Physics 323

Experiment # 5 - Semiconductor Diodes

References:	*Storey* 4e pp. 309-331.
	A. Ferendeci *Physical Foundations of Solid State and Electron Devices*, pp. 181-198
	R.A. Dunlap *Experimental Physics: Modern Methods*, pp. 28-39

1. Forward and Reverse Characteristics of a Diode

Theoretical Introduction

The basic diode current-voltage relationship that comes from the analysis of the drift and diffusion currents in a *p-n* junction is

$$I(V) = I_S\left(e^{eV/\eta k_B T} - 1\right)$$

where I_S represents the reverse bias saturation current. Obviously this is not $I=V/R$! η is an adjustable constant that is set to 1 for germanium diodes and 1.2 for silicon diodes. There are several approximations to this *I-V* curve. One of them, the *ideal diode*, has zero current for any voltage in the reverse bias direction and no voltage drop in the forward bias direction no matter how large the current (as if R=0). In this sense the diode only allows currents to flow in the forward bias direction and when they do flow in the forward bias direction there is no resistance. A refinement of this behaviour takes into account the *turn-on voltage,* where there is no current for any voltage below the turn-on voltage and the voltage drop is equal to the turn-on voltage for any current in the forward bias direction. A further refinement is to assume that the *I-V* curve beyond the turn-on voltage is linear and there is an effective non-zero resistance in this region. The *dynamic resistance* represents the reciprocal of the derivative of the *I-V* curve at any point on the curve.

In the circuit diagram the forward bias direction is with a positive voltage on the "triangle" part of the diode and the negative voltage on the "thick line". The thick line corresponds to the "*n*" side of the junction and is a source of electrons i.e. a cathode. The diodes themselves have a thick painted stripe on one side to indicate the cathode. Light-emitting diodes have a slightly flattened edge to indicate the cathode side.

Prelab

You are to measure the forward and reverse characteristics of a germanium diode but you cannot measure the voltage drop across the diode directly in the reverse bias direction - why not?

Sketch the I-V characteristics of a germanium diode and a silicon diode (you will need to look up the turn-on voltages).

Lab

The diode to be used is the 1N34, consult the General Electric Manual for the characteristics of the diode (there are also copies outside my office). Do <u>NOT</u> exceed maximum voltages and currents specified for this diode.

Use your digital voltmeter (DVM) to measure the exact resistance of the 700 Ohm resistor that you have in the above circuit. Connect the diode into the circuit in Fig. 1.

Use the DVM in a two-step process to measure the voltage across the resistor and the voltage across the supply. From the voltage across the resistor determine the current through the diode and from the difference of the two voltages determine the voltage across the diode. (If you are using a computer to plot the data you can use "Quick Transform" or other options to do these two steps.) You will need to exchange the + and – plugs to obtain the reverse characteristic. You will also need to use a 10 kΩ resistor for some of the larger reverse bias settings. (once you have done it, explain why)

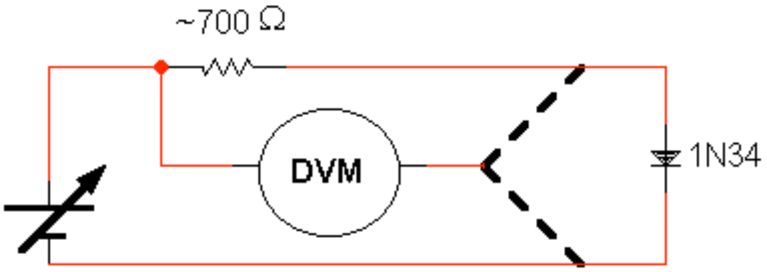

Figure 1: The circuit for the "two-step" *I-V* characteristic measurement.

Make two plots of the *I-V* characteristic. On one of them show the forward bias and the other show the reverse bias.

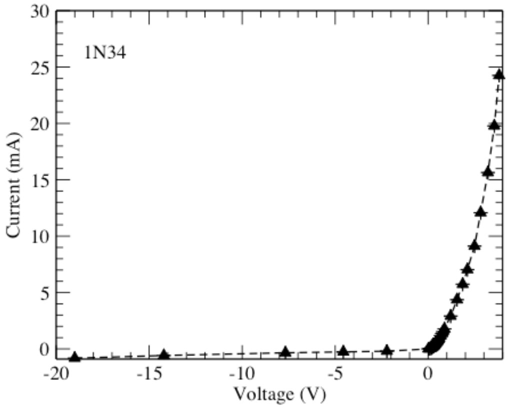

Figure 2: Example data for the *I-V* characteristic. You will make two separate plots.

Give an estimate of I_S from your reverse-bias plot. Also estimate the turn-on voltage and the dynamic resistance beyond the turn-on voltage from the forward-bias plot.

2. <u>Diode Circuits</u>

Prelab

Sketch the waveforms you expect for the half-wave rectifier, at its input and output assuming it is a 6 V transformer and the turn-on voltage is 0.7 V.

Sketch the output waveform for the full-wave rectifier (again assuming a 6 V transformer) and predict the duration of any 'flat' regions.

The ripple is the amount of voltage drop at the load (often given as a percentage) that results from the discharge of the capacitor while the rectifier is not directly providing power. It is determined by the *RC* constant of the load resistor and smoothing capacitor and the amount of time that passes before the rectifier begins to provide power again. Calculate the size of 'ripple' you would expect for the 4.7 μF and 470 μF capacitors for the full-wave rectifier operating at 60 Hz.

Lab

(a) Half-wave rectifier

Construct a half-wave rectifier circuit with the ~6 V transformer and a 1N914 diode. Connect a 2.2 kΩ load and look at the voltage from the transformer (the input) and across the load (the output) using the CRO. Make a sketch.

Measure V_{peak} - explain.

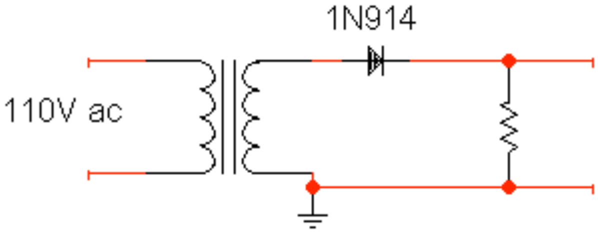

Figure 3: Half-wave rectifier. Use a 2.2 kOhm resistor as the load.

(b) Full-wave bridge rectifier

Construct a full-wave bridge rectifier using 1N914's as shown in Fig. 4.

WARNING: This is one of the times you cannot use the CRO probes to look at the input from the transformer and the output at the load at the same time. You can only look at the output waveform with the CRO. ***Disconnect the probe connected to the transformer output before you construct this circuit.*** The reason for the problem is that the probes are connected to the "ground" of the oscilloscope and you end up putting too much current through the diodes. If you need to investigate the voltages across individual diodes just use one probe and move the ground around the circuit.

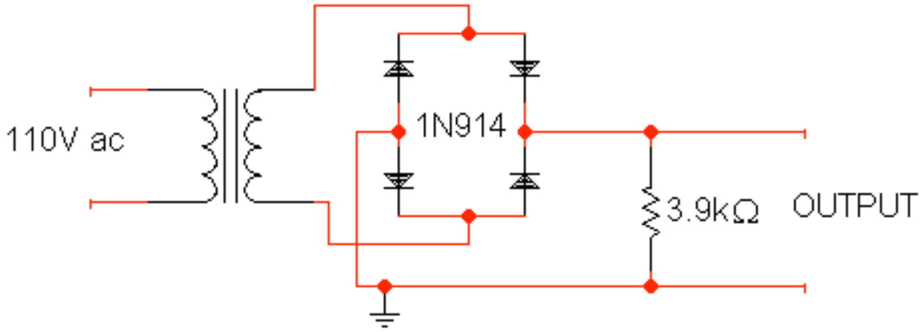

Figure 4: Full-wave rectifier without the smoothing capacitor.

Does the output make sense? Measure V_{peak} and comment. Examine the region of the output waveform that is near zero volts. Measure the time duration of the flat regions and explain.

Connect a 4.7 µF smoothing capacitor across the output. Make sure you observe the correct polarity; the lead connected between the two diode cathodes is positive. Now, does the output make sense? Measure the ripple and compare with your calculation. Now put a 470 µF capacitor across the output and see if the output ripple agrees with your prediction.

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