Project
Waveguide Bragg Grating Laser Resonator

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1. Introduction

Semiconductor lasers embedded on chips are becoming more useful and commonplace in today's society. This new introduction of using lasers in this way creates an exciting landscape of possibilities and many companies are putting serious resources in this direction. Some examples include VCSEL's on smartphones for facial recognition, LiDAR for self-driving vehicles, and using optical links for communication within computer systems. The purpose of this project was to design a laser at 1310nm and analyze the results. The objective is to design a resonator using two Bragg gratings and a Fabry-Perot cavity at a target wavelength of 1310nm. The waveguide is designed to be 220nm x 350nm and operating in TE mode. This waveguide can be analyzed using tools and a compact model can be constructed using Lumerical MODE. The goal is to maximize the Quality factor (Q).

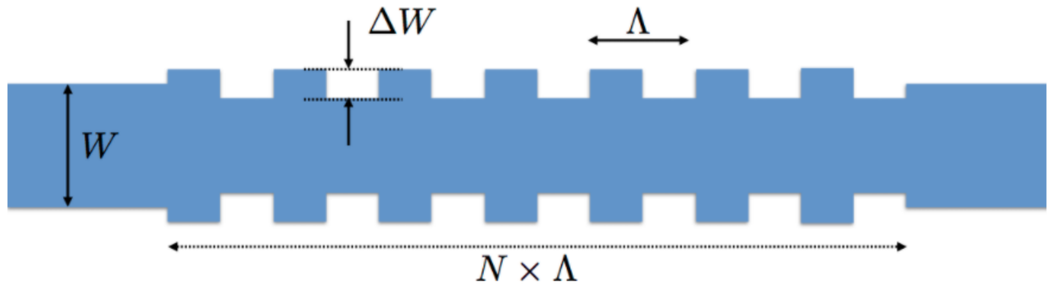


Figure 1. Bragg Grating

2. Theory

LASER stands for Light Amplification by Stimulated Emission of Radiation. What this means is that the conditions for lasing occur when emission of radiation is taking place. However, a very specific type of emission not to be confused with spontaneous emission which is normally seen in nature. Essentially, spontaneous emission can be used to make an LED, but stimulated emission is necessary for a laser.

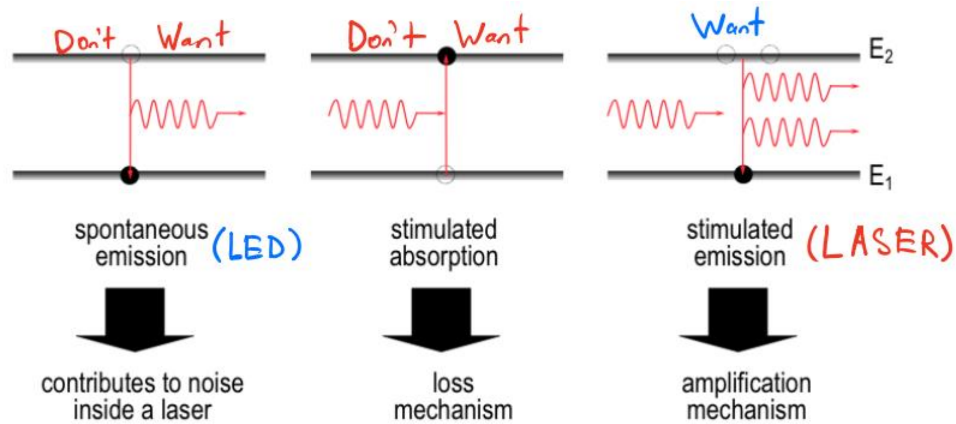


Figure 2. Emission of Radiation Diagram

A laser is comprised of 3 main components: A cavity, pump, and gain element. If the gain is less than the loss then lasing will not be achieved. If the gain is greater than the loss the laser will "blow up." Therefore, a laser only operates at a very specific condition at which the gain and loss are equivalent. In our case the cavity is a Fabry-Perot Cavity with two mirrors at either side (Bragg Gratings) so that the photons can bounce back and forth within the cavity and generate stimulated emission.

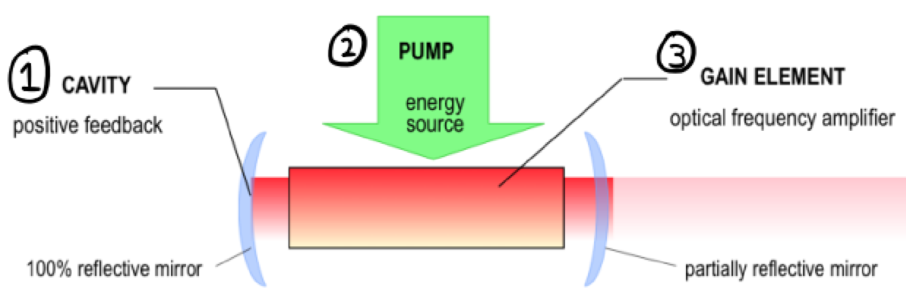


Figure 3. Laser Diagram

3. Modelling and Simulation

The first step is to model the waveguide in Lumerical MODE. Parameters of 220nm and 350nm corresponding to the waveguide width and thickness are input into MODE. Simulations can then be run to obtain the effective index n_{eff}, group index n_g, and loss.

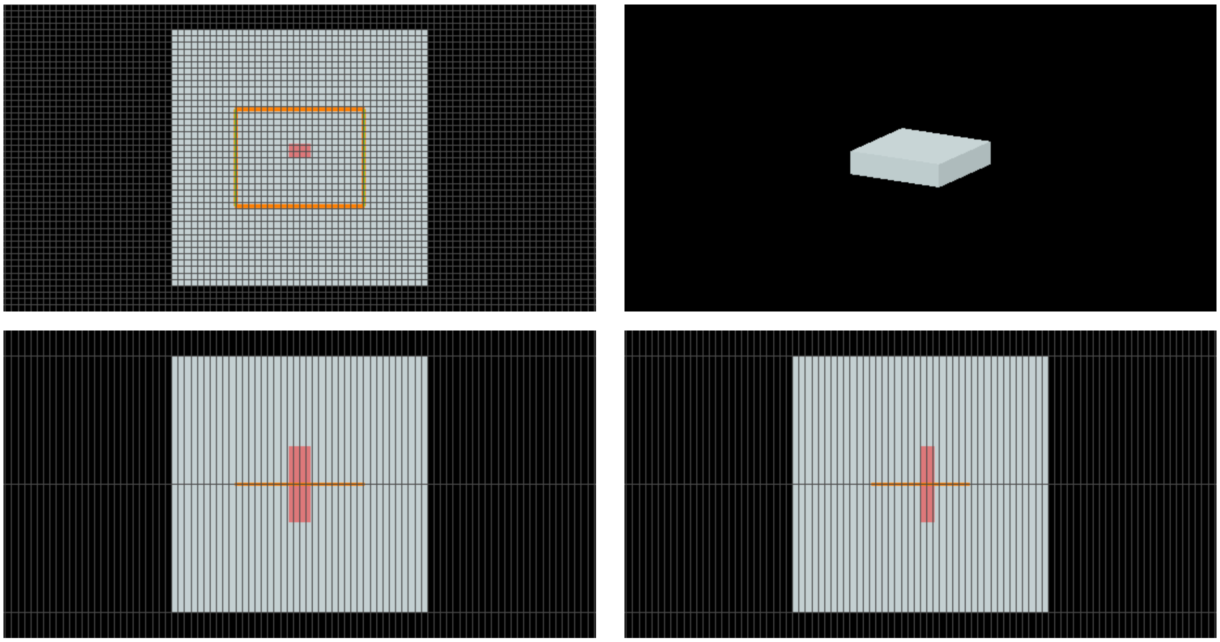


Figure 4. Lumerical MODE Waveguide Model

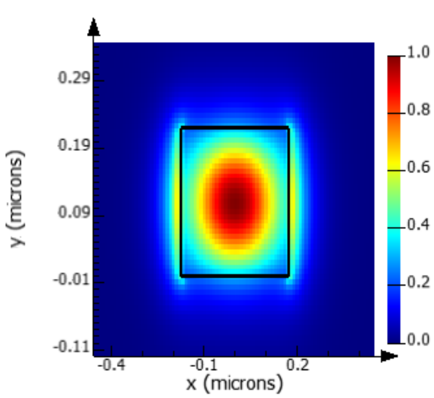


Figure 5. E Intensity Linear Scale

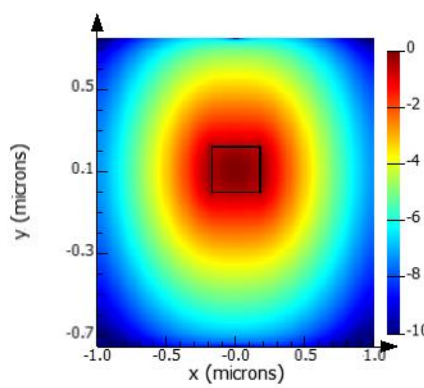


Figure 6. E Intensity Log Scale

mode #	effective index	wavelength (µm)	loss (dB/cm)	group index	TE polarization fraction (Ex)	waveguide TE/TM fraction (%)	effective area (µm^2)
1	2.431067+1.582099e-09i	1.31	0.00065911	4.500402+3.723744e-09i	98	70.55 / 84.1	0.141829

Figure 7. MODE Simulation Results

The results of the simulation show that the effective index n_{eff}, group index n_g, and loss were as follows:

$$n_{eff} = 2.43$$

$$n_g = 4.5$$

$$Loss = 6.59\text{E}{-4}$$

Using this, the Bragg Period can be calculated at the central wavelength ($1310nm$)

$$\Lambda = \frac{\lambda_0}{2n_{eff}} = \frac{1310nm}{2 * 2.431067} = 269.429nm$$

This can also be used to generate plots in MODE governed by the following equation

$$n_{eff} = 2.431067 - 1.57999 \quad * (\lambda - \lambda_0) - 0.0754095 * (\lambda - \lambda_0)^2$$

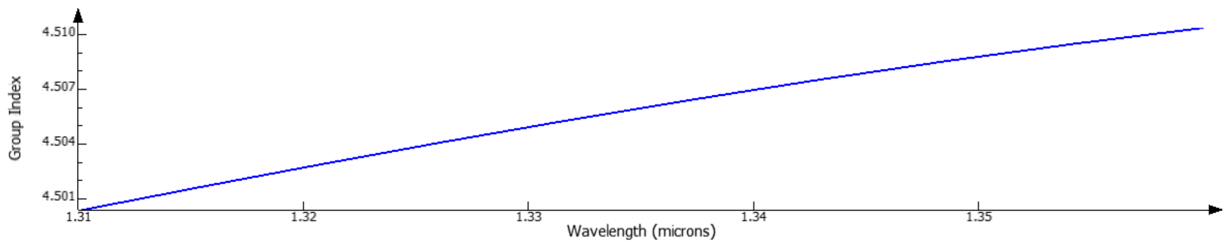


Figure 8. Group Index vs Wavelength (um)

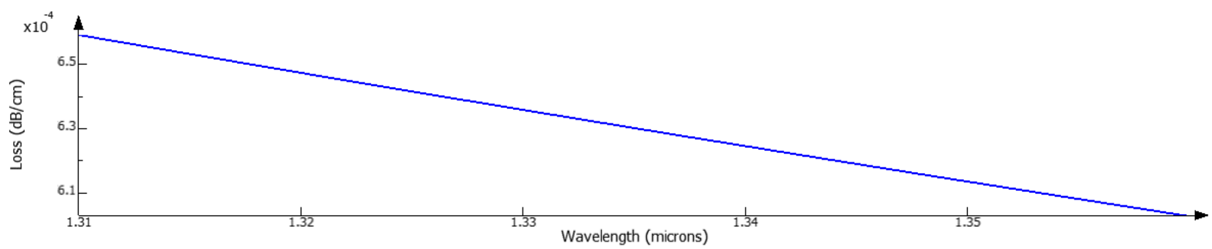


Figure 9. Loss (dB/cm) vs Wavelength (um)

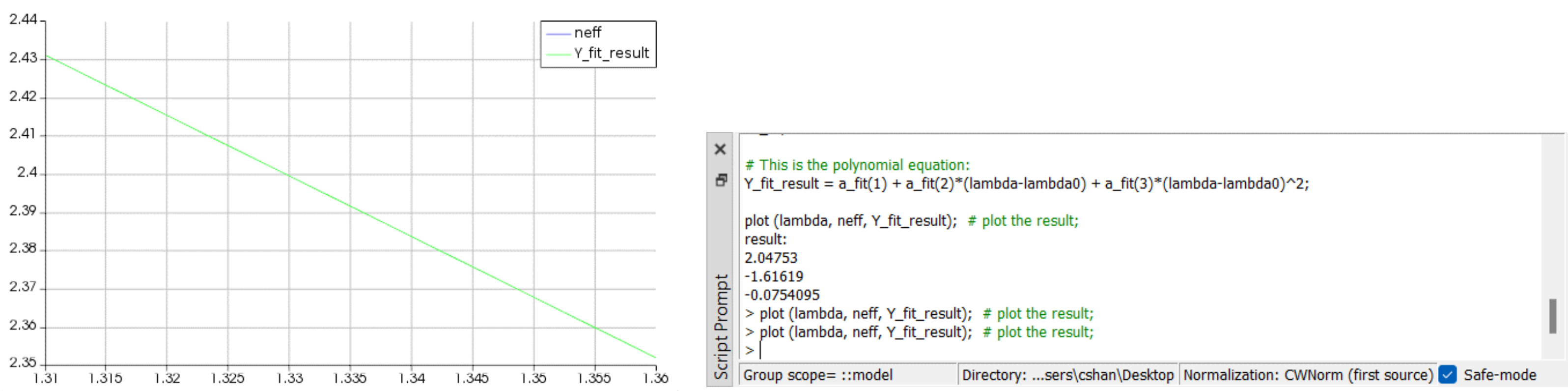


Figure 10. Polynomial Fit Plot and Results

4. Experimental Results

The next step in the design of the resonator was to create a schematic in Klayout which would then be sent to be fabricated. Starting from the left, 9 designs were constructed all at a center wavelength of 1310nm, a grating period of 0.269um, and a grating width of 0.35um. I varied the corrugation width to try to obtain a design with the highest Q factor and also experimented with one short (back to back gratings) and one very long cavity design.

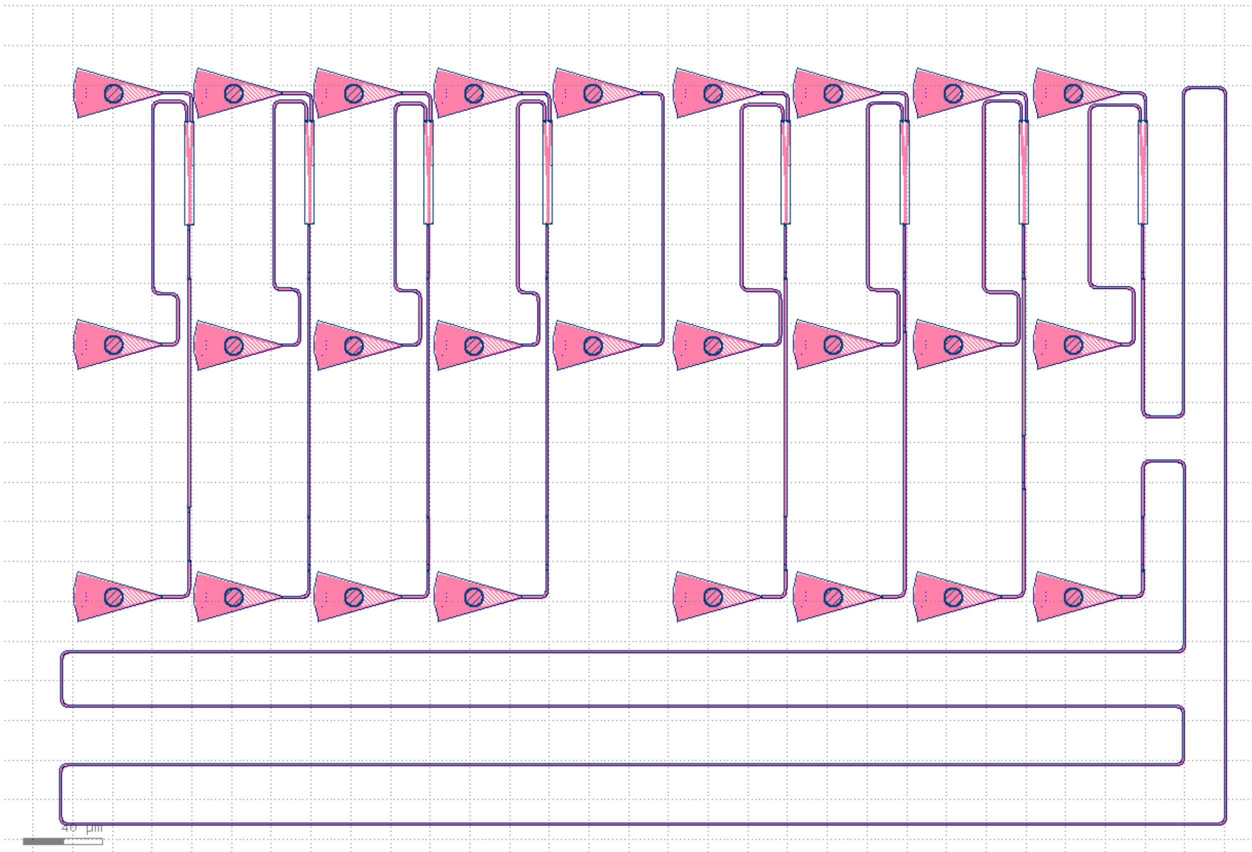
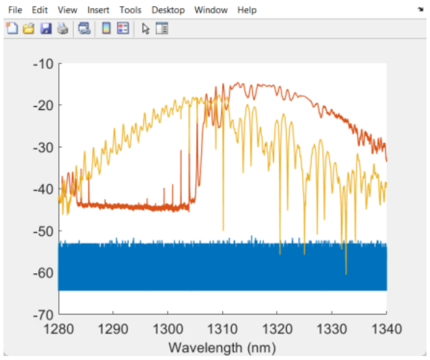


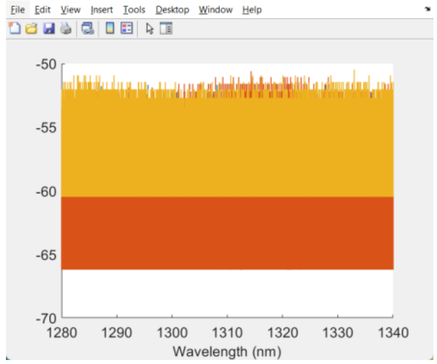
Figure 11. Klayout Design

Design	Wavelength (nm)	Period (um)	W (um)	dW (um)	Cavity Length (um)
1	1310	0.269	0.35	0.04	115
2	1310	0.269	0.35	0.045	120
3	1310	0.269	0.35	0.05	120
4	1310	0.269	0.35	0.055	120
5	1310	0.269	0.35	N/A	145
6	1310	0.269	0.35	0.06	120
7	1310	0.269	0.35	0.05	0
8	1310	0.269	0.35	0.05	80
9	1310	0.269	0.35	0.05	3141

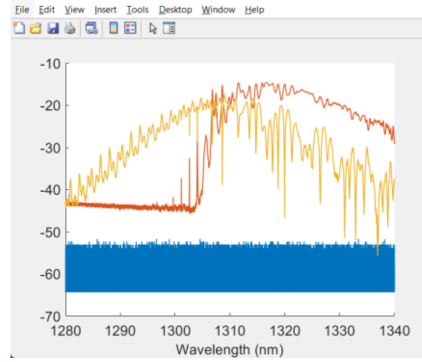
Table 1. Design Parameters



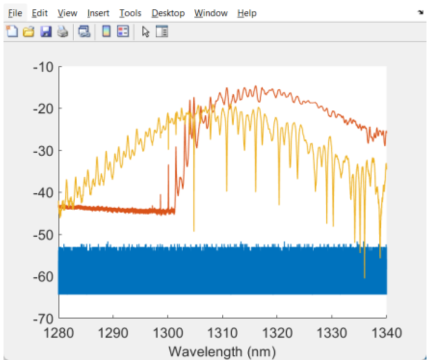
Design 1



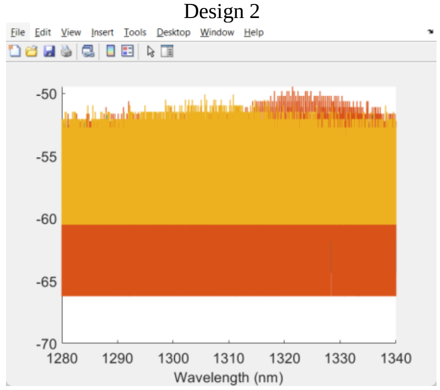
Design 2



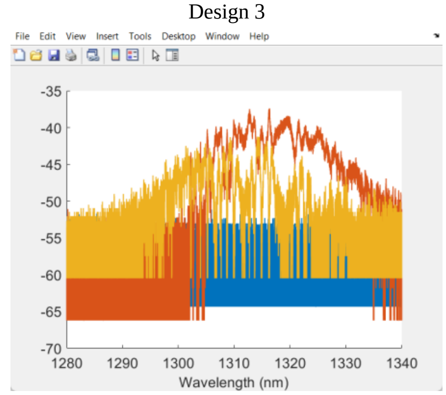
Design 3



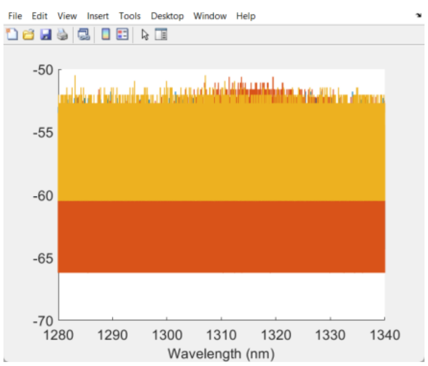
Design 4



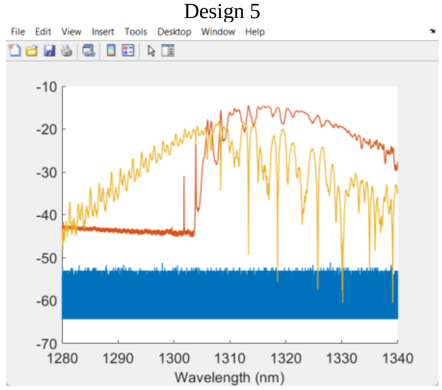
Design 5



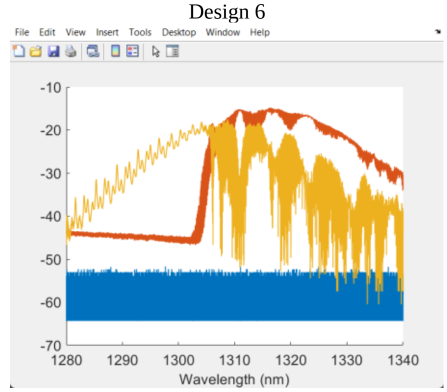
Design 6



Design 7



Design 8



Design 9

Figure 12. Laser Sweep Results

5. Analysis

Of these designs, some were more informative than others. Some ended up being pure noise or indecipherable from the plot but this was expected and the reason for doing multiple designs. Design 8 has a very clear peak and is worth analyzing. A peak can be seen centered at 1301.79nm which is what was expected from the measurement of the physical design (10nm shift in either the right or left direction).

Design 8	
Wavelength (nm)	1310
Period (um)	0.269
W (um)	0.35
dW (um)	0.05
Cavity Length (um)	80

Table 2. Design 8 Parameters

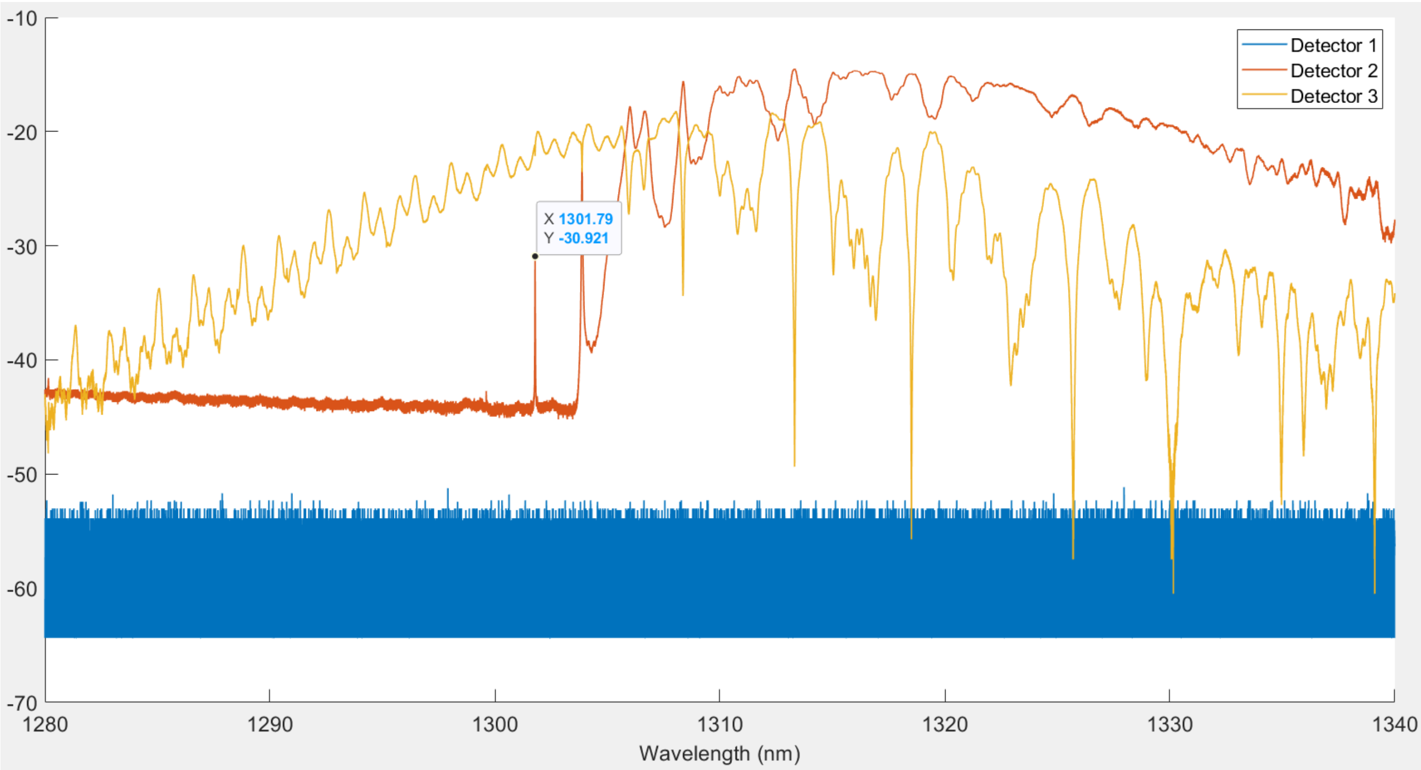


Figure 13. Design 8 Laser Sweep

6. Conclusion

The purpose of this design was to study TE polarized waveguides and their behavior at centered at 1310nm. The goal was to vary certain parameters of the design and achieve a high Q Factor. Unfortunately, I was not able to complete all of these calculations and measure certain values such as Kappa and Q Factor as my Lumerical License expired and I could not figure out how to renew it in time to complete these calculations. However, the data seen in the Laser sweeps was still very informative and comparing different designs and changing parameters still proved to be a useful exercise.

7. References

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