ELEC 413
Project 2

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1 Introduction

Silicon has been studied as an excellent material system for building up photonic and electronic devices. The silicon device industry has been developed for more than 50 years, and various companies and academics make application of silicon materials and technology [1]. Due to the demand for faster and better data transmission for new technologies, silicon photonics has attracted great interest and has been pursued by large companies such as Intel in recent decades [2]. The silicon photonics market is expected to grow to USD 4.6 billion by 2027 [3].

There are several types of opportunities for silicon photonics, and one of the most important opportunities is photonic systems engineering. When a variety of photonic devices are available as library elements, it is important to think about how to make a good design to produce something useful with these elements. As one of the photonic components, the Fabry-Perot (FP) cavity-based phase-shifted Bragg grating acts as an optical resonator that allows the transmission of light with a narrow range of wavelengths. Such a structure design is important in the semiconductor laser to ensure narrow linewidth and single frequency mode. The aim of this report is to design a structure of Fabry-Perot cavity with Bragg gratings (BGFPC) to achieve the highest quality factor (Q-factor) and make the central wavelength of 1310 nm. The outline of the report includes the relevant theory, modelling and results of simulation using different tools such as Lumerical MODE, FDTD INTERCONNECT and Matlab.

2 Theory

A schematic of a BGFPC is shown in Figure 1. This structure consists of two Bragg grating waveguides as resonators on either side and a cavity waveguide in between them.

Figure 1: A schematic of Fabry-Perot cavity based bragg gratings

The Q factor of BGFPC can be expressed by the formula (1) below:

$$Q = 2\pi \frac{c}{\lambda} \frac{n_g}{c} \frac{1}{\alpha} = 2\pi \frac{n_g}{\lambda \alpha} \tag{1}$$

The grating coupler is defined by the formula (2):

$$\kappa = \pi n_g \frac{\Delta\lambda}{{\lambda_B}^2} = \frac{2\Delta n}{\lambda_B} \tag{2}$$

The peak reflectivity of BGFPC can be predicted by the coupled-mode theory (3):

$$R_{peak} = tanh^2(\kappa L) \tag{3}$$

The free spectral range (FSR) is the spacing between adjacent modes of the filter, and is (4):

$$\delta v = \frac{c}{2nl} \tag{4}$$

In the equation (4), the length of the cavity is inversely proportional to the frequency difference. The longer the length of the cavity, the smaller the FSR that can be obtained. Parameter adjustment is discussed in the INTERCONNECT simulation section, where the length of the cavity is varied to optimise the quality factor and obtain as many peaks as possible in the stopband region.

According to the formula (1) and (2) above, the Q factor is directly proportional to the group index n_g, and n_g is also proportional to kappa. Based on formula (3), the κ is proportional to reflectivity. Thus, by increasing the peak reflectivity of BGFPC, the high quality factor can be achieved.

The simulation based on a transfer matrix apporach which is shown below. The matrix presents how the forward and backward propagating light at input of the device transform into the the forward and backward propagating light at the output of the device.

$$\begin{bmatrix} A_1 \\ B_1 \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} A_2 \\ B_2 \end{bmatrix}$$

For a uniform periodic structure, the transfer matrix can be expressed by $T_p = Th_{w-1} T_{is-12} Th_{w-2} T_{is-21}$ for field propagation in one unit period. Thus, in the case where the number of Bragg grating periods is equal to n, the whole transfer process can be described in terms of the matrix as $T_{total} = (T_p)^n$.

In general, the goal of the project is to adjust the parameters such as period, width, length and corrugation width of the Bragg gratings to optimize the reflectivity of the cavity, and design the central wavelength to be 1310 nm.

3 Model and Simulation

The unit cell of the bragg gratings will be built up in the Lumerical MODE tool. By setting geometry and material properties (Si and SiO_2) of the Bragg grating waveguide, one can make the simulation to gain the group index and effective index of the material, the result of the graphs are shown below (Fig. 2 and 3):

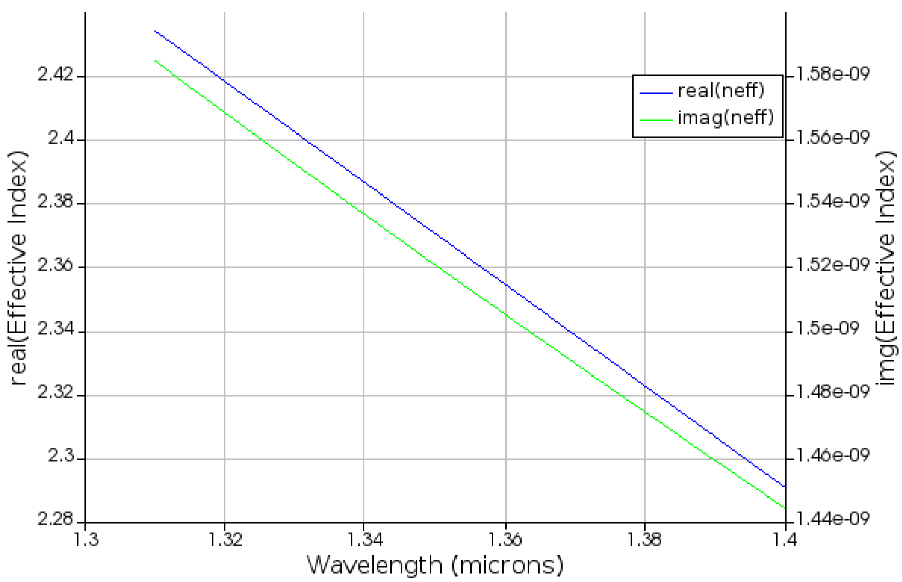

Figure 2: effective index versus wavelengths

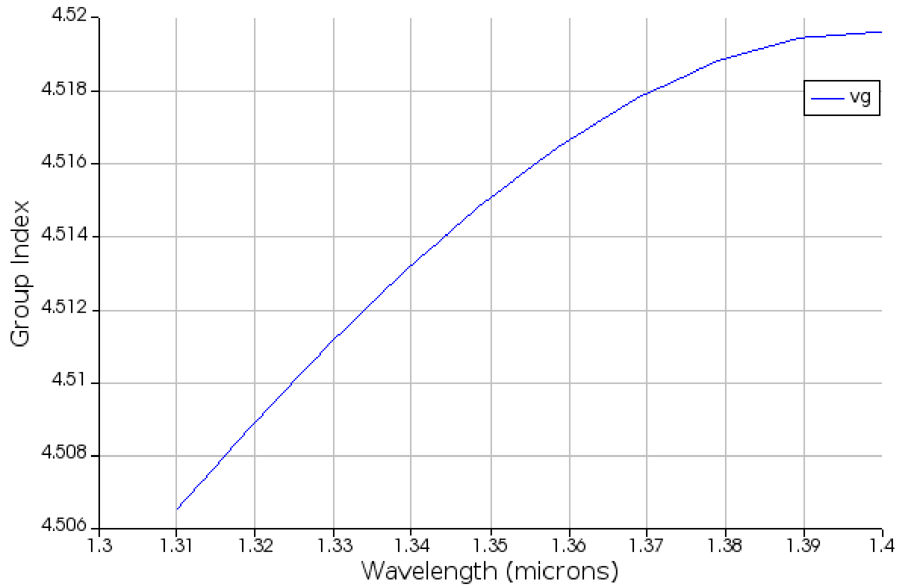

Figure 3: Group index versus wavelengths

The diagram of modal field is shown in Figure. 4. As shown in the graph, the main propagation mode is TE mode in this simulation and the fraction of TE polarization (Ex) is 98%.

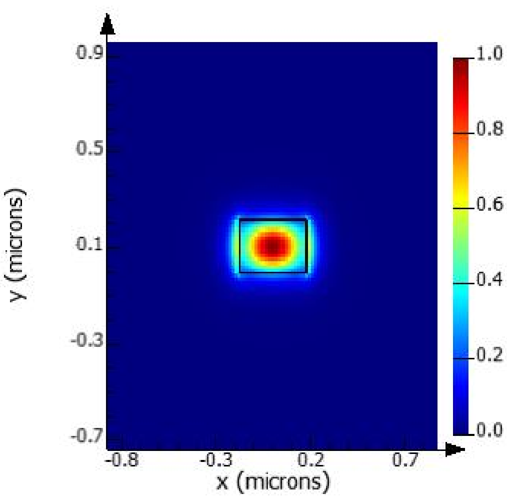

Figure 4: Group index versus wavelengths

According to the result from MODE, the group index of the materials is around 4.5. In the FDTD simulation, the parameters of group index, width, period, number of period and shape of the Bragg grating unit cell (sinusoidal or rectangular). To make a central wavelength around 1310 nm, different parameters are tried in simulation, and lastly one group of parameter gain the result of central wavelength closed enough 1310 nm (Fig. 5): Group Index (n_g):4.5, Width (W): 0.362 um, Corrugation Width (δ W): 0.055 um, Period: 0.270 um

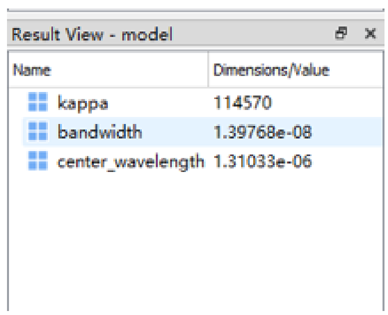

Figure 5: Simulation Results of FDTD

The screenshot of simulation results of FDTD is shown as above.

The κ obtained from the FDTD is 114570 1/m. By inserting the value of κ in the INTERCONNECT tool, one can build up a circuit which can simulate the BGFPC to obtain the spectrum of reflectivity and transmissivity. The picture of INTERCONNECT simulation is shown below (Fig. 6).

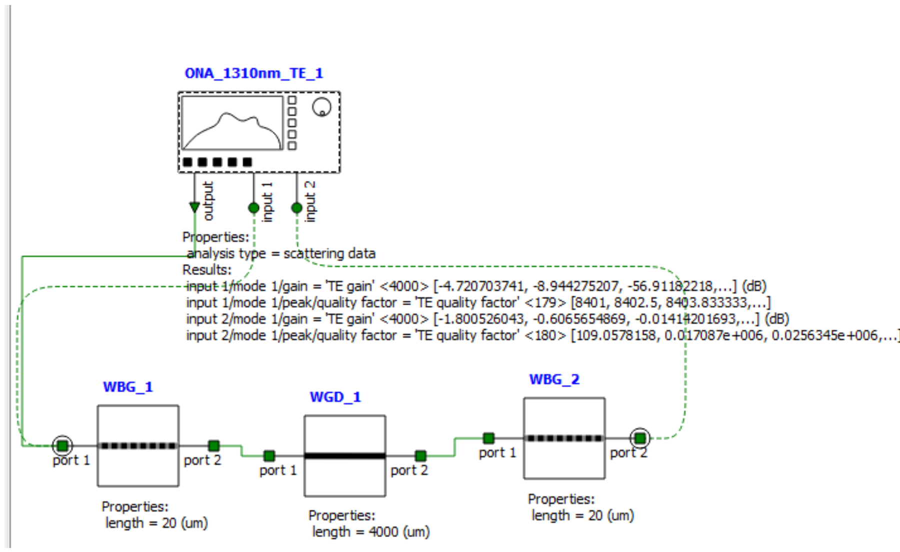

Figure 6: Picture of designed Fabry-Perot cavity based bragg gratings in INTERCONECT

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The κ obtained from the FDTD is 114570 1/m. By inserting the value of κ in the INTERCONNECT tool, one can build up a circuit which can simulate the BGFPC to obtain the spectrum of reflectivity and transmissivity. As shown in the picture of designed circuit (Fig. 5), two Bragg grating components are put at two sides with a cavity in between them. The legnth of Bragg grating can be calculated by number of period (N) times length of period. By adjusting the lengths of Bragg gratings and cavity, the central of the stop band is set to around 1310 nm. For the length of Bragg grating, it can not be set to too long otherwise the light is not able to transmit through the mirrors and reach the cavity. However, setting the length of Bragg grating too short will lead to a small quality factor since the reflectivity will be low.

To achieve smaller FSR, the length of cavity is greatly increase so that as many as possible frequencies can be included in the stopband. In addition, lower length of Bragg gratings has some effect on reducing FSR. After some attempts of simulation, the length of cavity is set to 4000 um and the length of Bragg gratings is 20 um. The corresponding spectrum of reflectivity and transmissivity is shown below (Fig. 7).

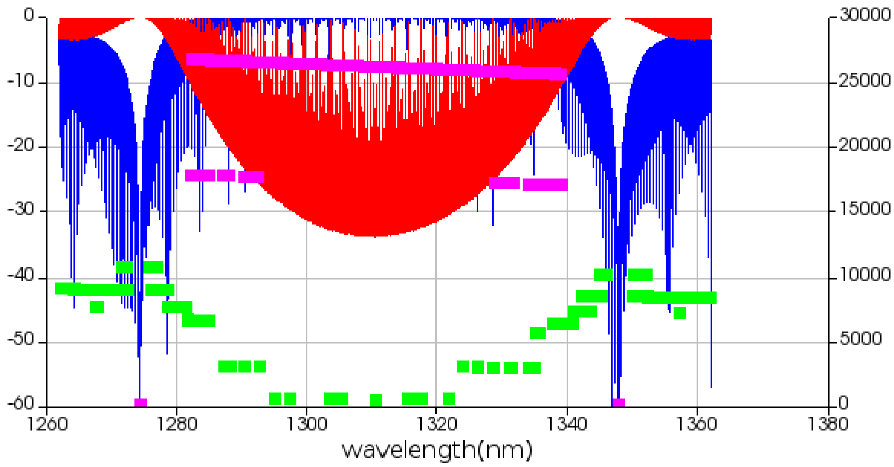

Figure 7: Spectrum of reflectivity and transmissivity

The FSR is shown in the zoomed in picture which is around 0.2 or smaller, the zoomed in spectrum is shown below (Fig. 8)

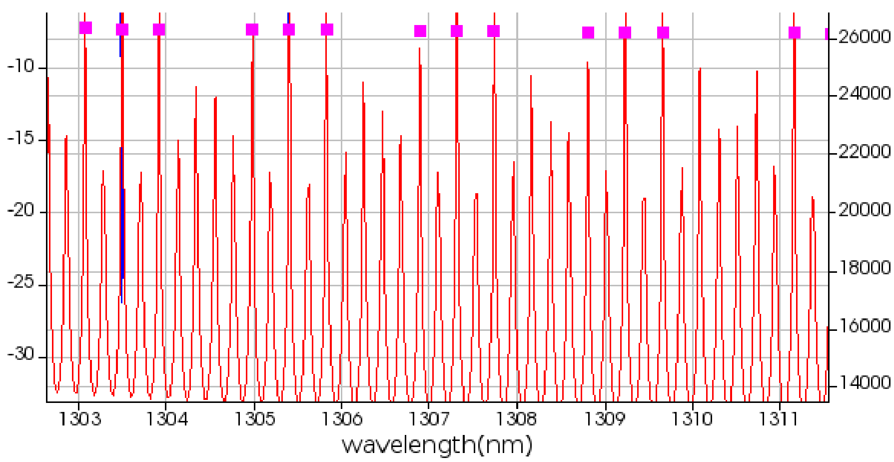

Figure 8: Zoomed in picture of spectrum

In the last step, The BGFPC structure is designed and drew in the Klayout tool by using the parameters mentioned above (Table 1).

Experimental Parameters	
Parameters	Value
Group Index (n_g)	4.5
Width (W)	0.362 um
Corrugation Width (δ W)	0.055 um
Period	0.270 um
Bragg Grating Shape	Rectangular
Number of Period	74
Cavity Length	4000 um
Highest Q Factor	25634

4 References

1.Chrostowski, Lukas, and Michael Hochberg. Silicon photonics design: from devices to systems. Cambridge University Press, 2015.
2.https://www.intel.com/content/www/us/en/architecture-and-technology/silicon-photonics/silicon-photonics-overview.html
3.https://www.marketsandmarkets.com/Market-Reports/silicon-photonics-116.html