Portland State
UNIVERSITY

DEPARTMENT OF ELECTRICAL
AND COMPUTER ENGINEERING

ECE 515: SPRING 2023 - **FIRST PROJECT**
FUNDAMENTALS OF SEMICONDUCTOR DEVICES

DEVICE CHARACTERIZATION
PN JUNCTION

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Introduction:

Diodes are essential semiconductor devices used in various electronic applications. In this project, we will become familiar with the current-voltage characteristics of a pn-junction diode by analyzing its behavior at different temperatures. We will compare theoretical models with experimental data, and use graphical analysis to extract parameters. This project will reinforce our learning from class and homework, and provide a deeper understanding of the characteristics of pn-junction diodes.

1. Linear and semilog graphs at room temperature:

In this section, I will use measurements taken at room temperature (25°C) to plot the IV characteristics of the PN junction. I will create both linear and semi-log scale plots, with current (I) on the y-axis and voltage (V) on the x-axis.

a. (5 points) Graph 1: Linear plot of I-V characteristics (V on the x axis in linear scale, I on the y axis in linear scale).

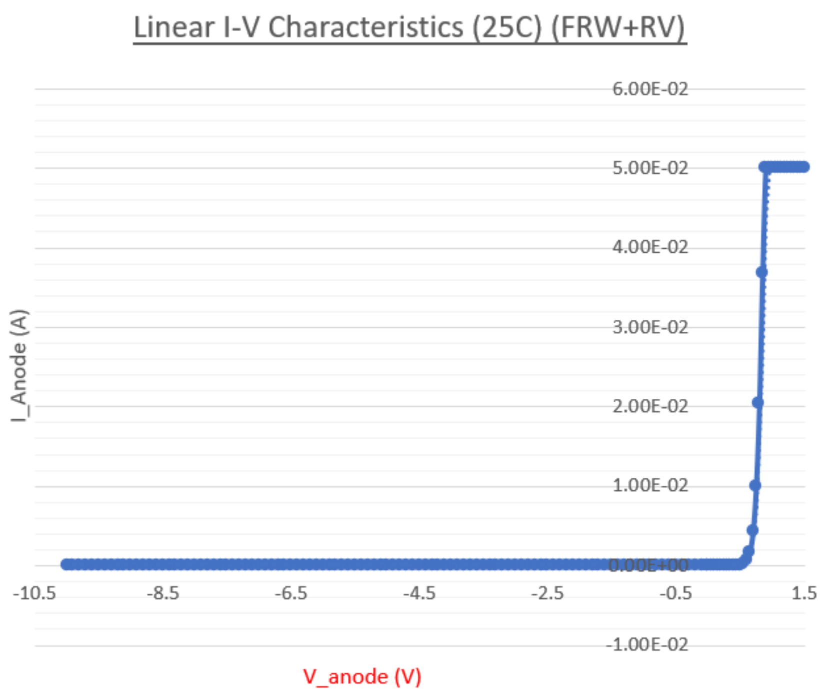


Figure 1 Linear IV Plot at room temperature.

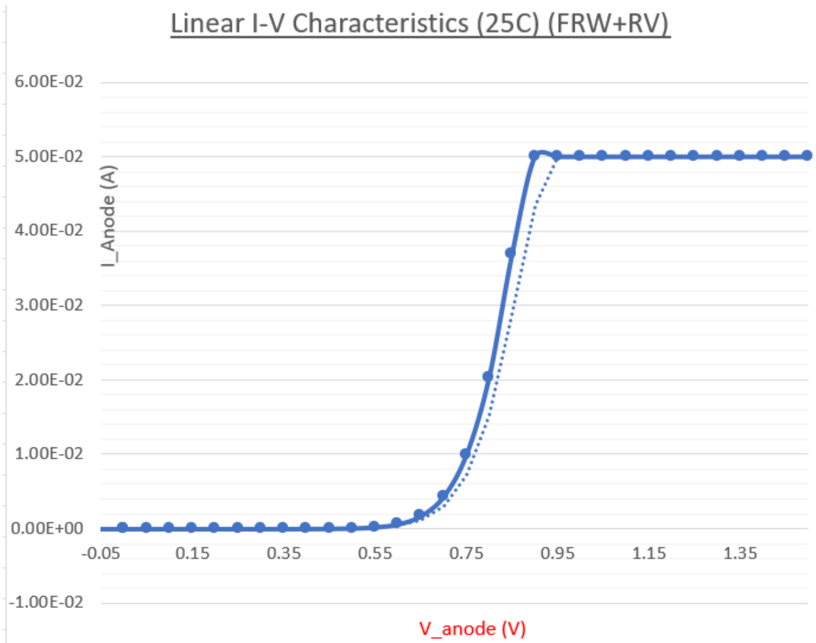


Figure 2 Linear IV Plot at room temperature. This plot is just zoomed in towards the forward region.

b. (5 points) Graph 2: Semi-logarithmic plot of I-V characteristics (V on the x axis in linear scale, I on the y axis in logarithmic scale).

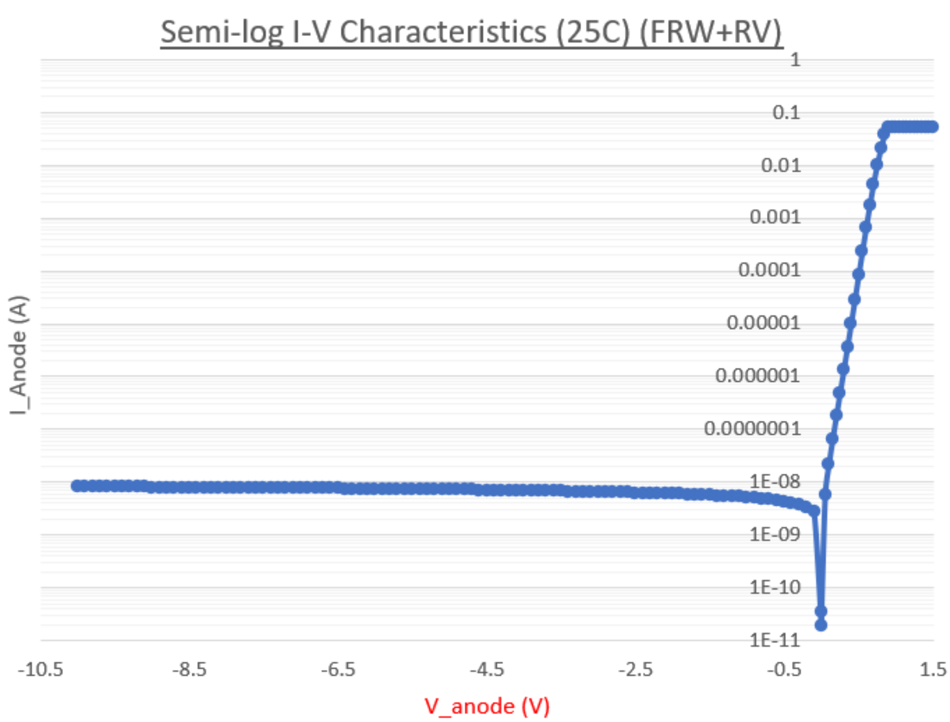


Figure 3 Semi log IV Plot at room temperature.

2. Disregard.

3. Fitting the data to an idea diode, using the ideality factor “n”.

- Part a):

Equation of an ideal diode with ideality factor n, $I = I_0\left[e^{\left(\frac{qV}{nkT}\right)} - 1\right]$

I need to find a way to extract/find the saturation current I_0 from the given data.

To find I_0,

$$I = I_0\left[e^{\left(\frac{qV}{nkT}\right)} - 1\right]$$

$I \cong I_0 e^{\left(\frac{qV}{nkT}\right)}$, since V is much higher in forward direction, we can ignore -1

By taking the natural log of both sides, we get:

$$\ln(I) = \ln\left(I_o e^{\left(\frac{qV}{nkT}\right)}\right) = \ln I_o + \frac{V}{nV_t}$$

$$\therefore \ln(I) = \ln(I_o) + \frac{V}{nV_t}$$

This is basically a line equation on the semilogarithmic scale! $y = c + mx$

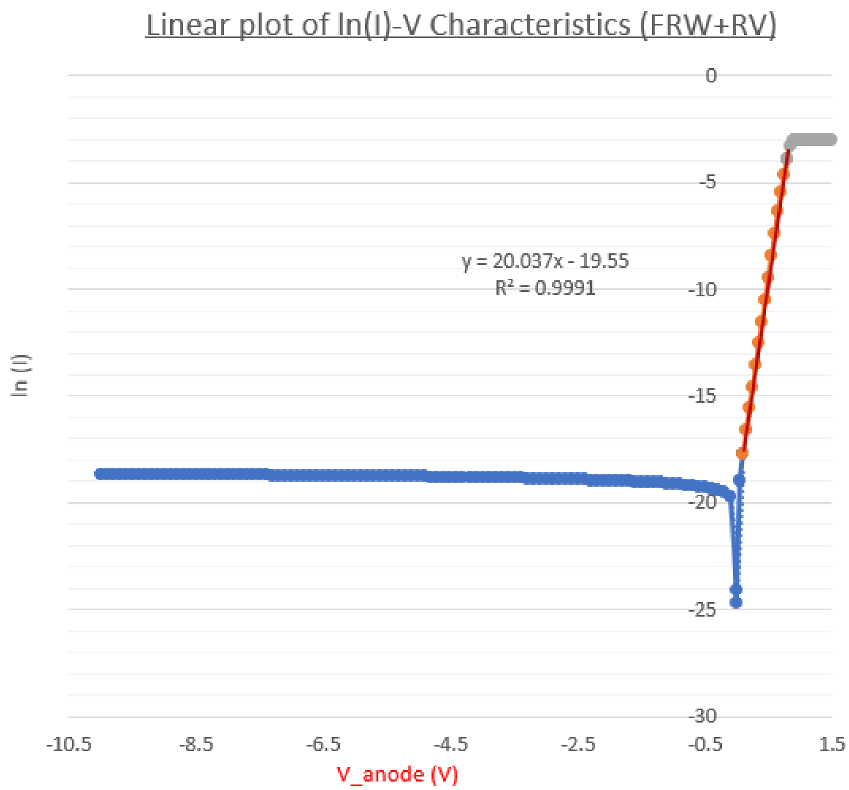
The saturation current I_o is simply the natural exponent of the y intercept

$I_o = e^{y\text{ intercept}}$, on the semilog scale

From excel, the y-intercept is $= -19.549563$

$$I_o = e^{-19.549563} = 3.23 \times 10^{-9}A = 3.23nA$$

I included the plot in the report, although it may appear unconventional. Since the linear fit didn't work well on the semilog plot and the exponential fit didn't provide a line equation, I decided to plot ln(I) vs. (V) for visual purposes. This allowed me to achieve a linear fit, enabling me to determine the slope from the graph and calculate 'n,' while the y-intercept helped me find the saturation current.



	ln(I_o)	-19.549563
Saturatior	I_o	3.23E-09

Figure 3 This s a "linear" plot of ln(I) Vs V. I needed to plot it this way such that the y-intercept of the linear fit would be the saturation current.

<u>Now to find the ideality factor:</u>

$$\frac{I}{I_0} \cong e^{\left(\frac{qV}{nkT}\right)}, \qquad V_t = \frac{kT}{q}$$

By taking the natural log of both sides, we get:

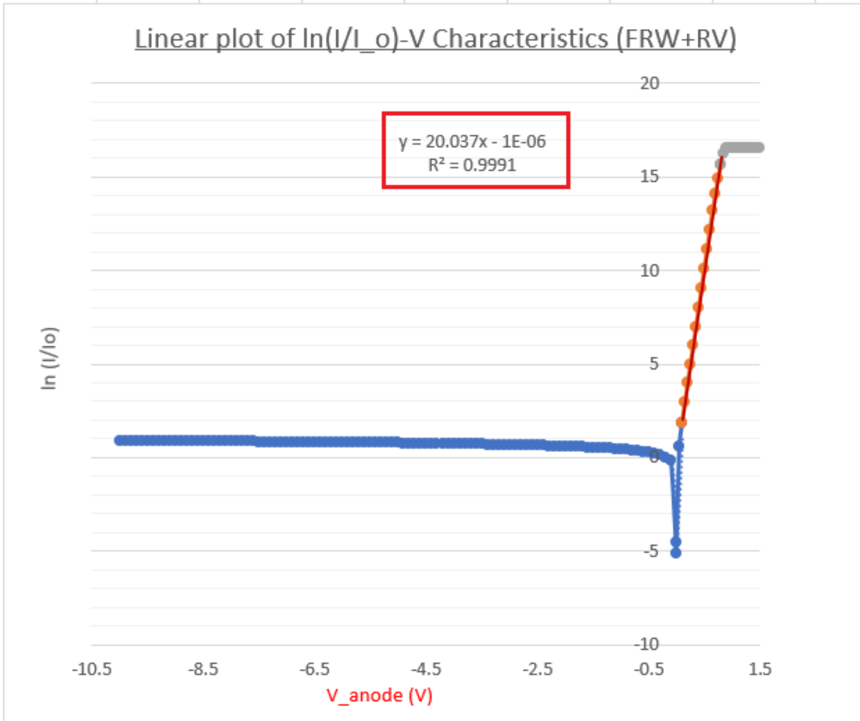
$$\ln\left(\frac{I}{I_0}\right) = \frac{V}{nV_t}, \qquad n = \frac{\ln\left(\frac{I}{I_0}\right)}{V} \times V_t$$

$$\therefore \ln(I) - \ln(I_o) = \ln\left(\frac{I}{I_o}\right) = \frac{V}{nV_t}$$

$$\text{slope} = \ln\frac{\left(\frac{I}{I_o}\right)}{V}, \qquad \therefore \text{the ideality factor is}, \qquad n = \frac{1}{\text{slope} \times V_t}$$

Using excel, I found the slope to be = 20.03679

$$V_t \cong 0.025\ \mathrm{V}, \qquad \therefore\ n = \frac{1}{\text{slope} \times V_t} = \frac{1}{20.03679 \times 0.025\mathrm{V}} = 2$$



Slope	20.0368
n	1.99633

Figure 4 This s a "linear" plot of ln(I/Io) Vs V. I needed to plot it this way such that the y-intercept of the linear fit would be the saturation current.

$$\text{Boltzmann constant } k = 1.38 \times 10^{-23}\,\frac{\mathrm{J}}{\mathrm{K}}, \qquad 1\mathrm{eV} = 1.6 \times 10^{-19}\mathrm{J},$$

$$k = \frac{1.38 \times 10^{-23}\mathrm{J/K}}{1.6 \times 10^{-19}\mathrm{J}} = 8.625 \times 10^{-5}\,\frac{\mathrm{eV}}{\mathrm{K}}$$

$$25\mathrm{C}\ \approx 300\mathrm{K}, \qquad \text{we have } kT = 8.625 \times 10^{-5}\,\frac{\mathrm{eV}}{\mathrm{K}} \times 300\mathrm{K} = 0.0258\ \mathrm{eV} \cong 0.025\mathrm{eV}$$

$$V_t = \frac{kT}{q} = \frac{0.025\mathrm{eV}}{e} = 0.025\mathrm{V}$$

- <u>Part b):</u>

<u>Explain your extraction scheme.</u>

Here is my simple scheme to extract the saturation current (Is or I0) and ideality factor (n) given the PN junction IV measurements and plots from the previous part:

1. I used the Semilog scale IV plot, with the logarithmic scale for the current (I) on the Y axis, and a linear scale for the voltage (V) on the X axis).
2. I Identified the Forward Bias Region of the plot where the current starts to increase rapidly with voltage.
3. I applied a linear Fit to the forward bias region of the semilog plot. This is equivalent to fitting the equation $\ln(I) = \ln(Is) + V/(nVt)$ to the data, which is linear in V and ln(I).
4. I extracted the parameters from the Fit, where the slope of the fitted line gives 1/(nVt), and the y-intercept gives ln(Is). Hence, I can calculate:

- The ideality factor n as 1/(slope * Vt).
- The saturation current Is as exp(y-intercept).

- What should the current value be for voltage V = 0V?

According to the Shockley diode equation, in an ideal diode, at V = 0V, the current (I) should also be 0A. This is because, in theory, there is no potential difference to drive the charge carriers across the junction.

- What do you do if that is not what you measure?

If the current is not zero at V = 0, this could indicate some offset or error in the measurements, meaning that we might need to correct for this offset the data, . It could also indicate that this diode is not behaving ideally.

in reality, we might measure a non-zero current at V = 0V due to various factors such as leakage current or the presence of impurities, or of course due to offset errors in the measurement equipment.

- Is it necessary for your data?

Having data around V = 0 can be helpful for verifying the fit and the consistency of the data, but it's not strictly necessary for the fitting process and my scheme above, which primarily uses data from the forward bias region.

In terms of whether this data point is necessary, this depends on the specifics of the experiment or study. However, in general, it is important to have data around V = 0V. This is because the behavior of the diode in this region can give us valuable information about its characteristics, allowing us to see if your diode is behaving as expected based on the ideal diode model.

4. The more realistic model with parasitic series resistance

The Shockley diode equation is an ideal model that doesn't include effects such as parasitic series resistance or recombination/generation in the space-charge region. However, these factors can significantly affect the I-V characteristics of a real-world diode.

$$I = I_0 \left[e^{\frac{q(V - IR_S)}{nkT}} - 1 \right]$$

a. Examine the slope on the semi-log plot:

- Low Voltage: At low voltages, the diode is in forward bias, but the current is still small. Recombination in the neutral regions might be significant here, resulting in an apparent ideality factor greater than 1. This is because the recombination current has a different temperature dependence than the diffusion current, which dominates at higher voltages. The series resistance is usually not a significant factor at low voltages.
  - Parasitic Series Resistance: In this region, the current starts to increase significantly, but it's usually not large enough for the series resistance to have a substantial effect.
  - Recombination/Generation in the Space Charge Region: In the low voltage forward bias region, majority carriers start to get injected across the junction, and the current is primarily due to the diffusion of these carriers. Recombination in the space charge region is typically not significant here as the carriers have enough energy to cross the junction.
- Medium Voltage: The current continues to increase but the slope of the I-V curve starts to decrease, suggesting that the current is no longer increasing exponentially with voltage. This behavior might suggest that recombination in the neutral region or high-level injection effects are starting to become significant.
  - Parasitic Series Resistance: The series resistance starts to become more significant in this region because the current is larger. The voltage drop across the series resistance starts to become a noticeable part of the applied voltage.
  - Recombination/Generation in the Space Charge Region: As the forward voltage increases, more carriers get injected, and recombination in the neutral regions or high-level injection effects may start to become significant.
- High Voltage: In the high voltage region (around 0.8V and above), the current seems to saturate at around 0.05 A. This is likely due to the series resistance that begins to dominate at higher currents and voltages, thus limiting the current.

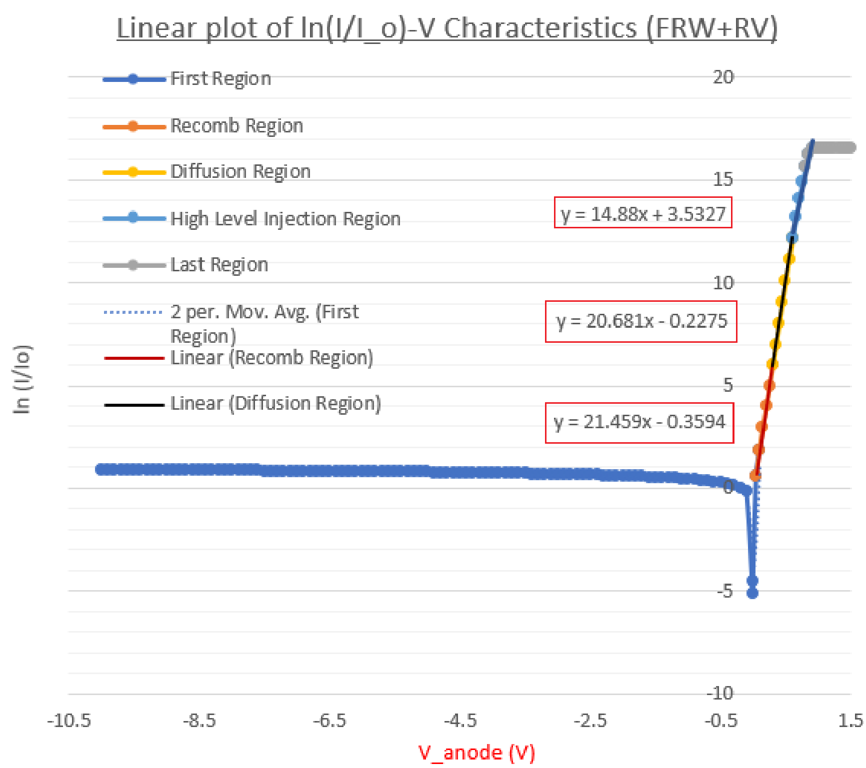
This could also be due to the device reaching its physical limits. The current appears to reach a plateau, suggesting that the diode is now in the ohmic region where the current is limited by the series resistance. The slope of the I-V curve in this region in a semi-log plot is almost flat, indicating that the parasitic series resistance is significant in this region.

  - Parasitic Series Resistance: In the high voltage region, the series resistance becomes very significant. The current is large, and the voltage drop across the series resistance is a substantial part of the applied voltage, which effectively limits the current.
  - Recombination/Generation in the Space Charge Region: In this region, the current is mostly limited by the series resistance, not by the properties of the pn junction itself. Therefore, recombination or generation in the space charge region is typically not significant in this region.

- Reverse Bias: The current in this region is almost constant, showing a slight decrease as the voltage becomes more negative. This behavior is typically associated with the reverse saturation current due to minority carrier injection and recombination in the space charge region, which can be significant in this region.
  - Parasitic Series Resistance: In this region, the series resistance is not usually significant because the current is relatively small.
  - Recombination/Generation in the Space Charge Region: In the reverse bias region, the space charge region widens, and current is primarily due to minority carrier injection and subsequent recombination or generation in the space charge region. This is the dominant effect in this region and leads to the nearly constant reverse saturation current.

b. Adjust the ideality factor "n" for each region:

Given the potential changes in the behavior of the diode across different voltage regions, I will use a piecewise linear approximation with different values of n for different voltage ranges. As I have been trying with different regions, I found out that the ideality factor is sensitive to the points picked.



Slope	21.4591	Slope	20.6813	Slope	14.8801
n	1.86401	n	1.93412	n	2.68816

Figure 5 This is a "linear" plot of ln(I/Io) on the y axis, and V on the x axis to get a line equation of each of the 3 forward bias regions to calculate n.

- Recombination region: (low voltage)

I fitted a line in the region from 0.05V to 0.3V and found the ideality factor $n = 1.864$.

- Diffusion current region: (Medium voltage)

I fitted a line in the region from 0.3V to 0.6V and found the ideality factor $n = 1.9341$.

- High-Level injection region: (High voltage)

I fitted a line in the region from 0.6V to 0.9V and found the ideality factor $n = 2.688$.

- In the reverse bias region, the ideality factor is not well-defined, but there is a slight upward slope due to generation/recombination in the space-charge region.

<u>I did not want to consider voltages higher than 0.9V in this high voltage region because the current starts to saturate around 0.05A and the linear fit scheme doesn't give a real representation anymore.</u>

5. Finding the parasitic series resistance (Second order model)

The effect of the series resistance (Rs) becomes significant at high voltages when the diode is strongly forward biased. This is because the current flowing through the diode also flows through the series resistance, causing a voltage drop that reduces the effective voltage across the diode. This results in a deviation from the ideal exponential I-V characteristic.

The effect of the series resistance modifies the Shockley diode equation to:

$$I = I_0 \left[e^{\frac{q(V - IR_s)}{nkT}} - 1 \right]$$

$$\frac{I}{I_0} = \left[e^{\frac{q(V - IR_s)}{nkT}} - 1 \right], \qquad \ln\left(\frac{I}{I_0}\right) = \ln\left(e^{\frac{q(V - IR_s)}{nkT}}\right) - \ln(1)$$

$$\ln\left(\frac{I}{I_0}\right) + \ln(1) = \ln\left(\frac{I}{I_0} + 1\right) = \frac{q(V - IR_s)}{nkT}, \qquad V_t = \frac{kT}{q}$$

$$\ln\left(\frac{I}{I_0} + 1\right) = \frac{(V - IR_s)}{nV_t}, \qquad V - IR_s = (nV_t)\ln\left(\frac{I}{I_0} + 1\right)$$

$$\therefore V = (nV_t)\ln\left(\frac{I}{I_0} + 1\right) + IR_s$$

- <u>My scheme to find the series resistance, based on the analysis above:</u>

Assuming we're in a forward bias region, where V is not increasing much while I is rapidly increasing, we can make an approximation that $\ln\left(\frac{I}{I_0} + 1\right) \cong \ln\left(\frac{I}{I_0}\right) = \text{constant}$

From my calculations, over the forward bias range, I found $\ln\left(\frac{I}{I_o}\right)$ to be approximate 15 to 16 and didn't change much as I changed. Therefore, I'll make a linear approximation as such:

$$V = \text{Constant} + IR_s, \qquad \text{line equation}, \qquad y = mx + b$$

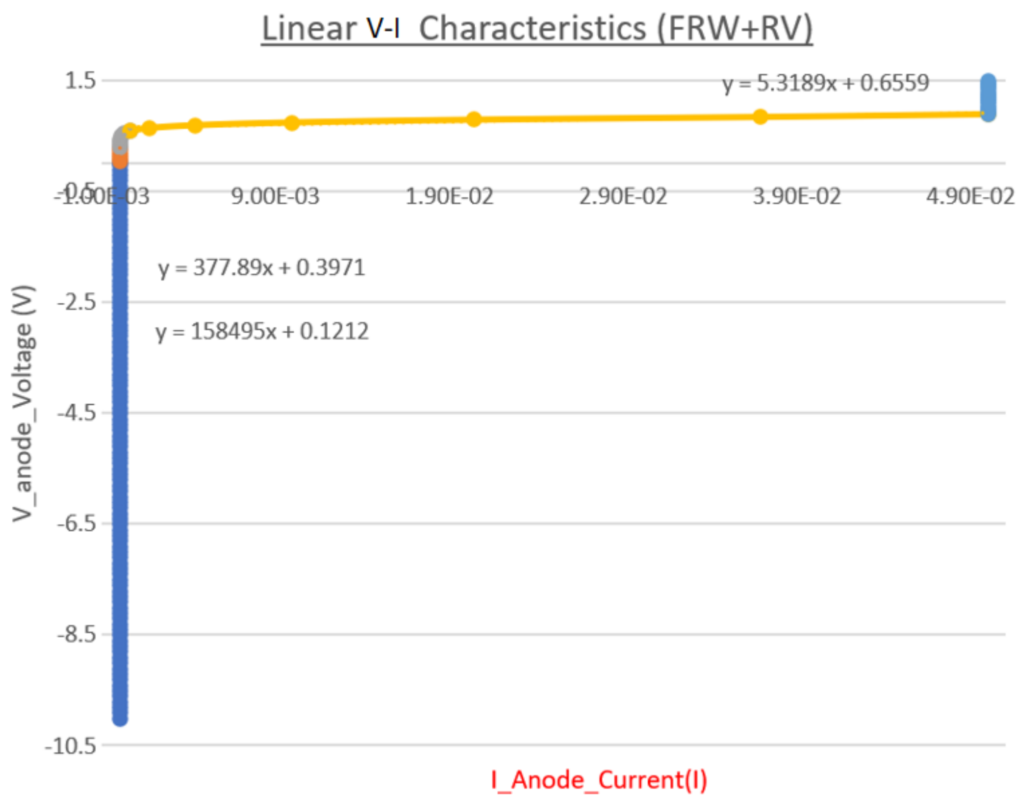
By plotting V-I characteristics this time (V on the y-axis and I on the x-axis), the slope of the line would be the series resistance Rs.

From excel, if I consider the main part of the Forward region (0.6V to 0.9V), I found that value to be

$$R_s \cong 5.3\ \Omega$$

In this case, the factor $\ln\left(\frac{I}{I_0} + 1\right)$ can be considered as a correction/approximation factor, but our linear approximation should be reasonable in the region we're considering.

If a more specific series resistance value is needed for each region of the forward region, I can fit a line in the 3 forward regions. Though, I'll be ignoring the value of n here as part of the constant/y intercept.



Series Resistance	Slope	5.318858

Figure 6 A linear plot of V on the y axis, and I on the x axis this time. I fitted a line in the forward bias region to find the slope, which is the series resistance in my scheme.

To get a better understanding of the parasitic series resistance I wanted to use the same scheme to find the parasitic series resistance in difference forward bias region, but as the ln(I/Io) term becomes more significant at lower voltages, the slope of the line approximation method starts becoming dramatically inaccurate. As seen above, the slope of the curve between V=0.5V and 0.3V is 158495, suggesting that the parasitic series resistance is that value in that region, and from V=0.3V to 0.6V the slope was 377.89, these do not really represent reasonable or accurate parasitic series resistance because my simple approximation scheme will not work in this region (the assumption that $(nV_t)\ln\left(\frac{I}{I_0}+1\right)$ can be considered as a constant will not hold). Therefore, I'll assume that the parasitic series resistance is roughly 5.31886Ω across the whole forward bias region.

6. Comparing the experimental and the theoretical characteristics

In this part of our study, I will compare the experimentally obtained electrical characteristics of a p-n diode with the theoretical predictions made by models provided in Streetman's solid-state electronic devices book.

I will plot three distinct data sets on the same graph for comparison:

1) The experimental measurements of the diode's I-V characteristics. (Symbols)
2) Predictions of the ideal diode model (Dashed line)
    - which will be computed using the findings from the previous part of this study (4b). The ideal diode model does not consider real-world imperfections such as series resistance, recombination, and generation in the space charge region.
3) Predictions of a more sophisticated second order model that includes series resistance. (Continuous line)
    - This model attempts to provide a more accurate representation of the diode behavior by incorporating the effects of series resistance on the I-V characteristics.

Plotting the I-V characteristics of the model that includes series resistance can be challenging as the current (I) appears on both sides of the equation. To overcome this, I will first solve the equation for voltage (V), compute V as a function of I, which was already done in part 4 and 5 above so now I'll substitute for expected values of I within the range of interest, calculate V, then plot I versus V.

From par 5 I had:

$$V = (nV_t)\ln\left(\frac{I}{I_0} + 1\right) + IR_s$$

I'll use this equation in excel to find V for each range of my n values. I will not put the tables here as suggested in the guidelines, but this is my process. I'll make that table on excel, and use those values to plot the IV Characteristics.

Notes and assumptions:

As I calculated, and gathered the data needed to plot the different graphs, I could not plot the I=0A at V=0V that's predicted by the linear and second order models on the semilog plot, so those points were left off on the semilog plots.

For the second order model, since we have the term in the voltage formula above, negative values of current could not used to calculate the voltage in this model, which is okay since the effect of the second model really comes into play in the forward bias region. So I used the reverse bias voltage and current values from the ideal model, put them into the second order model, and only updated the forward bias region with the new values calculated with the V formula above.

A) Graph 5: Linear Plot of I-V. (V in the X axis in linear scale, I in the y axis in linear scale).

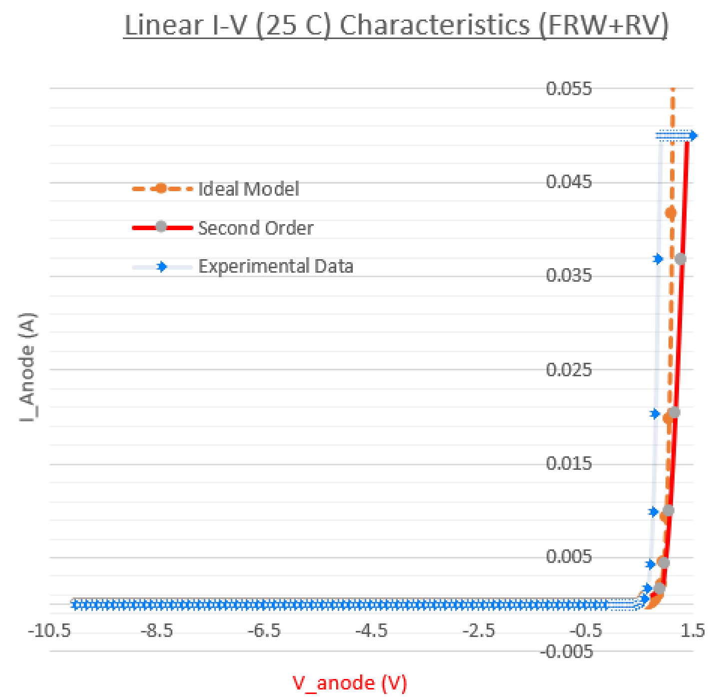


Figure 7 Linear IV plot of the experimental data (symbol), the linear model (dashed line), and the second order model (continuous red line).

I will zoom in a little bit into the forward region to make it easier see the difference.

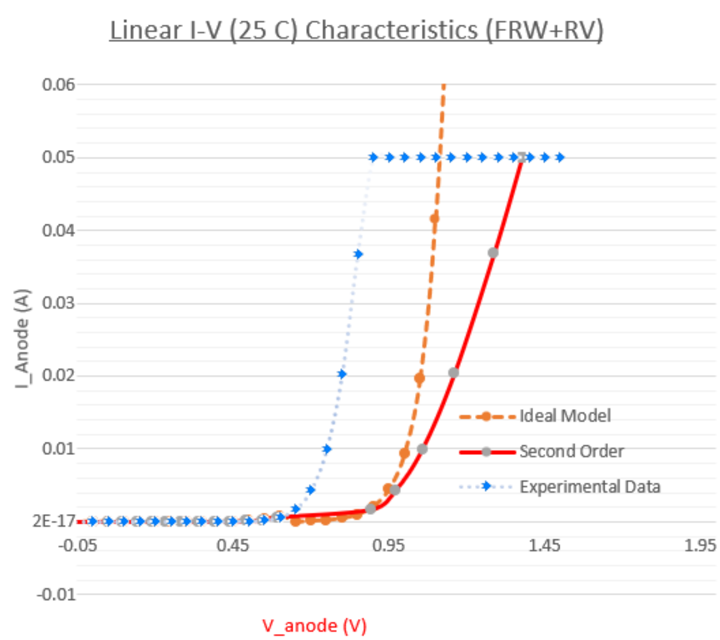


Figure 8 Zoomed-in linear IV plot of the experimental data (symbol), the linear model (dashed line), and the second order model (continuous red line).

Discuss the graph.

Based on the observations from the graph and the characteristics of the plotted lines, it seems that the experimental data does not perfectly match either the ideal diode model or the second-order model, highlighting the limitations of these models and the complexity of real-world devices.

- **Shift of Experimental Data:** The shift of the experimental data towards the left indicates that the diode starts conducting at lower voltages than predicted by the models. This could be due to several factors, including the presence of leakage currents, surface recombination, or the effects of series and shunt resistances not perfectly accounted for by the models. Leakage current can result from imperfections in the semiconductor material, such as impurities or defects, which can create additional energy levels in the bandgap and allow charge carriers to 'leak' across the junction even at low voltages.

- **Steepness of Ideal Model**: The ideal model is steeper, indicating that it predicts a more rapid increase in current with voltage. This suggests that the ideal model overestimates the diode's response to increasing voltage, particularly in the forward bias region. This could be due to the ideality factor not perfectly representing the non-idealities of the real diode, including the effects of recombination and generation in the depletion region.

- **Second-Order Model Characteristics:** The second-order model curves more to the right, indicating that it predicts a slower increase in current with voltage. However, it seems to match the experimental data better than the ideal model, suggesting that accounting for series resistance improves the accuracy of the model. The deviation might be due to other factors not accounted for in the model, like high-level injection or high bias effects.

These findings emphasize the importance of considering real-world factors when creating models for semiconductor devices. While ideal models provide a useful starting point, they often need to be adjusted and expanded with additional parameters to accurately predict the behavior of real-world devices.

B) Graph 6: Semi-logarithmic plot of I-V. (V in the x axis in linear scale, I in the y axis in logarithmic scale).

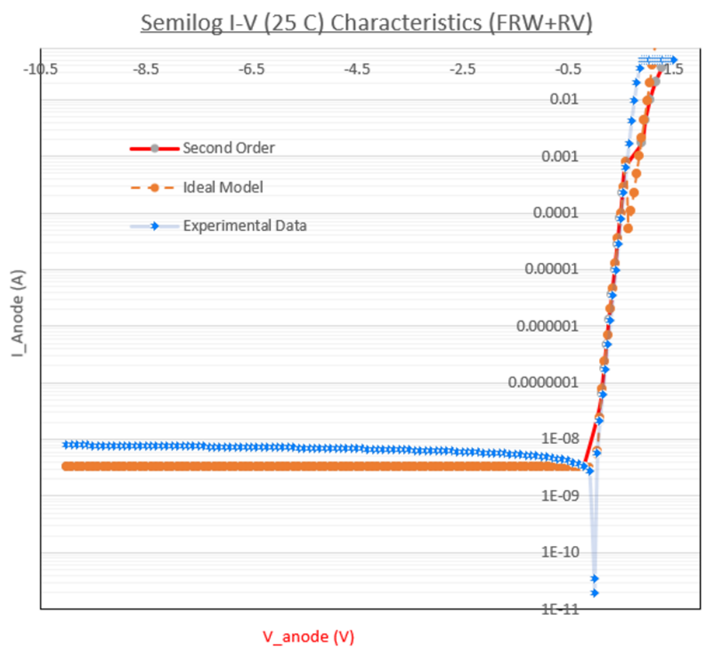


Figure 9 Semilog IV plot of the experimental data (symbol), the linear model (dashed line), and the second order model (continuous red line). V (linear) on the x axis, and I (logarithmic) on the y axis

I will zoom in a little bit into the forward region to make it easier see the difference.

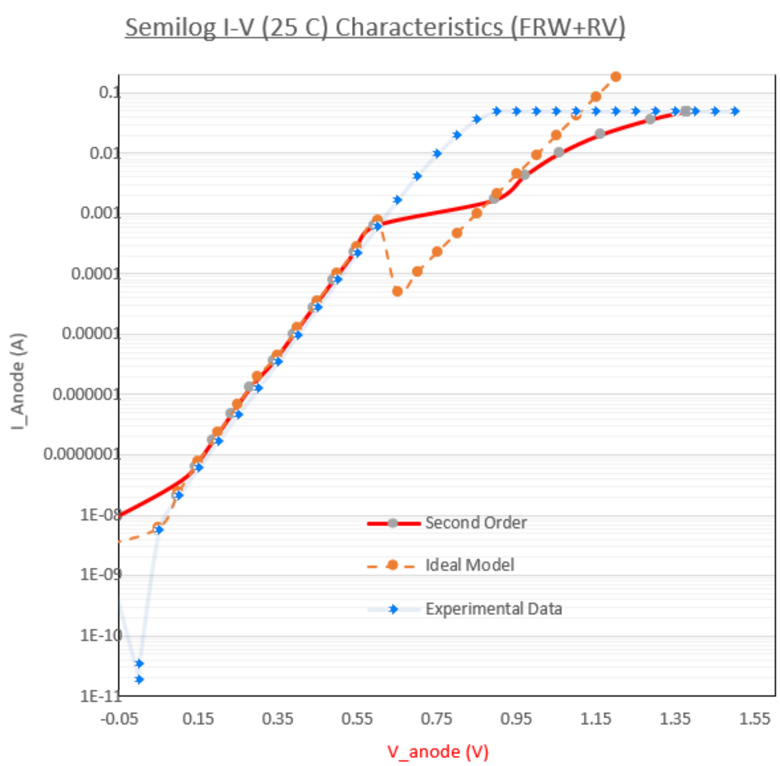


Figure 10 Semilog IV plot of the experimental data (symbol), the linear model (dashed line), and the second order model (continuous red line). V (linear) on the x axis, and I (logarithmic) on the y axis – Zoomed to show the difference

Discuss the graph.

Observations from the semi-logarithmic I-V characteristics plot provide valuable insights into the behavior of the diode in different voltage regions and the performance of the two models:

- Forward Medium Voltage Region (0.3V to 0.6V): In this region, both the ideal and the second-order models closely fit the experimental data, indicating that the assumptions and parameters used in these models are reasonably accurate in this voltage range. This suggests that in this region, the diode behaves nearly ideally, with minimal influence from factors such as recombination, leakage currents, and series resistance.

- Low Forward Voltage Region (0V to 0.3V): The discrepancy between the models and the experimental data in this region indicates that there are additional factors at play that the models do not adequately account for. This could be due to leakage currents or recombination effects, which are more pronounced at low voltages and are not fully captured by the ideality factor or the series resistance in the models. The linear model seems to be closer to the experimental data here compared to the second order model.

- High Forward Voltage Region (0.6V to 0.95V): Here, both models underestimate the current compared to the experimental data, with the second-order model providing a closer fit. This suggests that the series resistance included in the second-order model helps improve the accuracy of the prediction in this region. The discrepancy could also be due to high-level injection effects or recombination in the neutral regions, which are not adequately captured by the models.

- Model Limitations at High Voltages: The lack of current saturation in the models at high forward voltages indicates a limitation of these models when dealing with high bias conditions. Real-world diodes often exhibit current saturation due to high-level injection and heavy doping effects, which are not considered in these models.

- Effect of Ideality Factor and Series Resistance: The slight variations in the plots of the models compared to the experimental data could indeed be due to the different ideality factors used in different regions and the inclusion of series resistance in the second-order model. These findings underscore the importance of using different ideality factors in different regions to capture the complex behavior of real diodes.

- In the reverse bias region, the ideal diode model predicted slightly lower currents compared to your experimental data. This discrepancy might be attributed to real-world factors like leakage current and series resistance, which are not accounted for in the ideal model. The model's limitations become apparent under reverse bias conditions, underlining the importance of these often-overlooked factors in real-world applications.

Overall, these observations underscore the importance of considering the various non-idealities and real-world factors when modelling the I-V characteristics of diodes. While the ideal and second-order models provide a reasonable approximation in certain voltage ranges, their limitations become apparent when dealing with low and high forward voltages. Further refinements to the models could potentially improve their accuracy in these regions.

7. Higher temperature measurements and analysis.

Now I will plot the measured characteristics at higher temperature, and compare them to the room temperature measurements.

a. Graph 9: Linear plot of I-V characteristics (V in the x axis in a linear scale, I in the y axis in a linear scale).

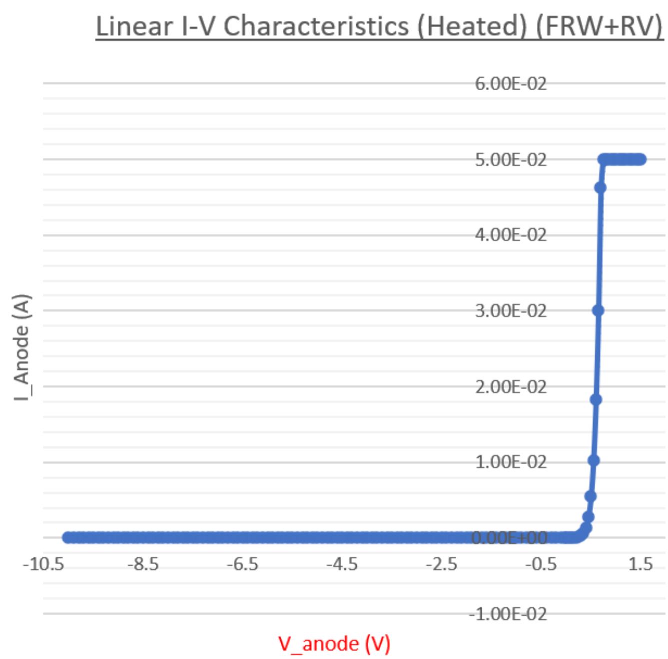


Figure 11 (Heated) Linear IV Characteristics plot with V on the x axis, and I on the y axis

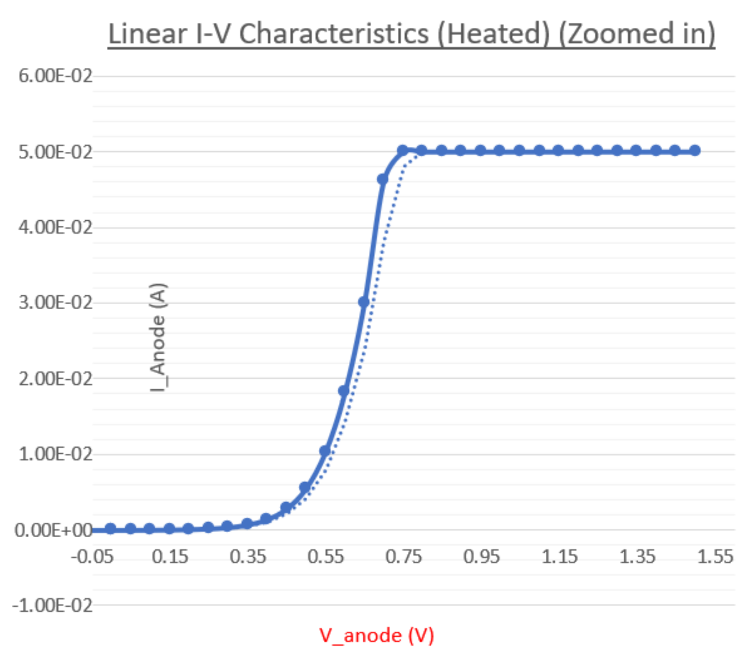


Figure 12 (Heated) Linear IV Characteristics plot with V on the x axis, and I on the y axis (Zoomed in)

b. Graph 10: Semi-logarithmic plot of I-V characteristics (V in x axis in linear scale, I in y axis in logarithmic scale)

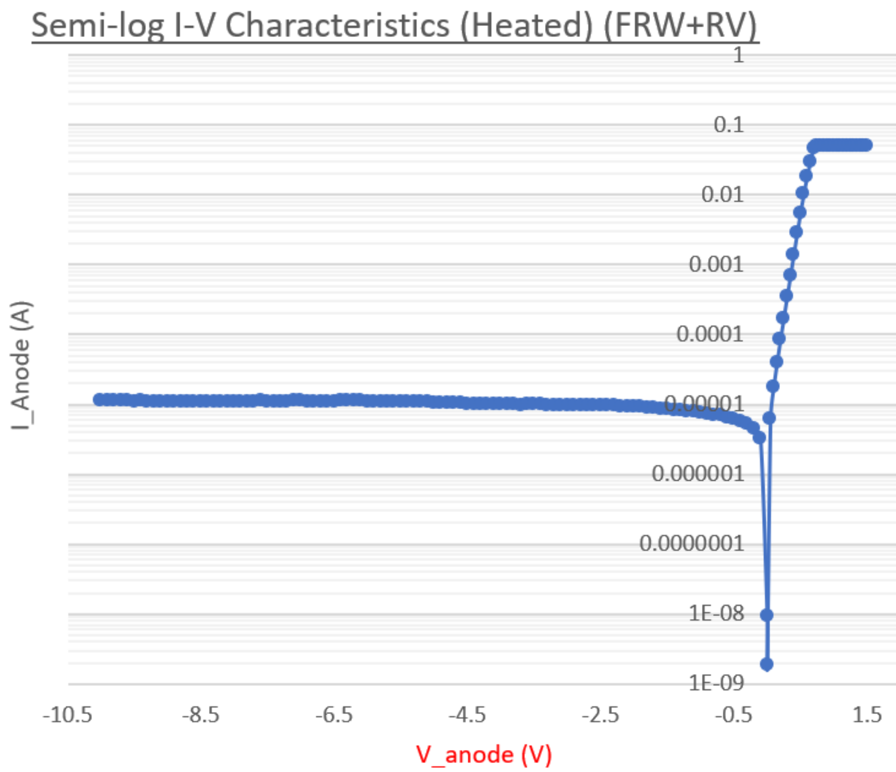


Figure 13 (Heated) Semilog IV plot with V linear on the x axis, and I on the y axis in a logarithmic scale

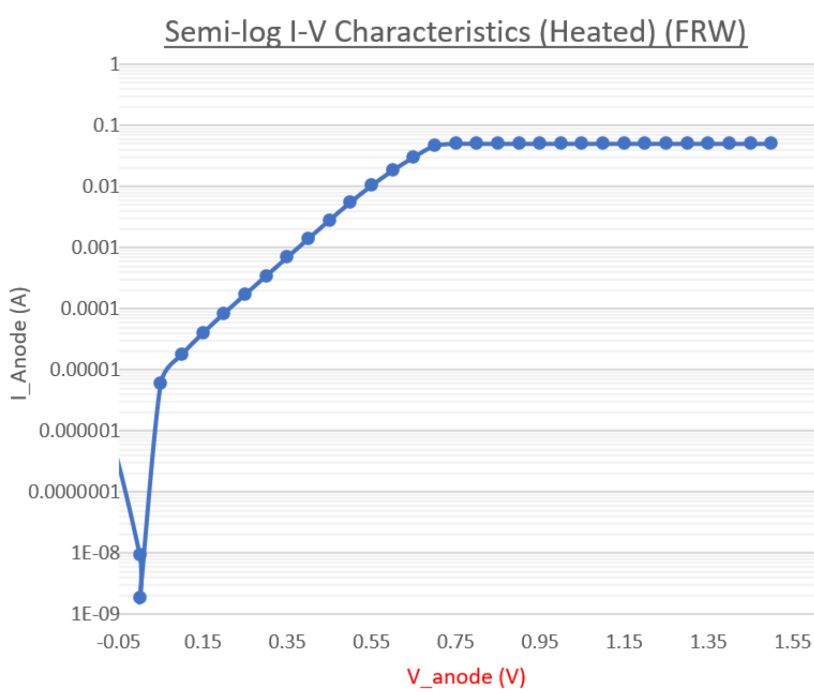
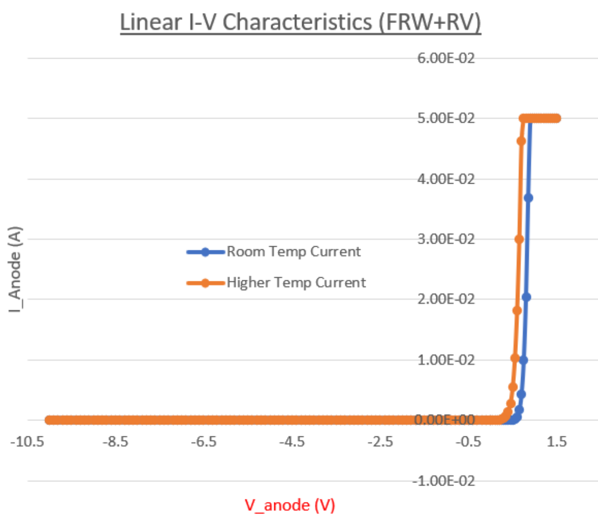


Figure 14 (Heated) Semilog IV plot with V linear on the x axis, and I on the y axis in a logarithmic scale (Zoomed-in)

c. Graph 11: Plot I-V diode characteristics for room and higher temperatures on the same semi-logarithmic plot (V in x axis in linear scale, I in y axis in logarithmic scale) and describe differences you notice. Explain these differences based on real diode behavior.

(I understand the linear plot is not required, I'm plotting it here for completion and for me to deeply understand what's happening).



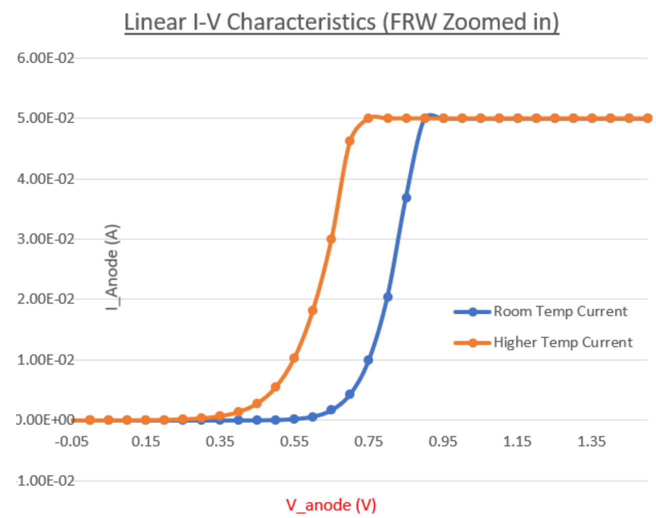


Figure 15 Linear IV plot with V linear on the x axis, and I linear on y axis. Room temperature Vs higher temperature measurements.

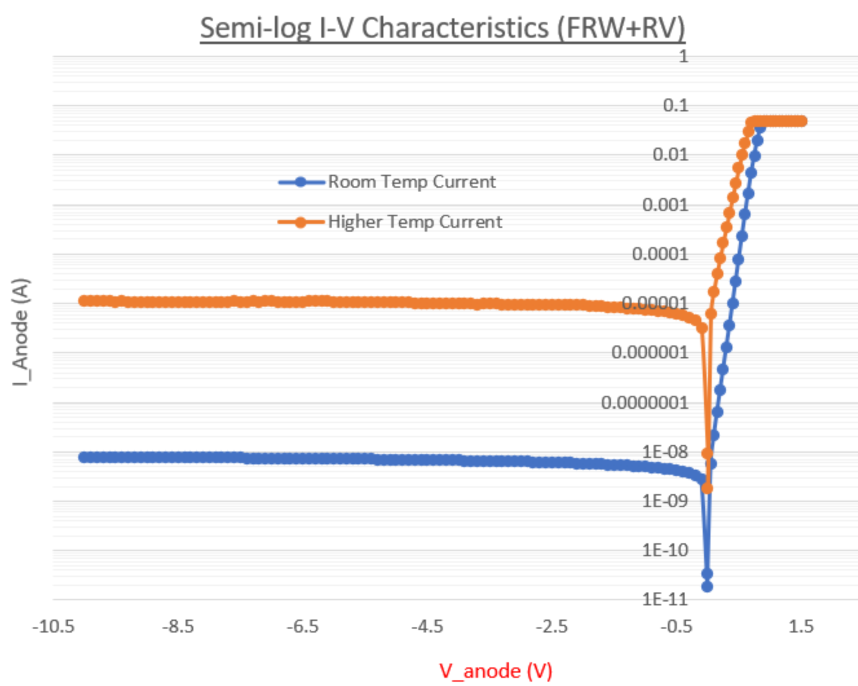


Figure 16 Semilog IV plot with V linear on the x axis, and I on a logarithmic scale on y axis. Room temperature Vs higher temperature measurements.

To get better appreciation of the difference between the plots, I'll zoom in on the middle region.

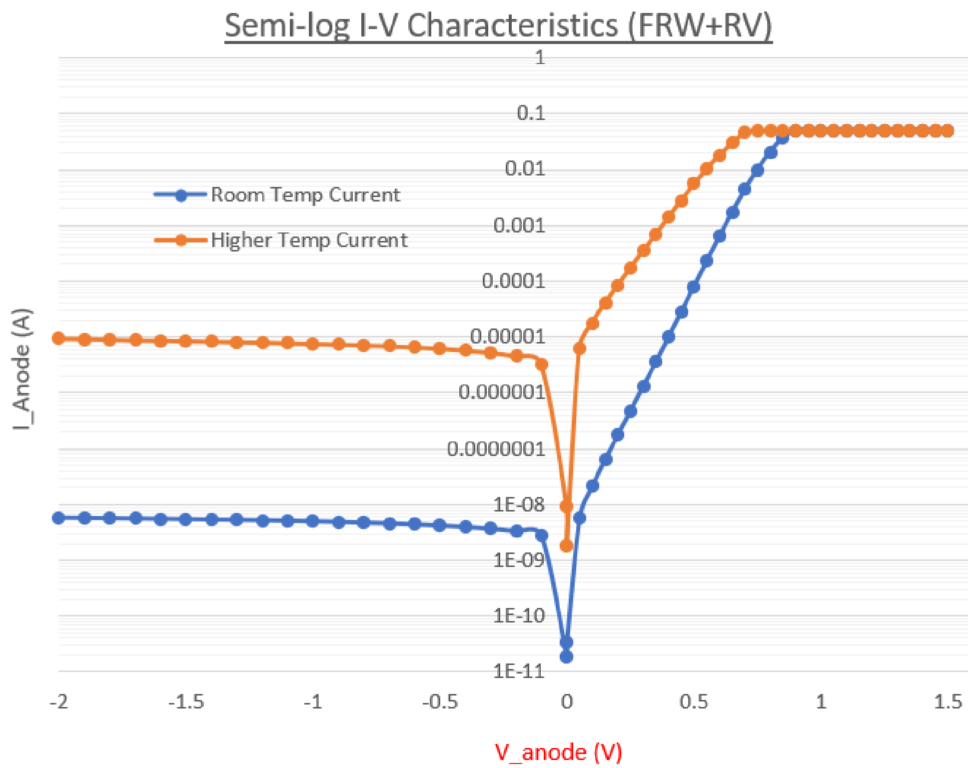


Figure 17 Semilog IV plot with V linear on the x axis, and I on a logarithmic scale on y axis. Room temperature Vs higher temperature measurements. (Zoomed in to show the difference)

- **<u>Describe differences you notice.</u>**

When comparing the diode's, I-V characteristics at room temperature and a higher temperature, I noticed a notable change in the curve.

At the elevated temperature, the diode's saturation current increases noticeably. This results in a shift towards the left in the forward bias region on the I-V plot. This means that at the higher temperature, the diode reaches a certain current level at lower voltages than it does at room temperature.

These observations arise from how diodes naturally behave. As the temperature rises, the diode generates more carriers, which in turn increases the saturation current. This increase causes the diode to reach the same current at lower voltages, explaining the leftward shift in the I-V curve. This shift emphasizes the diode's sensitivity to temperature and how it significantly affects the device's performance.

- **Explain these differences based on real diode behavior.**

Increase in Saturation Current:

The saturation current of a diode is given by the equation Is = AT^2exp(-Eg/(k*T)), where A is a constant, T is the absolute temperature, Eg is the energy gap of the semiconductor, and k is the Boltzmann constant. As the temperature increases, the exponential term becomes larger, leading to an increase in the saturation current. This is because higher temperatures provide more thermal energy to semiconductor carriers, leading to an increase in the number of carriers that can overcome the energy barrier at the junction.

Shift in the Forward Bias Curve:

The shift to the left in the forward bias curve at higher temperatures is also a result of the increased saturation current. The diode equation in the forward bias region is I = Is * (exp(V/nVt) - 1). At higher temperatures, since Is is larger, the same current I can be reached at a lower voltage V, resulting in a shift to the left of the I-V curve on a semi-log plot.

Conclusion:

In conclusion, I have characterized a pn-junction diode by measuring its characteristics at room temperature and elevated temperature. The plotted data has been analyzed, compared to the ideal diode model, and a scheme to find the ideality factor and saturation current has been devised. The non-ideal diode model has also been compared to the ideal diode. Through this project, I have gained an understanding of the characteristics of a pn-junction diode and how it can be used in electronic circuits. This knowledge will also be useful in future electronic design and analysis.