Laboratory #1

Diodes

I. Pre-Laboratory Assignments

1. Number all the right-hand pages of your lab book in the upper right-hand corner with ink. Create a table of contents for your lab book on page 1. Do all of your pre-lab and laboratory work in your lab book in ink. Do not bring any loose paper to the lab, other than semi-log graph paper mentioned below.

2. Briefly explain the terms "forward bias" and "reverse bias" for a *pn* junction.

3. For a silicon diode with $n = 1.75$, $I_s = 10^{-9}$, and $V_T = 25$ mV, accurately plot the expected diode characteristic curve in the forward bias region using a semi-log scale. That is, use a logarithmic vertical scale for the diode current and a linear horizontal scale for the voltage.

4. Sketch the expected resistor voltage from the circuit shown in Fig. 2 below assuming a constant voltage drop model for D and an input sinusoid of 10-V peak amplitude and a frequency of 100 Hz.

5. Simulate the circuit of part 4 above with a circuit simulation package using a 1N4148 silicon diode. Compare these results with those from part 4. Repeat this simulation for a 1N5817 Schottky diode. What differences do you detect compared to the same circuit with the 1N4148 diode? Is this expected? Why?

   You are welcome to use whatever circuit simulator you like. The only requirement is you use 1N4148 and 1N5817 diodes in the simulation, not ideal diodes. One suggestion is to use Keysight *Advanced Design System* (ADS).

6. What are the main differences in the terminal characteristics of small-signal silicon and Schottky diodes?

II. Laboratory Experiments

Note: you are advised to bring semi-log graph paper to the lab.

Diode measurement with an ohmmeter†

1. An ohmmeter (often a digital multimeter set to measure resistance) is quite useful for rapid diagnostics of diodes. When measuring resistance, an ohmmeter actually injects a known test current into a device, measures the voltage, and then infers the resistance of the device under test. Here we will use the ohmmeter as an indirect diode tester.

(a) Connect the leads of a digital multimeter (DMM) set to measure resistance to the two terminals of a silicon 1N4148 diode. Measure the resistance. Now, interchange the DMM leads and remeasure the resistance. What do you conclude about rectification? What do you conclude about the ohmmeter voltage polarity and the direction of current flow?
(b) Use a second DMM to measure the voltage V_D across the diode while its "forward resistance" R is being measured by the ohmmeter. What is the significance of V_D/R?
(c) Repeat 1(b) and record these measurements for different ohm scale settings on the DMM. Comment on the results.

Note that some ohmmeters have selectable ranges of resistance measurement where the internal currents are intentionally so low that the diodes will not present a measureable voltage drop. If this is the case, you need to try a different range, or use a different ohmmeter for such a test.

Characterization of a silicon diode

2. Measure the current-voltage characteristic curve for a silicon diode.
   (a) Choose a resistor in the range of 500 Ω to 1,000 Ω and measure its resistance as accurately as you can.
   (b) Construct the circuit shown in Fig. 1 using this resistor, a silicon 1N4148 diode, and one pair of output terminals from the DC power supply. Attach one DMM as a voltmeter across the diode using the auto-range and DC voltage scale. Make sure the power supply voltage is turned to zero volts. Use a second DMM in the circuit to measure the current.
   (c) Slowly increase the power supply voltage and carefully observe the current. Record values of current in the circuit versus voltage across the diode.
   (d) On a linear graph in your notebook, plot diode current versus diode voltage with current on the vertical axis and voltage on the horizontal axis. Make sure your diode current is extended into the exponential range of the diode. Plot your data as you are recording it. Do these measurements only for the forward bias region.
   (e) On semi-log paper, plot current versus voltage as you did in 2(d). From the slope of this graph, determine the emission constant of the diode. (See the discussion at the end of this lab.) Permanently fasten this semi-log plot into your notebook.
   (f) From the measured emission constant and your diode characteristic curve data, choose three or four widely spaced values of current and, with their respective voltages, determine the saturation current of the diode. (See the discussion at the end of this lab.)

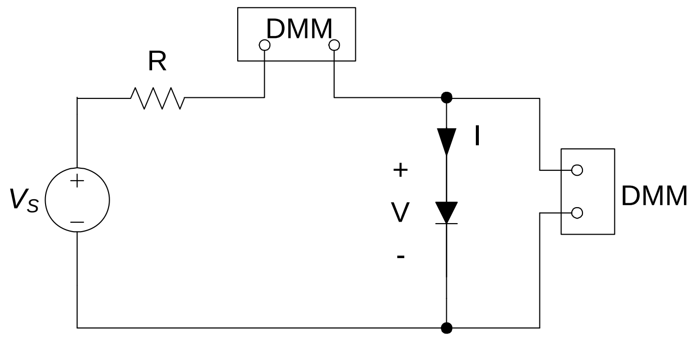

Figure 1 Diode characteristic-curve measuring circuit.

Ideal rectification†

3. Assemble the simple rectification circuit shown in Fig. 2 using a silicon 1N4148 diode for *D*. The input should be a 100-Hz sinusoid with 10-V peak amplitude and zero average value. Set the oscilloscope input to DC coupling for the following voltage measurements.
   (a) Measure and sketch the voltages at nodes A and B.
   (b) Measure the difference in voltage between the input and output for about 10 time intervals within one-quarter cycle of the output voltage (when it's nonzero). Note that for small output voltage this difference increases as the output voltage increases. Why? This difference then reaches a constant voltage. Why?
   (c) Adjust the input voltage to a square wave with the same peak amplitude and frequency. Measure and record the voltages at nodes A and B. Explain the operation of the circuit with this square-wave input voltage.
   (d) Repeat 3(a) using a Schottky 1N5817 diode. Comment on the differences between these measurements and those in 3(a).
   (e) Repeat 3(a) using the silicon 1N4148 diode and the oscilloscope set to AC input coupling. Discuss the difference with the measurements in 3(a).

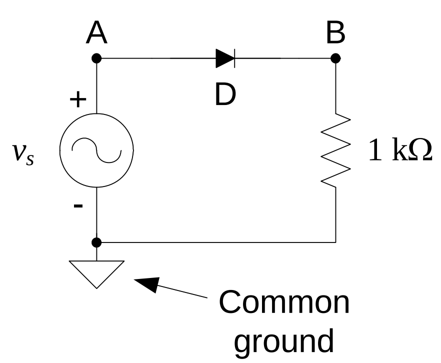

Figure 2 Simple diode rectification circuit.

III. Diode Characteristic Curve

The current I versus voltage V relationship for the diode circuit element is given by

$$I = I_S \left(e^{\frac{V}{nV_T}} - 1 \right) \tag{1}$$

where

I_S = Saturation current
V = Voltage across the diode
n = Emission constant
V_T = Thermal voltage (= 25 mV at room temperature 20 ºC)

It is apparent from this equation that I and V are not linearly related to one another. That is, we see that the current is not linearly dependent on the voltage. Hence, we say that the diode is a *nonlinear* circuit element.

The circuit for measuring the diode characteristic curve is shown in Fig. 1. A positive voltage V results in a forward bias current, I, through the diode. For reasonable values of the (positive) voltage, the exponential term in (1) is much greater than 1 and the current is almost exactly represented by a purely exponential curve. Thus, we may approximate the current as

$$I \approx I_s e^{\frac{V}{nV_T}} \tag{2}$$

Taking the logarithm (base 10) of this equation yields

$$\log_{10}(I) = \log_{10}(I_s) + \frac{V}{nV_T} \log_{10}(e) \tag{3}$$

Notice that this is simply the equation of a straight line. If we assign the vertical axis to $\log_{10}(I)$ and the horizontal axis to V, the slope is then

$$\text{slope} = \frac{\log_{10}(e)}{nV_T} \tag{4}$$

At room temperature where T = 20 ºC (293 K)

$$V_T = 0.025 \text{ V} . \tag{5}$$

Because $\log_{10}(e) = 0.434$ then the slope is given as

$$\text{slope} = \frac{16.7}{n} \tag{6}$$

The value of the emission coefficient, *n*, can then be easily calculated from the plot of the *I-V* characteristic curve of the diode using this equation.

By choosing three or four different values of current from the graph along with their corresponding voltage values, an average value of the saturation current of the diode can also be calculated using the measured value of *n*.

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† Adapted from Kenneth C. Smith, *Laboratory Explorations for Microelectronic Circuits*. New York: Oxford University Press, fourth edition, 1998.