REPORT PROJECT 1

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Abstract— **This document is about a project in which I design different fabry perot cavities for a central wavelength of 1310 nm using silicon Bragg grating, couplers and waveguides. These designs will be fabricated and measurements will be obtained which we will analyse with the simulations carried out.**

I. Introduction

In this design we are going to explain the different parameters that I have chosen to realize several designs of the Fabry perot cavity. Furthermore, I am going to explain the process that I have followed to obtain these parameters. We will also compare the simulations with the actual measurements that we get experimentally.

II. Lumerical Mode and parameters

First, in Lumerical mode I simulated the waveguide with a thickness of 220 nm and a width of 350 nm. Thanks to this, we have been able to obtain the effective index for the central wavelength of 1310 nm. I have also performed a frequency sweep in order to obtain the polynomial expression for the effective index that we would use later in the TMM [1]

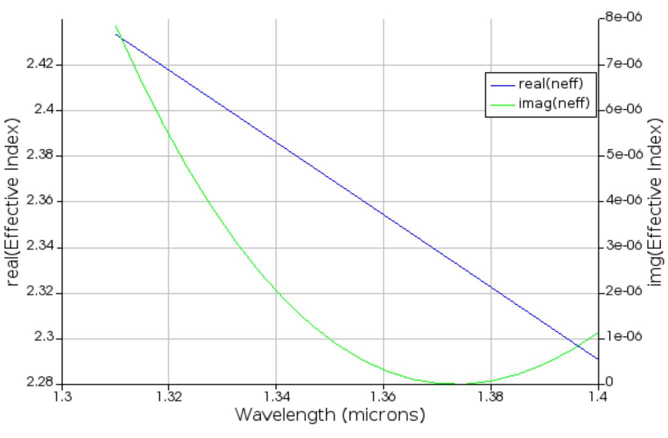

Fig. 1 Frequency Sweep to obtain the effective index

From these results, we can obtain:

- $Effective\ index$: 2.433
- $Bragg\ period = \frac{\lambda_B}{2*n_f} = 269.21\ nm$
- $Effective\ indices$: $2.433 \mid -1.577 \mid -0.04567$ [2]

The next step is the simulation of a unit cell of a Bragg grating waveguide using Lumerical FDTD. With this simulation we can obtain kappa from different parameters such as waveguide width (W), corrugation width (ΔW) or Bragg period. In this case, we are changing dW to obtain the desired kappa and the central wavelength of 1310 nm.

Here we have the parameters obtained from the simulations:

ΔW (nm)	Kappa	Central Wavelength (nm)	Bandwidth (nm)	Δn
55	12539	1295	14.88	0,081190
40	12344	1316	15.141	0,081256
50	12615	1311	15.38	0,082794
45	12434	1314	15.208	0,081733

Table 1. Parameters obtained from the simulations in the FDTD Model.

One parameter really important that is obtained from kappa is Δn. Later we will use it in the Transfer Matrix Method.

$$\Delta n = \frac{k*\lambda_B}{2} \quad (1.1)$$

III. Device Design

Here we use all the parameters we obtained previously for designing our different devices. We use the polynomial expression for the effective index and we also use Δn. We have more parameters involved in this method. Depending on these parameters, we can create different designs. In my case, I have created 10 designs in KLayout. We can see their characteristics in the table 2 (Annex).

A. *Bragg Period Error*

In all the cases we are using the same Bragg Period (269 nm). However, there is an error related with the manufacturing that makes the bragg period smaller than it was designed for. Here we can see the results provided by Mustafa Hammood, graduate

[1] Transfer Matrix Method [2] Indices correspond to the polynomial expression

student of Professor Jaeger, who shows how this error causes a wavelength shift to smaller values (Fig. 2). So in order to avoid having my central wavelength shifted to the left and therefore keep the design target of 1310 nm, I have decided to choose a period of 276 nm, based on Mustafa's data, for most of my designs. There are some that I have not done so because I wanted to check how severe this shift actually is. For the designs 1, 3, 5, 6, 7 and 10 I have used a Bragg Period of 276 nm

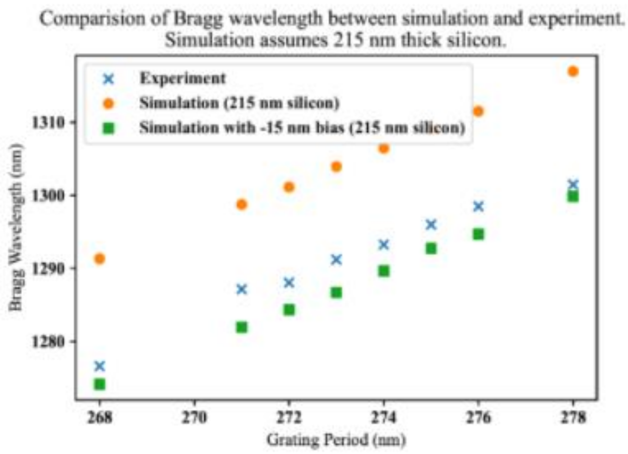

Fig. 2 Mustafa Hammond data

B. Loss Aproximation

In our TMM we have to take into account the losses on the cavity. For this Project we are going to use the analysis of Mustafa Hammood, who made a table with the losses in different waveguides and for different wavelengths. In the next figure we can see this data.

Structure	Polarization	WG Width	Wavelength	Loss
Waveguide **Straight**	TE	350 nm	1310 nm	2.5 dB/cm
		500 nm	1550 nm	1.1 dB/cm
	TM	350 nm	1310 nm	2.58 dB/cm
		500 nm	1550 nm	5.8 dB/cm
Waveguide **Spiral**	TE	350 nm	1310 nm	6.8 dB/cm
		500 nm	1550 nm	5.5 dB/cm
	TM	350 nm	1310 nm	11.1 dB/cm
		500 nm	1550 nm	8.05 dB/cm

Fig 3 Mustafa analysis of the losses in the waveguide

So I am considering a loss of 2.5 dB/cm.

IV. Simulations vs Real Performance

Then after having designed my models, I carry out simulations using my TMM model implemented in Matlab. Here I am going to show only a few simulations (Not for all the models) because I will also compare these simulations with the real behaviour of the models and I will examine whether my assumptions and simulations match reality. In the table of the annex, we can see the Quality factor for all the models.

After analysing the data received after the measurements of the devices, I am going to study the devices V1, V3 and V8 because are the most interesting. Also most of the others have not worked due to measurements or fabrication problems. Also the V4 and V8 models have worked, but as expected and as mentioned before, due to the manufacturing error regarding the Bragg period, this is altered and therefore, the central frequency is shifted to the left. In the figure 4 we can see this effect.

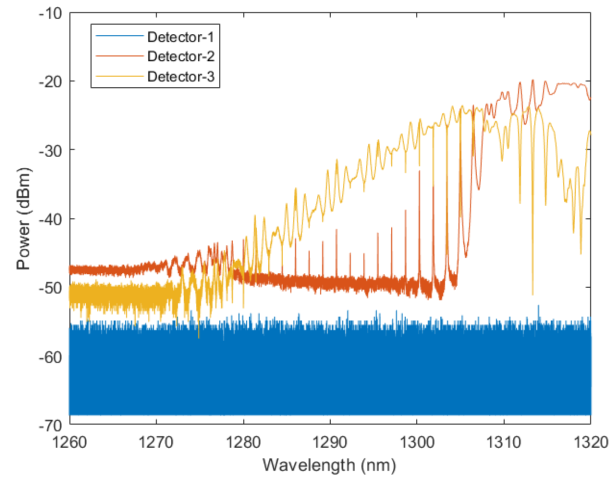

Fig. 4 Measurements for the device V4

A. Device V1

This device has a length of 34.289 µm, so we are expected to see more than 1 peak (In total we see 5).

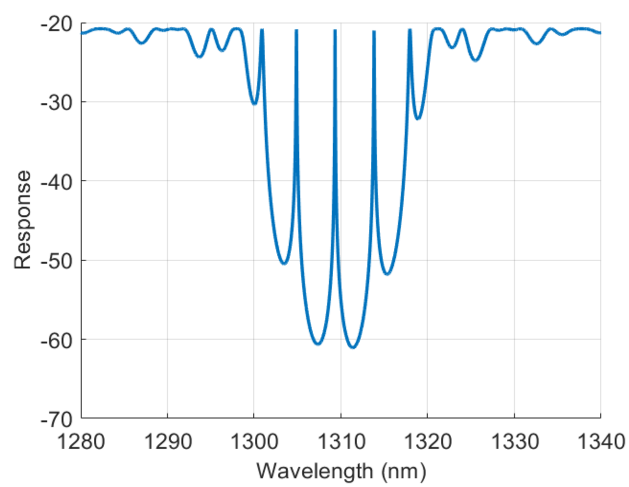

Fig. 5 Simulation for the device V1

Then we can compare the simulation with the real measurements. We can see in the fig 6 that the peaks are in the same wavelength as it should be. We can also observe that the Insertion loss is really similar for both graphs for the peak in 1317 nm (around -21 dBm). However, the others peak has less power while in the simulation, all the peaks has the same power.

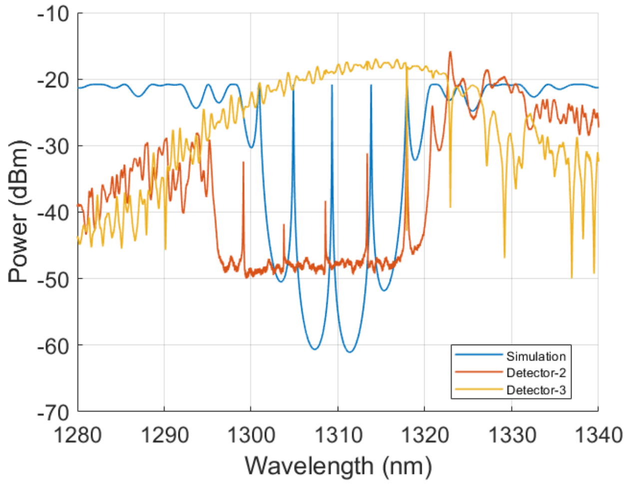

Fig. 6 Simulation VS Measurements for V1

Furthermore, I analyse the Quality factor for the central peak (~1309 nm) and I get similar values for both simulation and Measurements. See these values in the table 3 in the Annex. The Quality factor is determined by:

$$Q = \frac{\lambda_c}{\Delta\lambda} \quad (1.2)$$

Where $\Delta\lambda$ is the 3 dB wavelength width of the peak.

B. Device V3

This device has a long cavity so we will have multiple wavelength. The length is 304.131 μm.

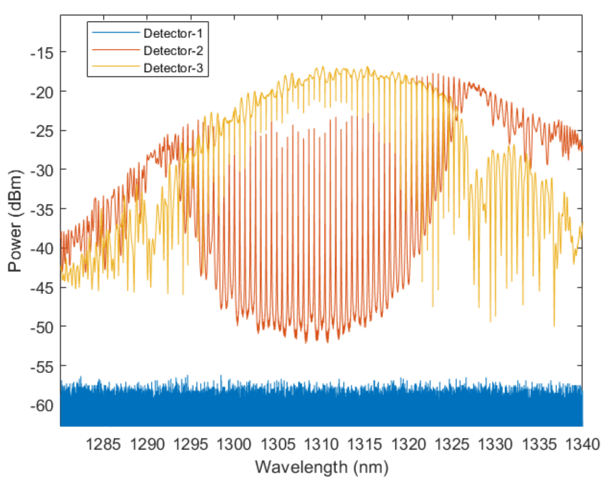

Fig. 7 Measurements for V3

We can compare our measurements with our simulations as we did before. We can observe in the fig 8 that the performance is similar but we have differences between both curves. As before, in the simulations we have the same Power for all peaks but for the measurements, these are different and also some of them (the ones in the right) are higher.

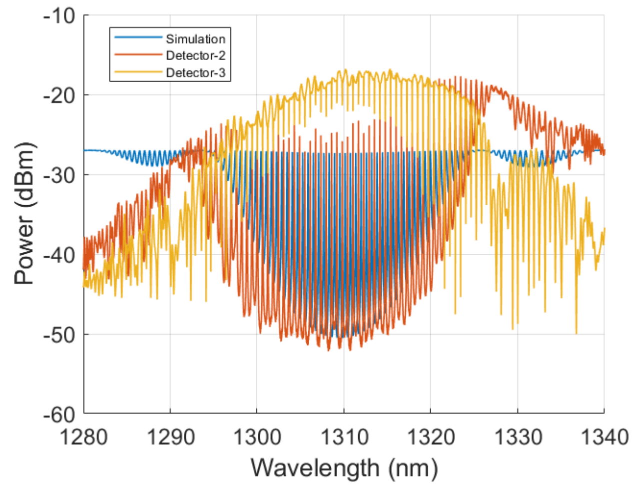

Fig. 8 Simulation VS Measurements for V3

I made a sweep through the wavelength to find a peak with a high quality factor and I determined that for the wavelength of 1309.8 μm, we get a quality factor of 137062. However, in the simulations we get for the same peak less Q (I get for all the peaks more or less the order of 50K).

C. Device V8

As I mentioned before, the device V8 has suffered a shift in the central wavelength due to an error in the Bragg period. In order to compensate for this displacement in our simulation to match our measurements, I have reduced the Bragg period in my TMM model. Specifically, to the value of 263.4 nm. In the fig 9 we can see both graph and how the peaks match.

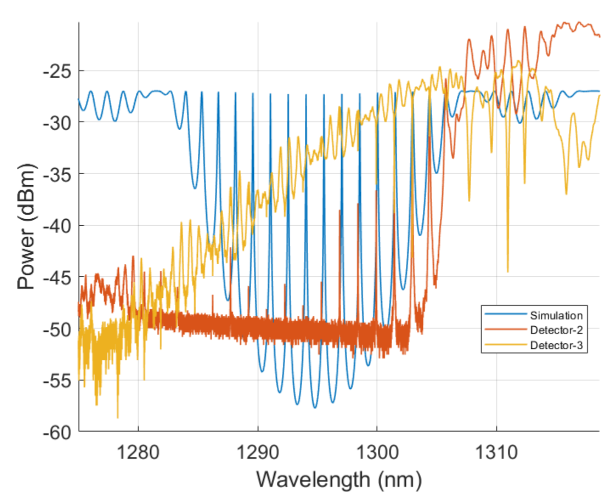

Fig. 9 Measurements vs Simulation for V8

For this device we get high Q factor for the peaks in the right. Also we can see that we only get peaks on the right and on the left they disappear, I think due to an error in the measurements. We get a quality factor of 104150 for a wavelength of 1300 nm. For the others peaks similar values, being the mean 90k.

V. Conclusion

In this project we have analyzed and studied the design of several models to create fabry perot cavities. We have seen how different parameters affect their behavior. We have also simulated and compared these simulations with the real behavior after measurements. We have been able to observe how an error in the bragg period due to external factors (manufacturing) affects our final behavior and how we have had to adapt to this error. The quality factors of our measurements are similar to the simulated ones as well as we have seen that the graphs on the behavior of both (simulations and measurements) are similar, and therefore we can conclude that our simulations have been on the right direction and are accurate.

Annex

Design	**N° of Grating Periods**	Δn	**dW (nm)**	**Length of the cavity in the mid (µm)**
1	80	0.08279	50	34.289
2	120	0,08279	50	0.1345 (Bragg period/2) Back-to-Back
3	50	0,08279	50	304.131
4	65	0,08279	50	48.81 (2 micros width)
5	80	0,08173	45	34.129
6	90	0,08279	50	39.31
7	70	0,08279	50	0.1345 (Bragg period/2)
8	70	0.08173	45	116.464
9	130	0,08119	40	34.649
10	100	0.08173	45	0.1345 (Bragg period/2)

Table 2. Parameters used to create the 10 designs.

Quality factor (Simulation)	**Quality factor (Measurements)**
52131	51323
134760	-
48481	137062
24521	110180
43621	57062
94563	-
4985	-
60496	104150
126880	-
34977	-

Table 3. Results from the simulations and the designs.

References

[1] Chrostowski, L., & Hochberg, M. (2015). System design. In Silicon Photonics Design: From Devices to Systems (pp. 311-312). Cambridge: Cambridge University Press.
[2] Mustafa Hammood's Analyses and experiments.
[3] Student partner Justin Schulz's function in Matlab for the Quality factor.