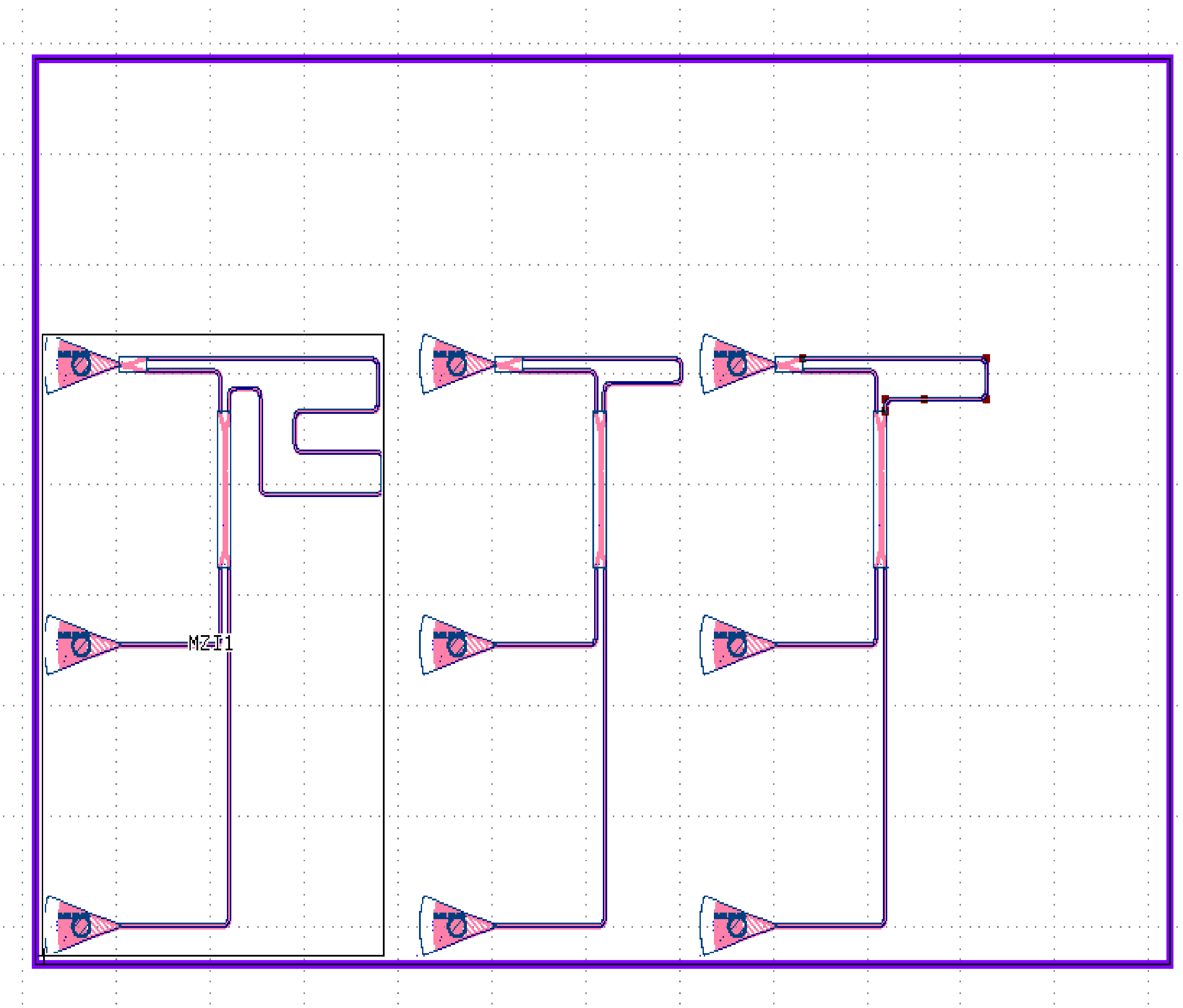


Figure 5 MZI layout draft in klayout

REFERENCES AND FOOTNOTES

[1] H. Subbaraman *et al*, ”Recent advances in silicon-based passive and active optical interconnects,” Opt. Express 23, 2487-2511 (2015)
[2] K. Roberts *et al*, ”High Capacity Transport100G and Beyond,” Journal of Lightwave Technology , vol.33, no.3, pp.563,578, Feb.1, 1 2015
[3] Y. Shoji *et al*, ”Low-crosstalk 2 2 thermo-optic switch with silicon wire waveguides,” Opt. Express 18, 9071-9075 (2010)
[4] T. Li, E. Willner and I. Kaminow, ”Optical Fiber Telecommunications VA: Components and Subsystems,” Academic
Press, 2010.
[5] L. Chrostowski and M. Hochberg, “Silicon Photonics Design: From Devices to Systems”, Cambridge University Press,2015.
[6] *Lumerical MODE* software. https://www.lumerical.com/tcad-products/mode/
[7] *Lumerical INTERCONNECT* software. https://www.lumerical.com/tcad-products/interconnect/ [8] Components library, SiEPIC, University of Washington. http://goo.gl/B9IRn8
[9] *KLayout* software. http://www.klayout.de/
[10] GDS file of the current report (Tiago Lima), draft version. https://goo.gl/ZAdctK