Design Proposal: Silicon Photonics Mach-Zehnder Interferometers

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1. Introduction

The objective of this design project is to create and characterize a series of unbalanced Mach-Zehnder Interferometers (MZIs) on a silicon photonics platform. The primary goal is to extract the waveguide group index (ng) of the fabricated strip waveguides. By designing MZIs with varying path length differences (Delta L), we can measure the Free Spectral Range (FSR) from the transmission spectra. This experimental data allows for the accurate characterization of the waveguide's dispersion properties, which is a critical step in verifying the fabrication process and calibrating compact models for future circuit designs.

2. Theory

The Mach-Zehnder Interferometer operates by splitting an input optical signal into two paths of different lengths and recombining them. The phase difference induced by the path length difference (Delta L) causes constructive or destructive interference at the output.

The normalized power transmission is given by:

$$I_{out} / I_{in} = 0.5 * (1 + \cos(\beta * \Delta L))$$

Where the propagation constant (beta) is defined as:

$$\beta = (2 * \pi * n_{eff}) / \lambda$$

The Free Spectral Range (FSR), which is the spectral spacing between adjacent constructive interference peaks, is related to the group index (ng) by the following equation:

$$FSR = \lambda^2 / (n_g * \Delta L)$$

By experimentally measuring the FSR and knowing the designed Delta L, the group index can be extracted:

$$n_g = \lambda^2 / (FSR * \Delta L)$$

3. Modeling and Simulation

3.1 Waveguide Geometry

The designs utilize standard silicon strip waveguides on a Silicon-on-Insulator (SOI) platform. The specific geometry and parameters are as follows:

- Waveguide Width: 500 nm
- Waveguide Height: 220 nm
- Polarization: Quasi-TE
- Cladding: 2.2 µm Oxide (SiO_2)
- Box Layer: 3 µm SiO_2

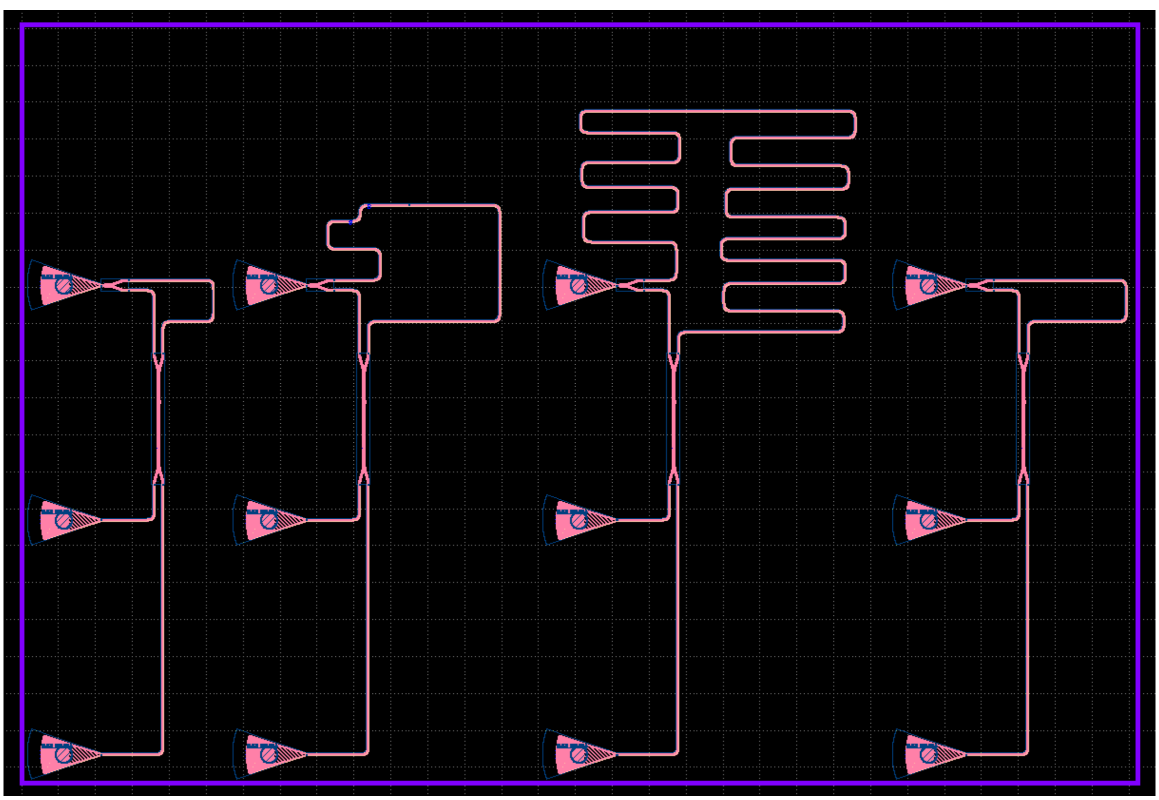
3.2 Design Variations

Four specific MZI designs have been implemented. The path length differences (Delta L) were chosen to provide a range of FSR values suitable for measurement within the C-band (1500-1600 nm). The expected FSR values below are calculated assuming a group index (ng) of approximately 4.2 at 1550 nm.

Design	Delta L (µm)	Expected FSR (nm)	Splitter Type
MZI 1	108.335	5.28	Y-Branch
MZI 2	324.427	1.76	Y-Branch
MZI 3	1218.048	0.47	Y-Branch
MZI 4	159.855	3.58	Y-Branch

4. Layout

The physical layout of the four MZI designs is shown below. The design includes grating couplers for fiber coupling and standard Y-branch splitters.



5. Fabrication

The devices are designed to be fabricated at the Washington Nanofabrication Facility (WNF). The process flow involves the following key steps:

- Substrate: Silicon-on-Insulator (SOI) wafers with 220 nm Silicon on 3 μm Buried Oxide.
- Lithography: 100 keV Electron Beam Lithography (JEOL JBX-6300FS).
- Resist: Hydrogen Silsesquioxane (HSQ) negative resist.
- Etching: Inductively Coupled Plasma (ICP) etching using chlorine gas chemistry.
- Cladding: Deposition of 2.2 μm PECVD Oxide.

6. Experimental Plan

Post-fabrication, the devices will be characterized using an automated optical test setup. Light from a tunable laser (Agilent 81600B) will be coupled into the chip using grating couplers. The transmission spectrum will be swept from 1500 nm to 1600 nm. The resulting data will be processed using Python scripts to identify peak locations and extract the FSR for each MZI design.

7. Conclusion

This design proposal outlines a robust method for extracting the group index of silicon waveguides. By implementing multiple unbalanced MZIs with varying path lengths, we ensure that accurate FSR measurements can be obtained regardless of specific fabrication variations. The results from this experiment will provide essential feedback for the calibration of photonic process design kits (PDKs).

8. References

1. Chrostowski L., Hochberg M., 'Silicon Photonics Design', Cambridge University Press, 2015.
2. Bojko R.J., et al., 'Electron beam lithography writing strategies for low loss silicon optical waveguides', J. Vac. Sci. Technol. B, 2011.