Design of a Bragg Resonator to Maximize the Quality Factor

Madison Maurice

Department of Electrical and computer Engineering

2356 Main Mall, Vancouver, BC V6T 1Z4

Abstract - This report highlights the steps taken to design a resonator for a photonic integrated circuit containing a laser. The objective is to obtain a high Quality Factor and an FSR below 0.2 nm.

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 resonator for fabrication with a central wavelength of 1310 nm with the highest possible Quality Factor (Q) and a FSR under 0.2 nm. This paper outlines the steps taken including design, simulation, and fabrication to select the parameters of the Bragg cavity to optimize the Quality Factor and obtain the necessary FSR.

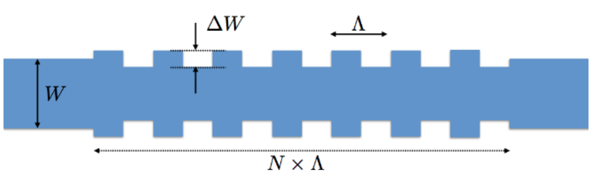

Figure 1: Bragg Cavity schematic showing the defining parameters, N = number of grating period, delta W = corrugation width, W = waveguide width, and = grating period [1]

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:

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

FSR determines how close together the peaks in the cavity are. The reason we aim for 0.2 nm is that the current tunning of the laser. If the FSR is greater than 0.2 then the cavity might miss the laser peak and the device is not be a success.

The cavity was modeled using the Transfer Matrix Method (TMM) in MATLAB and verified using Lumerical INTERCONNECT. 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, INTERCONNECT, 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.

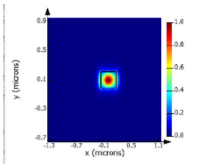

Figure 2: Mode of waveguide with a width of 335 nm and a height of 220 nm.

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

$$n_0 = 2.38053$$

$$n_1 = -1.66228$$

$$n_2 = -0.0630663$$

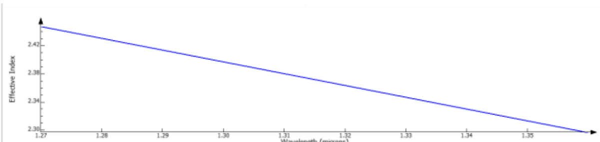

Figure 3: n_{eff} graph used to calculate coefficients for wavelength dependant effective index.

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

Lumerical INTERCONNECT was used to model the cavity. The parameters used are:

Parameter	**Value**
Period	268 nm
Corrugation width	50 nm
Width	350 nm
Kappa	146058
Bandwidth	17.3 nm

Table 1: INTERCONNECT Parameters used based on FDTD and MODE analysis.

Using this as a starting point the cavity length and grating periods were adjusted to find their optimal values to decrease the FSR and maximize the Quality factor. A Fabry-Perot cavity was constructed in INTERCONNECT to simulate the design set up. A cavity length of 1000 um was chosen as a starting point. The INTERCONNECT setup is shown figure 4. Only one design was chosen for fabrication.

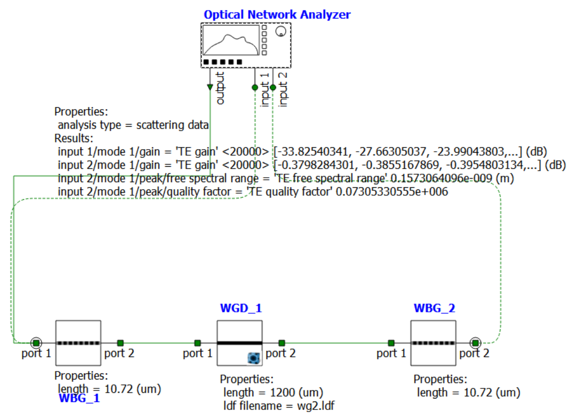

Figure 4: INTERCONNCT Setup for the Resonator.

The transmission cavity peaks must also be greater that -20 dB to ensure the laser will work with the cavity.

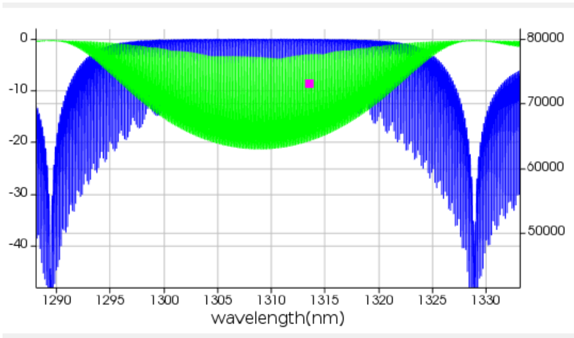

Figure 5: INTERCONNECT Bragg Grating with a FSR < 0.2 nm.

Through different trails the final parameters are shown in Table 2.

Parameter	**Value**
Grating Period	268 nm
Cavity Length	1200 um
Number of Grating periods	40
Type Square	Square
Corrugation Width	50 nm
Width of Waveguide	350 nm
Quality Factor	73053
FSR	0.157 nm

Table 2: Design Parameters for the Fabry-Perot Cavity determined in INTERCONNECT.

V. Fabrication

The device was fabricated using Klayout. The design was added to the main file for simulation. To be connected to one of the 64 branches. The design is shown in figure 6.

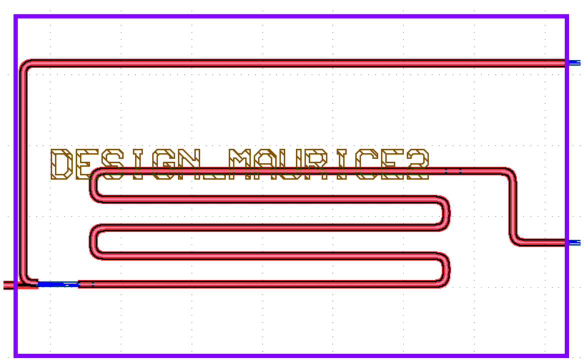

Figure 6: Klayout Design

VI. Analysis

VII. Discussion

Acknowledgments

Conclusion

References

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