

ECE 320 - Homework #2

Semiconductors, PN Junction. Due Monday, Jan 25th

Please make the subject "ECE 320 HW#2" if submitting homework electronically to Jacob_Glower@yahoo.com (or on blackboard)

Semiconductors

- 1) Why does the resistance of silicon decrease as temperature goes up?

As temperature goes up, you get more and more thermal electron / hole pairs.

More electrons & holes means more charge carriers.

More charge carriers means less resistance.

Resistance goes down as temperature goes up for semiconductors.

This also holds for photo-resistors

Resistance goes down as light intensity goes up

- 2) What doping of Boron (p-type) do you need to make an 1206 resistor have a resistance of 7500 Ohms? The dimensions of an 1206 resistor are

$$L = 3.20\text{mm}, W = 1.60\text{mm}, H = 0.95\text{mm}$$

$$R = \frac{\rho L}{A}$$

$$7500\Omega = \frac{\rho \cdot 0.32\text{cm}}{0.16\text{cm} \cdot 0.095\text{cm}}$$

$$\rho = 356.25 \Omega \text{ cm}$$

$$\sigma = \frac{1}{\rho} = 0.002807 = n_p \cdot q \cdot \mu_p$$

$$0.002807 = n_p \cdot (1.6 \cdot 10^{-19}) \cdot (500)$$

$$n_p = 35.09 \cdot 10^{12} \frac{\text{atoms}}{\text{cc}}$$

3) A thermistor has the following resistance - voltage relationship

$$R = 1000 \exp\left(\frac{3905}{T+273} - \frac{3905}{298}\right) \Omega$$

where T is the temperature in degrees C. What is the resistance you'll read at

-70C Dry ice

- 460.6k Ohms

0C Freezing point of water

- 3320 Ohms

+650F Temperature of a soldering iron

- 343.3C
- 1.150 Ohms

PN Junction

4) Why can current flow p to n but not n to p?

several answers - any of them are valid

a) When current flows p to n, you're using majority carriers. A large number of charge carriers means low resistance.

When current flows n to p, you're using minority carriers. A small number of charge carriers means high resistance.

b) A depletion exists which prevents current from flowing.

When you apply voltage p to n, you decrease the size of the depletion zone. When it reaches zero (at 0.7V for silicon), the diode conducts.

When you apply voltage n to p, you just make the depletion zone larger.

c) A potential energy barrier exists at the pn junctions.

If you apply enough voltage to overcome the potential energy barrier (about 0.7V for silicon), current flows.

If you apply less than 0.7V for silicon, the electrons don't have enough energy to overcome the potential energy barrier and current doesn't flow.

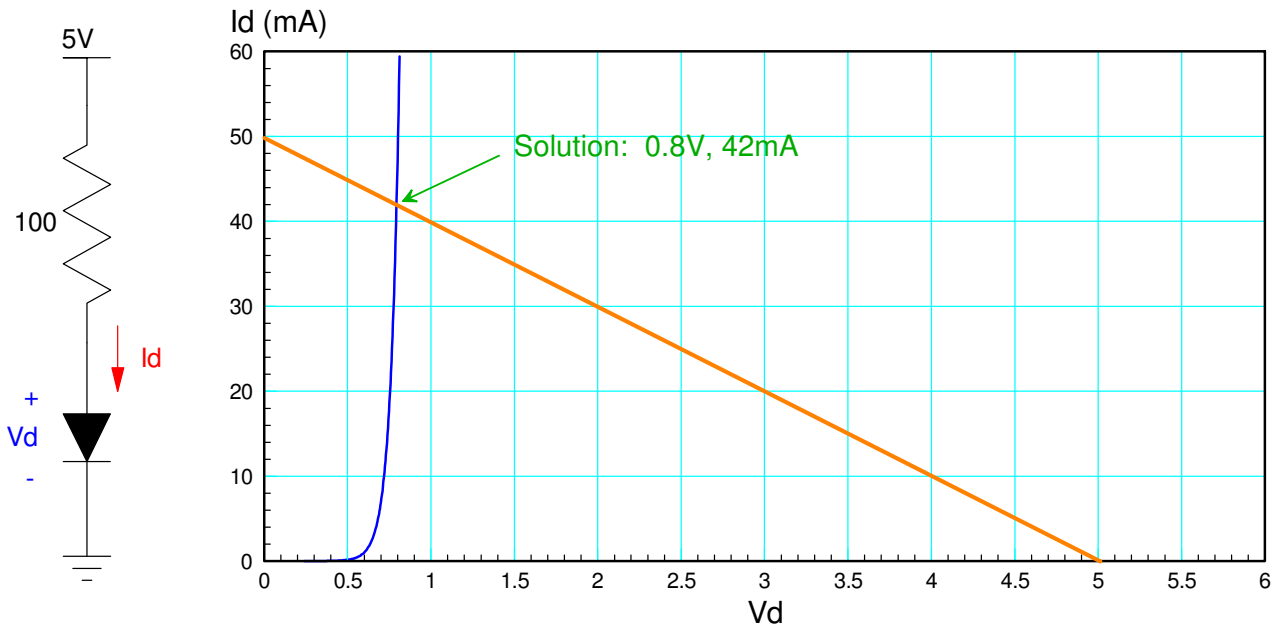
Diode VI Characteristics

Assume the VI characteristics for a diode are

$$V_d = 0.052 \cdot \ln\left(\frac{I_d}{10^{-8}} + 1\right) \quad I_d = 10^{-8} \left(\exp\left(\frac{V_d}{0.052}\right) - 1 \right)$$

5) For the 1-diode circuit next page)

5a) Draw the load-line for the following circuit (next page). Determine V_d and I_d from the graph.



5b) Write the voltage node equations and solve for V_d and I_d assuming the VI equations above

$$V_d = 0.052 \cdot \ln\left(\frac{I_d}{10^{-8}} + 1\right)$$

$$V_d + 100I_d = 5V$$

Solving using numerical methods. Create a function in Matlab where you guess V_d and it computes the error squared:

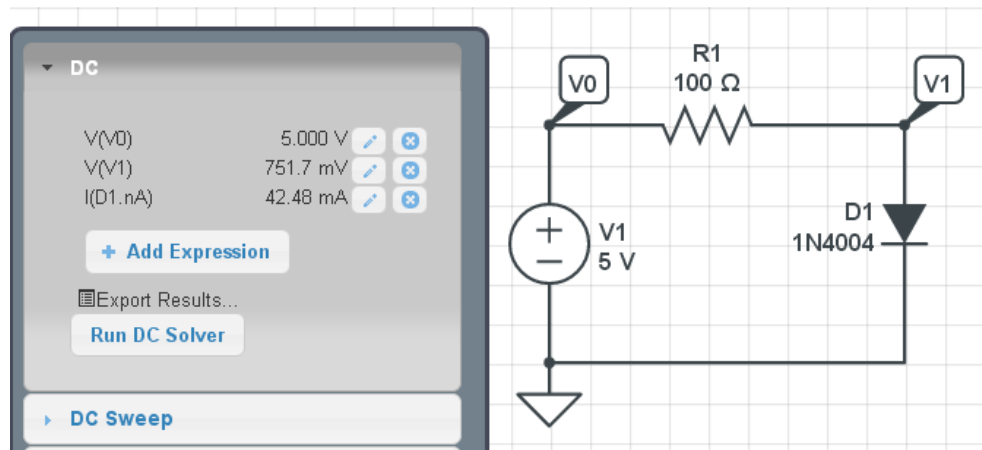
```
function [ J ] = Diode1( z )
    Vd = z(1);
    Idss = 1e-8;
    nVt = 0.052;
    Id = Idss* exp( Vd/nVt - 1 );
    e1 = 100*Id + Vd - 5;
    J = (e1)^2;
end
```

Solve using `fminsearch`

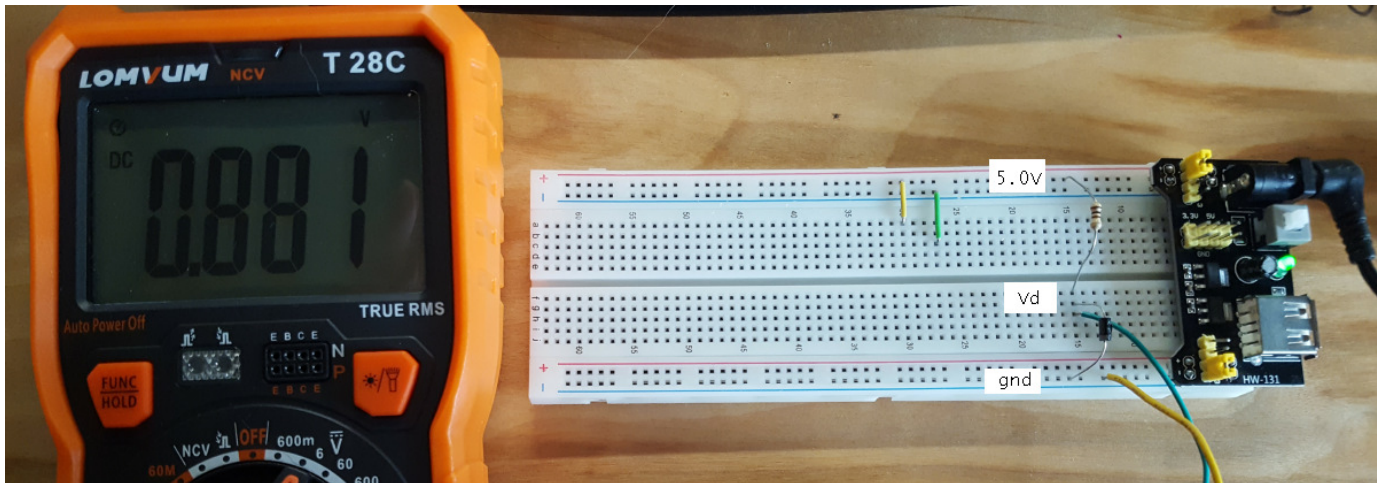
```
>> [Vd,e] = fminsearch('Diode1', 0.7)
Vd = 0.8444
e = 7.5531e-006

>> Id = (5 - V)/100
Id = 0.0416
```

6) Build this circuit in CircuitLab and solve for V_d and I_d . (Use a 1N4004 diode)



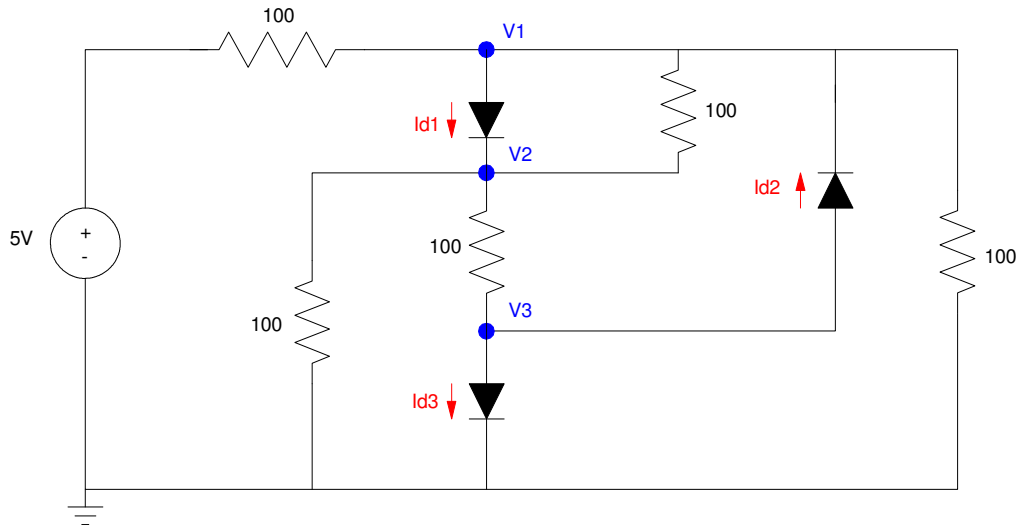
7) Build this circuit on your breadboard and measure V_d . From this, compute I_d



	V_d	I_d
5a) Graphical solution	800 mV	42 mA
5b) Numeric Solution	844.4 mV	41.6 mA
6) Simulation (CircuitLab)	751.7 mV	42.8 mA
7) Lab (experimental)	881 mV	41.19 mA

Problem 8 - 10: For the following circuit...

8) Write the voltage node equations assuming nonlinear diodes. Solve for {V1, V2, and V3} using Matlab.



Note: Resistors changed to 1k resistors due to availability

Diode equations

$$I_{d1} = 10^{-8} \left(\exp \left(\frac{V_1 - V_2}{0.052} \right) - 1 \right)$$

$$I_{d2} = 10^{-8} \left(\exp \left(\frac{V_3 - V_1}{0.052} \right) - 1 \right)$$

$$I_{d3} = 10^{-8} \left(\exp \left(\frac{V_3}{0.052} \right) - 1 \right)$$

Voltage Node equations

$$\left(\frac{V_1 - 5}{1000} \right) + I_{d1} + \left(\frac{V_1 - V_2}{1000} \right) - I_{d2} + \left(\frac{V_1}{1000} \right) = 0$$

$$-I_{d1} + \left(\frac{V_2 - V_1}{1000} \right) + \left(\frac{V_2}{1000} \right) + \left(\frac{V_2 - V_3}{1000} \right) = 0$$

$$\left(\frac{V_3 - V_2}{1000} \right) + I_{d2} + I_{d3} = 0$$

Write an m-File which

- Is passed your guess of V1, V2, V3
- Computes the resulting diode currents
- Computes the error in the voltage node equations, and
- Returns the sum squared error

```

function [ J ] = Diode3( z )

V1 = z(1);
V2 = z(2);
V3 = z(3);

Idss = 1e-8;
nVt = 0.052;

Id1 = Idss* exp( (V1 - V2)/nVt - 1 );
Id2 = Idss* exp( (V3 - V1)/nVt - 1 );
Id3 = Idss* exp( (V3 - 0)/nVt - 1 );

e1 = (V1 - 5)/1000 + Id1 + (V1-V2)/1000 - Id2 + (V1)/1000;
e2 = -Id1 + (V2-V1)/1000 + (V2 - V3)/1000 + (V2)/1000;
e3 = (V3-V2)/1000 + Id2 + Id3;

J = (e1)^2 + (e2)^2 + (e3)^2;
end

```

Solve using Matlab

```
>> [V,e] = fminsearch('Diode3',[2.1,1.4,0.7])
```

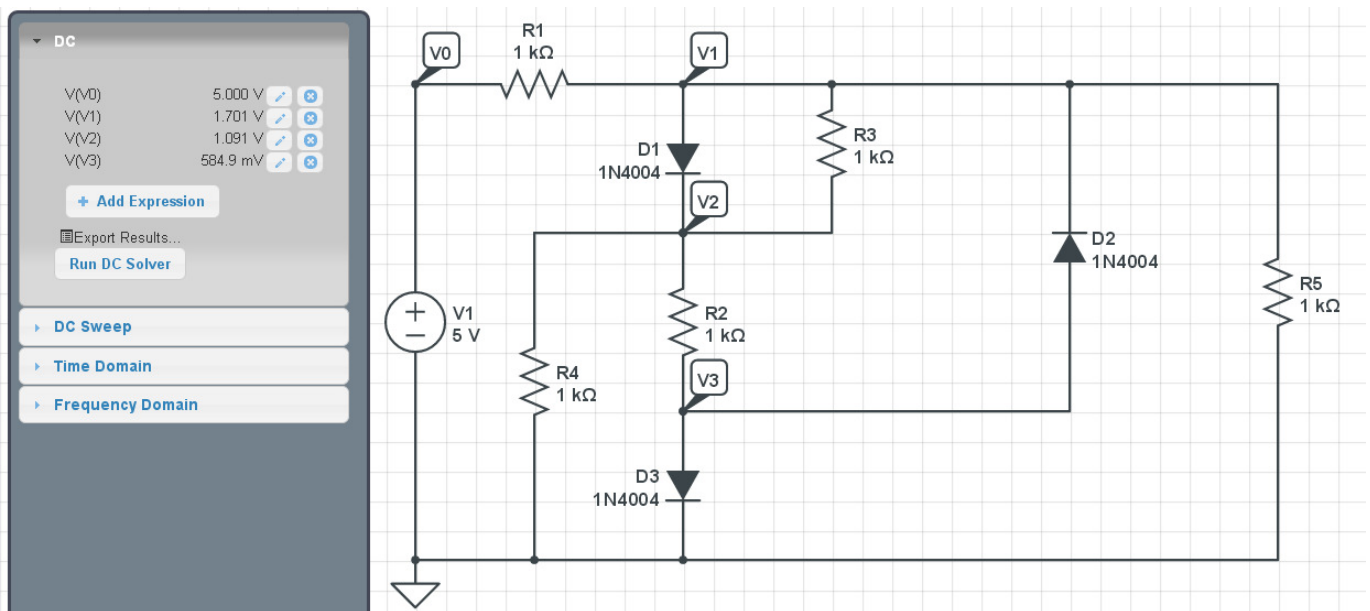
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      V1      V2      V3
V =    1.7255    1.0801    0.6113

e =    2.8487e-014

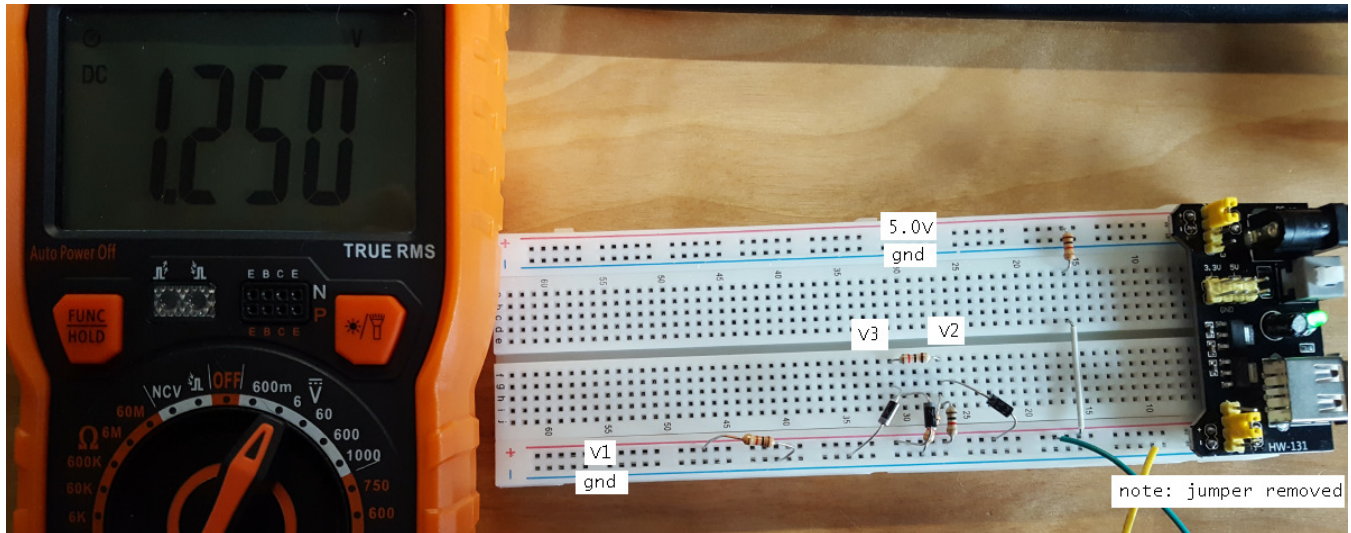
```

9) Simulate this circuit in CircuitLab. From this, determine {V1, V2, and V3}



10) Build this circuit with your breadboard and measure {V1, V2, V3}

- note: 1k resistors are used (brown - black - red) instead of 100 Ohm resistors



	V1	V2	V3
8a) Numeric Solution	1.7255 V	1.0801 V	0.6113 V
9) Simulation (CircuitLab)	1.701 V	1.091 V	0.5849 V
10) Lab (experimental)	1.250 V	0.716 V	0.622 V