Design of a Bragg Resonator to Maximize the Quality Factor

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Abstract - This report highlights the steps taken to design a Fabry-Perot cavity that consists of two Bragg cavity separated by a waveguide of 100 um. The goal is to obtain the highest possible Quality factor while maintaining a central wavelength of 1310 nm. This was obtaining using Lumerical MODE, INNERCONNECT, and FDTD and simulated using MATLAB. The parameters obtained were a grating period of 273 nm, width of the waveguide at 350 nm, corrugation width of 48 nm, and number of grating periods of 60.

I. Introduction

Bragg gratings are a fundamental component for achieving wavelength selective functions of optional devices. Some of their uses include semiconductor lasers and fibers [1]. Over the past few years there has been a push to integrate them in silicon waveguides to use them on chips.

The objective of this project is to design a Bragg resonator for fabrication with a central wavelength of 1310 nm with the highest possible Quality Factor (Q). This paper outlines the steps taken including design, simulation, and fabrication to select the parameters of the Bragg cavity (figure 1) to optimize the Quality Factor.

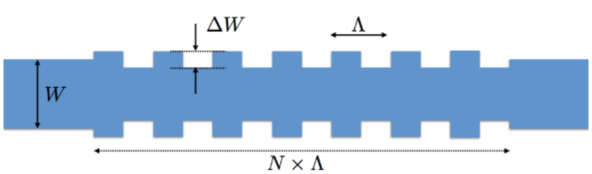

Figure 1: Bragg Cavity schematic showing the defining parameters, N = number of grating period, delta W = corrugation width, W = waveguide width, and = grating period [1]

II. Theory and Model

Bragg Gratings are optical filters that are based on the width, number of Bragg periods, period, and properties of Silicon. The light that enters the Bragg cavity goes through periodic modulation of two different reflective indexes n1 and n2, in the propagation direction of the optical mode [1]. The varying reflective index is based on the different dimensions of the Bragg teeth. The Fabry-Perot cavity is the combination of two Bragg cavities connected by a straight waveguide. The Quality factor of this cavity is:

$$Q = \frac{\lambda}{\Delta\lambda_{3dB}}$$

The cavity was modeled using the Transfer Matrix Method (TMM) in MATLAB and verified using Lumerical INNERCONNECT. The transfer matrix for a homogeneous section of a waveguide is shown in equation 3. Beta is the complex propagation where n_{eff} is the effective index and alpha represents the loss. Equation 4 is in index step matrix for the boundary between n1 and n2. n1 and n2 are the index of refraction of the alternating sections in the Bragg waveguide and are calculated.

$$n_{1,2} = n_{eff} \pm \frac{\Delta n}{2}$$

After the transfer matrix for the homogenous section and index refraction is obtained the final step is to perform a cascaded multiplication $T_p=T_{hw1}*T_{is12}*T_{hw2}*T_{is21}$. This represents one grating. For N gratings the matrix becomes T_p^N. For the whole cavity the matrix is $T = T_p^N *T_{cavity}* T_p^N*T_{is1eff}*T_{iseff2}$.

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

$$T_{is-12} = \begin{bmatrix} 1/t & r/t \\ r/t & l/t \end{bmatrix} = \begin{vmatrix} \frac{n_1 + n_2}{2\sqrt{n_1 n_2}} & \frac{n_1 - n_2}{2\sqrt{n_1 n_2}} \\ \frac{n_1 - n_2}{2\sqrt{n_1 n_2}} & \frac{n_1 + n_2}{2\sqrt{n_1 n_2}} \end{vmatrix}$$

$$\beta = \frac{2\pi n_{eff}}{\lambda} - i\frac{\alpha}{2}$$

III. Design Methodology

For this project a 220 nm thick piece of Silicon with an oxide cladding of SiO2 was used. The central wavelength was set to 1310 nm. The parameters of the Bragg cavity were determined through running extensive simulations using Lumerical MODE, INNERCONNECT, FDTD, and MATLAB. The parameters needed for the Bragg cavity is the width, number of Bragg periods,

The width was set to 350 nm based on the central wavelength of 1310 nm. A width of 335 nm was used during simulation to take into account the shrinking bias of 15 nm that happens during fabrication.

The first step was to determine the effective index and group index using Lumerical MODE. The effective index was fit to a second order polynomial seen below. The group index (n_g) was determined to be 4.557.

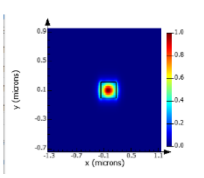

Figure 2: Mode of waveguide with a width of 335 nm and a height of 220 nm.

$$n_{eff} = n_0 + n_1 * (\lambda - \lambda_0) + n_2 * (\lambda - \lambda_0)^2$$

$$n_0 = 2.38053$$

$$n_1 = -1.66228$$

$$n_2 = -0.0630663$$

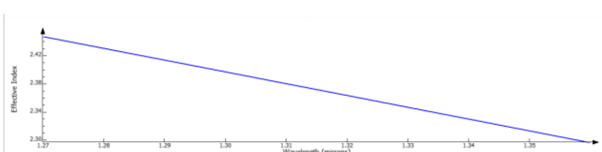

Figure 3: n_{eff} graph used to calculate coefficients for wavelength dependant effective index.

Based of the calculated effective index an approximate period was calculated to be 268 nm (Equation 2). This period was used as a starting point when the simulations in FDTD were performed but was optimized later in the report.

$$Period = \frac{\lambda}{2n_{eff}} = \frac{1310\ nm}{2 * 2.4469} = 268\ nm$$

IV. Simulations

A. FDTD

The goal of the simulations in FDTD was to maximize kappa which having the central wavelength is focused at 1310. FDTD simulated a single Bragg. Two sweeps were performed to determine the optimal values of period and corrugation width (dw) to use. Figure 4 shows the optimal period to maximize kappa is between 277 nm and 278 nm. For this project 273 nm was chosen to ensure the closest simulated wavelength to 1310 nm. Figure 5 represents the relationship between corrugation width (dw) and kappa. The value of dw chosen was 48 nm to optimize kappa while keeping the central wavelength as close to 1310 as possible.

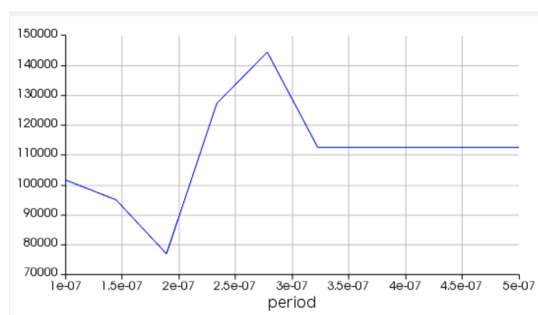

Figure 4: Sweep of period verse Kappa value.

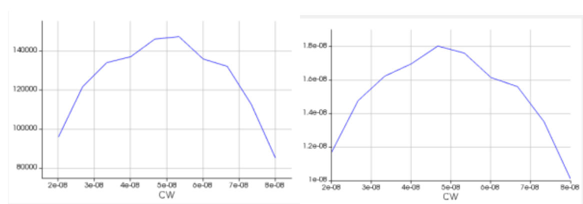

Figure 5: Sweep of Kappa verse dw (left) and Kappa verses bandwidth (right)

Based on the period and corrugation width parameters found above the FDTD simulation was ran again to obtain kappa, bandwidth, and the central wavelength found in Table 1. The goal of the FDTD sweep was to get the highest value of kappa possible as kappa is directly proportional to Q.

Parameter	Value
Kappa	146918
Bandwidth	17.8 nm
Central Wavelength	1312 nm

Table 1: Values of Kappa, central wavelength, and bandwidth found in FDTD.

B. Calculations

Next the theoretical value of kappa was calculated and compared with the simulation results. The calculated value is 106870 compared to the value obtained during simulation of 146918. The differences are due to loss and other factors that alter the simulation to deviate from the theoretical value. The value of Δn used was an estimate from [1] and therefore is not that accurate.

$$Kappa = \frac{2\Delta n}{\lambda_B} = \frac{2 * 0.07}{1310 * 10^{-9}} = 106870$$

C. TMM Simulation

Using the TMM method a plot for the Bragg cavity of obtained (Figure 11). The value of delta n was set to 0.0962 using the kappa obtained in the FDTD simulation. The loss was assumed to be 3 dB/cm which is a conservative loss estimate. The length of the waveguide is 100 um and a grating period of 60 was used. The method to obtain the TMM was described in section II.

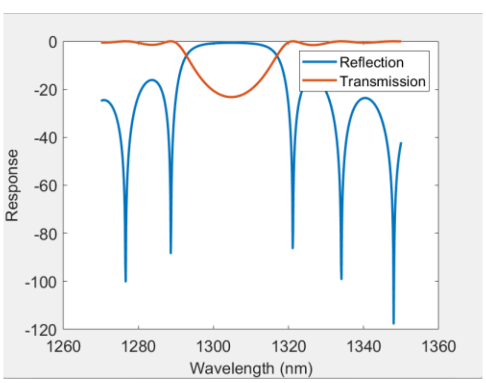

Figure 6: Reflection and Transmission Response of Single Bragg Grating Obtained in MATLAB

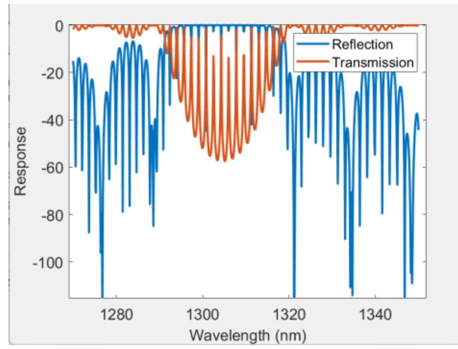

Figure 7: Reflection and Transition Response of the Fabry-Perot Cavity Obtained in MATLAB

D. Lumerical

The grafts obtained in MATLAB were compared to graphs from INNERTCONNECT.

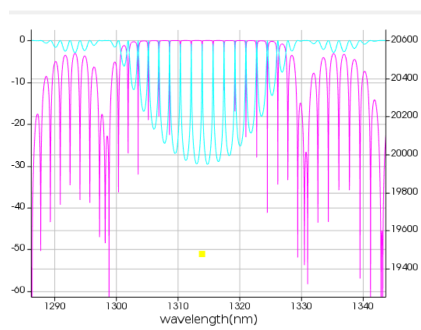

Figure 8: Reflection and Transition Response of the Fabry-Perot Cavity Obtained in INNERTCONNECT

When comparing the two graphs there are a couple of slight differences including the central wavelength and the decibel values of the peaks. The INNERTCONNECT graph is a closer resemblance to the central wavelength obtained in the FDTD simulation. These differences can be caused by rounding differences, and other factors that might impact the MATLAB plot.

V. Fabrication

The device was fabricated using Klayout. Ten separate designs were fit onto the layout shown below. Braggs 1-3 were fabricated using the optimal parameters found in the previous sections. This was done to increase the chances of a successful cavity and to account for errors in manufacturing and dust. Brags 4-6 were designed using less conservative estimates for loss.

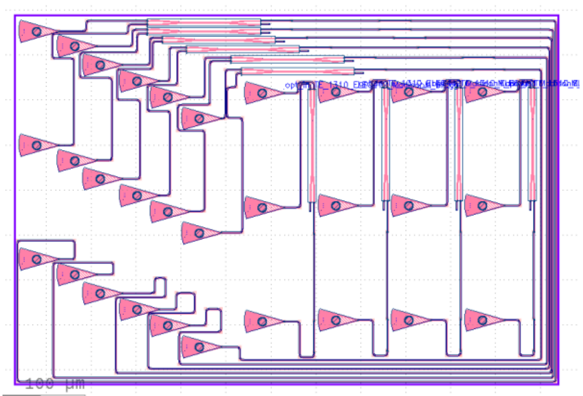

Figure 9: Klayout Design

VI. Analysis

A. Comparing Sine Verses Square Kappa and Corrugation Width

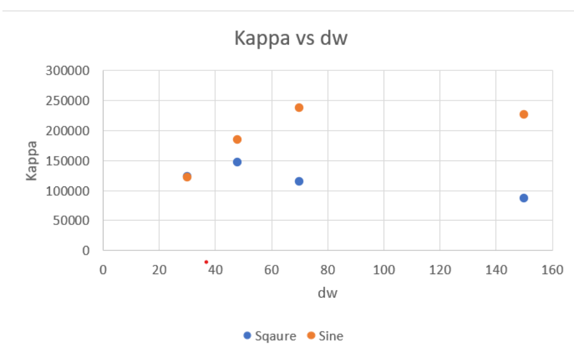

Figure 10: Kappa verses dw for square and sine waves.

There was a large different in kappa value when using sine verses square waves in FDTD. The value of kappa increased when dw increase when using a sine wave however when using a square wave kappa peaked around 50 nm and decreased after this value. This proves the optimal value of dw is around 50 nm to take into account the Bragg grating are supposed to be square in an ideal world but due to manufacturing tend to have a slight sine shape instead.

B. Calculating Q

Calculations to come*

Discussion

A. Variations

Parameter	**Braggs 1-3**	**Braggs 4-6**
Grating period	273 nm	268 nm
Width of Waveguide	350 nm	350 nm
Corrugation Width	48 nm	50 nm
Type	Square	Square
Number of grating periods	50	100
Cavity length	100 um	100 um

Table 2: Design Parameters for Bragg Layouts One Through Six Klayout Waveguides.

Parameter	**Braggs 7-8**	**Braggs 9-10**
Grating period	270 nm	268 nm
Width of Waveguide	350 nm	350 nm
Corrugation Width	40 nm	45 nm
Type	Square	Square
Number of grating periods	70	60
Cavity length	100 um	100 um

Table 3: Design Parameters for Bragg Layouts Seven Through Ten Klayout Waveguides.

Acknowledgments

Conclusion

References

[1] L., Chrostowski, M., Hochberg, “Silicon Photonics Design” From Devices to Systems, pp. 92 – 161
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