Design of a Silicon Photonic 1310nm Waveguide Bragg Grating based Fabry-Perot Laser Resonator Cavity Design

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I. Introduction

Future integrated photonics applications require laser integration with silicon fabrication (CMOS electronics, silicon photonics, etc). (e.g. Apple Watch with TLDS for temperature and glucose monitoring). One of a laser's three essential parts is a resonator (other two being an optically amplifying material, and a power source). The objective of this design project is to design the highest possible quality factor resonator operating at a wavelength of 1310nm using the SiEPIC-EBeam Process Design Kit (PDK), while maintaining a FSR of below 0.2 microns.

II. Theory

The fundamentals of optical waveguides, Bragg gratings, and Fabry-Perot cavities are the foundation of the silicon photonic 1310nm waveguide Bragg grating based Fabry-Perot laser resonator cavity design. Structures called optical waveguides contain and direct light within a substance. Periodic structures called Bragg gratings can transmit some wavelengths of light while reflecting others. Certain wavelengths of light can resonate between two parallel reflectors to generate Fabry-Perot cavities, which are optical resonators. A waveguide with Bragg gratings at both ends serves as the two parallel reflectors of the Fabry-Perot cavity in this system, forming the laser resonator cavity. Standing wave patterns are produced inside the cavity when light is pumped into the waveguide and reflected back and forth between the Bragg gratings. The cavity's resonance frequency, which is governed by the distance between the Bragg gratings, the waveguide material's refractive index, the cavity's effective length, and many more features determines the wavelength of the laser output. The usefulness of the 1310 nm wavelength in optical communications led to its selection. The laser can be made to emit a narrow and stable output wavelength by carefully designing the waveguide characteristics and Bragg grating parameters. Numerous uses for this kind of laser exist, including optical communications, sensing, and metrology.

III. Modelling and Simulation

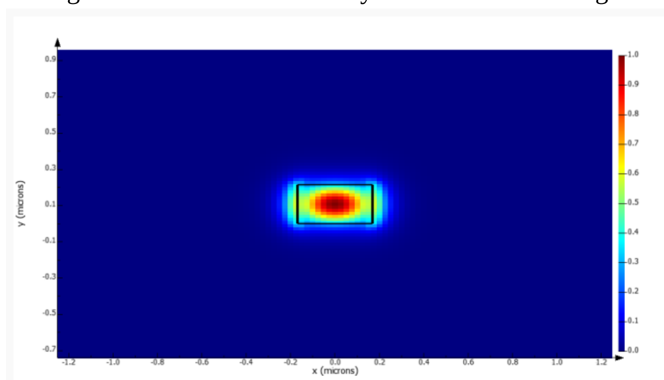
The purpose of this section is to illustrate the modelling and simulation process utilized and to discuss the results and parameters found in the many different simulations. While the width of the cavity to be modelled is defined as 350nm wide, due to a set fabrication bias, the simulations and models were built with a fabrication shrink built in, thus a width of 335nm was used as the measured results after fabrication will be similar to the simulated results of 335nm.

A. Lumerical MODE

The first simulation conducted was done in Lumerical MODE. The "eigenmode solver" is the main piece of this software. Designing, analyzing, and optimizing guided wave components like silicon photonic waveguides are done using this tool. This device helps us figure out the propagation constants for optical waveguides. Solvers for modelling the propagation of optical fields are also a part of Lumerical MODE.

The first step in MODE was to define the waveguide geometry and the eigenmode solver simulation area. This was done by selecting the material properties of our two layers to be Si and SiO2. We then selected the size of the Si chip as well as the SiO2 etch size for the eigenmode solver.

Figure1. Electric field intensity of TE mode in waveguide



We then ran a frequency sweep to extrapolate values of effective index plotted against wavelength in microns.

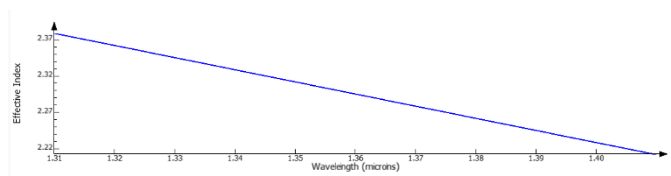


Figure 2. Effective index vs wavelength plot

The same frequency sweep was conducted to obtain a plot of group index with respect to wavelength of a single mode waveguide.

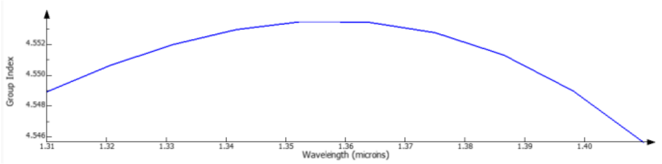


Figure 3. Groupd index vs wavelength plot

Our final step in MODE was to run a script to allow us to obtain our n effective relationship coeeficients to match the equation of a compact model for the waveguide using a Taylor expansion around the center wavelength of 1310nm

$$n_{\text{eff}}(\lambda) = a_1 + a_2(\lambda - \lambda_0) + a_3(\lambda - \lambda_0)^2$$

By running the script, we found our coefficients to be:

a_1=2.37869

a_2=-1.65982

a_3=0.00755813

B. *Lumerical FDTD*

The next simulation tool used was Lumerical FDTD to model and measure the waveguide Bragg gratings as seen below.

By imputing parameters of group index, uncorrugated waveguide width, dw, period, waveguide thickness, and sinusoidal input, multiple important values regarding the Bragg grating band structure were able to be calculated for a single unit cell (depicted below); such as the gratings kappa value, bandwidth, and central wavelength. The figure below illustrates the imputed parameters into the MAIN_bandstructure script in FDTD.

```
ng = 4.549;  # group index of the waveguide (average width)
W = 335e-9; # uncorrugated waveguide width
dW = 50e-9; # waveguide corrugation
period = 279.8e-9; # corrugations period
rib = false; # enable or disable rib layered waveguide type (do not ena
sidewall_angle = 90;

thickness_device = 220e-9; # waveguide full thickness
thickness_rib = 90e-9; # waveguide rib layer thickness
thickness_superstrate = 2e-6; # superstrate thikness
thickness_substrate = 2e-6; # substrate thickness
thickness_handle = 300e-6; # handle substrate thickness

mat_device = 'Si (Silicon) - Palik'; # device material
mat_superstrate = 'SiO2 (Glass) - Palik'; # superstrate material
mat_substrate = 'SiO2 (Glass) - Palik'; # substrate material
mat_handle = 'Si (Silicon) - Palik'; # handle substrate material

Bragg_draw;
Bragg_simulate;
#Bragg_analysis;
```

Figure 4. MAIN_bandstructure parameters

Figure 5. Single cell simulated in FDTD

The simulation above resulted in a kappa value of 152567, a bandwidth of 1.84077e-08, and a calculated central wavelength of 1.31311e-06. These parameters were then stored and used later in the modeling and simulation process.

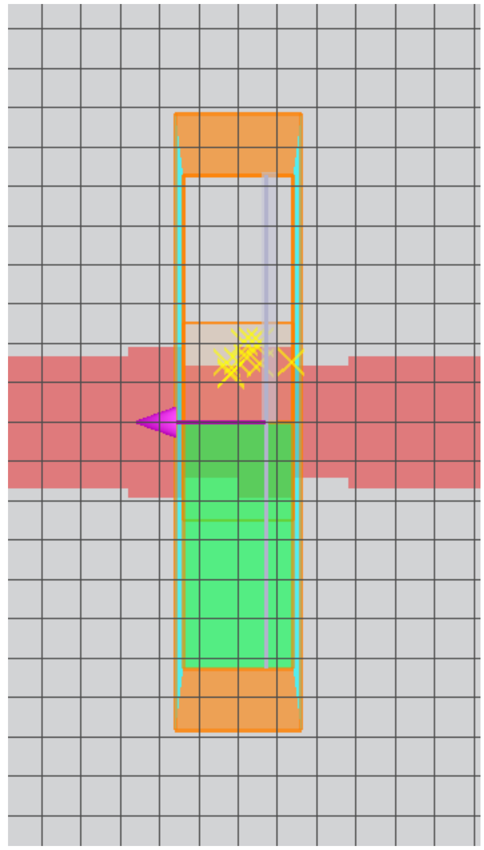


Figure 6. Single cell FDTD simulation

C. *Python TMM Script*

The next simulation conducted was a TMM script to identify the waveguide Bragg grating characteristics and response curves. The parameters calculated in FDTD and MODE were utilized here. A cavity length of 100e-6 was chosen for the first run of the code, while the period, lamda_Bragg value, n_effective coefficients, and kappa were all carried over from previous simulations. The last parameter that was chosen was the number of gratings, selected to be 100 periods left of the cavity, and 100 periods right of the cavity. These parameters resulted in the following response structure.

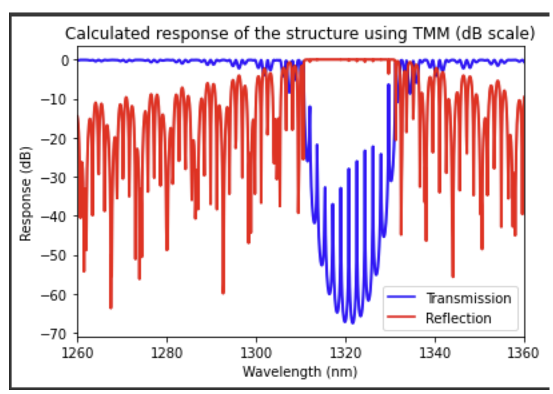
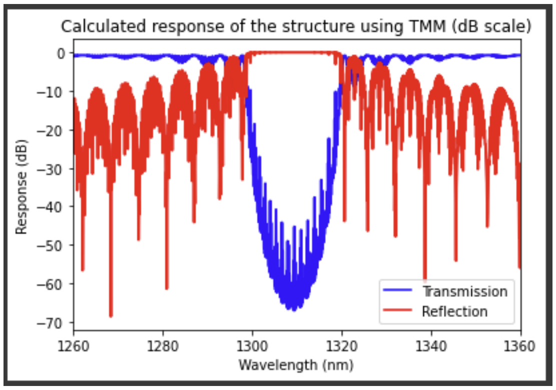


Figure 7. Calculated response of structure using TMM (db scale)

From the figure it was identified that the central wavelength was no longer at 1310nm, but it had shifted to 1320nm. This was most probably caused by a combination of error in kappa, period, and dw. Once a response structure was calculated using the parameters found in the simulations, the script was repeatedly run until values could be maximized to the objective of the project. Upon further runs, the period was changed to 275e-9, and the cavity length was adjusted to 1000e-06, resulting in much more responsive and center shifted response with a considerably lower FSR.

Figure 8. Improved response structure plot



D. KLayout

The final step was to depict the new parameters in KLayout. This was done by downloading the python script in KLayout. The parameters entered were those in the updated TMM script after optimization, and a turtle path reflectivity of the updated cavity length of 1000e-06.

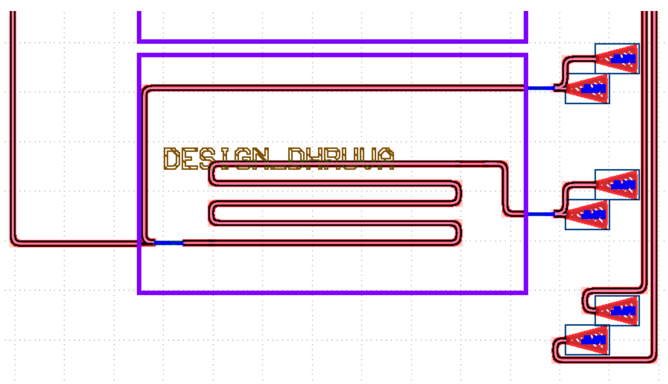


Figure 9. KLayout configurations