Design Proposal for a Bragg Grating Fabry-Perot Laser Resonator with an FSR<0.2 nm at 1310 nm

Aileen Zhang, *ELEC 413, University of British Columbia*

***Abstract*—This document describes a series of proposed designs for a Fabry-Perot laser resonator, with a Bragg Grating on either side.**

***Index Terms*—Semiconductor laser, Fabry-Perot resonator, Bragg Grating.**

I. Introduction

In this document, we are proposing a Fabry-Perot resonator that uses Bragg Gratings to increase resonance in the cavity. Our resonator will operate in the O-band regime, between wavelengths of 1270 nm to 1330 nm with an ideal operation wavelength of 1310 nm. On-chip distribute feedback lasers are becoming increasingly more accessible. However, these lasers have a short tuning range ($< 0.2nm$). As such, we need to design a resonator with a fine FSR to accommodate this.

II. Key Terminology and Abbreviations

For clarity, here is a list of frequently used symbols/abbreviations and their definitions

- α - total power loss per length
- β - change in amplitude and phase of an electromagnetic wave per length
- BG - Bragg Grating
- c - speed of light in vacuum
- Δw - corrugation width
- FP - Fabry-Perot
- FSR - Free spectral range
- L - length of Fabry-Perot cavity
- λ - wavelength in vacuum
- λ_B - Bragg wavelength
- Λ - Bragg Grating period
- κ - grating strength
- n_g - group index
- n_{eff} - efffective index
- N_G - number of gratings
- Q factor - quality factor

III. Theory

The key idea behind the functionality of our resonator is that an electromagnetic wave can split into a reflected portion and a transmitted portion when it encounters a change in index of refraction.

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A FP resonator is a linear optical cavity with one reflector on each end and only resonates at certain frequencies. The requirement for resonance is that the distance of an integer number of round trips must equal an integer multiple of the wavelength (i.e. we have constructive interference). In mathematical terms, this corresponds to $\delta = \frac{2\pi}{\lambda} n_{eff} 2L$ where δ is the phase shift of a round trip.

BGs act as the reflectors for our cavity. The fundamental idea behind a BG is that it acts like an optical filter, with high reflection for a band of wavelengths and low reflection outside of that band. It achieves this through a periodic optical structure with a changing index of refraction. Each change in index of refraction causes a reflection and, for the correct wavelengths, the reflections constructively interfere for a high overall reflectance. The peak reflection of a BG is dependent on both the number of gratings and the grating strength through the equation $R_{peak} = tanh^2(\kappa N_G \Lambda)$ so that both increasing the grating strength and the number of gratings increases the peak reflection. The grating strength also affects the size of the band of wavelengths; the higher the grating strength (often achieved through an increase in the perturbation of n_{eff}), the greater the bandwidth of the BG.

IV. Modelling and Simulation

Our overall modelling and simulation process is to:

1) Model a waveguide in Lumerical MODE
2) Model a BG unit cell in Lumerical FDTD, using the Bloch mode approach.
3) Model the entire BG using the Transfer Matrix Method (TMM) in Python.
4) Verify Python results in Lumerical INTERCONNECT.

Although we will be fabricating our resonator with a 350 nm width, all of our modelling and simulations will be for 335 nm width to account for bias in the fabrication process (-15 nm shrinkage).

A. Lumerical MODE

Our design's geometry is 335 nm width and 220 nm height. The simulated lowest TE mode profile in the waveguide for light at 1310 nm can be seen in Figure 1.

We are also able to gain information about n_{eff} and n_g as a function of wavelength, as seen in Figures 2 and 3.

Since the effective index is dependent on wavelength, a compact model of the waveguide was developed using Lumerical MODE's scripting functionality (See Appendix A1 for script).

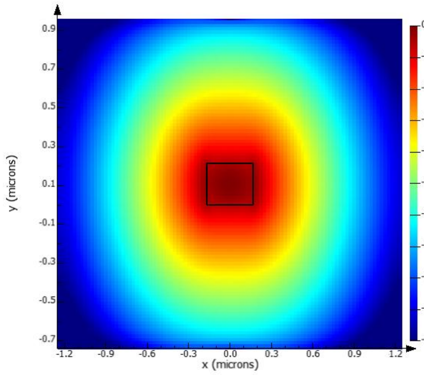

Fig. 1. Electric field intensity of lowest TE mode on a log scale.

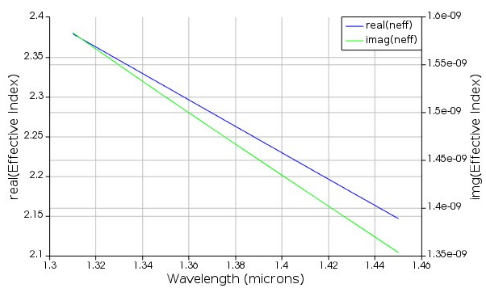

Fig. 2. Change in n_{eff} as a function of wavelength.

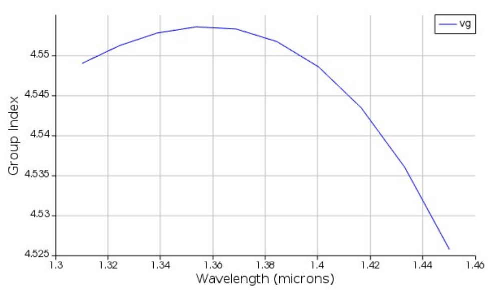

Fig. 3. Change in n_g as a function of wavelength.

Our compact model is:

$$n_{eff} = 2.37873 - 1.66374(\lambda - 1.31) + 0.0504277(\lambda - 1.31)^2$$

where λ is in um.

We can also use our n_{eff} at exactly 1310 nm to develop an estimate of what our Λ should be. Using the equation $\lambda_B = 2n_{eff}\Lambda$, where λ_B is $1310nm$ and n_{eff} is 2.379 as per our simulation, we get that $\Lambda = 275nm$.

B. Lumerical FDTD

Using Lumerical FDTD with a mesh of 3 and the parameters described above, we can develop a model for how λ_B and κ change as a function of Δw. Although n_g is wavelength-dependent, we choose to approximate it with the value at 1310 nm ($n_g = 4.5488$), The simulation results can be seen in Figures 4 and 5.

We note, from these graphs, that values near $\Delta w = 32.5nm$ result in $\lambda_B \approx 1310nm$. We also note that near $\Delta w =$

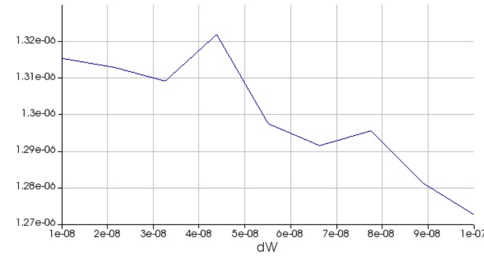

Fig. 4. Change in λ_B as a function of Δw.

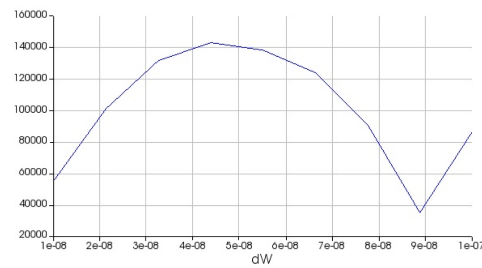

Fig. 5. Change in κ as a function of Δw.

$32.5nm$, our κ value is 131585, which is near the peak of the graph. In this context, a high κ value is desirable to increase the bandwidth of the resonator, which increases the likelihood that the input laser will be able to sweep over a resonance of the cavity.

Although it is also possible to sweep over the BG period, at this time, we have chosen not to explore this avenue.

C. Transfer Matrix Method

The TMM is a tool used to simulate transmission and reflection of light through a structure, often with many changes in index of refraction. The key idea is to construct a series of matrices describing how the inputs and outputs of one end of each chunk of the structure relate to the inputs and outputs of the other end of each chunk. Multiplying together all these matrices gets us our final transmission and reflection values.

Matrix for propagation through a homogeneous medium:

$$\begin{bmatrix} A_1 \\ B_2 \end{bmatrix} = \begin{bmatrix} e^{j\beta L} & 0 \\ 0 & e^{-j\beta L} \end{bmatrix} \begin{bmatrix} A_2 \\ B_1 \end{bmatrix}$$

Matrix for step change in index of refraction:

$$\begin{bmatrix} A_1 \\ B_2 \end{bmatrix} = \begin{bmatrix} \frac{n_1+n_2}{2\sqrt{n_1 n_2}} & \frac{n_1-n_2}{2\sqrt{n_1 n_2}} \\ \frac{n_1-n_2}{2\sqrt{n_1 n_2}} & \frac{n_1+n_2}{2\sqrt{n_1 n_2}} \end{bmatrix} \begin{bmatrix} A_2 \\ B_1 \end{bmatrix}$$

The Python code used can be found in Appendix XXX.

We first want to determine the number of BGs we want. Although we want a high peak reflection, the amount of reflection must still be less than 100% or it will be impossible to measure the response of the cavity. Because we expect a very long cavity to decrease the FSR, we will have a lot of loss due to propagation. As such, we will aim for 0.9 as our peak reflection. Using the earlier equation, we calculate that 50 gratings is our ideal number. In addition, we will use the typical 2.4 dB/cm as our loss. A graph showing the simulated

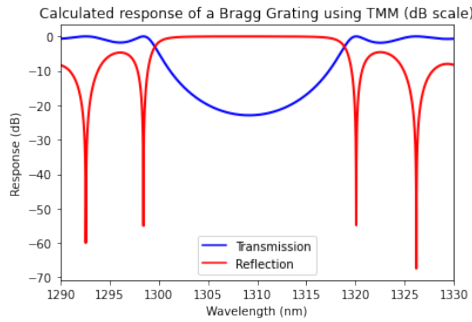

Fig. 6. Response of a Bragg Grating at different wavelengths.

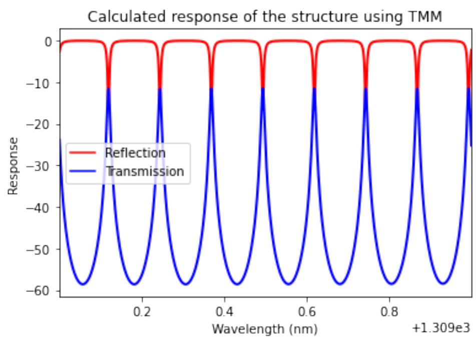

Fig. 7. Response of a FP Resonator at different wavelengths.

results using these values, $\Delta w = 32.5nm$ and associated values, and other parameters described earlier can be seen in Figure 6. This graph confirms that the peak reflection is high at $1310nm$ and we have a bandwidth of approximately 20 nm.

We can then apply the TMM to our entire cavity. Using the equations stated earlier for a length of $1500nm$, we can achieve a theoretical FSR of $0.125nm$, which is within the range we are aiming for. Using this and all earlier listed parameters, we simulate the response of the FP resonator using the same code as for the BG, with results seen in Figure 7. We do see resonances in the $1310nm$ range as required, and the response is greater than $-20dB$, which means that it will be measurable during testing.

V. REFERENCES