A Mach-Zehnder Interferometer on a Photonic Integrated Circuit

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I. Introduction

SOME general introduction to photonic integrated circuits (PICs)... work in progress...

A. Fabrication and testing

The PICs presented in this report are fabricated and tested through the openEBL program offered by the Silicon Electronics-Photonics Integrated Circuits Fabrication (SiEPICfab) program [1], [2]. The SiEPICfab uses a state-of-the-art JEOL 8100FS 100 keV electron-beam lithography tool (e-beam).

The PICs will be fabricated on a 200 mm SOI wafer. Each designer is allowed an area of 605 µm × 410 µm. This is enough room to fit approximately 5–10 simple photonic circuits.

The openEBL program offers automated optical measurements in the C-band, between approximately 1480 and 1580 nm; therefore, any spectral features that I intend to measure must fall within this range.

II. Design

A. Waveguide

For this first design, I decided to keep the design parameters very simple in order to achieve at least one working design. I chose to use the TE polarization with a waveguide height of 220 nm (fixed for the openEBL program) and a width of 500 nm.

I simulated these waveguide dimensions using Ansys Lumerical MODE. The simulated electric field intensity is shown in Fig. 1. For the TE mode at $\lambda = 1550$ nm, the simulated effective index is $n = 2.4468$, the group index is $n_\mathrm{g} = 4.2037$, and the TE polarization fraction is 0.98 (nearly entirely TE). The effective index and group index are plotted in Fig. 2 and Fig. 3.

The simulated effective index data was fitted with the following polynomial model (i.e., *compact model*):

$$n \approx 2.45 - 1.13 \cdot (\lambda - 1.55) - 0.044 \cdot (\lambda - 1.55)^2 \qquad (1)$$

B. Imbalanced Mach-Zehdner Interferometer

Mach-Zehdner interferometers (MZI) are common optical devices used in PICs to create switches and filters. They are constructed using simple waveguides and Y-branch splitters, as well as fiber grating couplers for the input and output signals.

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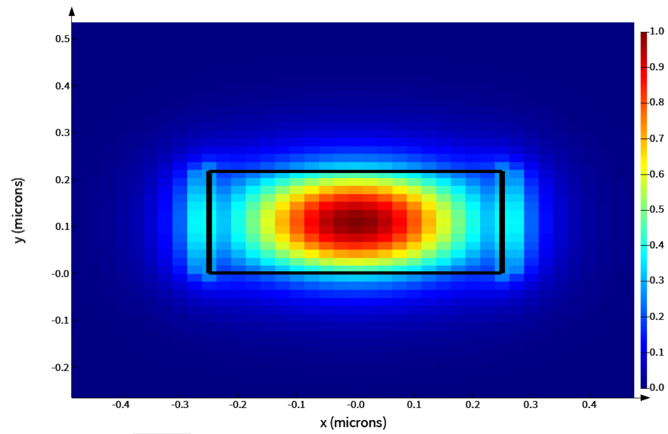

Fig. 1. Electric field intensity at $\lambda = 1550$ nm simulated using Ansys Lumerical MODE. Note that I zoomed-in on the waveguide to show the field distribution. The total simulation area was 2.5 µm × 1.7 µm.

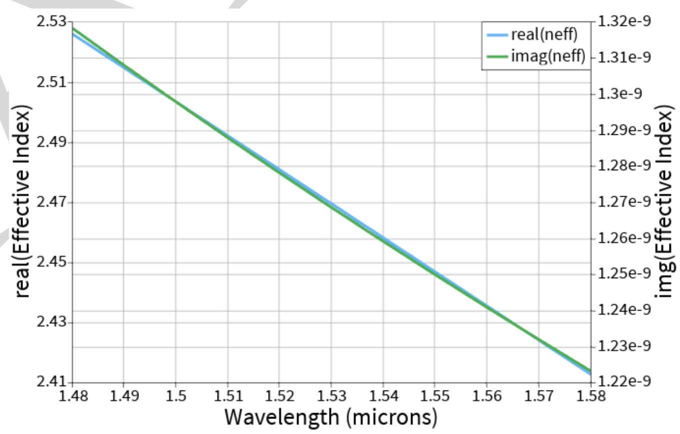

Fig. 2. Effective index simulated using Ansys Lumerical MODE.

The transfer function of a lossless imbalanced MZI is:

$$\frac{I_o}{I_i} = \frac{1}{2}\left[1 + \cos\left(\beta\,\Delta\ell\right)\right] \qquad (2)$$

where I_i and I_o are the input and output intensity, respectively; β is the propagation constant and $\Delta\ell$ is the length mismatch between the two branches of the MZI.

The goal of this design is to extract the group index from the MZI transmission spectra. The free spectral range (FSR) of an imbalanced MZI is:

$$\mathrm{FSR} \approx \frac{\lambda^2}{\Delta\ell\, n_\mathrm{g}} \quad [\mathrm{m}] \qquad (3)$$

where $\Delta\ell$ is the length mismatch between the two legs of the MZI, λ is the free-space wavelength, and n_g is the

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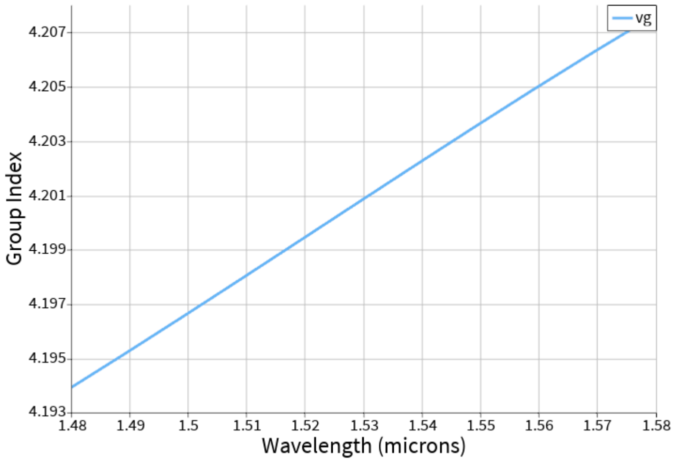

Fig. 3. Group index simulated using Ansys Lumerical MODE.

TABLE I
SUMMARY OF MZI VARIATIONS.

Num. of minima	$\Delta\ell$ (µm)	FSR (nm)
10	60	10.0
20	120	5.0
30	180	3.3

ground index. Therefore, by measuring the distance between the minima in the transmission spectra, we can extract the group index.

A target of 10 minima is will give us enough samples within the C-band measurement window to see the shape of the group index. This corresponds to a length mismatch of:

$$\Delta\ell \approx \frac{\lambda^2}{\mathrm{FSR} \cdot n_\mathrm{g}} \quad [\mathrm{m}] \tag{4}$$

With a bandwidth of 100 nm, I want an FSR of $\sim$10 nm for 10 minima within the measurement window. Assuming $n_\mathrm{g} \approx 4$, this gives a length mismatch of $\Delta\ell \approx 60$ µm. I can also create variants with 20 and 30 minima. These require length mismatches of $\Delta\ell \approx 120$ µm and $\Delta\ell \approx 180$ µm, respectively. These design variants are summarized in Table I.

These length mismatch values were validated using Ansys Lumerical INTERCONNECT, along with the SiEPIC E-Beam PDK. The gain of the imbalanced MZI with $\Delta\ell \approx 60$ µm is shown in Fig. 4. We can see 10 minima, as intended. The FSR at approximately 1556 nm is 9.2 nm. Rearranging Eq. 3, this is equivalent to a group index of:

$$n_\mathrm{g} \approx \frac{\lambda^2}{\Delta\ell \cdot \mathrm{FSR}} = 4.35 \tag{5}$$

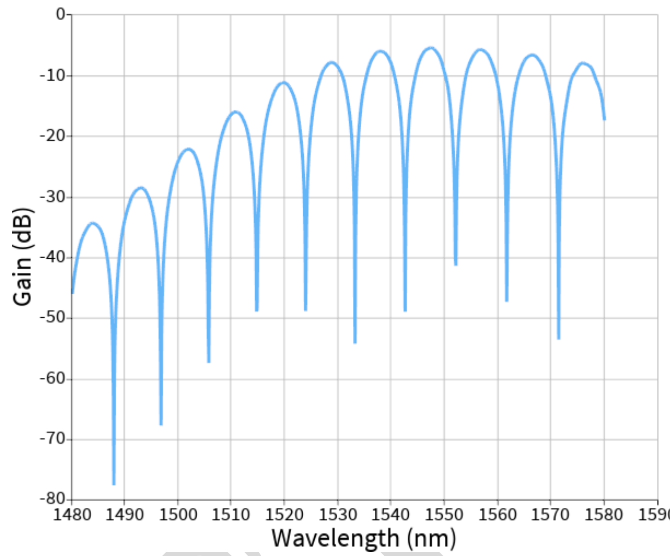

Fig. 4. Simluated gain of the imbalanced MZI with a length mismatch of $\Delta\ell \approx 60$ µm.

REFERENCES

[1] L. Chrostowski, Z. Lu, J. Flueckiger, X. Wang, J. Klein, A. Liu, J. Jhoja, and J. Pond, "Design and simulation of silicon photonic schematics and layouts," in *Proc. SPIE 9891, Silicon Photonics and Photonic Integrated Circuits V*, 989114, May 2016.

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