Design proposal for the Mach-Zehnder Interferometer

Silicon Photonics Design

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Abstract

This report describes the design of a Fabry Perot Resonator Cavity to be fabricated using Electro-Beam lithography. The purpose of this design was to design a Fabry Perot Resonator Cavity to support the highest possible Q factor through experimentation and variation of the device parameters.

Simulated results and analytical evaluations are presented in order to support the final design choices and thoroughly explain the thought process behind the determined parameter values. The design was modelled using various simulation methods including, Lumerical MODE, Lumerical INTERCONNECT and MATLAB to determine the various parameters.

To all peer assessment reviewers, I had a minor mental breakdown while trying to get this done so I have handed in what I had prior to said mental breakdown. Any advice on how to complete kappa, Q, and FSR calculations and the interconnect simulations would be greatly appreciated.

(State conclusion/outcome here)

1. Introduction

1.1. Project Objective

The objective of this project is to design a Waveguide Bragg Grating using a Fabry-Perot Cavity with the overall goal of achieving the highest possible quality factor. We will first simulate a waveguide that can operate at a central frequency of 1310nm. We design this waveguide with a geometry of 350nm x 220nm to be operated using the TE polarization. Using these dimensions and specifications we will then simulate the effective and group indices for the waveguide using Lumerical MODE. Once the waveguide parameters have been determined we will using the Transfer Matrix Method of a Bragg Grating to determine the optimal corrugation width range, number of gratings and cavity length. This will all be done using various MATLAB scripts. ONce we have determined the parameter ranges and parameters we would like to vary we will simulate our designs using Lumerical INTERCONNECT. If the INTERCONNECT simulations are successful we will finally use KLAYOUT to design out devices on a Silicon Photonic chip to be fabricated using Electro-Beam Lithography.

2. Theory

In it's simplest form the Fabry-Perot Cavity is simply two partially reflective mirrors spaced at a de-

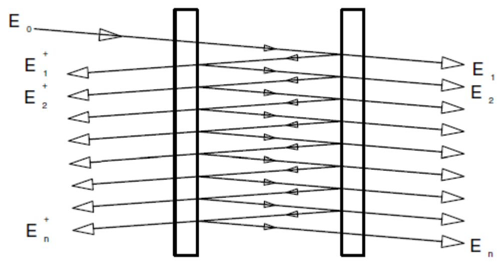

Figure 1: Simplified Fabry-Perot Cavity

termined distance from one another. When light hits this cavity some is transmitted

(Add theory)

3. Modelling and Simulation

3.1. Waveguide Equation

For this Fabry-Perot Cavity design we plan to operate using 1310nm as our central Frequency, as such we begin by modelling a waveguide to support this frequency. 1310nm places our operating region in the Oband, due to this the width of our waveguide must be 350nm, however we plan to fabricate our device using Electro-Beam Lithography which means the final device will likely be closer to 335nm in width. Due to this all calculations and simualtions will be operated with a waveguide width of 335nm and a depth of 220. We also choose to model the waveguide such that it will support a TE polarization.

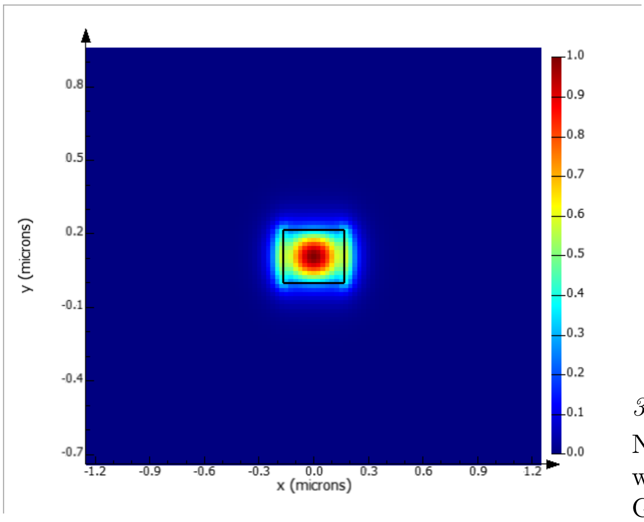

Figure 2: TE mode profile

3.2. Waveguide Compact Model

Once we have the geometry and mode data for our waveguide configured we can model the effective and group indices of the waveguide using the following Taylor expansion,

$$n_{eff}(\lambda) = n_1 + n_2(\lambda - \lambda_0) + n_3(\lambda - \lambda_0)^2$$

with this model we get the graphical relationship seen in figures 3 and 4.

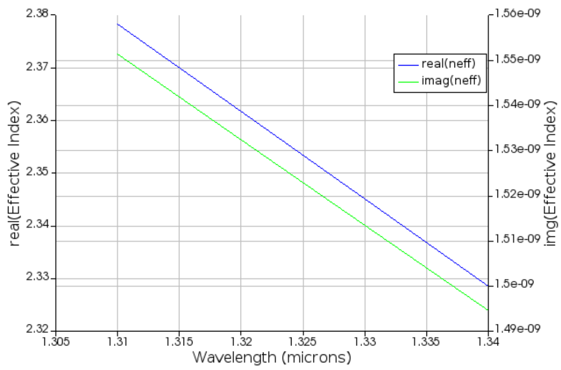

Figure 3: Effective index vs Wavelength

Using a MATLAB script we find our final compact waveguide model to be

$$n_{eff}(\lambda) = 2.3782 - 1.6552(\lambda - 1.31) - 0.0386(\lambda - \lambda_0)^2$$

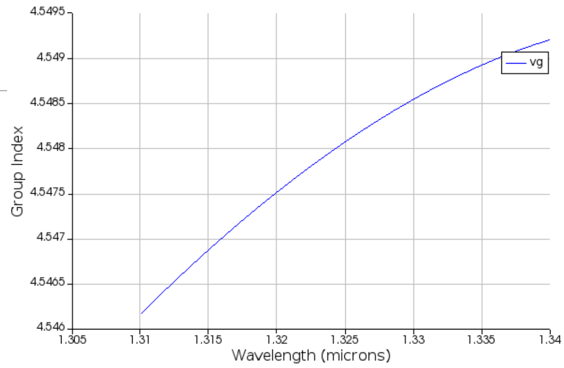

Figure 4: Group index vs Wavelength

3.3. Bragg Grating Parameters

Now that the waveguide properties have been set we can determine the parameters of our Bragg Gratings.We can begin by determining the Bragg grating period that satisfies a central wavelength of 1310nm, the equation for the Bragg Period is as follows where λ_B = Central Wavelength

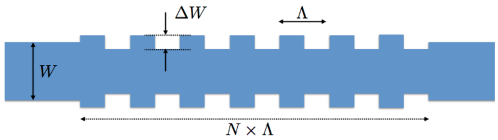

Figure 5

$$\Delta = \frac{\lambda_B}{2n_{eff}}$$

Now that we have the Bragg Period there are only a few more parameters to find in regards to our bragg grating, namely the corrugation width (dW), the Number of gratings, the Bandwidth and the kappa value. (Explain what these are)

$$\kappa = \frac{\pi * BW}{\lambda^2}$$

We can use FDTD to find this information using a unit cell simulation provided by Professor Lukas Chrostrowski. For our design we will keep the width and the Bragg grating fixed and vary the number of gratings and corrugation width. However we must determine the general operating points of these values if we want to maximize our Quality Factor. To gather the operating points of these parameters we will sweep our corrugation width from 10nm to 100nm. WE can then directly extract the Bandwidth and central wavelength values corresponding to our various corrugation widths and calculate the relationship between kappa and corrugation width, the results for these simualtions are shown in the following plots.

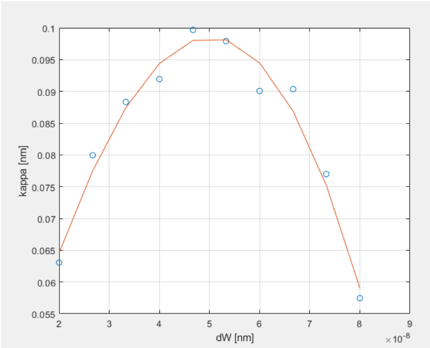

Figure 6

$$\Delta n = \frac{\kappa \lambda_B}{2}$$

3.4. Transfer Matrix Method

The transfer Matrix method (TMM) is used to analyze the propagation of an electromagnetic wave travelling through a medium of varying effective indices. Using this method we can produce reflection and transmission spectrum's for our Fabry Perot Cavity. We can use the TMM to model our fabry perot cavity as a series of high and low index waveguides.

$$T_{cavity} = T_{hw2}T_{is21}T_{hw1}T_{is1c}T_{hwc}T_{isc1}T_{hw1}T_{is12}T_{hw2}$$

we can model the left and the right bragg gratings as the following, where NG is the number of gratings, T_{hw*} is the transfer matrix for a homogeneous waveguide, and T_{is**} is the transfer matrix for a boundary.

$$T_{left} = (T_{hw2}T_{is21}T_{hw1}T_{is12})^{NG-1}$$

$$T_{right} = (T_{is21}T_{hw1}T_{is12}T_{hw2})^{NG-1}$$

The propagation matrix for a homogeneous waveguide T_{hw*} is defined as follows

$$T_{hw} = \begin{bmatrix} e^{jL} & 0 \\ 0 & e^{j\beta L} \end{bmatrix}$$

and the propagation matrix for a boundary is

$$T_{is} = \begin{bmatrix} \frac{n_1+n_2}{2\sqrt{n_1 n_2}} & \frac{n_1-n_2}{2\sqrt{n_1 n_2}} \\ \frac{n_1-n_2}{2\sqrt{n_1 n_2}} & \frac{n_1+n_2}{2\sqrt{n_1 n_2}} \end{bmatrix}$$

where L is the waveguide length and is the propagation constant ($= \frac{2\pi n_{eff}}{\lambda} - \frac{\alpha}{2} * j$ where α is loss

To find the effective indices for each section of the waveguide we use the following equations

$$n_1 = n_{eff} - \frac{\Delta n}{2}$$

$$n_2 = n_{eff} + \frac{\Delta n}{2}$$

where n_{eff} is the compact waveguide model found previously and $\Delta n = \frac{\kappa \lambda_B}{2}$

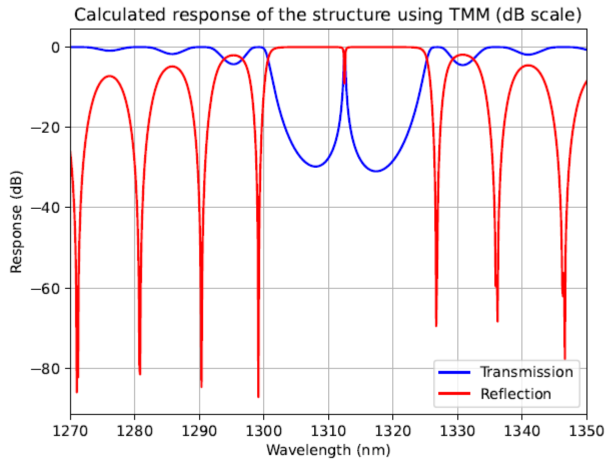

Figure 7: Transmission and Reflection Spectrum at 55nm dW and NG = 65

$\lambda_B[nm]$	$L[um]$	$dW[nm]$	NG	$L[nm]$	T_{peak}	$FSR[nm]$
1310	100	50	50	100		
1310	100	50	60	100		
1310	100	55	50	100		
1310	100	55	60	100		
1310	100	60	50	100		
1310	100	60	60	100		
1310	100	65	50	100		
1310	100	65	60	100		
1310	100	70	50	100		
1310	100	70	60	100		

Table 1: FSR for varying ΔL, without fibre gratings

3.5. Conclusion

To be done later