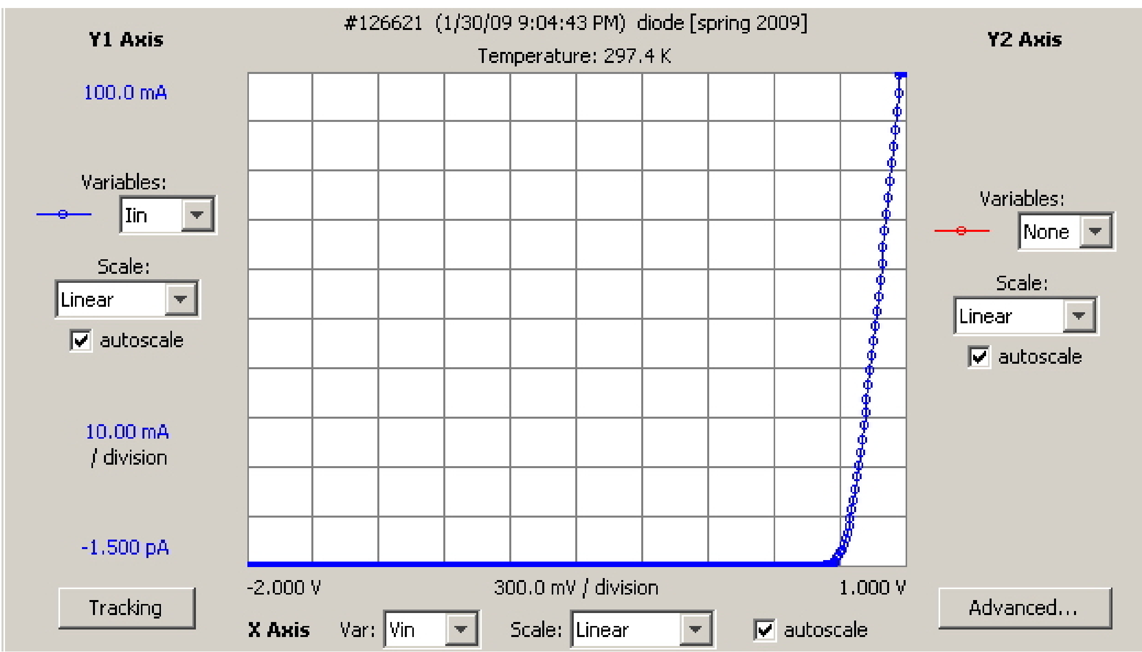
Spring 2009 6.012 Microelectronic Devices and Circuits Prof. C.G. Sodini

Device Characterization Project #1 – February 4th 2009

PN DIODE CHARACTERIZATION

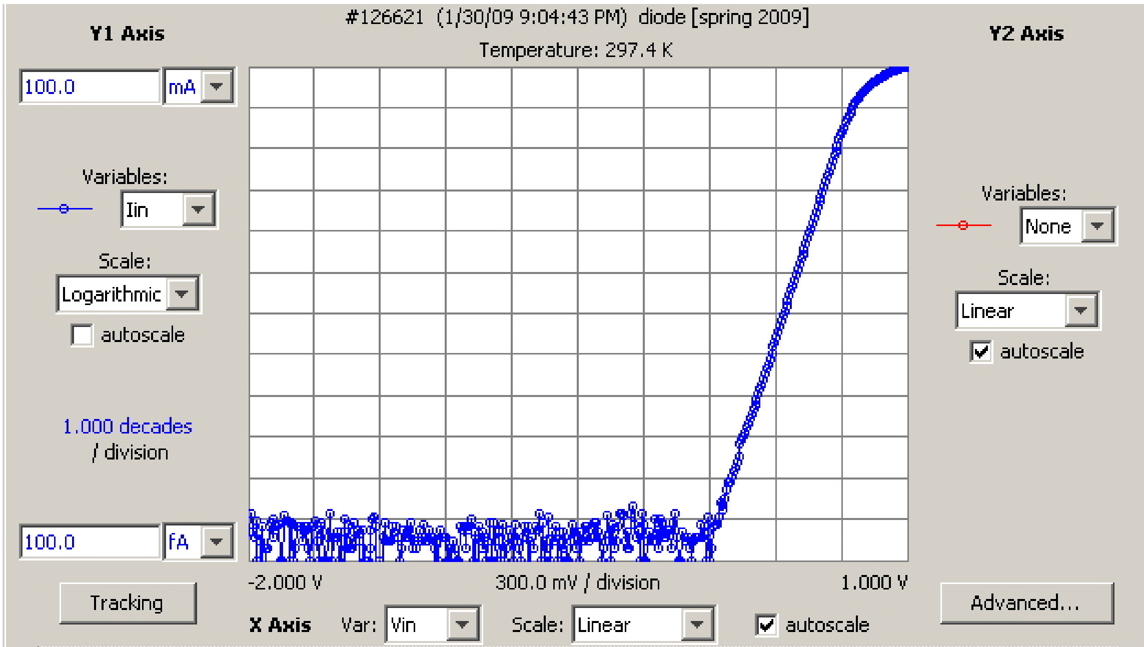
Solutions
(prepared by Ming Tang)

In order to obtain Graph 1, we must sweep the diode's applied bias between -2V and 1V. The following plot was acquired by sweeping the voltage at SMU1, the anode, from -2V to 1V and grounding SMU2, the cathode. A step size of 7.5mV was used. The current from SMU1 was recorded.



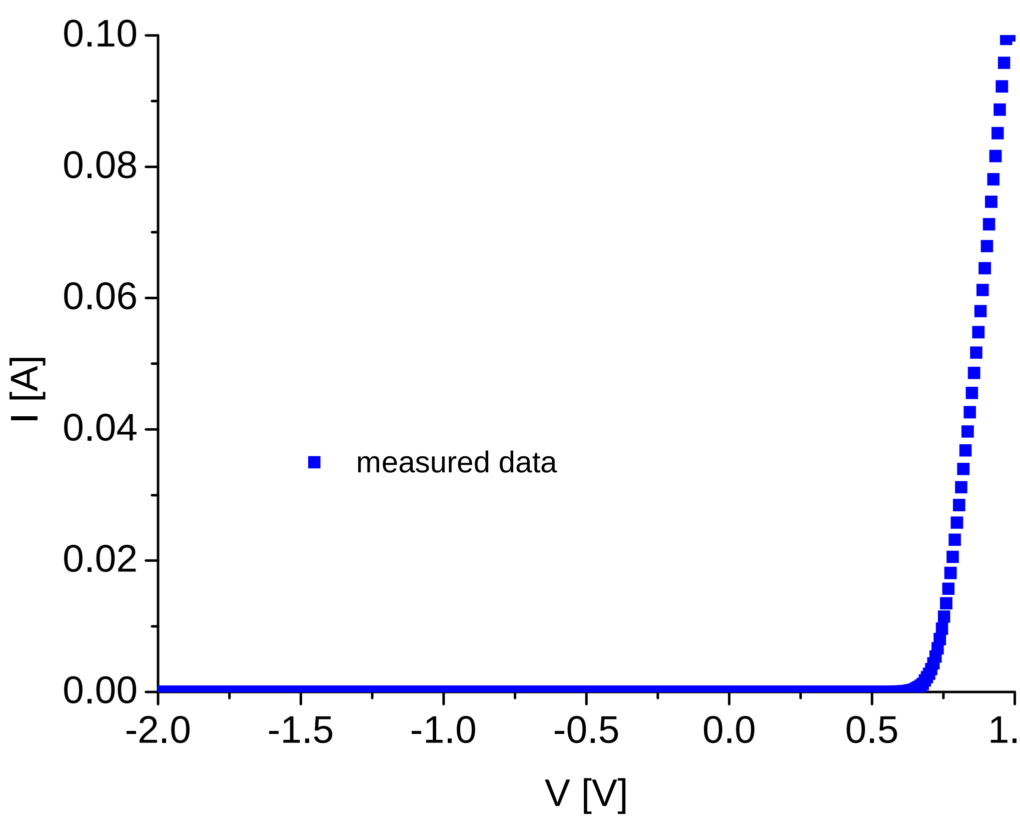
Graph 1. Linear plot of the diode current versus applied bias.

By changing the y-axis to logarithmic scale, Graph 2 is obtained. As in Graph 1, we see that the temperature of the diode is **297.4K**. This is important to record, as we will compare this value to the value extracted using the diode equation.

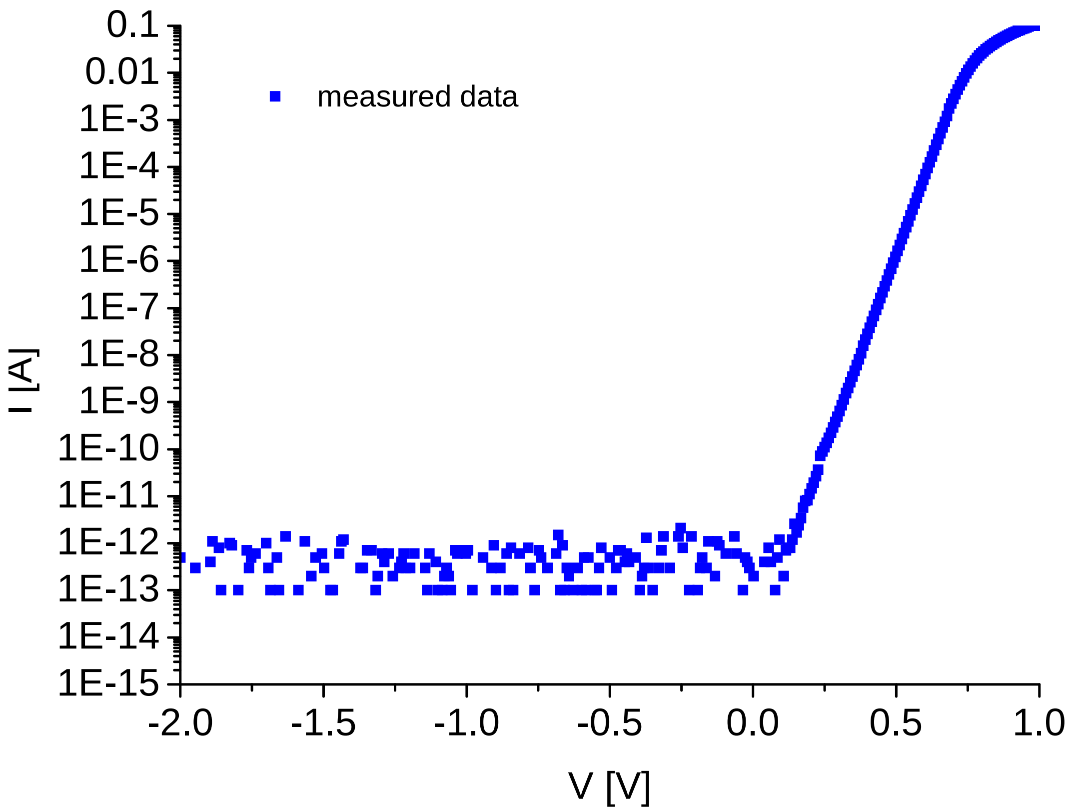


Graph 2. Semilog plot of the diode current versus applied bias.

Exporting the data from Weblab and importing it to Origin gives Graphs 3 & 4.



Graph 3. Linear plot of the diode current versus applied bias using Origin.



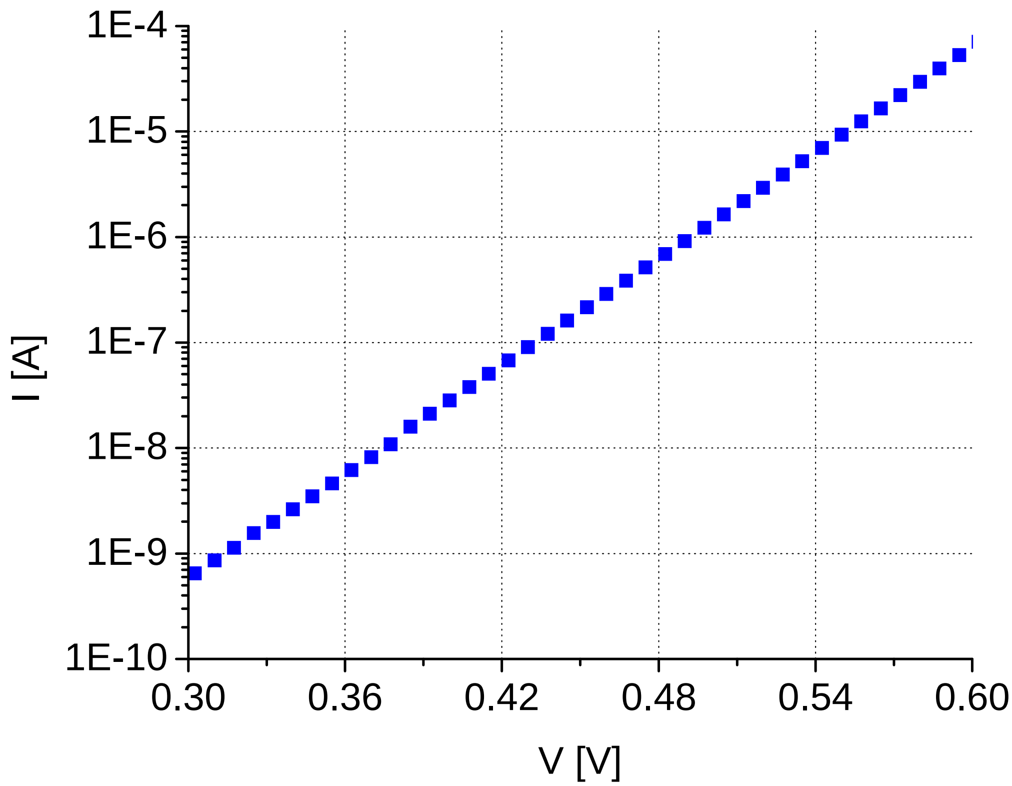
Graph 4. Semilog plot of the diode current versus applied bias using Origin.

At forward bias (V>0V), the first term in the first order diode equation dominates.

$$I = I_s\left[\exp\left(\frac{qV}{kT}\right) - 1\right] \approx I_s \exp\left(\frac{qV}{kT}\right) \qquad \text{Equation 1}$$

Using the above approximation, the temperature T can be obtained from the slope of the diode equation in the forward bias regime ($q=e$ and $k=8.617\text{x}10^{-5}$eV/K).

$$\log_{10}\left(\frac{I}{I_s}\right) = \left(\frac{qV}{kT}\right)\log_{10} e = 5040\left(\frac{V}{T}\right) \approx \frac{300}{60m}\left(\frac{V}{T}\right) \qquad \text{Equation 2}$$



Graph A. Semilog plot of the diode current versus applied bias using Origin.

Graph A is the zoom-in version of Graph 4. From Graph A, the slope is determined to be approximately **decade of I / 60mV**. In other words, *a 60mV increase in the applied diode voltage leads to a 10 fold increase in the diode current*. We should revisit this important finding later in the semester. Thus, using Equation 2, **T≈300K**. Note that **T=297.4K** is reported by Weblab.

Lastly, for I_s, we can simply extract it by using Equation 1 and the values of Graph A. For example, I≈0.6nA at V=0.3V and I≈6nA at V=0.36V. Thus, **I_s≈6fA**.

Theoretically, I_s can also be extracted using the following method. From the first order diode equation, the diode current at reverse bias (V<0V) will be approximately $-I_s$.

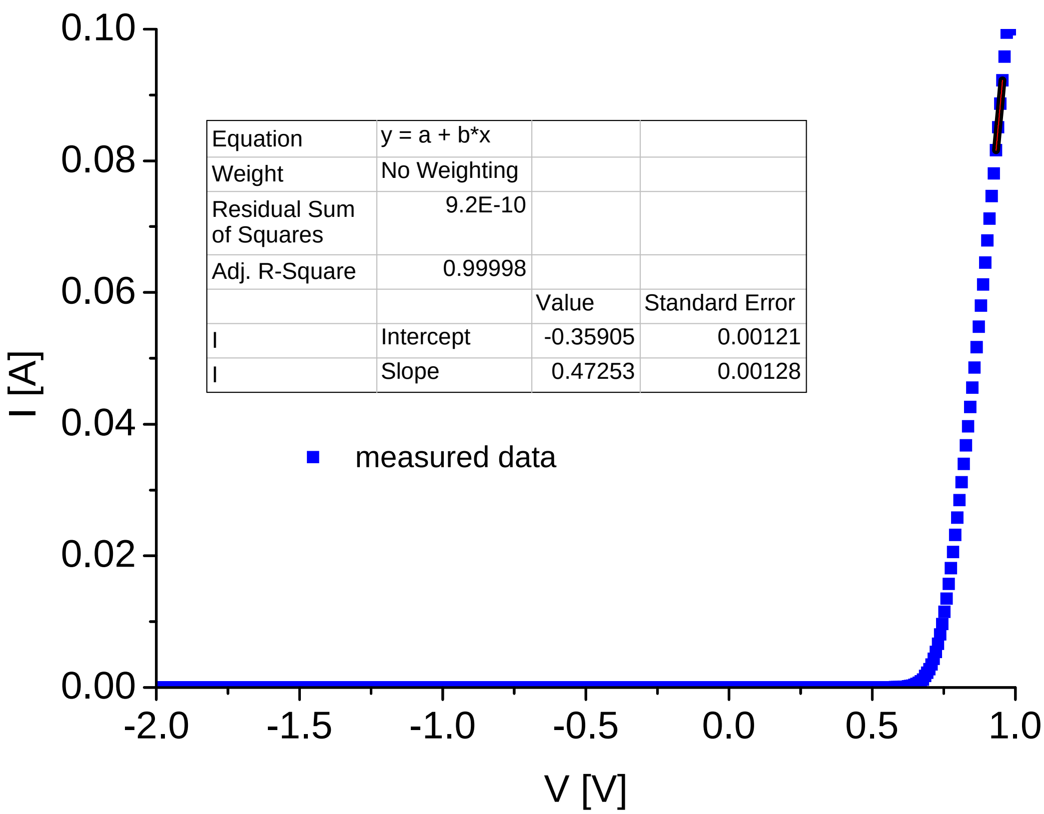
$$I = I_s\left[\exp\left(\frac{qV}{kT}\right)-1\right] \approx -I_s \qquad \text{Equation 3}$$

Therefore, one can easily extract I_s using Equation 3 and Graph 4. (Note that Graph 4 plots the absolute value of the current.) However, this approach is only valid given an accurate measurement. Since the instrument HP4155B can only measure current accurately down to 1pA, and we have a rough idea that I_s≈6fA, we cannot extract I_s using this method in this scenario. Keep in mind that *any measurement is only as good as the instrument's limitation.*

The first order diode model neglects the diode's series resistance, which we will find next to obtain a second order model. At high forward bias voltages, we can find the series resistance for the second order model equation.

$$I = I_s\left[\exp\left(\frac{q\left(V - IR_s\right)}{kT}\right) - 1\right] \qquad \text{Equation 4}$$

Since the series resistance becomes dominant at high forward bias voltages, we will look at data points in that region.



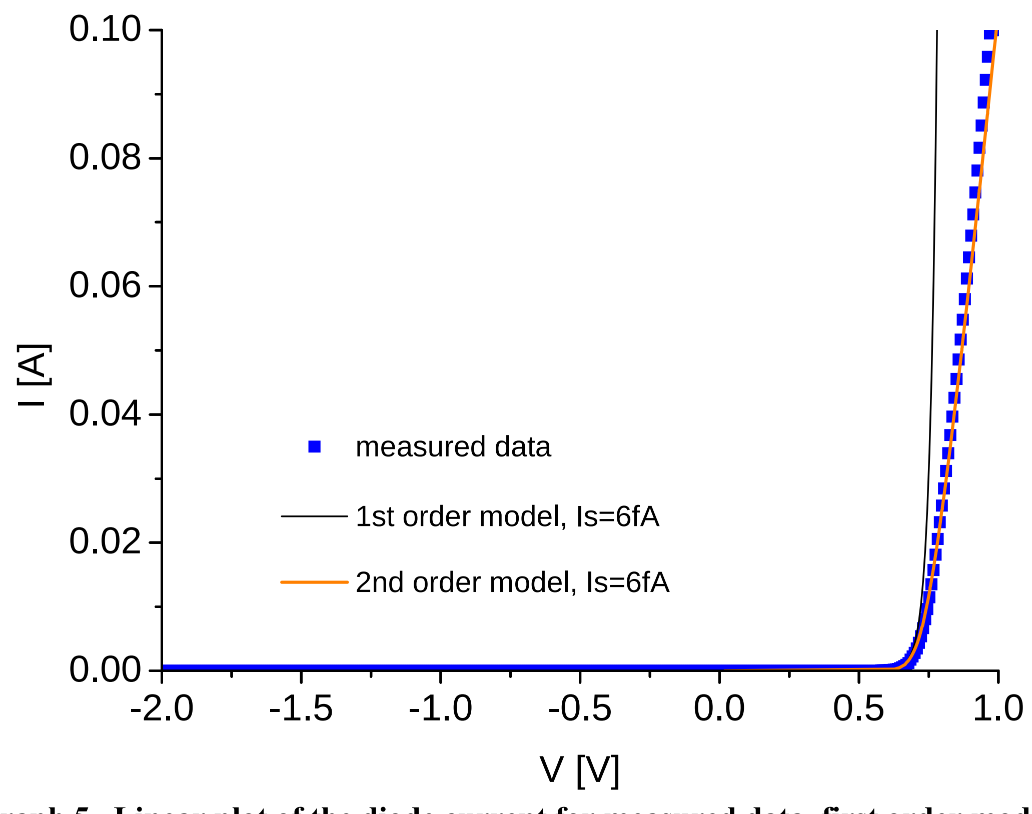
Graph B. Linear plot of the diode current versus applied bias using Origin with extracted slope.

At these high bias voltages, the slope of the I-V should be equal to $1/R_s$. The slope is found to be 0.47253/Ω. Solving for R_s yields **R_s=2.116Ω**.

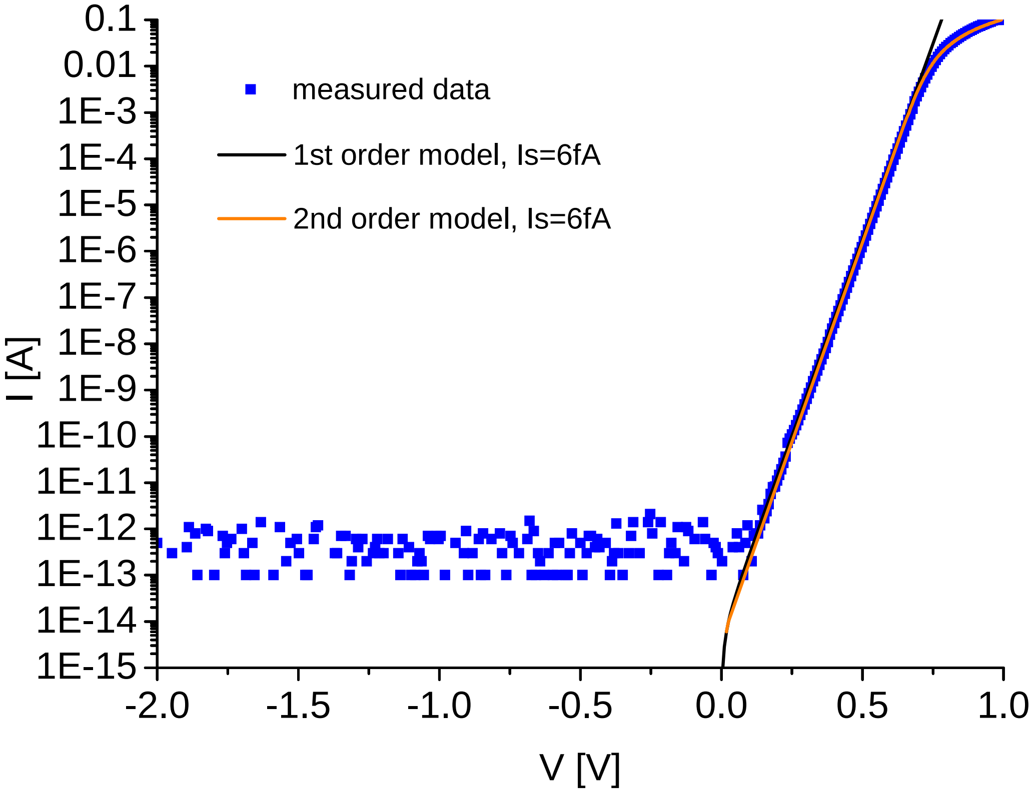
We now know all the model parameters for our first and second order models, Equations 1 and 4, respectively. Separating the *I* and *V* terms in Equation 4 results in,

$$I = I_s\left[\exp\left(\frac{q(V - IR_s)}{kT}\right) - 1\right]$$
$$\rightarrow (\frac{I}{I_s}+1)\exp\left(\frac{qIR_s}{kT}\right) = \exp\left(\frac{qV}{kT}\right)$$
Equation 5

Plotting these models (using T=297.4K, I_s=6fA, and R_s=2.116Ω) along with our measured data gives Graphs 5 and 6.



Graph 5. Linear plot of the diode current for measured data, first order model, and second order model using Origin.



Graph 6. Semilog plot of the diode current for measured data, first order model, and second order model using Origin.