Design, Fabrication and analysis of Silicon based Imbalanced Mach Zehnder Interferometer

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Abstract

This report is about designing, fabricating, optimizing and analyzing of Imbalanced Mach Zehnder Interferometer on a silicon photonic integrated circuit. The device will be fabricated and tested by the program offered by SiEPIC-fab (Silicon Electronics Photonics Integrated Circuits fabrication).The measured values will be compared and analysed with the simulation results obtained using Lumerical MODE and INTERCONNECT.

1 Introduction

Silicon photonics is a technology platform that enables the integration of optical components on a silicon substrate using fabrication processes compatible with complementary metal oxide semiconductor (CMOS) technology. By exploiting the high refractive index contrast between silicon and silicon dioxide, silicon photonics provides strong optical confinement and enables compact device footprints. This compatibility with mature CMOS manufacturing processes allows scalable and cost-effective production of photonic integrated circuits (PICs), in which multiple optical functions like waveguides, couplers, modulators, filters and photodetectors are integrated on a single chip. Among the fundamental building blocks of silicon PICs is the Mach Zehnder interferometer (MZI), which consists of two optical splitters and two arms in which the relative phase of light can be controlled. In silicon photonics, MZIs are widely used for modulation, switching and filtering by inducing phase shifts through thermo-optic, carrier based effects or varying pathlength which precise control of optical interference at the output. In this work, we present the fabrication of Mach–Zehnder interferometers (MZIs) with different optical path lengths and analyze the resulting output variations as a function of phase changes that give rise to interference effects

2 Theory

An unbalanced Mach Zehnder interferometer (MZI) is a fundamental photonic device in which the two optical paths (arms) have unequal lengths, introducing a controlled phase difference between light propagating in each arm. This path length difference, ($\Delta L = L_2 - L_1$), produces wavelength-dependent interference at the output, which can be exploited for filtering, sensing, or wavelength-division multiplexing. Unlike balanced MZIs, which are primarily used as modulators or switches, unbalanced MZIs generate spectral interference fringes, enabling precise control over the transmitted intensity as a function of wavelength. The phase evolution of light in each arm is determined by the effective index (n_{eff}) of the guided mode, which depends on waveguide geometry and material properties. The phase difference between the two arms at a wavelength (λ) is expressed as:

$\Delta \phi = \frac{2\pi}{\lambda} n_{\text{eff}} \Delta L$

This phase difference directly affects the interference at the output: constructive interference occurs when $\Delta \phi = 2m\pi$ (with m an integer), resulting in maximum intensity, while destructive interference occurs when $\Delta \phi = (2m+1)\pi$, producing intensity minima.

The group index ((n_g)) defines the propagation of optical pulses or modulated signals in the waveguide,

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accounting for material and waveguide dispersion:

$n_g = n_{\text{eff}} - \lambda \frac{dn_{\text{eff}}}{d\lambda}$.

The group index also determines the free spectral range (FSR)of the unbalanced MZI, which is the wavelength spacing between adjacent intensity maxima:

$\text{FSR} = \frac{\lambda^2}{n_g \Delta L}$.

A larger path-length difference (ΔL) results in a smaller FSR, producing closely spaced interference fringes in the transmission spectrum.

The intensity-based transfer function of an ideal lossless unbalanced MZI is given by:

$I_{\text{out}}(\lambda) = I_{\text{in}} \cos^2\left(\frac{\pi n_{\text{eff}} \Delta L}{\lambda}\right)$,

where I_{in} is the input intensity and I_{out} is the output intensity at a given wavelength. By carefully designing ΔL, n_{eff}, and n_g, unbalanced MZIs can be tailored to achieve desired spectral characteristics, making them essential components in silicon photonic circuits for filtering, sensing, and wavelength-selective routing

3 Modelling and Simulation

The waveguide dimensions are width=500nm and thickness=220nm with TE polarization. The operating wavelength is 1550nm.

The fitted model for effective index in wzaveguide compact model is obtained as:

$2.444 - 1.130(\lambda - 1.55) - 0.038(\lambda - 1.55)^2$

The effective index and group index dependency on wavelength for silicon waveguide is plotted using Lumerical MODE. The layout for imbalanced MZI configurations is constructed in Klayout and corresponding spectrum is obtained in Lumerical INTER-CONNECT.

4 Fabrication

to be completed
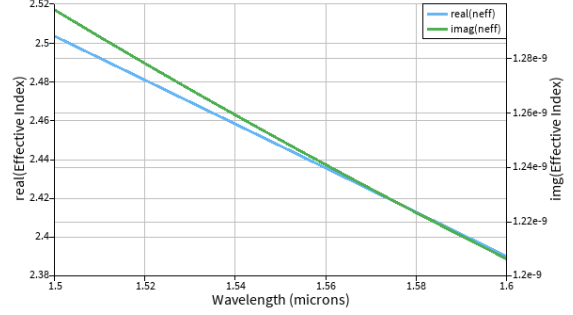
5 Experimental Data

to be completed

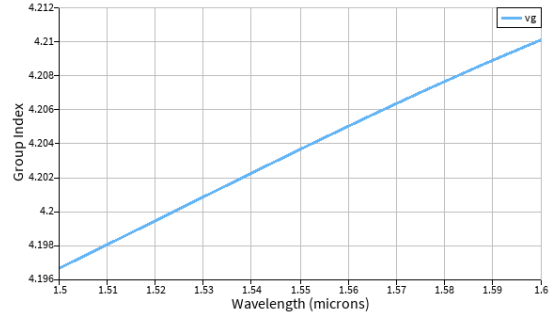Figure 1: Effective index simulated using Lumerical MODE

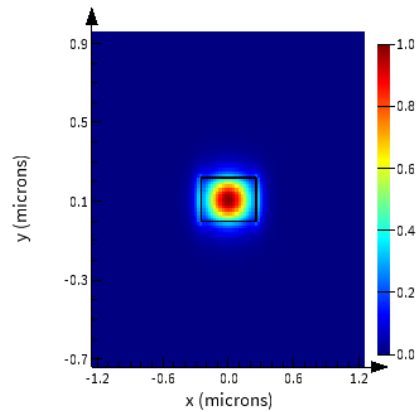Figure 2: Group index simulated using Lumerical MODE
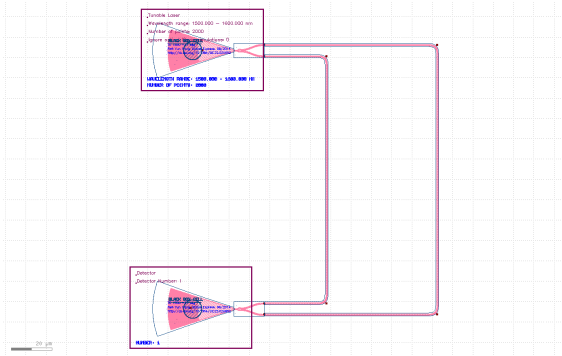

Figure 3: Mode profile for first order TE mode
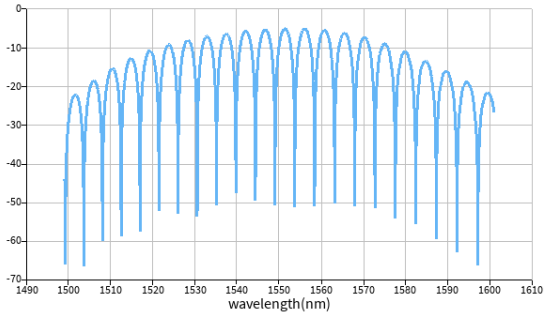
Figure 4: Simple MZI layout in Klayout

Figure 5: Output spectrum at the detector using Lumerical INTERCONNECT for $\Delta L =$120nm

6 Analysis

to be completed

7 Conclusion

The conclusion goes here.

References

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