EE321 Lab 3 - Diodes

24th April 2005

1 Purpose

There are several goals in this experiment:

1. To study the nonlinear characteristics of a real diode.
2. To make precision measurements of the diode.
3. To confirm that it really does match the "diode equation":

$$I = I_s(e^{v/nV_T} - 1)$$

4. For extra credit, to build and use a simple "curve tracer" to see the I/V characteristic of the diode on a scope.

At home, you need to do two more experiments:

1. By curve fitting, verify that the diode really does fit the curve, and determine its "saturation current" (I_s).
2. Using the saturation current you determined, verify that it is correct using simulation.

2 Overview

You need to make voltage and current measurements on a diode using the available equipment.

The second step is to use a DC power supply instead of the sweep, and precision voltmeters instead of the scope. You will make a chart of current and voltage. From there, you can verify that it really does have an exponential (or logarithmic depending on how you look at it) characteristic.

Since you will be making precision measurements, it is important that all connections must have as low resistance as possible. It is best to build it entirely on the binding posts.

If you have time, use a transformer to generate a sweep voltage, and a scope in "XY" mode to display a curve. Since the scope measures only voltage, we will use a 10K resistor as a sense element. By measuring its voltage, we can determine the current.

3 Parts and equipment needed

- Diode to be tested.
- 10K resistor. Measure it to find its exact value.
- AC line transformer, to generate a sweep voltage.
- Digital voltmeter (you need 2, so get one more from the crib).

4 Procedure

4.1 Check your equipment

Before beginning the real experiment, verify that your equipment is working.

1. Set both meters to voltage, 20 volt scale.
2. Connect both, in parallel, across the power supply.
3. With the power supply still off, turn the current adjustment all the way down, then up by a half turn.
4. Turn on the power supply, and adjust it so that both meters read 15 volts.
5. Turn off the power supply and disconnect the meters.

4.2 Precision measurements, forward biased

In this step, you will substitute a DC source for the sweep, and voltmeters for the scope, to measure voltage and current precisely. If the two voltmeters are different, use the better meter to measure the diode voltage. The new schematic is this:

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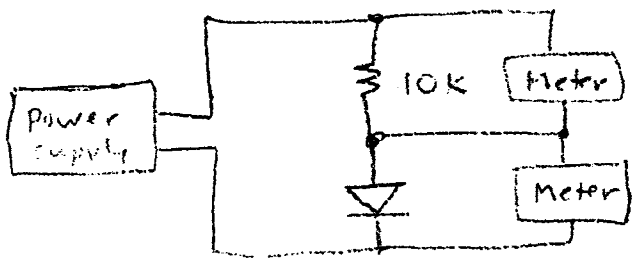


Build the circuit in the schematic. Build it entirely on the binding posts.

Make a chart of voltages and currents. You can find the current by measuring the voltage across the 10K resistor:

Resistor voltage	Current, mA	Diode voltage	Difference
31.6	3.16		xxxxxx
10	1		
3.16	.316		
1	.1		
.316	.0316		
.1	.01		

To make this chart....

1. Set the power supply to get the desired voltage across the sense resistor.
2. Measure the diode voltage, as accurately as you can.
3. Repeat for all lines in the table.

You can confirm that the current really is an exponential function of voltage, or that voltage is a logarithmic function of current by comparing adjacent voltages in the table. Enter the differences in the table. The difference between any pair of adjacent voltages in the table should be the same, probably about .04 volts. Diode voltages should be between .5 and .8 volts.

Before moving on, make a simple determination of I_s and n . Read the section of this assignment on "Theory, Fit the curve". Use the two points at 1 mA and .1 mA to determine the coefficients for the equation:

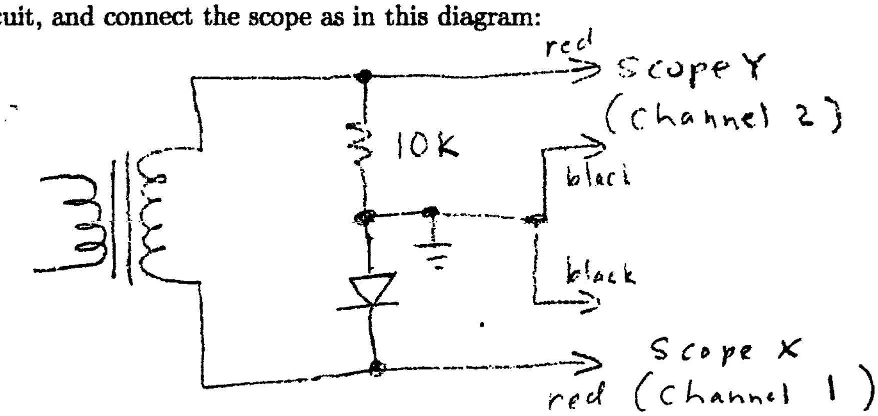
$$\ln(I) = \ln(I_s) + \frac{v}{nV_T}$$

4.3 Measurements, reverse biased

1. Reverse the power supply, so the diode is reverse biased.
2. Turn the voltage all the way up, observing the resistor and diode voltages as you do.
3. Observe that almost all of the voltage is across the diode, with almost no voltage across the resistor.
4. With 50 volts across the diode, what is the voltage across the resistor? What is the current? If it is about 5 uA (.05 volts), you are measuring the meter!

5 Extra credit, Curve tracer

Build this circuit, and connect the scope as in this diagram:



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1. Before applying any signal set the scope as follows:
   (a) XY mode (display, format, XY)
   (b) Intensity: overall=100, text/grat = 50, waveform = 100.
   (c) Horizontal scale (sweep) for sample rate of 10.0 KS/Sec.
   (d) X (Channel 1) scale to 5 volts/div.
   (e) Y (Channel 2) scale to 5 volts/div, which represents 500 uA/div.
   (f) Put the dot in the center. The vertical position control for channel 1 moves it horizontally. The vertical position control for channel 2 moves it vertically.
2. Apply the input and observe the scope image.
3. Sketch the image in your notes.
4. Expand the scale to better see the forward biased region:
   (a) X (Channel 1) to .2 volts/div.
   (b) Leave Y (Channel 2) at 5 volts/div, which represents 500 uA/div.
5. Sketch the image. Label it "forward biased".
6. Read visually the voltage (X) for currents of 1 mA and .3 mA, as accurate as you can. It should be match what you measured with the meter.
7. Reset the scope to see the reverse biased region:
   (a) X (Channel 1) back to 5 volt/div.
8. Observe that there is almost no current in the reverse direction.
9. Turn up the Y (channel 2) sensitivity to see some current in the reverse region. Note the current at -5 volts and -10 volts. If it is 10 uA (.1 volts) at 10 volts, and 5 uA (.05 volts) at 5 volts, and looks like a straight line, you are measuring the scope.
10. Sketch the image. Label it "reverse biased".

6 Your report

Please arrange your report in the order listed here.

6.1 Summary (on cover)

Give a summary for "the boss's boss". In one or two sentences, tell what you did.

1. In a table, state your values for I_s, n, and the correlation coefficient.
2. How much variation was there in the voltage difference between steps?
3. Write this last, but put it on the cover.

6.2 More detailed summary

The detailed summary should be about 1 page:

1. A chart showing the important results, including a comparison to the simulation.
2. A paragraph with a summary of your experience. It should include a statement of the important concepts that you learned.
3. Write this second to last, but put it on the first inside page.

6.3 Journal

Your report should include a journal of what you did, with enough detail that someone else can repeat your experiment, complete with mistakes, and with the exact equipment that you used. Do not retype or rewrite it. Just include a photocopy of your actual lab records. It should tell what meters you used, and how they were set. You should give enough information so the reader knows which equipment you used.

If you did the extra credit, also include two screen images, showing the forward and reverse biased regions.

6.4 Theory, Fit the curve

Fit an exponential curve to the data. It is claimed that the data fits the expression:

$$I = I_s(e^{v/nV_T} - 1)$$

You need to determine the values of I_s and n. You can assume that V_T is .026 volts.

The best way to do this is by the "least squares" method. This will give you the values I_s and nV_T. It should also give you a "correlation coefficient". The "correlation coefficient" is an indicator of how good the fit is. A value of "1" is perfect. A value a little less than 1, such as .999 is very good. Most good calculators will do this automatically.

Another indication of the quality of the fit is how close the simple method you did in the lab matches the least squares method.

Some calculators will not fit exponentials, but will fit lines. If yours is one that only fits lines, you must convert the diode equation to a line. You can do this by taking the natural log of both sides. To make it easier, ignore the -1 term.

Using this simplified diode equation:

$$I = I_s(e^{v/nV_T})$$

Take the log:

$$\ln(I) = \ln(I_s(e^{v/nV_T}))$$

$$\ln(I) = \ln(I_s) + \frac{v}{nV_T}$$

Now it fits the classic $y = mx + b$ form, where $y = \ln(I)$, $x = v$, $m = 1/(nV_T)$, and $b = \ln(I_s)$.

Indicate clearly what your answer is.

6.5 Simulate it

Now that you have the coefficients, try simulating your circuit to see if you get the same results. You should!

A diode is described in two parts:

The first part connects it to the circuit. It differs from components we have seen so far in that it requires a model name as the value. For example:

```
D1 1 2 mydiode
```

D1 is the label. The two numbers (1 2) are node numbers, anode first, cathode second. The word (mydiode) is the name of a model.

Now you must specify the model. A model statement begins with ".model", then the name of your model, then the word "D" to say it is a diode, then a list of parameters.

You need to specify two parameters, IS and N. The value of N is 1, so you can leave that one out. You must specify IS. For example:

```
.model mydiode D is=12.4e-15 n=1.3
```

The best place for this is in the netlist, just before or after the diode itself.

Here's my netlist:

```
I1 1 2 dc .001
R1 2 0 10k
d1 0 1 mydiode
.model mydiode d is=10.3e-15 n=1.24
```

Now you can sweep it:

```
print dc v(nodes) V(r1) I(r1) I(d1) V(d1) V(r1)
dc i1 10u .01 dec 2
```

The table should match your lab data. Comment on what you see.

To get you started on the simulator, I have attached a copy of my simulation run.

```
ucap 0.34
ie Gnu Circuit Analysis Package
lever trust any version less than 1.0
Copyright 1982-2002, Albert Davis
Gnucap comes with ABSOLUTELY NO WARRANTY
T   is free software, and you are welcome
t  edistribute it under certain conditions
according to the GNU General Public License.
See the file "COPYING" for details.
```

gnucap> build ← build the circuit

\>I1 0 1 dc .001 ← for now, set it to 1 milliamp.

\>R1 1 2 10k

\>D1 2 0 1N4001

\>.model 1N4001 D is=1.03e-12 n=1.24 ← substitute the numbers you calculated.

\> ← blank line to leave "build" mode

gnucap> list ← see how the computer interpreted my typing

```
I1  ( 0 1 )  DC  0.001
R1  ( 1 2 )  10.K
D1  ( 2 0 )  1N4001   area= 1.
.model  1N4001  d  (  tnom= 27.  is= 1.03p  rs= 0.  n= 1.24  tt= 0.
+  cjo= 0.  pb= 1.  mj= 0.5  egap= 1.11  xti= 3.  fc= 0.5)
*+()
```

g   p> print dc V(R1) I(R1) I(D1) V(D1) ← attach the meters — what to print.

gnucap> dc I1 .01e-3 10e-3 dec 2 ← Do a DC sweep — vary I1 from .01 mA to 10 mA in 2 steps per decade

#	V(R1)	I(R1)	I(D1)	V(D1)
10.u	0.1	10.u	10.u	0.51598
31.623u	0.31623	31.623u	31.623u	0.55291
100.u	1.	100.u	100.u	0.58983
316.23u	3.1623	316.23u	316.23u	0.62676
0.001	10.	0.001	0.001	0.66368
0.0031623	31.623	0.0031623	0.0031623	0.7006
0.01	100.	0.01	0.01	0.73753

gnucap>

↑ (V(R1)) ↑ (I(D1)) ↑ (V(D1)) This should agree with your measurements.