A project report on computer simulations and optimization of device parameters for the design of a nano-photonics chip

Project Report

SUBMITTED FOR THE PARTIAL FULFILLMENT OF THE INTERN RESEARCH ASSISTANT COURSE

BY

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Chapter 1

Introduction

This report is written as part of a research project aiming to develop an immensely scaled down version of an Optical Coherence Tomography (OCT) imaging system targeted to image the bronchi of the lungs as a photonics integrated chip. A single chip comprises of optical processors, light sources and detectors. In the scenario of developing countries like Nepal, it offers an unique solution being an extremely small, cheap, point-of-care system of diagnosing various stages of lung conditions, especially the top killer disease of countries like Nepal, Chronic Obstructive Pulmonary Disease (COPD). On a technological aspects, it exploits the high computation capabilities of electronics and the high communication bandwidth of photonics to develop innovative building blocks of photonic integrated circuits (PICs) using low-loss optical waveguides, IR sensors and CMOS camera. [1][2]

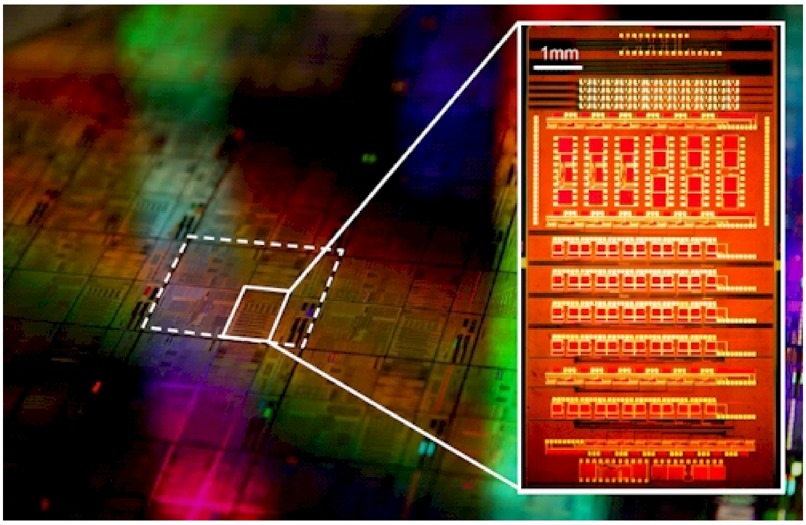

Figure 1.1: An example of silicon nano chips

Chapter 2

Waveguide

A waveguide is a structure that guides waves, such as electromagnetic waves or sound, with minimal loss of energy by restricting expansion to one dimension or two. There are different types of waveguides for each type of wave. The geometry of a waveguide reflects its function. Slab waveguides confine energy in one dimension, fiber or channel waveguides in two dimensions. The frequency of the transmitted wave also dictates the shape of a waveguide: an optical fiber guiding high-frequency light will not guide microwaves of a much lower frequency. [3]

2.1 Characterization of a Waveguide

In order for a waveguide to constraint the electromagnetic waves, it has to be optimized for the minimum radiation losses. The percentage of radiation losses depends on the wavelength, waveguide geometry and the geometry of the surrounding cladding layers. The first task I was assigned during the internship was to observe the propagation of different modes and conversion between them as they traverse the waveguide. Effective refractive indices, used to track the mode conversion, is essentially the average of the refractive indices of the waveguide. Using Python programming language, the waveguide was simulated and 1310 nm wavength light was used as source traversing 0.34μm height waveguide with varying width of 0.1-1μm with cladding of 1μm on the top and 2μm on the bottom of silica (SiO_2). The start and the end profile is shown in the Figure 2.1 and Figure 2.2 respectively.

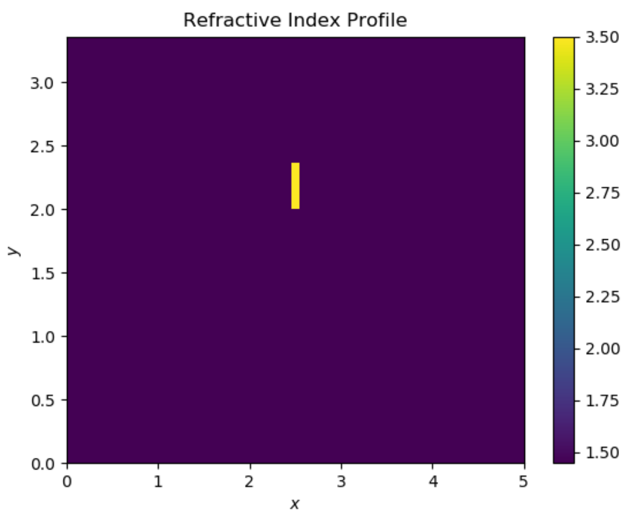

Figure 2.1: The starting profile of the waveguide structure

2.2 Mode conversion

Looking at waveguide theory it is possible to calculate that there are a number of formats in which an electromagnetic wave can propagate within the waveguide. These different types of waves correspond to the

Figure 2.2: The end profile of the waveguide structure

different elements within an electromagnetic wave.

- TE mode: This waveguide mode is dependent upon the transverse electric waves, also sometimes called H waves, characterised by the fact that the electric vector (E) being always perpendicular to the direction of propagation.

- TM mode: Transverse magnetic waves, also called E waves are characterised by the fact that the magnetic vector (H vector) is always perpendicular to the direction of propagation. [4]

The modsolverpy packages along with matplotlib, numpy and scipy were very helpful for obtaining plots as shown in the Figure 2.3 .

Moreover, the program also provided the data that shed light on the mode conversion which occured at specific taper width and effective index. In order to rotate the polarization of light as it traverses the waveguide, it is imperative to know such parameters. Using matplotlib and numpy, I was able to plot a graph showing the mode conversion phenomena as shown in Figure 2.4 .

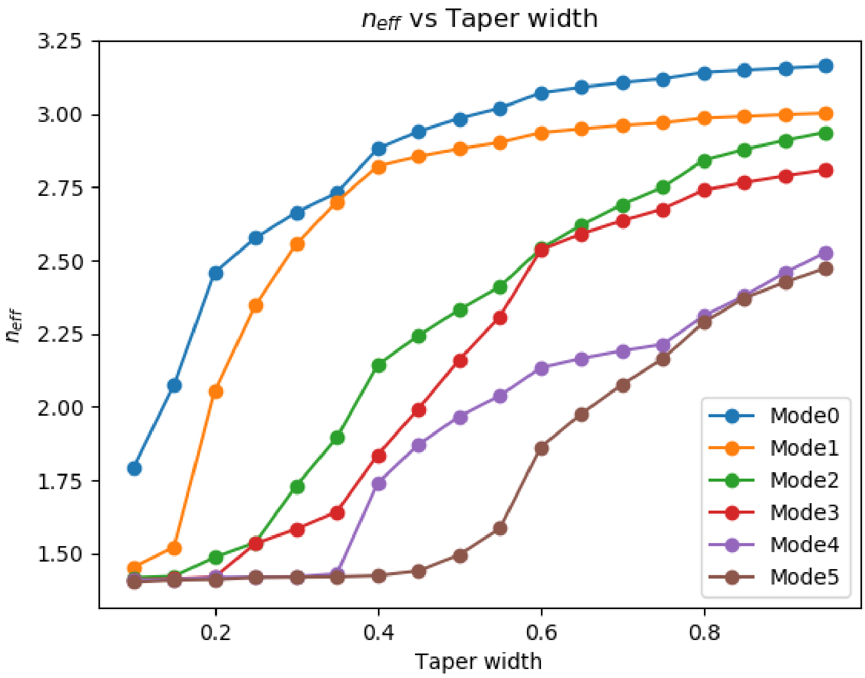

Figure 2.3: Plot showing the effective index and taper width of the waveguide structure

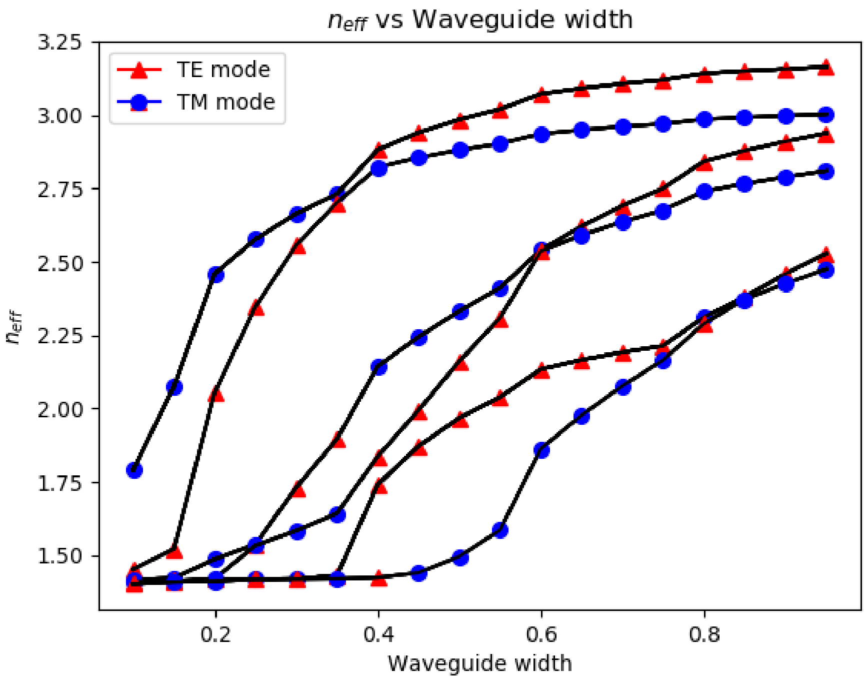

Figure 2.4: Plot showing the mode conversion in the waveguide structure

Chapter 3

Multi Mode Interferometer (MMI)

A multimode interferometer is essentially a broad waveguide with many (but a finite number) of guided modes. Each mode i, which we indicate as ψ_i, has a propagation constant. Because the modes are eigenmodes, they propagate independently from one another. When an MMI is excited by an incident wave, the field profile is decomposed into the eigenmodes. Even though there is no exchange of energy between these eigenmodes, they propagate at a different velocity, and the result is an interference pattern that changes along the length fo the MMI. [5]

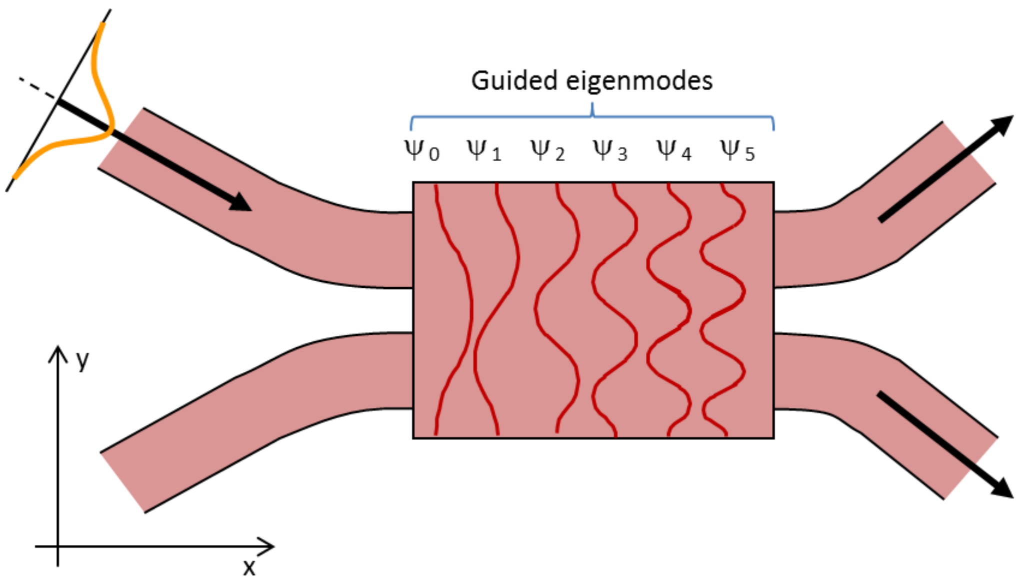

Figure 3.1: Modes on a Multi Mode Interferometer (MMI)

For the purpose of preventing reflection losses, tapers are added to guide the light into and out of the waveguide usually from the position where the interference peaks occurs. A standard design from Cornerstone is shown in the Figure 3.2 .

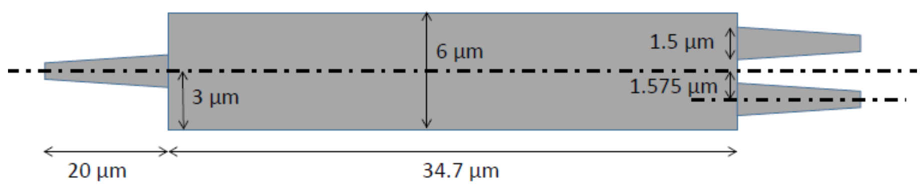

Figure 3.2: Standard design of a MMI

3.1 MMI design

Using Lumerical, a simulation was performed to optimize the MMI for minimum radiation losses which was achieved by pinpointing the peaks created by the interference pattern as the light traverses through the MMI. After many trials and errors method, a suitable MMI length was obtained for various MMI width of 5, 6 and 10 μm. A plot which shows the propagation of light through the MMI is shown in Figure 3.3 .

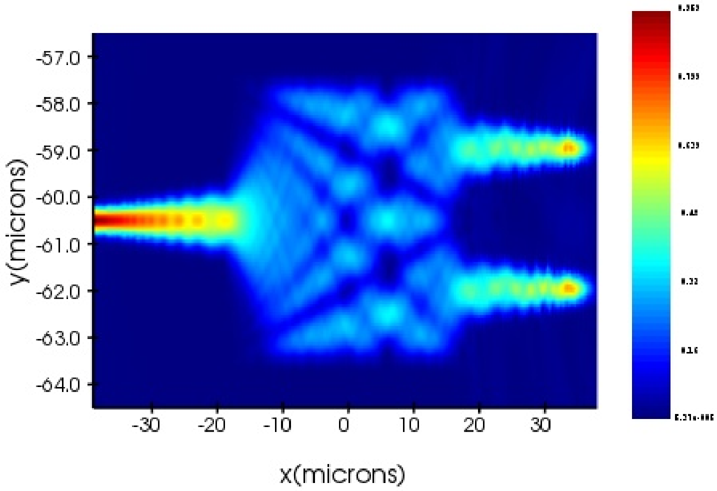

Figure 3.3: Propagation of light through the MMI

A table showing the percentage of radiation losses for varying MMI geometry is shown in Table 3.1 .

S. N.	MMI width	MMI length	Output dist. from centre width	Trans. on MMI input	Trans. on each MMI output s	Output/Input
1	5	31.9847	2.4924	1.019	0.502	0.985279686
2	6	38.0738	3.0032	1.0203	0.4995	0.9791237871
3	10	105.808	4.9672	0.991	0.46	0.9283551968

Table 3.1: MMI geometry and Transmission loss

3.2 Taper geometry

The taper geometry is equally important in order to reduce the amount of light passing out of the MMI. Hence, a suitable taper geometry is essential to design a MMI for minimized power losses. Using MODE solution from Lumericals, I was able to simulate taper of 10μm and 20μm length with 0.4μm and 1.5μm width at both ends respectively. Table 3.2 summarizes the results.

S. N.	Taper length	Pin	Pout	Pout/Pin	Ploss
1	10	1.08601	0.730343	0.672501174	0.2928501986
2	20	1.00813	0.944896	0.9372759466	0.0555519955

Table 3.2: Taper geometry and Power loss

Chapter 4

Grating Coupler

A grating coupler is a region on top of or below a waveguide where there is a grating. For specific combinations of incident angles and light frequency of the source, there is resonance, allowing the grating to couple light into a guided mode of the waveguide. The larger the diffraction efficiency of the grating, the larger percent of light that would be coupled in. If the grating is used as a coupling-out element, the larger the diffraction efficiency, the fewer periods would be needed to couple the light out.[6] The grating coupler with standard dimension from Cornerstone is shown in figure 4.1 .

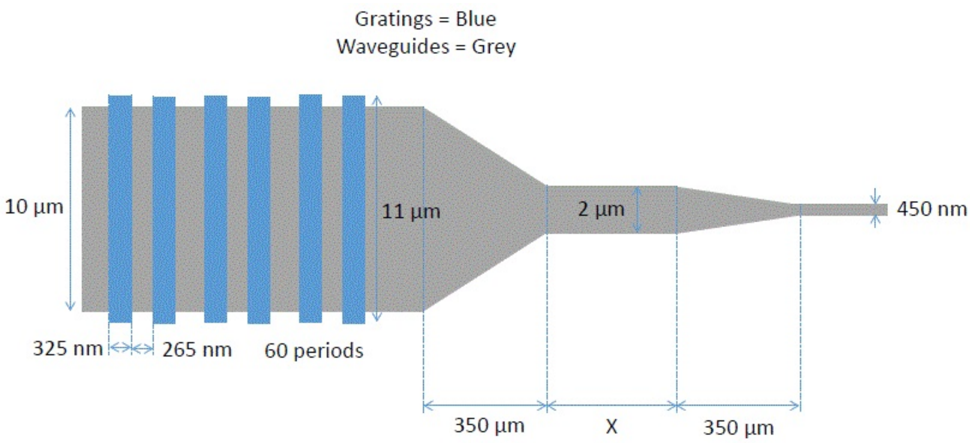

Figure 4.1: Grating coupler with standard dimension from Cornerstone

Using FDTD solutions from Lumerical, I was able to conduct simulation for grating coupler of etch dimension 0.25μm and feature width of 0.2, 0.26, 0.32 and 0.38μm using wavelength of 1260, 1283.6, 1308.9, 1333.54 and 1360 nm for fundamental TE mode. The result is summarized in the table as shown in 4.1 .

S. N.	Feature	Wavelength	1260	1283.6	1308.9	1333.54	1360
		Angle peak					
1	0.2		-9.97237	-15.2638	-20.8152	-26.4518	-32.5162
2	0.26		10.9055	5.68729	-0.516185	-2.81143	-6.4948
3	0.32		31.4344	25.9405	21.5533	16.0978	11.4901
4	0.38		49.2699	42.9752	37.7061	32.7886	29.4387

Table 4.1: Grating coupler and Incident angle peaks for fundamental TE mode

Chapter 5

Polarization Rotator

A polarization rotator (PR) is an optical device that rotates the polarization axis of a linearly polarized light beam by an angle of choice. Such devices can be based on the Faraday effect, on birefringence, or on TIR. Since laser beams tend to be linearly polarized, it is often necessary to rotate the original polarization to its orthogonal alternative. [7]

I order to convert a TE mode into TM mode for required properties, a PR is used for a linearly polarized light beam. It is crucial to measure the diffraction angle for such purposes. Table 5.1 shows the angle peak for a PR of 0.34μm height, etch dimension 0.25μm and feature width of 0.2, 0.26, 0.32 and 0.38μm using wavelength of 1262, 1285.6, 1310.09, 1335.54 and 1362 nm for fundamental TE mode.

S. N.	Feature	Wavelength	1262	1285.6	1310.09	1335.54	1362
		Angle peak					
1	0.2	TE	-16	-21	-25	-30	-37
		TM	-10	-16	-18	-23	-29
2	0.26	TE	15	9	4	-14	-15
		TM	12	10	-1	-2	-8
3	0.32	TE	30	25	20	16	11
		TM	26	21	18	14	10
4	0.38	TE	45	40	34	25	25
		TM	41	36	30	25	21

Table 5.1: Polarization rotator and Incident angle peaks for fundamental TE mode

Chapter 6

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