ELEC 413 - Project 1 (& 2) Design Document

Ian Pang
Engineering Physics
The University of British Columbia
Vancouver, B.C., Canada
ianrpang@student.ubc.ca

***Abstract*—This document outlines the design process of two projects INSERT WORD during the ELEC 413 course conducted from January to April of 2025. The two projects in question both involve the design of a Mach-Zehnder Interferometer (MZI). However, the way we will characterize each MZI will be different. Additionally, the cladding material for the waveguides will be different in each case.**

I. Project 1: Mach–Zehnder Interferometer 1

A. Project Introduction

TODO: Introduce what project is about and some details/background/usage?

B. Design Goals and Specifications

The Mach-Zehnder Interferometer is to be designed to produce a 25GHz Free Spectral Range (FSR) centered at a wavelength of 1310nm. This design will require the use of waveguides dimensions of 220nm (height) x 350nm (width). Key parameters that need to be determined to produce such a result include the **group index** n_g of the waveguide used, and the **length difference** ΔL between the two arms of the Interferometer. Other parameters such as the **effective index** n_{eff}, whose dependance on wavelength (i.e. $\frac{dn_{eff}}{d\lambda}$) can be used to determine the group index n_g via the relation,

$$n_g = n_{eff} - \lambda \frac{dn_{eff}}{d\lambda} \tag{1}$$

The equation of interest relating the Free Spectral Range (FSR) to the waveguide group index n_g is the following,

$$\Delta\nu \approx \frac{c}{\Delta L n_g} \tag{2}$$

where $\Delta\nu$ is the Free Spectral Range in GHz, and c is the speed of light. Given that we find the group index n_g we can determine an appropriate length difference ΔL to produce the desired Free Spectral Range (Add reference for these equations). As you will see in the proceeding sections I will use two different methods for determining ΔL. One involves determining n_g directly while the other utilizes the n_{eff} and Equation 1

C. Modeling Methods

This section goes over two different methods of determining the group index n_g, which thereby allows us to determine ΔL via Equation 2. The Ansys software Lumerical MODE will be used to determine n_g directly while MATLAB will be used in conjunction with Equation 1.

1) Modeling in Lumerical MODE:

This section aims to caluclate the group index of the waveguide, n_g, using Lumerical MODE. The waveguide simulated has dimensions of 220nm (height) x 350nm (width) with a silicon core and silicon dioxide cladding. Please see Appendix A for details on geometry and physical parameter setup.

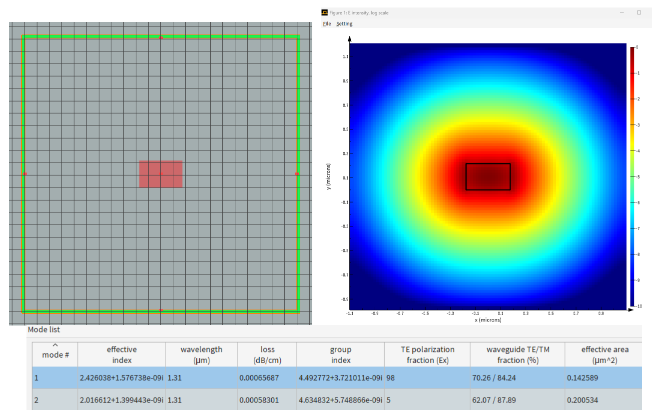

Fig. 1. **(a)** (top left): An image of the cross section of the waveguide in Lumerical MODE. The silicon core can be seen in red at the center surrounded by silicon dioxide cladding. **(b)** (top right): An image of the simulated TE mode within the waveguide. The field intensity is plotted on a log scale and sufficient decay of the field near the border of the simulation region is shown. **(c)** (bottom): A list of the modes calculated. See in the first row is the first TE polarized mode with a group index of 4.492772.

The waveguide created in Lumerical MODE can be seen above in Figure 1a, with its simulation shown to the right in Figure 1b. Looking at Figure 1c, we see that the group index n_g in the first row, corresponding to the first TE polarization mode, is $n_g = 4.492772$. We can determine the appropriate value for ΔL given the group index n_g found to be,

$$\Delta L \approx \frac{c}{\Delta\nu n_g} = \frac{299792458 \frac{m}{s}}{(25 \cdot 10^9 s^{-1}) \cdot 4.492772} = 2669.11 \mu m$$

2) Modeling in MATLAB:

D. Design

E. Design Variations

Work in progress

II. Project 2: Mach-Zehnder Interferometer 2

A. Project Introduction

TODO: Fill in

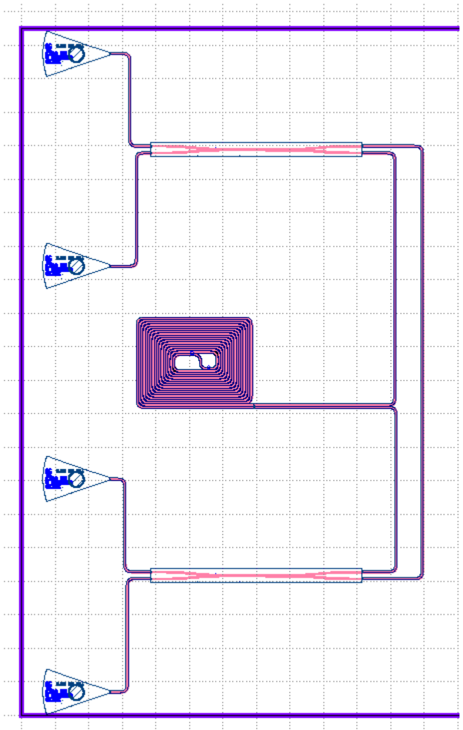

Fig. 2. Chip 1 Design TODO: Fill in. Note this image should be earlier in the document but latex is being uncooperative at the moment

B. Design Goals and Specifications

TODO: Fill in. Follows mostly the same as I-B

C. Modeling Methods

1) Modeling in Lumerical MODE: TODO: Insert images

The waveguide created and simulated in Lumerical MODE shown above (clearly not above at the moment but a picture will be there eventually), Seen in figure (add reference), the field intensity decays an adequate amount around the edges on the simulation frame. Above, we also see the group index for the first TE polarization mode is $n_g = 4.777233$. We can thus get an appropriate ΔL as,

$$\Delta L \approx \frac{c}{\Delta \nu n_g} = \frac{299792458 \frac{m}{s}}{(25 \cdot 10^9 s^{-1}) \cdot 4.777233} = 2510.177\mu m$$

2) Modeling in MATLAB: TODO: Insert images and results

D. Design

Seen below is the inital chip design for project 2. It incorporates a 50/50 directional couple to be able to interface with the on-chip laser and an external laser that will provide signal through the center grating coupler. A paperclip/spiral component is used to achieve the $\Delta L = 2510.177\mu m$ needed to produce a 25GHz FSR. Note: need to sim in interconnect to verify

E. Design Variations

Work in progress

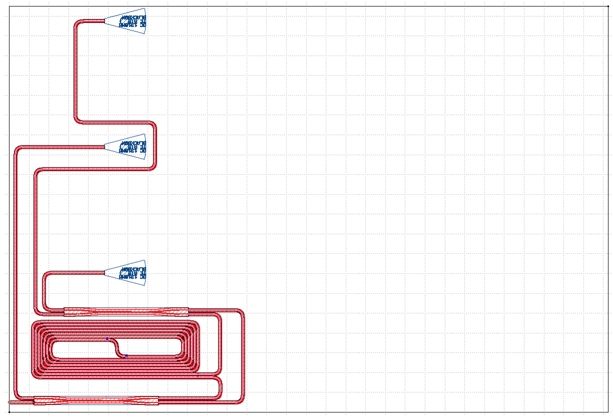

Fig. 3. Chip 2 Design TODO: Fill in

APPENDIX

Appendix A: Lumerical Mode Geometry and Physical Parameter Setup

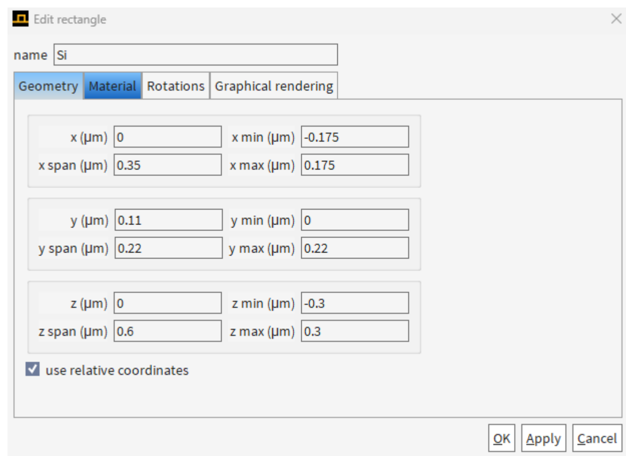

Fig. 4. View of the setup for the geometry of the silicon core. Seen above, it spans a width of 350nm and spans a height of 220nm centered at 110nm

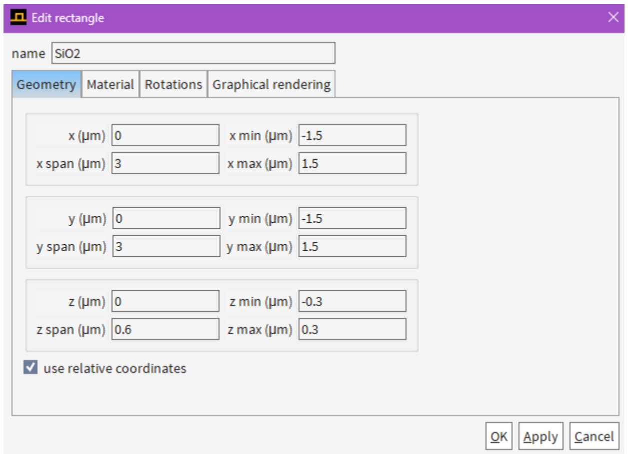

Fig. 5. View of the setup for the geometry of the silicon dioxide cladding. Seen above, the width and height span both $3\mu m$, centered at 0 for both x and y.

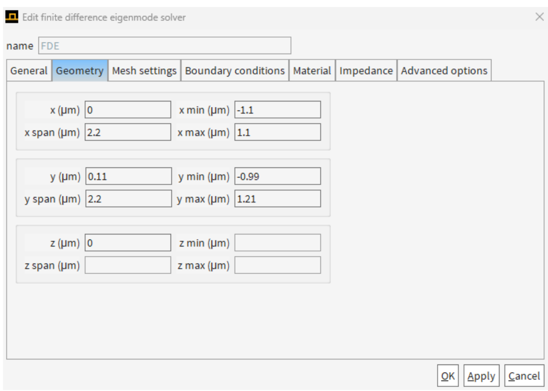

Fig. 6. View of the setup for the boundary of the simulation. Seen above, the simulation area is centered around the silicon core (i.e. centered at x = 0 and y = 0.11nm)

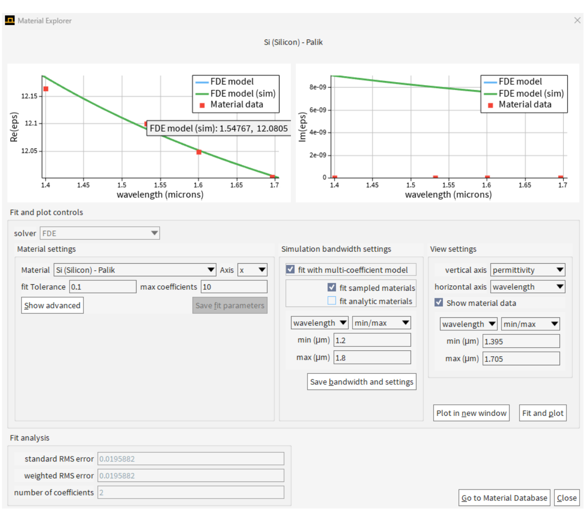

Fig. 7. A view of the material properties for silicon. A multicoefficient model was used to fit data within the wavelength range of $1.2\mu m$-$1.8\mu m$

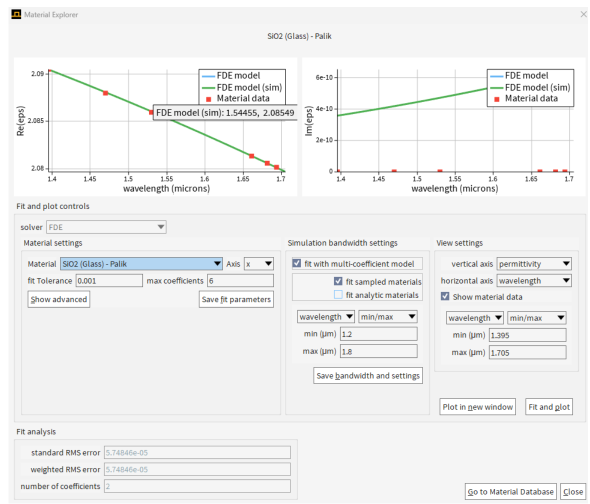

Fig. 8. A view of the material properties for the silicon dioxide cladding. A multicoefficient model was used to fit data within the wavelength range of $1.2\mu m$-$1.8\mu m$. Additionally, a fit tolerance of 0.001 was used to achieve a better fit.