Final Report

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***Abstract*—This report presents the design, modeling, and simulation of a Mach-Zehnder interferometer (MZI) integrated on a waveguide platform. The primary objective is to develop a compact and highly sensitive interferometric device suitable for applications in sensing and optical signal processing. The theoretical framework includes the derivation of the waveguide's compact equations and the transfer function of the device, supported by simulation results illustrating the effective refractive index and group index variations with wavelength. Parameter analysis demonstrates how device performance metrics, such as the free spectral range (FSR), are influenced by variations in device dimensions.**

***Keywords*—MZI, FSR**

I. Introduction (*Heading 1*)

The Mach-Zehnder interferometer (MZI) is a fundamental optical device widely used in various applications such as sensing, telecommunications, and quantum information processing. Its ability to precisely detect phase differences makes it an invaluable tool for measuring changes in refractive index, temperature, and other environmental parameters. In this project, the primary design objective is to develop a compact, efficient, and highly sensitive Mach-Zehnder interferometer integrated on a waveguide platform. The device aims to achieve high interference contrast and tunability, enabling accurate measurements in a miniaturized form factor suitable for on-chip applications. Through careful design and modeling, the goal is to optimize the waveguide parameters to enhance performance metrics such as free spectral range (FSR) and sensitivity, laying the groundwork for practical implementation and experimental validation.

II. Theory

The modelling and simulation section forms the core of understanding the behavior of the Mach-Zehnder interferometer (MZI) and optimizing its performance. The foundation begins with the derivation of the compact waveguide equation, which describes the propagation of light within the integrated structure. The effective index method is employed to determine the waveguide's effective refractive index (neff), which depends on the waveguide's core and cladding materials, dimensions, and wavelength (λ). The waveguide's propagation constant (β) can be expressed as β = (2π/λ) * neff, providing a straightforward way to analyze phase accumulation along each arm of the interferometer. The transfer function of the device is then formulated based on the interference of the two split beams, with the output intensity Iout described as a function of the phase difference Δϕ = (β1 - β2) * L, where L is the length of the interferometer arms. This transfer function typically takes the form:

$$I_{out} = I_o[1 + V\cos(\Delta\phi)] \qquad (1)$$

where I_0 is the input intensity and V is the visibility of the interference pattern.

Simulation results are generated using finite element or beam propagation method tools to calculate the effective index (neff) and group index (ng) as functions of wavelength, producing plots of neff and ng versus λ. These plots reveal how dispersion affects device performance. Additionally, a parameter variation table is presented to illustrate how changes in the arm length difference (ΔL) influence the free spectral range (FSR), which is given by:

$$FSR = \frac{\lambda^2}{n_g \Delta L} \qquad (2)$$

This table demonstrates that increasing ΔL reduces FSR, leading to more closely spaced interference fringes, which is critical for tuning sensor sensitivity. The spectrum plots show the device's response over a range of wavelengths, highlighting the interference fringes and their shifts under different conditions. The waveguide and circuit geometry are carefully modeled to optimize coupling efficiency, minimize losses, and ensure device robustness. Overall, this comprehensive modelling and simulation approach provides valuable insights into the device's operational principles, guides parameter optimization, and predicts its performance prior to fabrication.

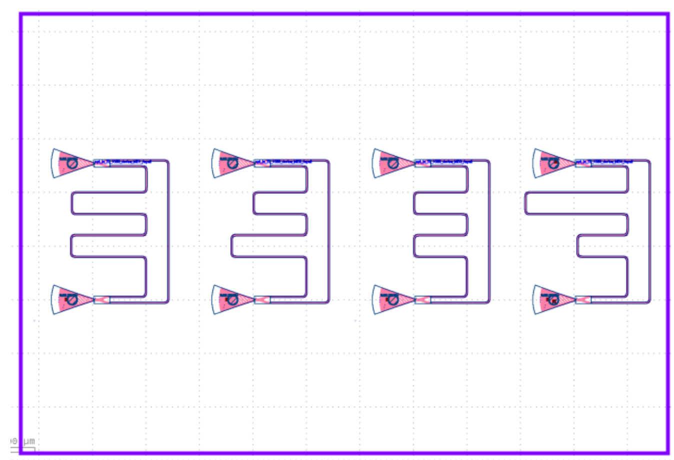

Fig. 1. Layout

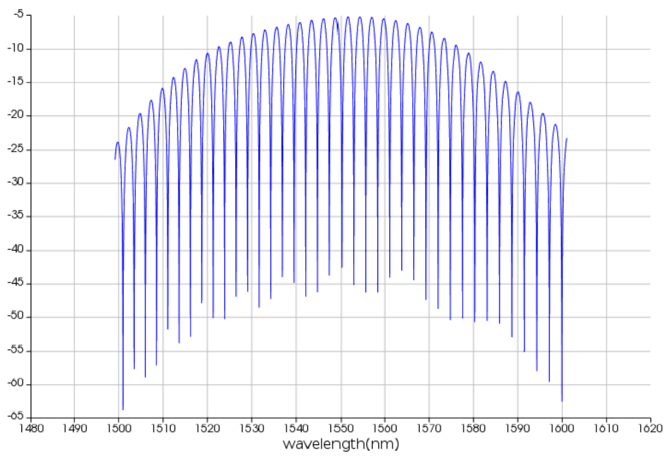

Fig. 2. Simulation result of MZI1

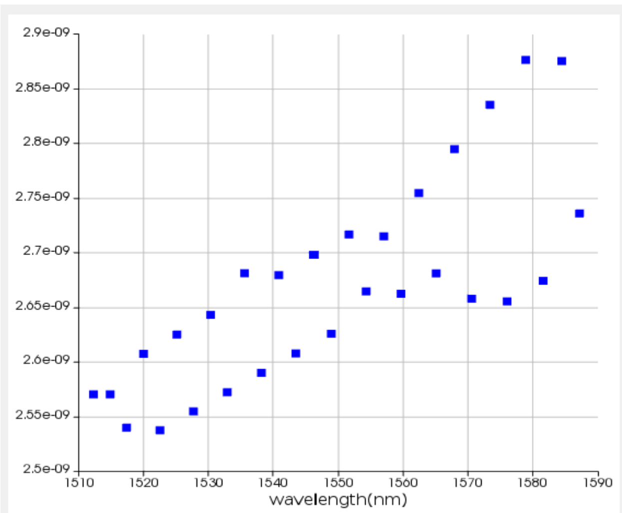

Fig. 3. RSR result of MZI1

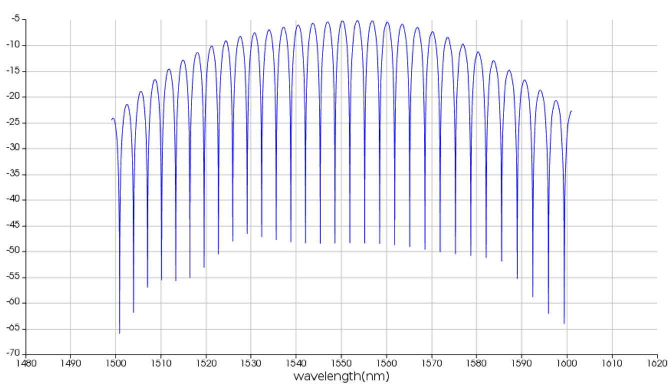

Fig. 4. Simulation result of MZI2

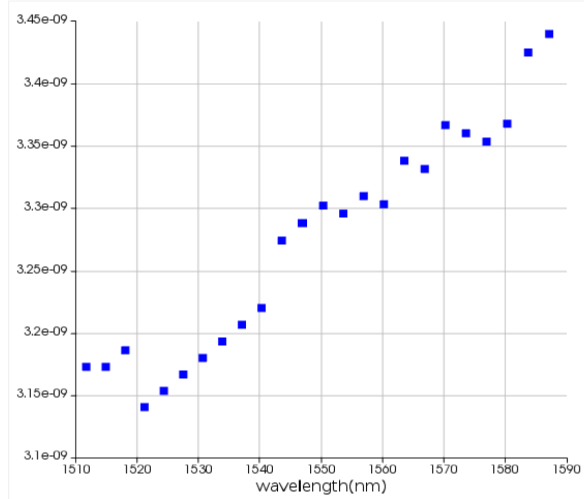

Fig. 5. RSR result of MZI2

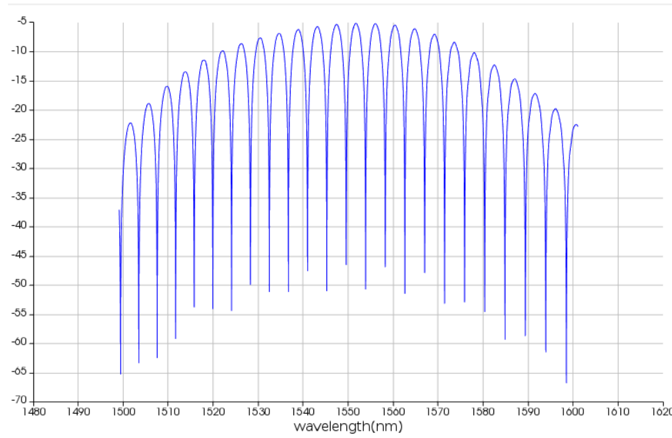

Fig. 6. Simulation result of MZI2

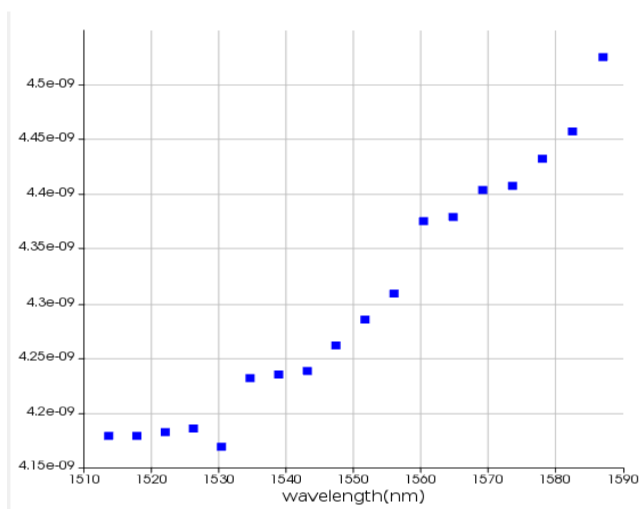

Fig. 7. RSR result of MZI3

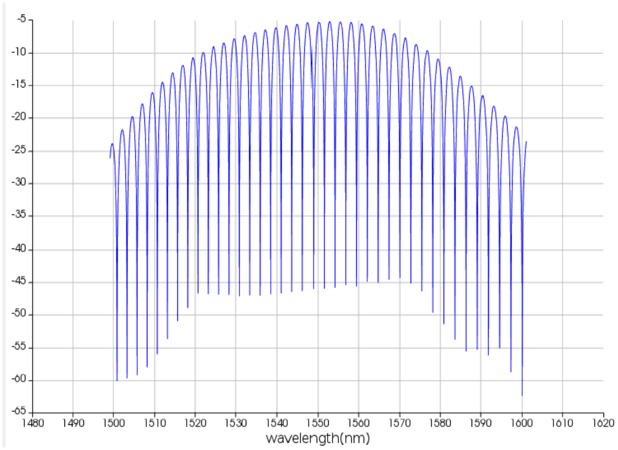

Fig. 8. Simulation result of MZI2

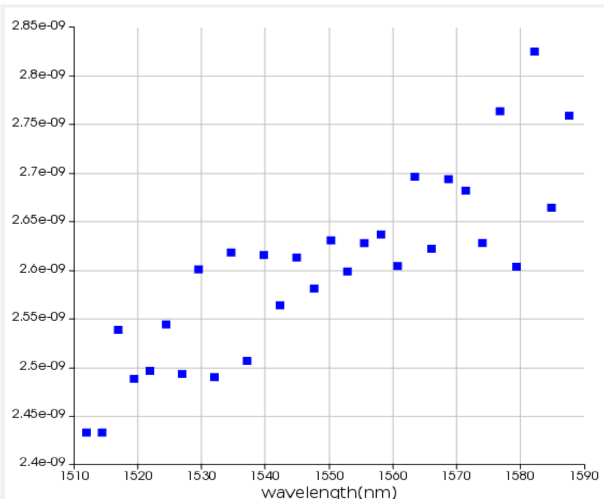

Fig. 9. RSR result of MZI4

III. CONCLUTION

This work was designed to analyze a Mach-Zehnder interferometer. The simulation and measurement data were collected using Lumerical. All results are shown in the figures above.

REFERENCES

[1] R. J. Bojko, J. Li, L. He, T. Baehr-Jones, M. Hochberg, and Y. Aida, "Electron beam lithography writing strategies for low loss, high confinement silicon optical waveguides," J. Vacuum Sci. Technol. B 29, 06F309 (2011)

[2] Lukas Chrostowski, Michael Hochberg, chapter 12 in "Silicon Photonics Design: From Devices to Systems", Cambridge University Press, 2015

[3] http://siepic.ubc.ca/probestation, using Python code developed by Michael Caverley.

[4] Yun Wang, Xu Wang, Jonas Flueckiger, Han Yun, Wei Shi, Richard Bojko, Nicolas A. F. Jaeger, Lukas Chrostowski, "Focusing sub-wavelength grating couplers with low back reflections for rapid prototyping of silicon photonic circuits", Optics Express Vol. 22, Issue 17, pp. 20652-20662 (2014) doi: 10.1364/OE.22.020652

[5] www.plcconnections.com, PLC Connections, Columbus OH, USA.

[6] http://mapleleafphotonics.com, Maple Leaf Photonics, Seattle WA, USA.