Waveguide Bragg grating Resonator Design Proposal

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Abstract

This paper reports a design proposal for a waveguide Bragg grating cavity resonator with a center wavelength of 1310 nm. The design was evaluated using both the Transfer Matrix Method and numerical simulation software, including MATLAB and Lumerical. The impact of varying key parameters, such as cavity length, Bragg period, and corrugation width, on the quality factor at the center wavelength was analyzed in detail. To validate the design, the proposed structure is planned to be fabricated and the measured results will be compared with the simulation data. The proposed BGCR features a Bragg period of 275.36 nm, a cavity length of 100 microns, and a rectangular-type Bragg grating with a corrugation width of 50 nm.

Introduction

The Bragg Grating Fabry-Perot Cavity (BGFPC) is a modern optical device that offers exceptional features, such as narrow-band filtering and high-quality factor resonances, thereby functioning as a selective wavelength component. Despite its recent inception in the late 1900s, this device has garnered immense popularity owing to its diverse applications in communication systems, such as Wavelength Division Multiplexing (WDM), optical filters, and sensing.

In the context of this project, we aim to design a BGFPC with a center wavelength at 1310 nm and a minimal Free Spectral Range (FSR) while ensuring the highest Quality Factor (Q-factor) possible. To accomplish this, we employed the Transfer Matrix method and employed various software, such as MATLAB and Lumerical, to simulate the structure. The outcome of these simulations allowed us to determine a set of parameters and specifications that meet the expectations of our project. The present report provides an overview of the methods, studies, and results of the design.

Theory and Parameters

The objective of the project is to develop a Bragg Grating Fabry-Perot Cavity with a high quality factor, Q, that is centered at a wavelength of 1310nm. Q is defined to be

$$Q = \frac{\omega}{\Delta\omega_{\frac{1}{2}}} \qquad (1)$$

where ω is the angular frequency and $\Delta\omega_{1/2}$ is the width of the signal at the -3dB point. The basic design of this model is made of two Bragg gratings, separated by a cavity. The optimal functioning of this model requires a delicate tuning of several crucial parameters of the Bragg gratings, as demonstrated in the accompanying Figure 1:

- Bragg period – **Λ**
- Corrugation width – ΔW
- Width – W
- Number of Gratings - N

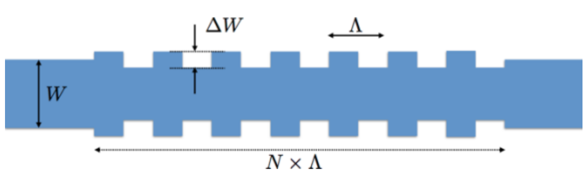

Figure 1 - Bragg Grating

For this project, the width of the waveguide has been established as 350nm. To determine the other parameters, a comprehensive series of simulations and analyses will be conducted utilizing various simulation tools, such as MATLAB and Lumerical, to refine the values of the remaining parameters to attain an optimal design. The optimized design will then be fabricated for evaluation and comparison with the simulated results. To enhance the robustness of the project and to account for any losses or discrepancies in the manufacturing process, a set of additional designs with slight variations in parameters such as corrugation width and number of gratings will also be manufactured.

Design and Simulations

As stated above, for this project we have a target Bragg wavelength of 1310nm. This parameter is given by the relation

$$\lambda_B = 2\Lambda n_{eff} \qquad (2)$$

where **Λ** is the grating period and n_{eff} is the average effective index. To design a high quality factor BGFPC we need to take into consideration the distributed mirror loss α_m, which depends on the peak reflectivity of the Bragg grating R_1 and R_2, as well as the length of the cavity L_C. The relationship is shown in equation 3 below:

$$\alpha_m = \frac{ln\sqrt{R_1 R_2}}{L_C} \qquad (3)$$

According to the coupled-mode theory [1], R_1 and R_2 are proportional to the length of the Bragg grating L_B, as well as the grating strength coefficient κ, which both are parameters we will adjust for our design.

The design of the BGFPC for this project involves the utilization of a symmetrical structure to achieve a R1 = R2 relationship for the peak reflectivity of the Bragg gratings.

The initial stage of the design process involved the creation of a compact waveguide model using Lumerical MODE, with the objective of determining the relevant material parameters such as the effective refractive index (n_{eff}) and the group refractive index (n_g). To account for fabrication biases, the width of the waveguide was specifically set at 335 nanometers. The model generated in Lumerical incorporates a silicon core with a thickness of 220 nanometers, as well as a silicon dioxide cladding.
Subsequently, a Modal Analysis was performed for a single TE mode to obtain the waveguide profile, as illustrated in Figure 2.

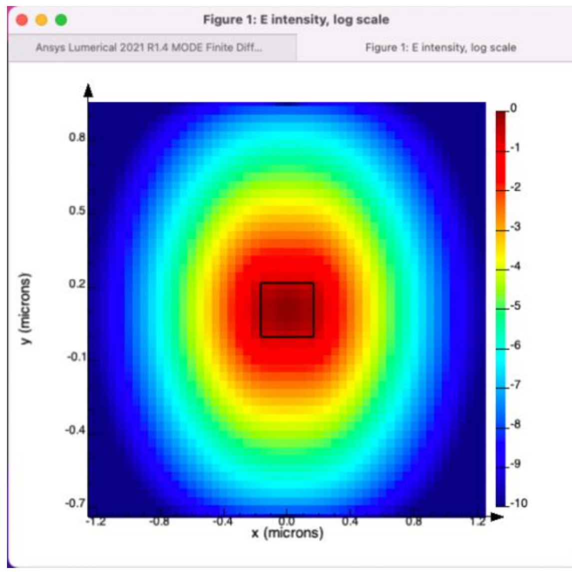

Figure 2 - TE mode Waveguide Profile

Following the Modal Analysis, a Frequency Sweep was executed to gather data that would be utilized in the creation of a compact model using MATLAB. The objective of this process was to obtain the polynomial value of the n_{eff} based on the parameters inputted in Lumerical MODE. The result of the calculation is presented below:

$$n_{eff}(\lambda) = 2.3787 - 1.6564\lambda - 0.075\lambda^2$$

The values obtained were utilized in the calculation of the Bragg period using the relationship specified in Equation 2. This resulted in a value of **275.36 nanometers**. The group refractive index (n_g) was measured to be **4.485**.

The corrugation width (Δw) and the coupling coefficient (κ) were determined through simulations performed with Lumerical FDTD, where design parameters such as the corrugation width and the number of gratings were systematically varied. By analyzing the influence of these parameters on the central wavelength and the kappa, the values of Δw and κ were accurately ascertained. Specifically, the analysis yielded a determined value of **50nm for the corrugation width (Δw)**, and a calculated value of **1.16e6 for the coupling coefficient (** $\boldsymbol{\kappa}$ **).**

The tables below summarize the calculated parameter values:

n_{eff}	n_g	kappa
2.3787	4.485	1.16e6

Grating Type	Grating Period	Waveguide Width
Rectangular	275.36	335nm

Corrugation Width	Number of gratings	Length of Cavity
50nm	-	100µm(?)

The design parameters described above were simulated using Lumerical INTERCONNECT to study the output of our Bragg grating Fabry-Perot cavity (BGFPC) and estimate the free spectral range (FSR) and quality factor. A schematic of the simulated system is provided in Figure 3. In this simulation, we assumed a loss rate of 3dB/cm.

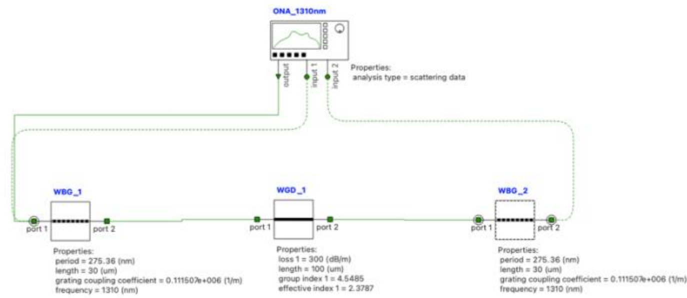

Figure 3 - Lumerical INTERCONNECT circuit

The output of the circuit simulation is presented in Figure 4, showcasing a theoretically calculated quality factor of 7387.5, as well as an estimated value of the FSR equal to X.

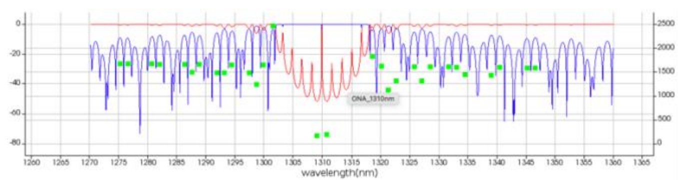

Figure 4 - Lumerical INTERCONNECT circuit response