Device Characterization Project #1

PN Diode Characterization - Solutions

This assignment gave you an introduction to modeling a device using a relatively simple and incomplete model, and also gave you an introduction to device measurement and data presentation. It will be quite lightly weighted in your final grade compared to the design project and second weblab, so there is no reason to worry about your final grade on its basis as long as you come back and learn the material in the upcoming assignments.

1) Screenshots of diode $I - V$ characteristics.

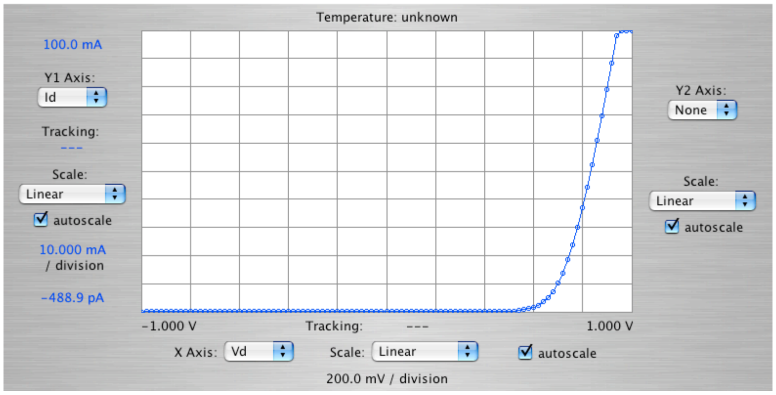

Figure 1: Linear plot of I-V characteristics

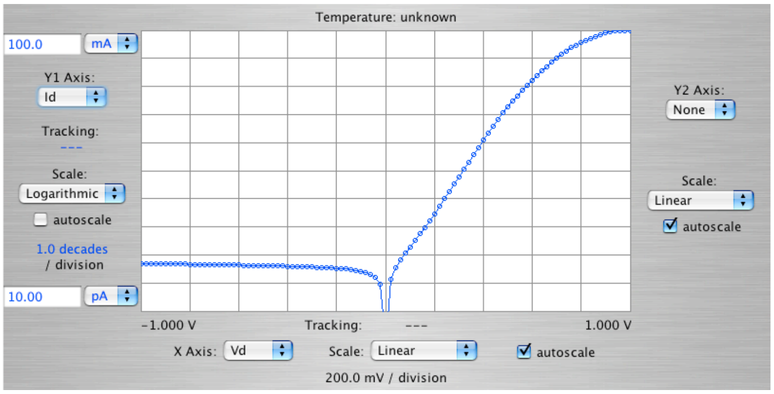

Figure 2: Semilogarithmic plot of I-V characteristics

2) Plotted graphs of diode $I - V$ characteristics

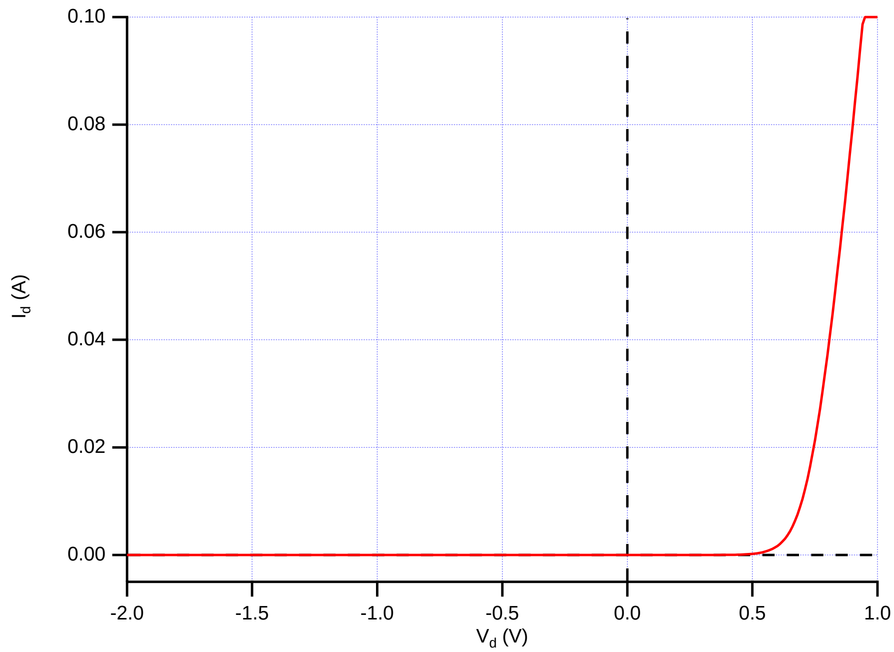

Figure 3: Linear plot of I-V characteristics

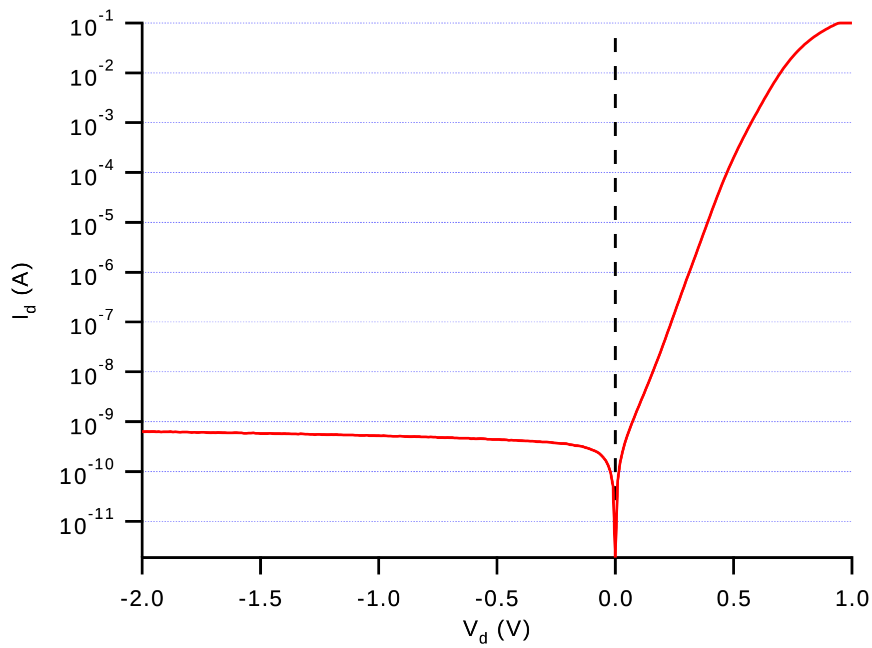

Figure 4: Semilogarithmic plot of I-V characteristics

3) The ideal model of the diode is the following

$$I_d = I_s\left(\exp\frac{qV}{kT} - 1\right) \tag{1}$$

For relatively large reverse bias, i.e. a negative value of V, this simplifies to the following:

$$\exp\frac{qV}{kT} \approx 0, \qquad I_d \approx -I_s \tag{2}$$

Therefore, the magnitude of I_d at a reasonable reverse bias (-1V) is to a first order approximation I_s. Though the fact is not contained in the models supplied to you, at larger reverse biases non-ideal effects may be felt, so an overly large reverse bias should not be chosen. For the case of these devices a first estimate would be,

$$I_s \approx 500 \text{ pA} \tag{3}$$

However, the data shows increasing current with increasing reverse bias suggesting non-ideal leakage. Therefore, this value may be somewhat refined following the discussion below.

Extracting the temperature requires a little more work. We notice that the ideal model of the diode has a temperature term in the exponential. Also, for even relatively small forward bias,

$$\exp\frac{qV}{kT} \gg 1, \quad \text{therefore } I_d \approx I_s\left(\exp\frac{qV}{kT}\right) \tag{4}$$

Taking the natural logarithm of both sides,

$$\ln(I_d) = \ln(I_s) + \frac{qV}{kT} \tag{5}$$

Graphically, the extraction of I_s and T are shown in Figure 5.

Therefore, on a semilog plot the slope of the straight section of the $I-V$ curve is proportional to $1/T$. Substituting the values of the constants q, k for this device we extract

$$T \approx 385 \text{ K} \tag{6}$$

This is a very high temperature. You were not expected to know this at this stage, but later in the course, you will learn that a more accurate model of a diode contains an additional term called the ideality factor, n, such that

$$\ln(I_d) = \frac{q}{nkT}V - c, \quad c \text{ is a constant} \tag{7}$$

If we assume that the diode is at room temperature, then $n \approx 1.3$.

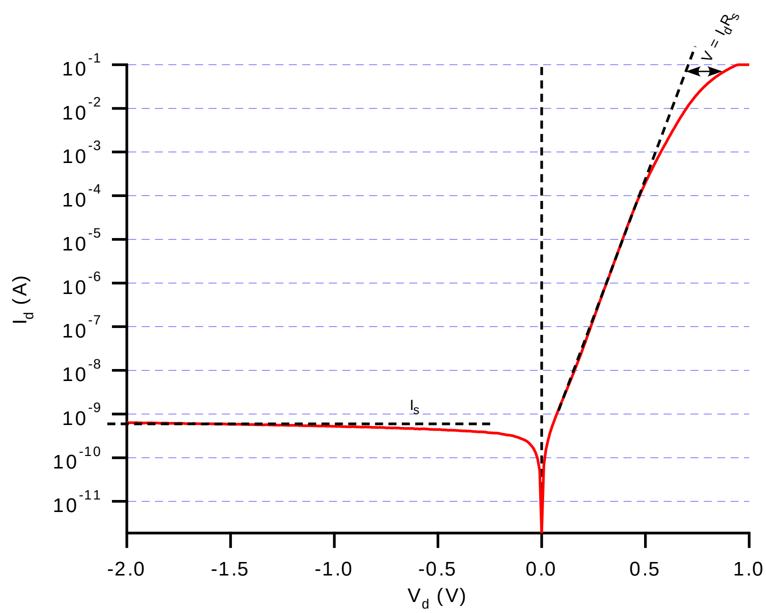

Figure 5: Semilogarithmic plot of I-V characteristics graphically showing the methods for extracting I_s, temperature T, and the parasitic series resistance R_s

Referring to Equation 5, we see that the straight region of the curve should cross $V = 0$ with $I_d = I_s$. This is not necessarily an accurate method of extracted I_s, but it is a sanity check to confirm our previous number. However keeping this in mind, and jumping ahead somewhat to question 5 where we graph the ideal model results and measured data together (and find an offset between the ideal and measured data), we can refine the extraction of I_s and say that in fact,

$$I_s \approx 250 \text{ pA} \tag{8}$$

4) A series resistance is seen graphically as a curving of the $I - V$ semilogarithmic plot at higher forward biases, i.e when the product $I_d R_s$ is comparable to applied bias V. Therefore, the $\Delta V = I_d R_s$ required to achieve the same I_d in the ideal and second-order model at a given tells us the R_s of the diode. This is shown in Figure 5. In the case of these devices,

$$R_s \approx 2.7 \ \Omega \tag{9}$$

Extracting the slope of the linear $I - V$ curve can also give a similar number, but that method is generally more likely to be affected by approximation error, especially as the data is cut off by the instrument's current compliance at 100 mA.

5) Plots of measured, calculated ideal model characteristics, and calculated second-order model characteristics. In both plots,

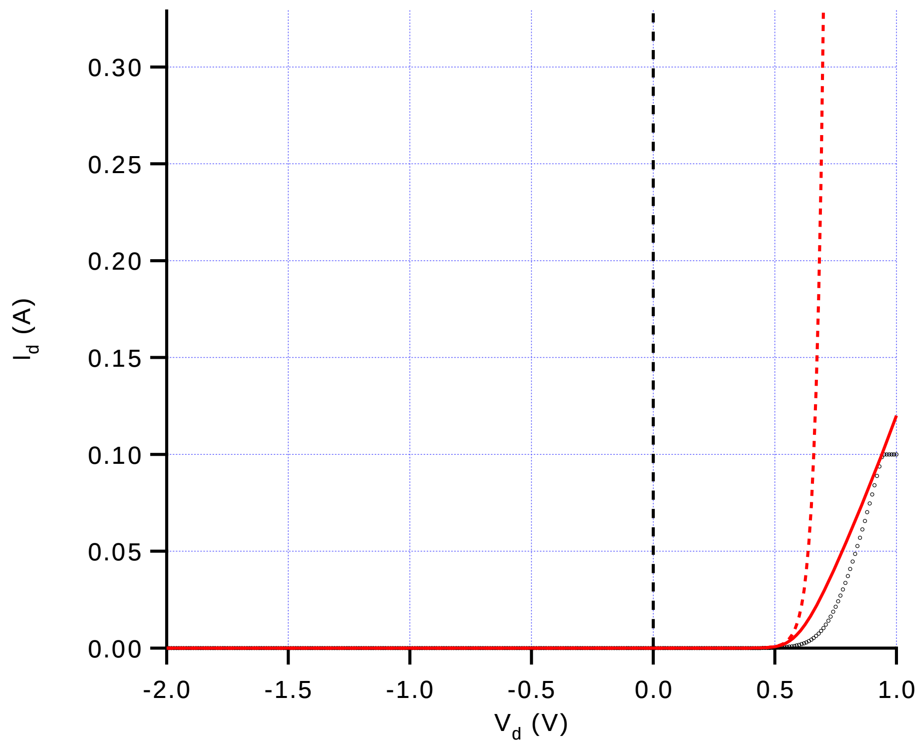

Figure 6: Linear plot of I-V characteristics. Measured data is shown by the small circles, ideal model calculations by the dashed line, and second-order model calculations by the solid line.

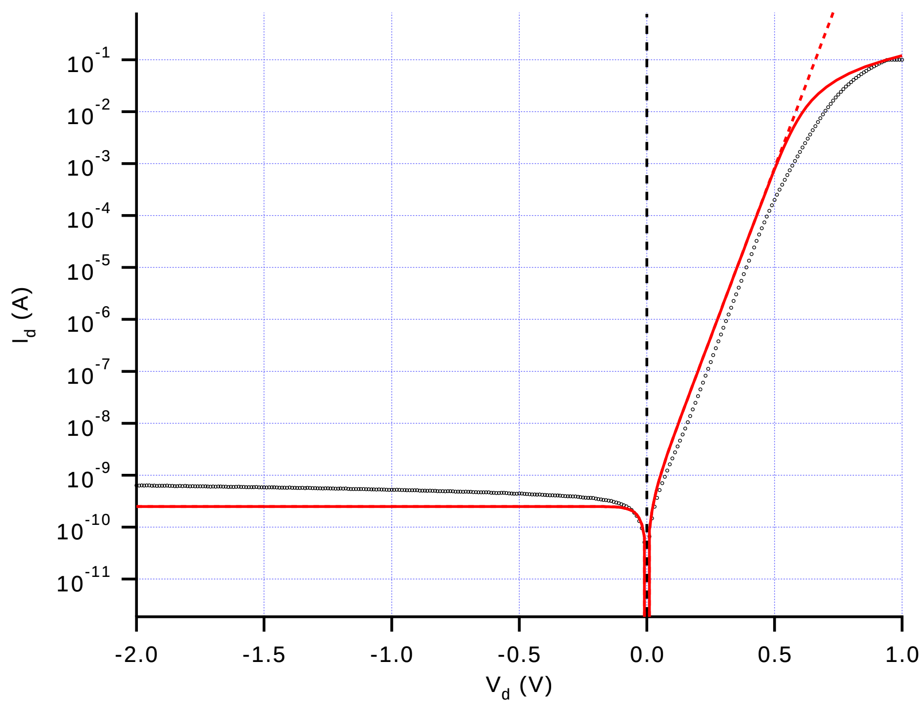

Figure 7: Semilogarithmic plot of I-V characteristics. Measured data is shown by the small circles, ideal model calculations by the dashed line, and second-order model calculations by the solid line.