ELEC413 Lab Report

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Q1:

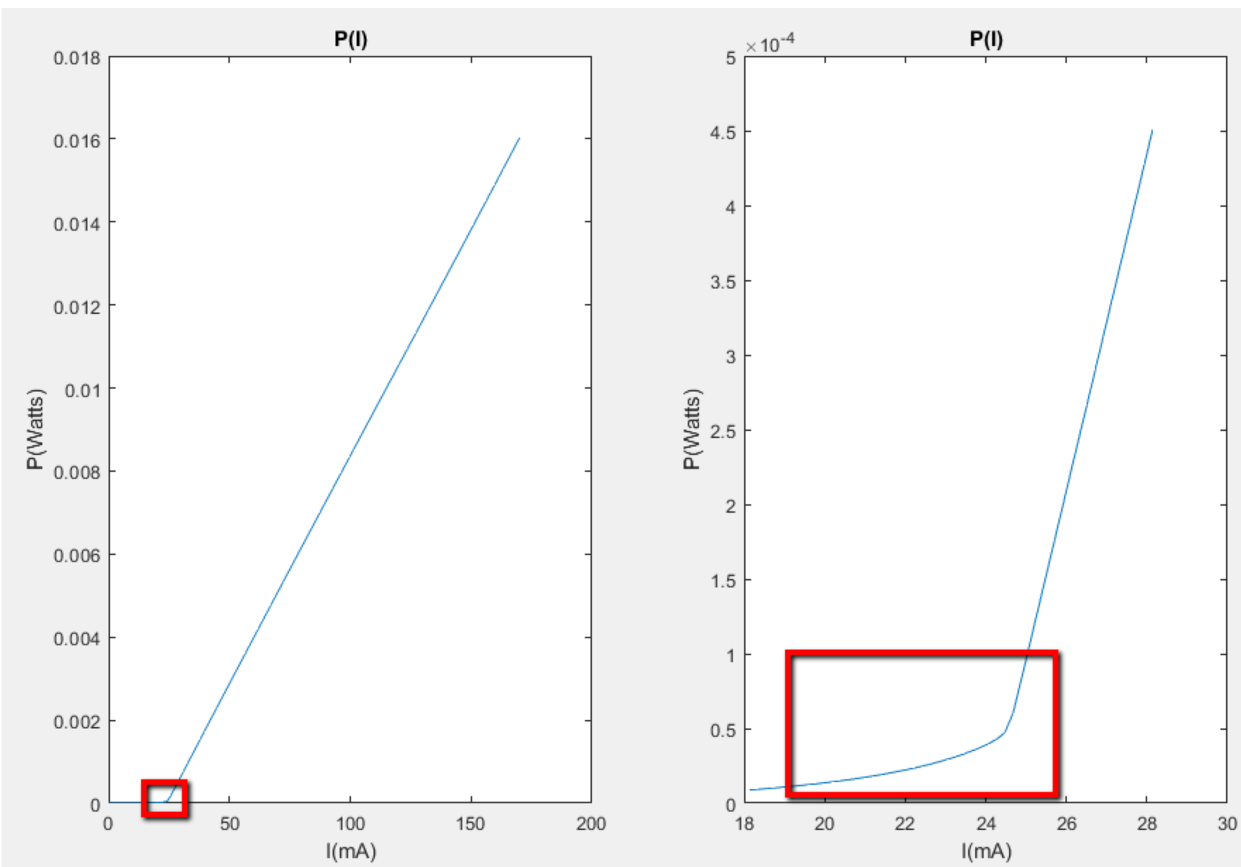
The laser light is determined by the lasing wavelengths or wavelength range. We can't see the laser light without the card as the lasing wavelength is not in the visible wavelength range (for the human eye).

The infrared card emits light in certain wavelength range (i.e. the infra red region) when the laser hits it and the light become visible on the card.

Q2:

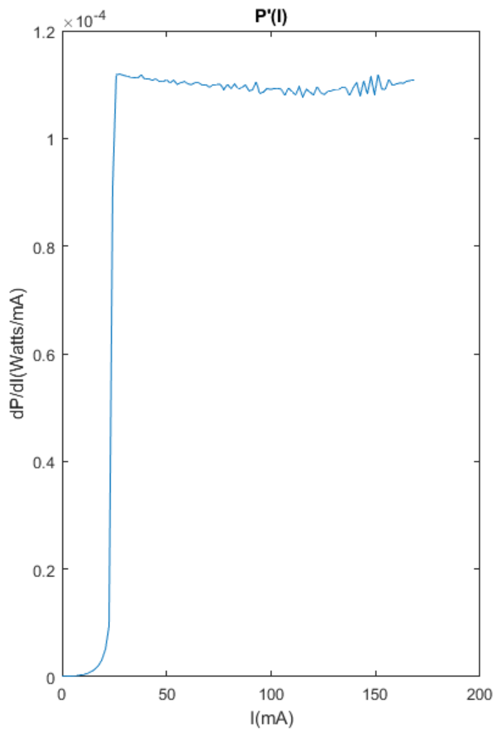
2.1: L(I) graph, where the Y-axis is the LIGHT/OPTICAL POWER. on the left 100 samples and on the right 50 samples.

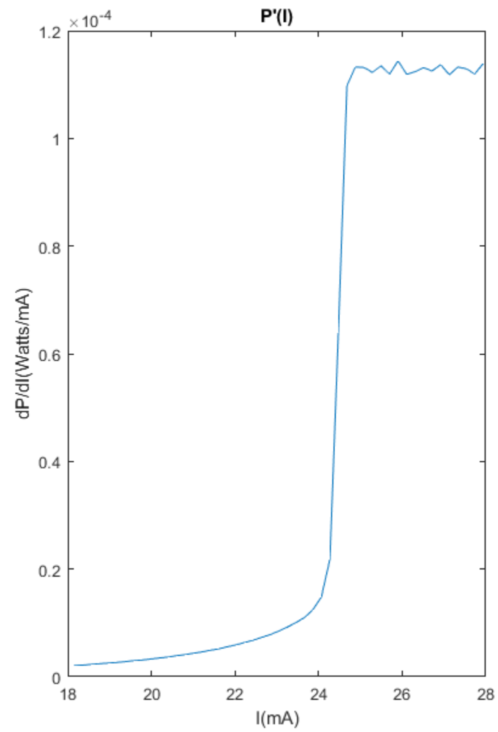
Note: we can see that we don't cross our power limitation of 20mWatts.



2.2 The threshold current is the current from which lasing starts (i.e. light power>0). Its value is within the red box in the graphs above. For a more precise value, the spectral gain results “around threshold” shows a significant ‘spike’ at **I=23mA**.

2.3 L’(I) graphs:





The maximum slope efficiency of this laser is

Matlab code:

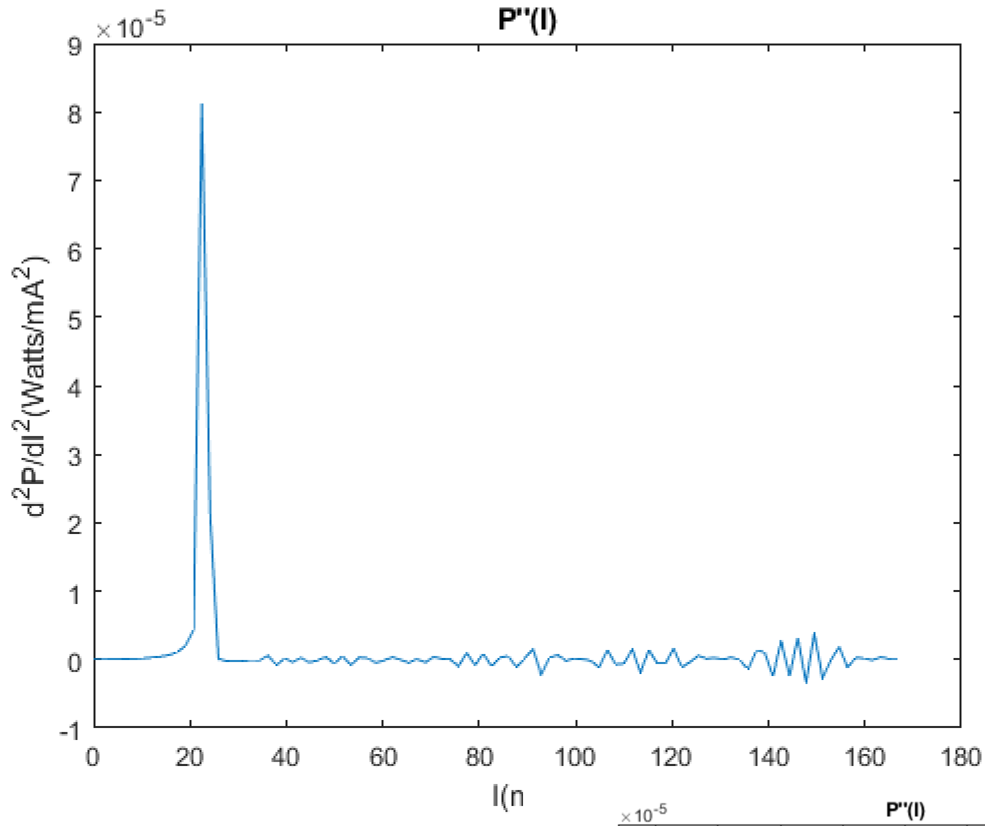
```
>> max(der1{1})

ans =

  1.1193e-04

>> I{1}(find(der1{1}==max(der1{1})))

ans =

  27.6199
```

```
>> max(der1{2})

ans =

  1.1442e-04

>> I{2}(find(der1{2}==max(der1{2})))

ans =

  25.9003
```

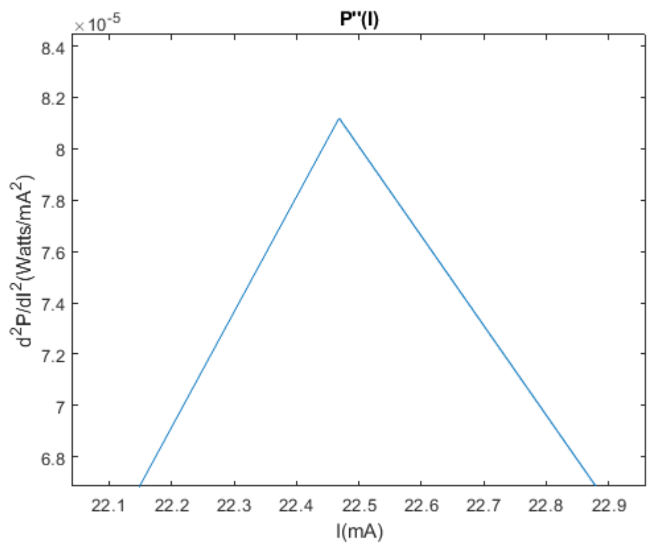
We can say that the max slope efficiency is in the range: $L'(I)max, range = [\mathbf{1.14} \rightarrow \mathbf{1.19}] * \mathbf{10^{-4}}\ [\frac{Watts}{mA}]$

And with current $\boldsymbol{I} = \mathbf{25.90} \rightarrow \mathbf{27.62}[\boldsymbol{mA}]$

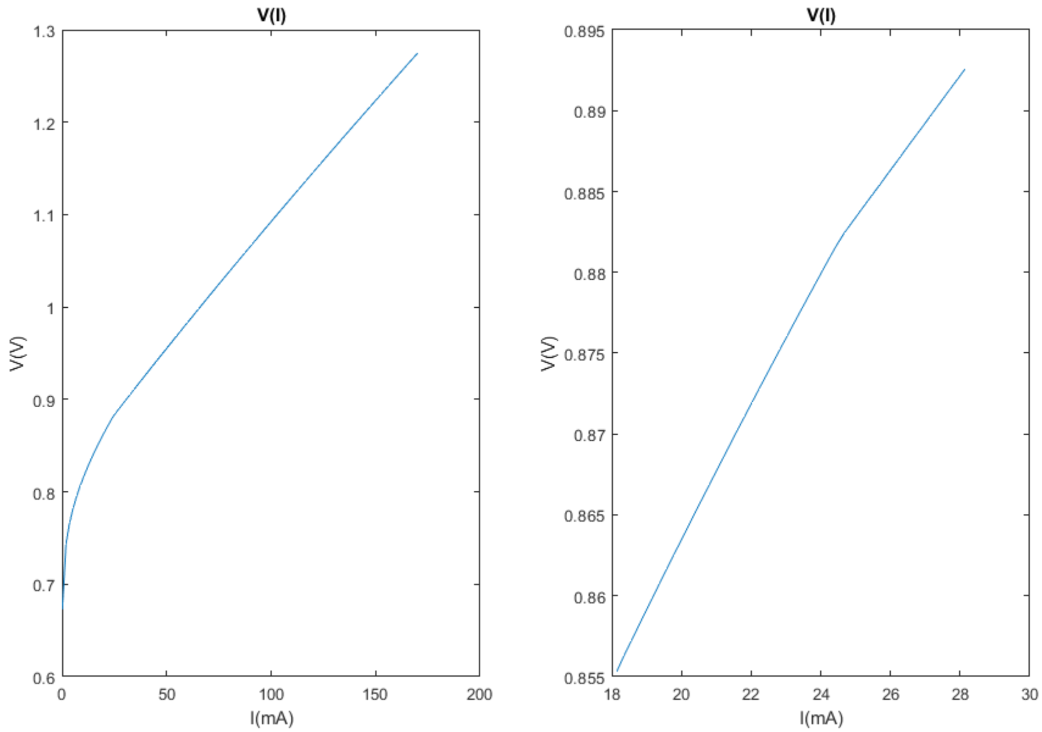
2.4 L''(I) graph:



The threshold can be determined by the location of the peak, zooming in we get: **I_peak=22.47mA.**

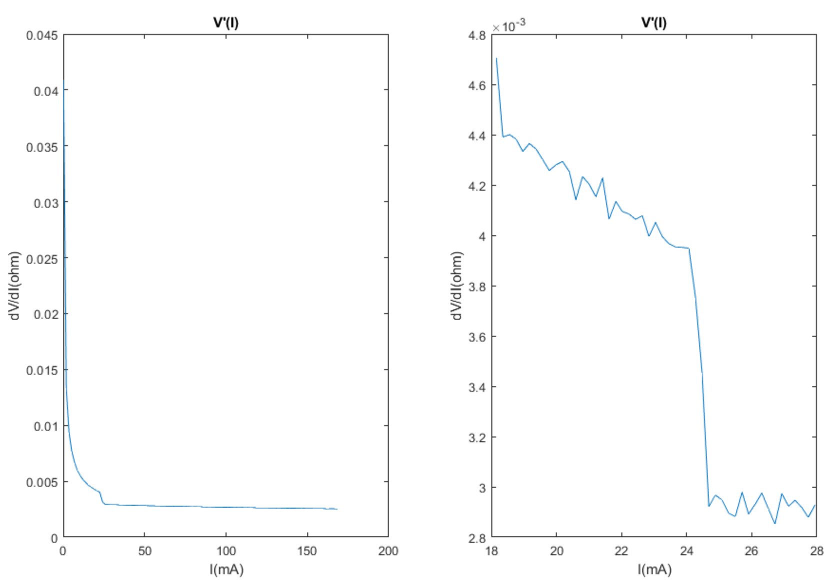


2.5 V(I) graphs:



Note: we can see that we don't cross our voltage limitation of 2Volts.

2.6 V'(I) graphs:



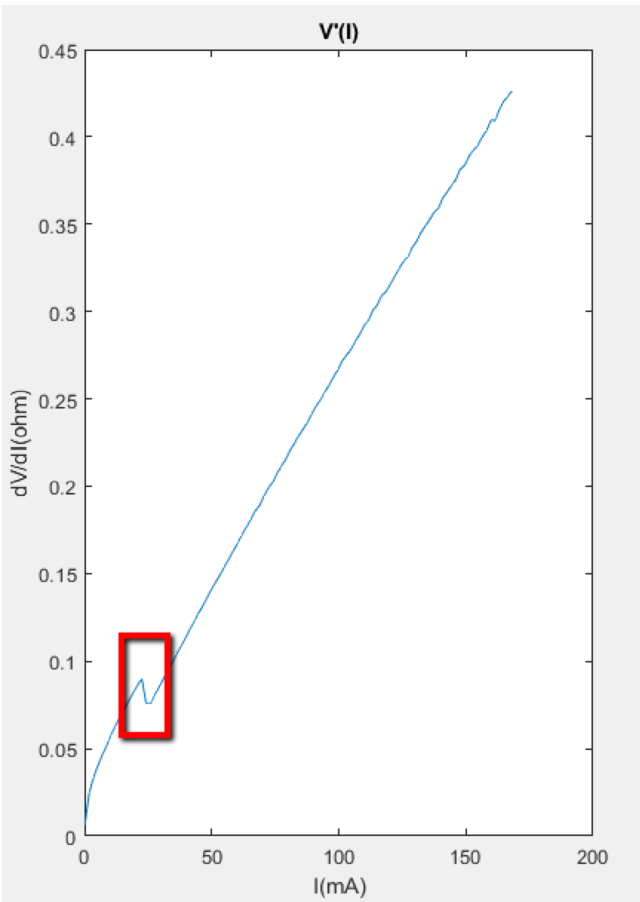
a) I will use the right graph to determine R, because its current is more accurate around the threshold.

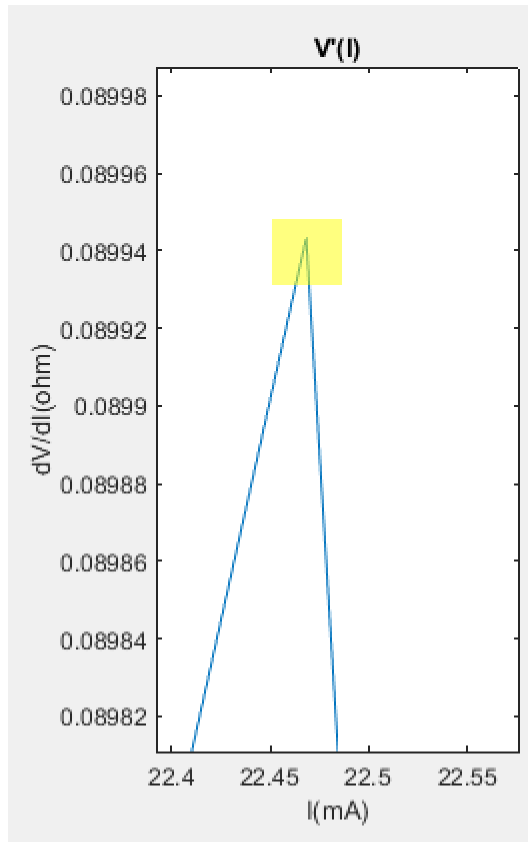
Resistance at threshold I= 22.84mA: **V'(I= 22.84mA) =0.0040[ohm]**

Note: I took values that exist, actual sampled points... that is why I=22.84mA and not 23mA.

b) I will use the left graph to determine R here because this current is only reached on the left graph. Resistance at 2X threshold I= 46.50mA: **V'(I=46.50mA) =0.0028[ohm]**

2.7 I*V'(I) graph – ONLY LEFT IMAGE:





The threshold can be determined by the "discontinuous area", where the direction of the graph changes (from increasing to decreasing) – red rectangle.

In the RIGHT IMAGE - Zooming in shows us that the value is about **22.47mA**, which is indeed the threshold current

2.8

Power at 2X threshold I=46.5mA: **P=I*V=44 [mWatts]**

```
>> I{1}(28)*V{1}(28)
ans =
  43.9530
```

And the optical power is: **L(46.5mA)=25 [mWatts]**

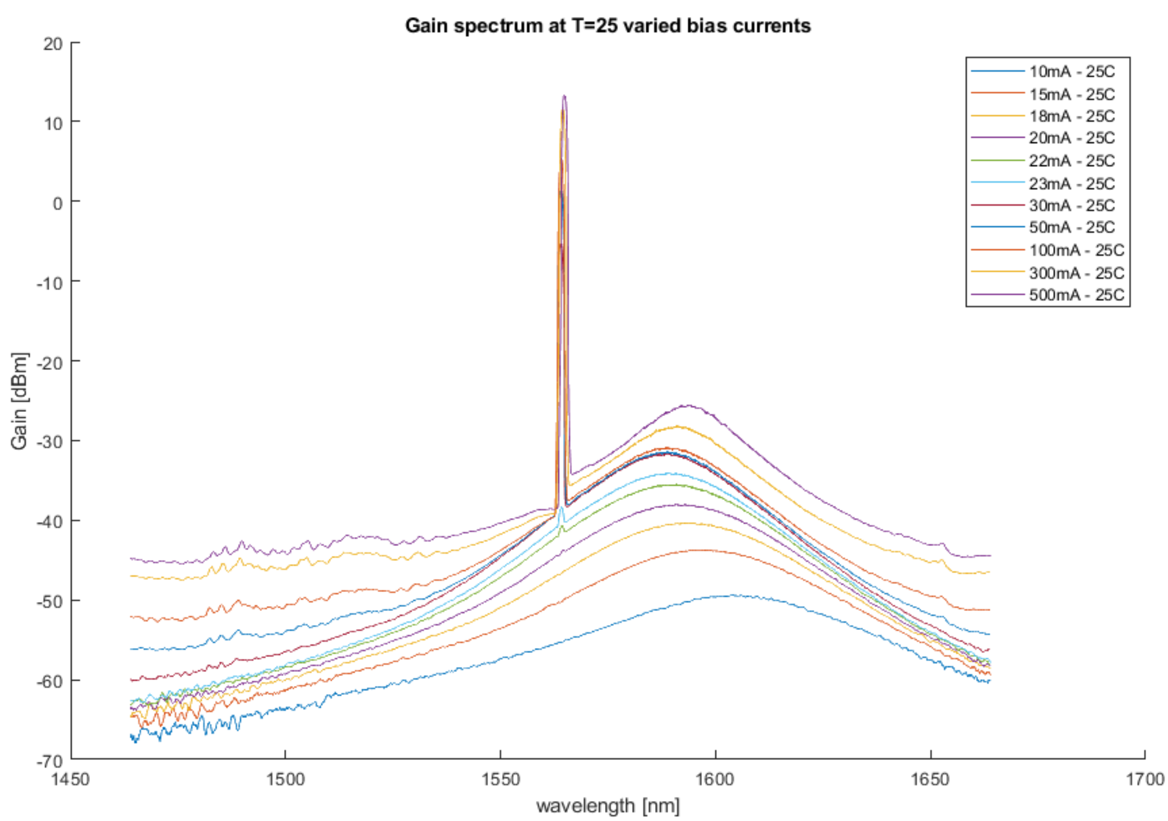
$$Efficiency = \frac{IV}{L} = \frac{25}{44} * 100 = \mathbf{56.82}\%$$

2.9

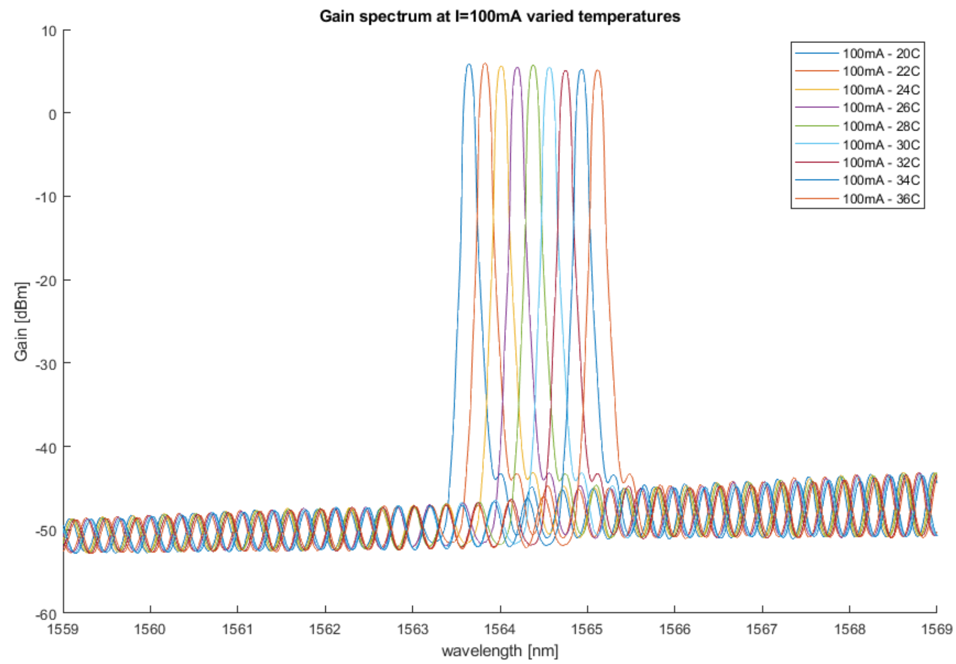
Below threshold we don't have stimulated emission, but we do have spontaneous emission, therefore we would get a small amount of light coming out of the laser even below threshold. Above threshold the curve is not a straight line due to 2 factors: near threshold: still because of spontaneous emission, light is emitted. High currents far from threshold: The L(I) reaches saturation and the graph is not linear anymore after a saturation current. Also due to sampling factor (quality of the sampler and quantization effects).

<u>Q3</u>:

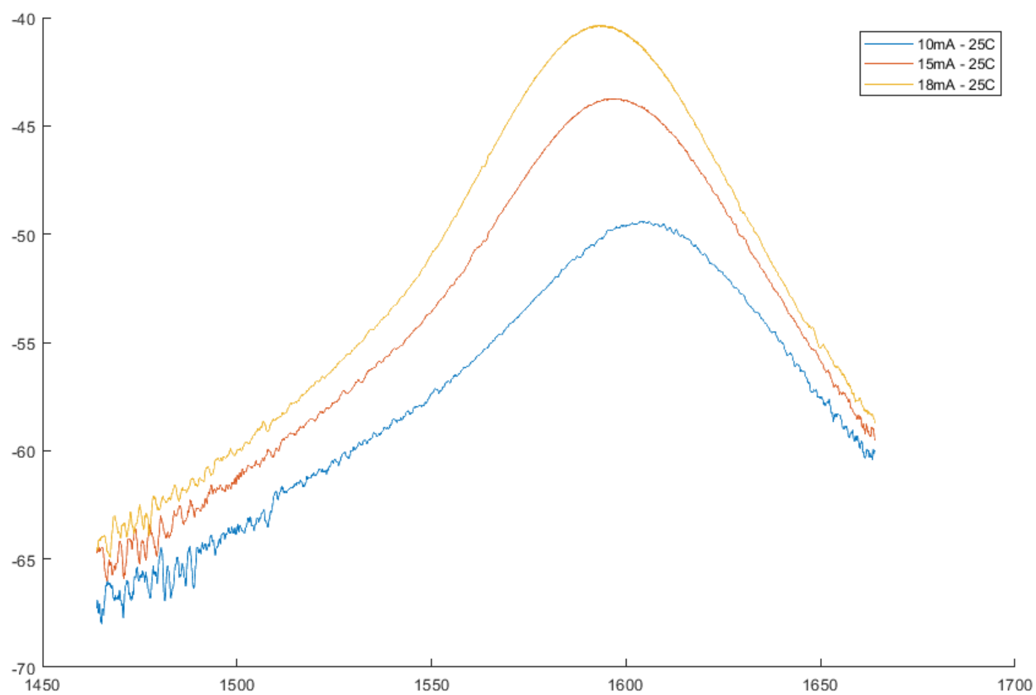
3.1 Same Temperature varying currents:



Varying Temperature same currents:



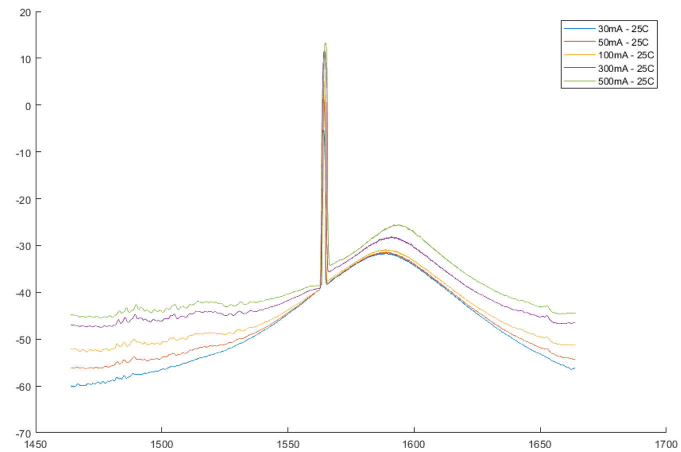
3.2 +3.4: Here are the results only below threshold:



3.2 Below threshold there is only spontaneous emission, which increases with bias current (more carriers injected and therefore emitted, therefore the gain is higher).

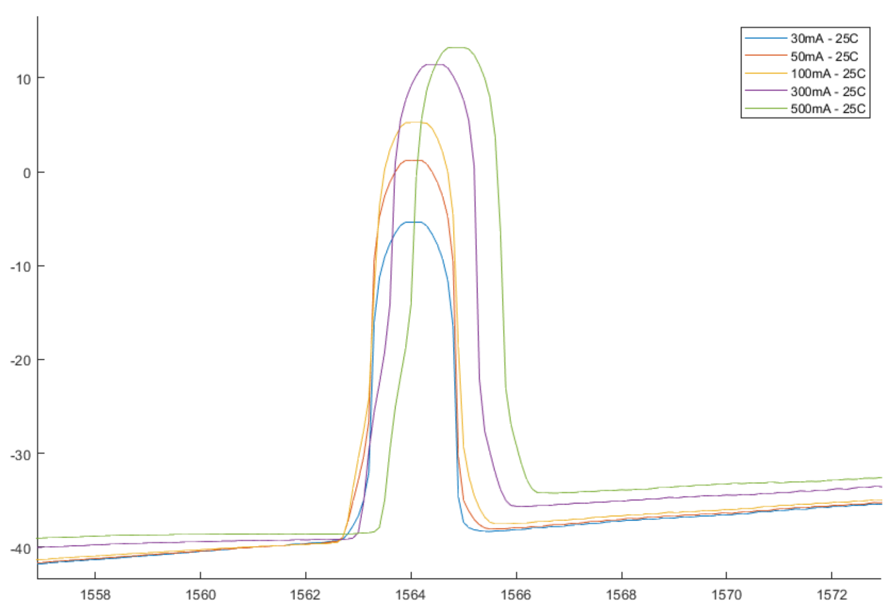
3.4 Below Threshold: We can see that the gain increasing with bias current. The gain peak shifts to higher frequency (lower wavelength) as bias current increasing.

Above Threshold graph:



We can see that the gain increases with bias current. The gain peak's wavelength increases with bias current (frequency decreases).

Zoom in:



3.3 3dB bandwidth: above, below, around threshold.

3 dB BW [nm]	I [mA]	T [Celsius]
47.7	10	25
41.2	15	25
37.6	18	25
35.7	20	25
32.3	22	25
30.3	23	25
1	30	25
0.9	50	25
1	100	25
0.9	300	25
1	500	25

Below and around threshold: Bandwidth decreasing with bias current, above threshold: stable bandwidth.

We can see that the bandwidth is stable above threshold, good sign.

Temperature varying:

3 dB BW [nm]	I [mA]	T [Celsius]
0.1	100	20
0.1	100	22
0.1	100	24
0.1	100	26
0.1	100	28
0.1	100	30
0.1	100	32
0.1	100	34
0.1	100	36

Stable bandwidth for the laser with varying temperatures. We can derive that temperature does not affect bandwidth.

Note: the results are strange, as the bw of 100mA|25C is 1nm and the bw of 100mA|24C is 0.1nm (and I would expect the bw to be the same, because the temperature does not influence bandwidth). I checked the graphs themselves and this is the real bandwidth..

3.5 Above threshold: Bias current effects the wavelength as with more current/power there is more thermal energy, the material expands, and the cavity length is larger, which shifts the lasing wavelength.

Tune up: taking two peaks with different central wavelength:

Central wavelength[nm]	I[mA]
1564	30
1564.3	500

$$Tune-up = \frac{\lambda_1 - \lambda_0}{I_1 - I_0} = \frac{1564.3 - 1564}{500 - 30} = 6.38 * 10^{-4}[\frac{nm}{mA}]$$

Temperature: we can also see that the wavelengths increases with temperature from the temperature graphs (for the same reason, material expansion).

Central wavelength[nm]	T[C]
1563.7	20
1564.2	26

$$Tune-up = \frac{\lambda_1 - \lambda_0}{T_1 - T_0} = \frac{1564.2 - 1563.7}{26 - 20} = 0.083\left[\frac{nm}{C}\right]$$

Conclusion: The temperature determines the shift in frequency more that the current does.

Matlab Code:

Question2_Or.m:

```
%Question2 - Or Bahari

clear all;
%Load data
LIV_data = {load('LIV/20190305132930_LIVsweep.mat')
    load('LIV/20190305133312_LIVsweep.mat')};

%save values in vars for the two results
I={LIV_data{1}.LIVsweep.I,LIV_data{2}.LIVsweep.I};
P={LIV_data{1}.LIVsweep.P,LIV_data{2}.LIVsweep.P};
```

```
V={LIV_data{1}.LIVsweep.V,LIV_data{2}.LIVsweep.V};

%%
%%Q2.1

figure(21);
bound=2;
for i=1:1:bound
   subplot (1,bound,i);
   plot (I{i},P{i});
   xlabel("I(mA)");
   ylabel("P(Watts)");
   title("P(I)");
end

%%
%Q2.3
figure(22);
der1={diff(P{1})./diff(I{1}),diff(P{2})./diff(I{2})};
bound=2;
for i=1:1:bound
   subplot (1,bound,i);
   plot (I{i}(1:end-1),der1{i});
   xlabel("I(mA)");
   ylabel("dP/dI(Watts/mA)");
   title("P'(I)");
end
%way to search for max: I{2}(find(der1{2}==max(der1{2})))

%%
%Q2.4
%der2={diff(der1{1})./diff(diff(I{1})),diff(der1{2})./diff(diff(I{2}))};
der2=diff(der1{1});
figure(23)
bound=1;
for i=1:1:bound
   subplot (1,bound,i);
   plot (I{i}(1:end-2),der2);
   xlabel("I(mA)");
   ylabel("d^2P/dI^2(Watts/mA^2)");
   title("P''(I)");
end

%%
%%Q2.5

figure(25);
bound=2;
for i=1:1:bound
   subplot (1,bound,i);
   plot (I{i},V{i});
   xlabel("I(mA)");
   ylabel("V(V)");
   title("V(I)");
end

%%
%Q2.6
figure(26);
R={diff(V{1})./diff(I{1}),diff(V{2})./diff(I{2})};
bound=2;
for i=1:1:bound
   subplot (1,bound,i);
   plot (I{i}(1:end-1),R{i});
   xlabel("I(mA)");
   ylabel("dV/dI(ohm)");
   title("V'(I)");
end

%%
%Q2.7
```

```
figure(27);
R={I{1}(1:end-1).*(diff(V{1})./diff(I{1})),I{2}(1:end-1).*(diff(V{2})./diff(I{2}))};
bound=2;
for i=1:1:bound
   subplot (1,bound,i);
   plot (I{i}(1:end-1),R{i});
   xlabel("I(mA)");
   ylabel("dV/dI(ohm)");
   title("V'(I)");
end
```

Question3_Or.m:

```
%Question3 - Or Bahari

%% Load Data
clear all;
above_th_data =     {load('./above threshold/20190305215333_OSAsweep_30mA_25degC.mat')
                     load('./above threshold/20190305215358_OSAsweep_50mA_25degC.mat')
                     load('./above threshold/20190305215421_OSAsweep_100mA_25degC.mat')
                     load('./above threshold/20190305215601_OSAsweep_300mA_25degC.mat')
                     load('./above threshold/20190305215627_OSAsweep_500mA_25degC.mat')};

around_th_data =    {load('./around threshold/20190305214718_OSAsweep_20mA_25degC.mat')
                     load('./around threshold/20190305215231_OSAsweep_22mA_25degC.mat')
                     load('./around threshold/20190305215304_OSAsweep_23mA_25degC.mat')};

below_th_data = {   load('./below threshold/20190305214612_OSAsweep_10mA_25degC.mat')
                    load('./below threshold/20190305214536_OSAsweep_15mA_25degC.mat')
                    load('./below threshold/20190305214649_OSAsweep_18mA_25degC.mat')};

temp_data =         {load('./temperature measurements/20190305215827_OSAsweep_100mA_20degC.mat')
                    load('./temperature measurements/20190305215952_OSAsweep_100mA_22degC.mat')
                    load('./temperature measurements/20190305220021_OSAsweep_100mA_24degC.mat')
                    load('./temperature measurements/20190305220050_OSAsweep_100mA_26degC.mat')
                    load('./temperature measurements/20190305220133_OSAsweep_100mA_28degC.mat')
                    load('./temperature measurements/20190305220155_OSAsweep_100mA_30degC.mat')
                    load('./temperature measurements/20190305220419_OSAsweep_100mA_32degC.mat')
                    load('./temperature measurements/20190305220516_OSAsweep_100mA_34degC.mat')
                    load('./temperature measurements/20190305220620_OSAsweep_100mA_36degC.mat')};

%%
%Q3.1
%Current dependence
figure(31); hold on;
bound1=length(below_th_data);
for i = 1:bound1
    plot(str2num(below_th_data{i}.OSAsweep.Wavelength),str2num(below_th_data{i}.OSAsweep.Power));
    g=str2num(below_th_data{i}.OSAsweep.Power).';
    w=str2num(below_th_data{i}.OSAsweep.Wavelength).';
    [peak, peakidx] = max(g);
    threedB = peak-3;
    peak = w(peakidx);
    [~,bw1idx] = min(abs(g(1:peakidx)-threedB));
    [~,bw2idx] = min(abs(g(peakidx:end)-threedB));
    bw1 = w(bw1idx);
    bw2 = w(bw2idx+peakidx-1);
    Bandwidth_below(i) = bw2-bw1;
end

bound2=length(around_th_data);
for i =1:bound2
    plot(str2num(around_th_data{i}.OSAsweep.Wavelength), ...
        str2num(around_th_data{i}.OSAsweep.Power))
    g=str2num(around_th_data{i}.OSAsweep.Power).';
    w=str2num(around_th_data{i}.OSAsweep.Wavelength).';
    [peak, peakidx] = max(g);
    threedB = peak-3;
    peak = w(peakidx);
    [~,bw1idx] = min(abs(g(1:peakidx)-threedB));
```

```
    [~,bw2idx] = min(abs(g(peakidx:end)-threedB));
    bw1 = w(bw1idx);
    bw2 = w(bw2idx+peakidx-1);
    Bandwidth_around(i) = bw2-bw1;
end

bound3=length(above_th_data);
for i = 1:bound3
    plot(str2num(above_th_data{i}.OSAsweep.Wavelength), ...
        str2num(above_th_data{i}.OSAsweep.Power))
    g=str2num(above_th_data{i}.OSAsweep.Power).';
    w=str2num(above_th_data{i}.OSAsweep.Wavelength).';
    [peak, peakidx] = max(g);
    threedB = peak-3;
    peak = w(peakidx);
    [~,bw1idx] = min(abs(g(1:peakidx)-threedB));
    [~,bw2idx] = min(abs(g(peakidx:end)-threedB));
    bw1 = w(bw1idx);
    bw2 = w(bw2idx+peakidx-1);
    Bandwidth_above(i) = bw2-bw1;
end
ylabel("Gain [dBm]");
xlabel("wavelength [nm]");
title("Gain spectrum at T=25 varied bias currents");
legend( "10mA - 25C","15mA - 25C","18mA - 25C", "20mA - 25C","22mA - 25C","23mA - 25C","30mA -
25C","50mA - 25C","100mA - 25C","300mA - 25C","500mA - 25C");
hold off;

%Temp dependence
figure(32); hold on;
bound4=length(temp_data);
for i = 1:bound4
    plot(str2num(temp_data{i}.OSAsweep.Wavelength),str2num(temp_data{i}.OSAsweep.Power))
    g=str2num(temp_data{i}.OSAsweep.Power).';
    w=str2num(temp_data{i}.OSAsweep.Wavelength).';
    [peak, peakidx] = max(g);
    threedB = peak-3;
    peak = w(peakidx);
    [~,bw1idx] = min(abs(g(1:peakidx)-threedB));
    [~,bw2idx] = min(abs(g(peakidx:end)-threedB));
    bw1 = w(bw1idx);
    bw2 = w(bw2idx+peakidx-1);
    Bandwidth_temp(i) = bw2-bw1;
end
ylabel("Gain [dBm]");
xlabel("wavelength [nm]");
title("Gain spectrum at I=100mA varied temperatures");
legend( "100mA - 20C","100mA - 22C","100mA - 24C", "100mA - 26C","100mA - 28C","100mA -
30C","100mA - 32C","100mA - 34C","100mA - 36C");
hold off;
%tune-up temp: (lambda1-lambda2)/(T1-T2)
%%
%Q3.2+3.4 (below threshold)
figure(33); hold on;
bound1=length(below_th_data);
for i = 1:bound1
    plot(str2num(below_th_data{i}.OSAsweep.Wavelength),str2num(below_th_data{i}.OSAsweep.Power))
end
legend( "10mA - 25C","15mA - 25C","18mA - 25C", "20mA - 25C");
hold off;


%%
%Q3.4 (above threshold)
figure(34); hold on;
bound3=length(above_th_data);
for i = 1:bound3
    plot(str2num(above_th_data{i}.OSAsweep.Wavelength),str2num(above_th_data{i}.OSAsweep.Power))
end
legend("30mA - 25C","50mA - 25C","100mA - 25C","300mA - 25C","500mA - 25C");
hold off; %tune-up current: (lambda1-lambda2)/(I1-I2)
```