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

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Abstract

This report is about designing, fabricating, optimizing and analyzing of Imbalanced Mach Zehnder Interferometer and Microring resonator 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, 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

A microring resonator is wavelength-selective cavitiy that enhance light–matter interaction. It consist of closed-loop waveguide, traps light by continuous total internal reflection and supports resonant circulation at specific wavelengths. When a straight waveguide is placed close to the ring, light can couple evanescently into it, but only wavelengths that satisfy the resonance condition build up constructively. These resonant wavelengths depend on the ring's radius, effective refractive index, and losses and they show up as sharp transmission dips or peaks in the coupled waveguide spectrum. Small changes in refractive index by temperature, electric fields or the presence of analytes can shift the resonance wavelengths, which makes microrings powerful for modulation, switching and sensing. Their compatibility on photonic chips and small footprint enables applications such as filters, wavelength-division multiplexing, compact lasers, nonlinear optics and biosensors. For a microring resonator, the resonance condition is obtained when accumulated phase shift equals an integer multiple of 2π.

$m\lambda = 2\pi R n_{eff}$

m is the mode number, R is the radius of the ring and n_{eff} is the effective refractive index.

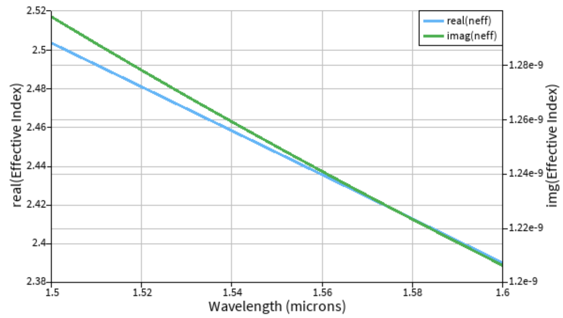

Figure 1: Effective index simulated using Lumerical MODE

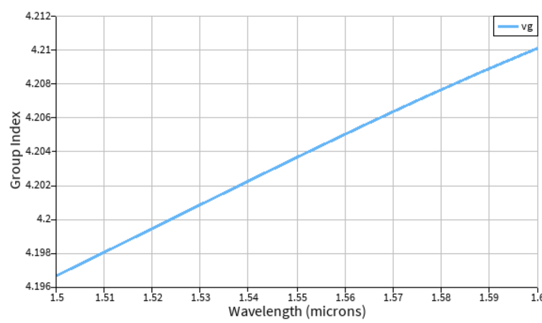

Figure 2: Group index simulated using Lumerical MODE

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 INTERCONNECT.

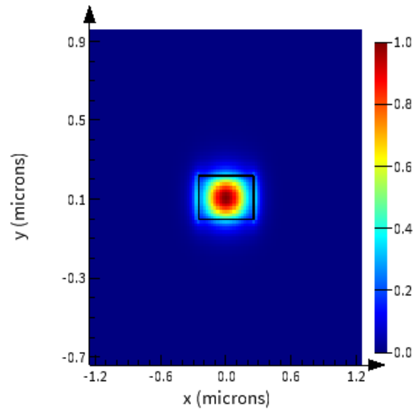

Figure 3: Mode profile for first order TE mode

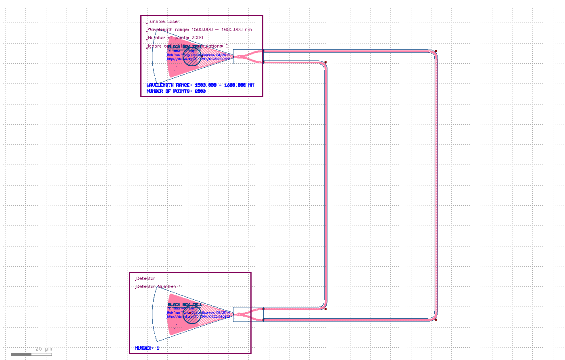

Figure 4: Simple MZI layout in Klayout

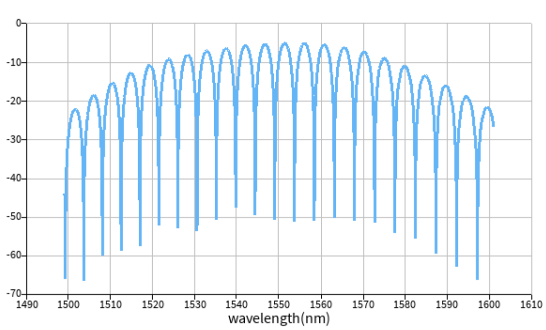

Figure 5: Output spectrum at the detector using Lumerical INTERCONNECT for ΔL =120nm

Table 1: MZI length variation and FSR at 1550nm

ΔL (μm)	FSR(nm)
270	2.120
330	1.742
422	1.361

4 Fabrication

to be completed

5 Experimental Data

to be completed

6 Analysis

to be completed

7 Conclusion

The conclusion goes here.

References

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