ECE 320 - Homework #2

Semiconductors, PN Junction, Ideal Diode. Due Wednesday, September 9th

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 electrons (and corresponding holes). More charge carriers means less resistance.

2) What doping of Boron (p-type) do you need to make an 0805 resistor have a resistance of 1000 Ohms? The dimensions of an 1206 resistor are

L = 3.20mm, W = 1.60mm, H = 0.95mm

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

$$1000\Omega = \frac{\rho \cdot 0.32cm}{0.16cm \cdot 0.095cm}$$

$$\rho = 47.5\ \Omega\, cm$$

$$\sigma = \frac{1}{\rho} = n_p \cdot (500) \cdot (1.6 \cdot 10^{-19} C)$$

$$n_p = 2.632 \cdot 10^{14}\ \frac{\text{atoms}}{cc}$$

3) A thermistor has the following resistance - voltage relationship

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

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

- 0F Temperature of a typical freezer
- 98.6F Temperature of a healthy person
- 103.0F Temperature with a fever

0F: T = -17.778C

R = 8992 Ohms

98.6F T = 37.00C

R = 602.15 Ohms

103.0F T = 39.44C

R = 545.64 Ohms

PN Junction

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

Option 1: p to n uses majority carriers. A large number of charge carriers means a low resistance
n to p uses minority carriers. A small number of charge charriers means a high resistance

Option 2: Voltage p to n reduces the depletion zone to zero (at about 0.7V for silicon diodes). When the depletion zone goes to zero, current flows.

Voltage n to p increases the size of the depletion zone, which block current flow.

Option 3: A potential energy barrier (about 0.7V for silicon diodes) prevents current from flowing. If you apply more then 0.7V p to n, the electrons have enough energy to overcome the potential energy barrier

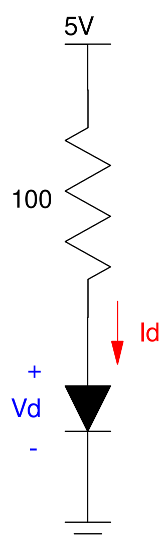
Diode VI Characteristics

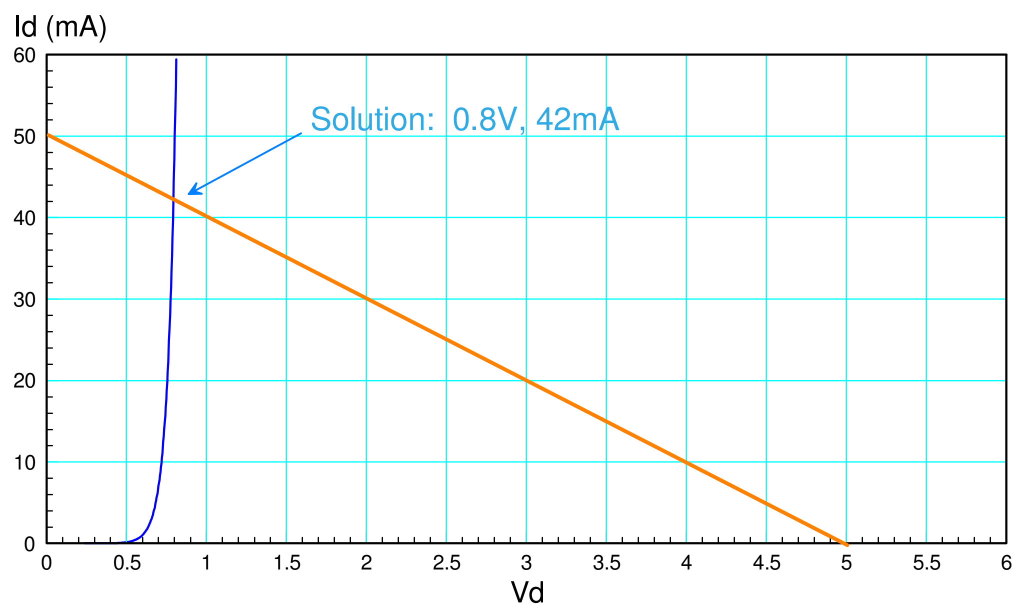
Assume the VI characteristics for a diode are

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

5) For the 1-diode circuit next page)

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





5b) Write the voltage node equations and solve for Vd and Id assuming the VI equations above

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

$$I_d + \left(\frac{V_d - 5}{100}\right) = 0$$

Solving in Matlab

```
function J = cost(z)

   Vd = z;
   Id = 1e-8 * ( exp( Vd / 0.052) - 1 );

   E = Id + (Vd-5)/100;

   J = E^2;

end
```

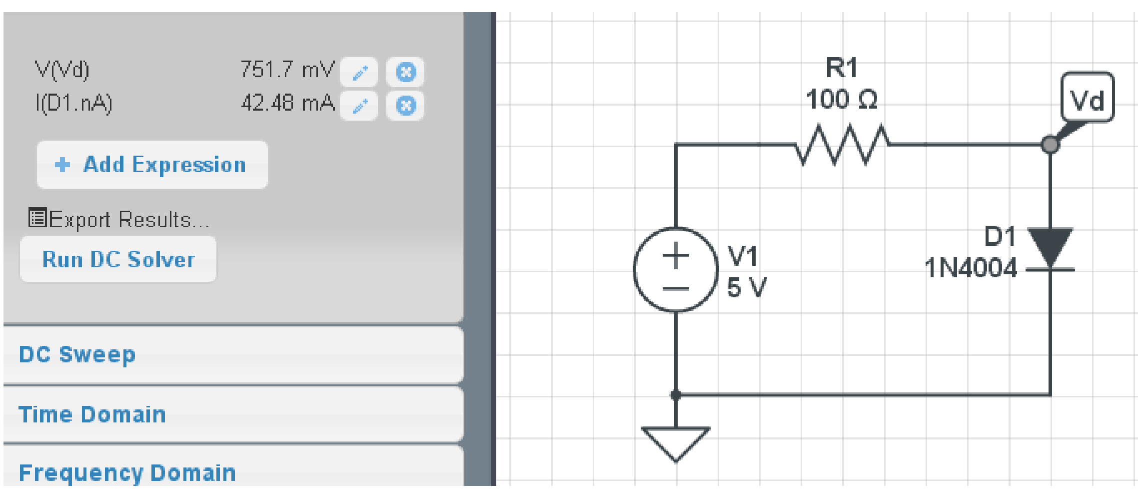
Calling this from Matlab

```
>> [Vd, e] = fminsearch('cost',0.7)

Vd =     0.7931

e =   7.6027e-011

>> Id = (5 - Vd)/100

Id =     0.0421
```

5c) Write the voltage node equations and solve for Vd and Id assuming ideal diodes (Vf = 0.7V)

```
>> Vd = 0.7;
>> Id = (5 - Vd)/100

Id =     0.0430
```

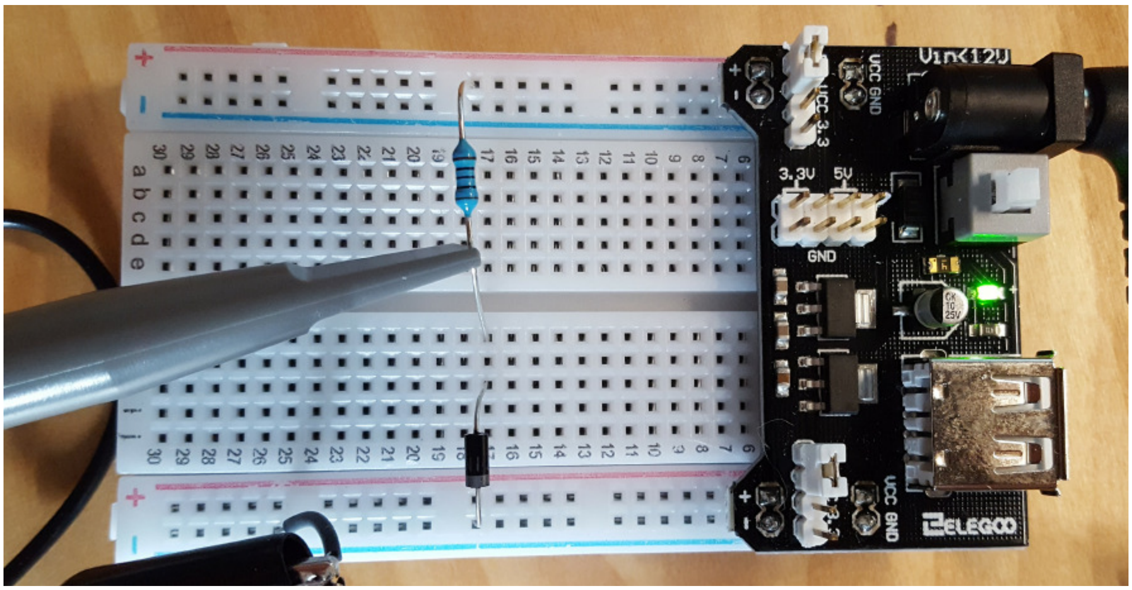
6) Build this circuit in CircuitLab and solve for Vd and Id



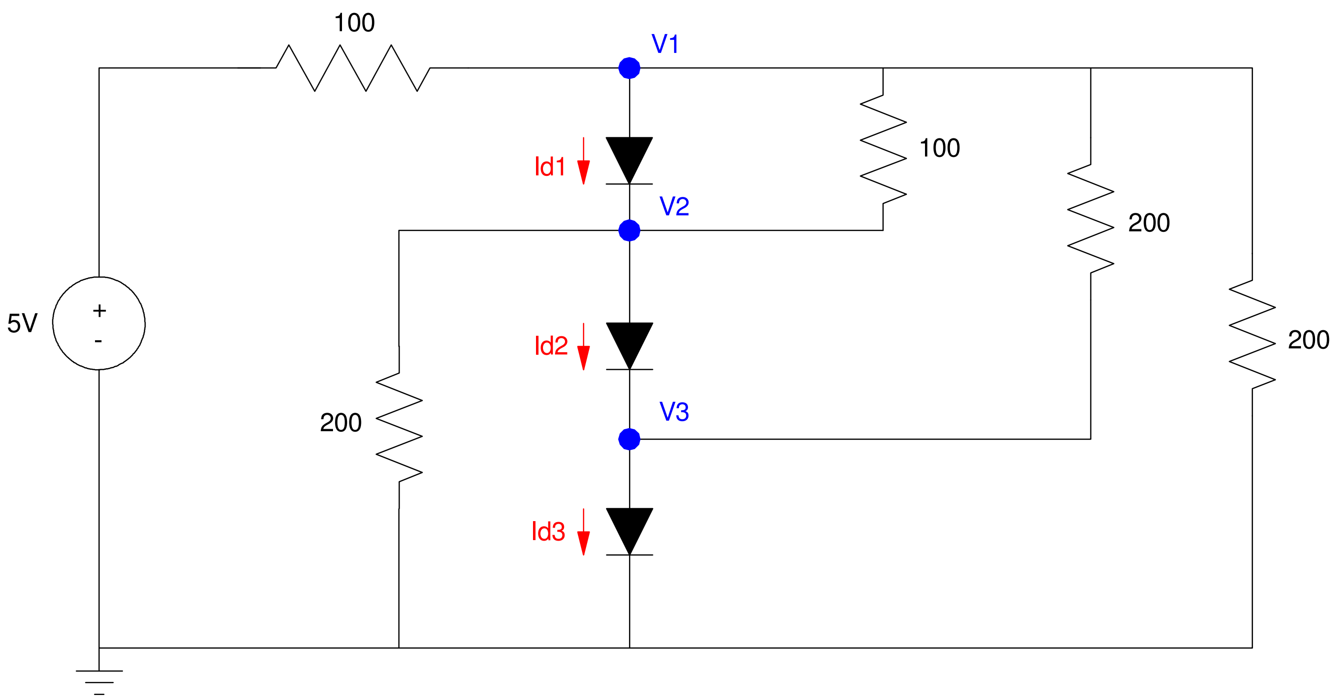
7) Build this curcuit on your breadboard and measure Vd. From this, compute Id

	Vd	Id
5a) Graphical solution	0.8V	42 mA
5b) Numeric Solution	0.7931 V	42.1 mA
5c) Ideal Diode Solution	0.7000 V	43.0 mA
6) Simulation (CircuitLab)	0.7517 V	42.48 mA
7) Lab (experimental)	0.744 V	42.6mA

Problem 5 to 7



Problem 8 - 10: Determine V1 .. V3 for the circuit below a) Assuming exponential VI relationships, b) Assuming ideal diodes, c) Using CircuitLab, d) Experimental (build the circuit)



8) Numeric Solution

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

$$I_{d2} = 10^{-8}\left(\exp\left(\frac{V_2-V_3}{0.052}\right) - 1\right)$$

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

$$\left(\frac{V_1-5}{100}\right) + I_{d1} + \left(\frac{V_1-V_2}{100}\right) + \left(\frac{V_1-V_3}{200}\right) + \left(\frac{V_1}{200}\right) = 0$$

$$-I_{d1} + I_{d2} + \left(\frac{V_2}{200}\right) + \left(\frac{V_2-V_1}{100}\right) = 0$$

$$-I_{d2} + I_{d3} + \left(\frac{V_3-V_1}{200}\right) = 0$$

Solve in Matlab

Matlab Function:

```
function [ J ] = cost_diode( z )

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

   Id1 = 1e-8 * ( exp( (V1-V2)/0.052 ) - 1);
   Id2 = 1e-8 * ( exp( (V2-V3)/0.052 ) - 1);
   Id3 = 1e-8 * ( exp( (V3)/0.052 ) - 1);

   V0 = 5;
   e1 = (V1-V0)/100 + Id1 + (V1-V2)/100 + (V1-V3)/200 + V1/200;
   e2 = -Id1 + Id2 + V2/200 + (V2-V1)/100;
   e3 = -Id2 + Id3 + (V3-V1)/200;

   J = e1^2 + e2^2 + e3^2;

   end
```

Command Window:

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

V =    2.0892    1.4067    0.7263

e =  1.1162e-011
```

b) Ideal Diode Solution: Assume all diodes are on

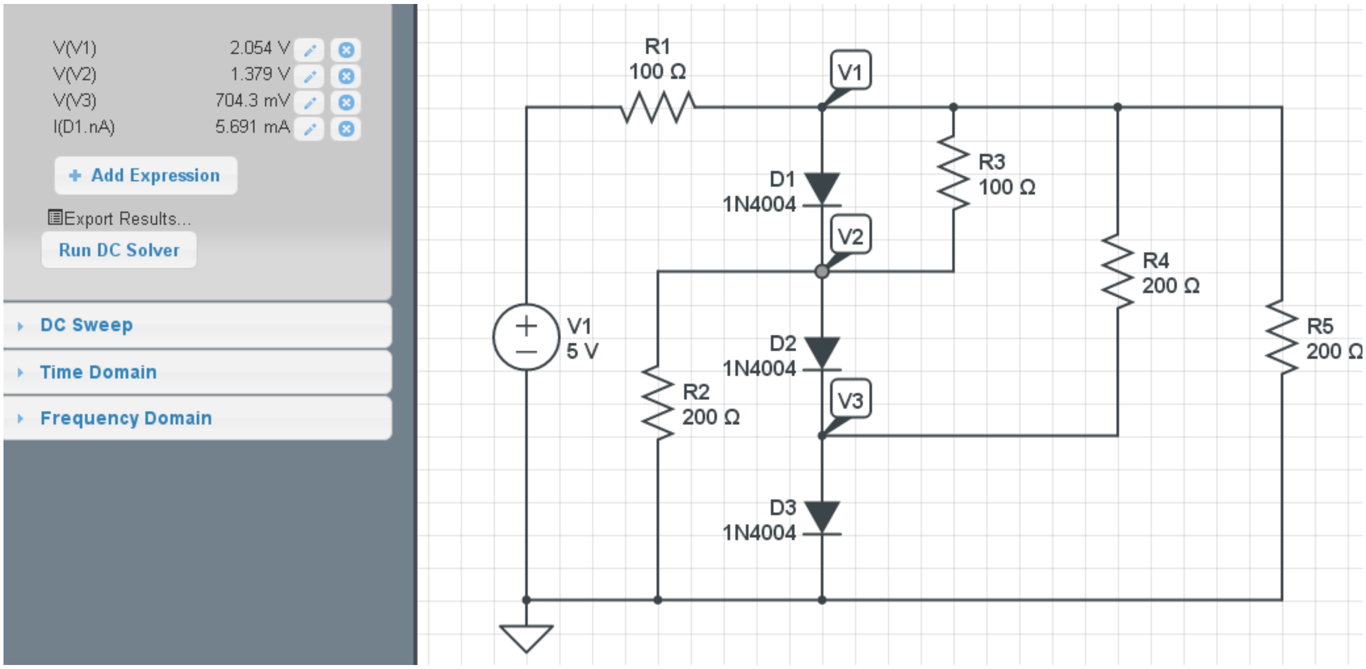
- V1 = 2.1V
- V2 = 1.4V
- V3 = 0.7V

Check: Current is positive

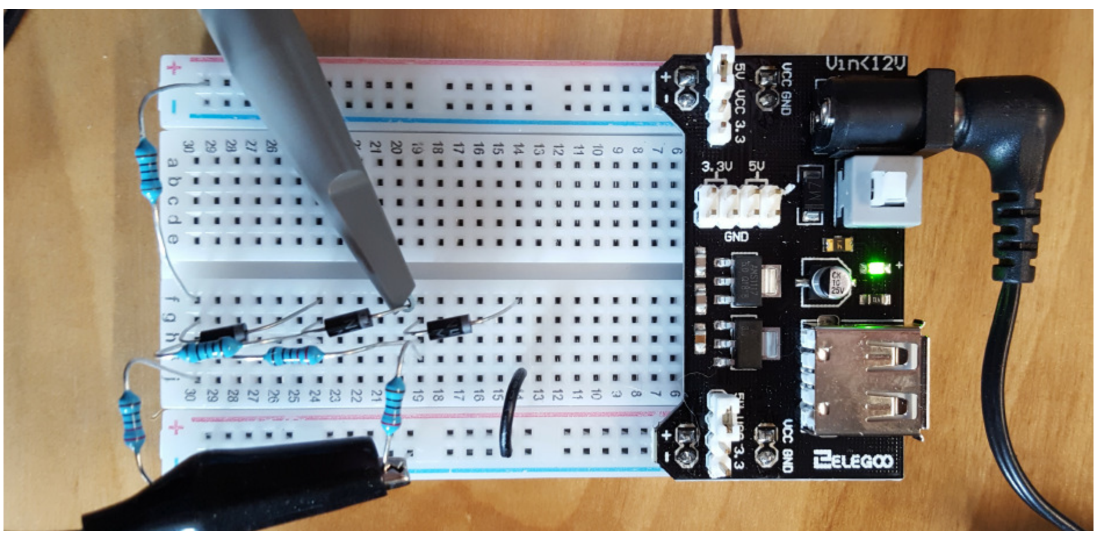
$$\left(\frac{V_1-5}{100}\right) + I_{d1} + \left(\frac{V_1-V_2}{100}\right) + \left(\frac{V_1-V_3}{200}\right) + \left(\frac{V_1}{200}\right) = 0$$

$$I_{d1} = 4.5mA > 0$$

c) CircuitLab Solution



d) Lab (experimental):



	V1	V2	V3
8a) Numeric Solution	2.0892	1.4067	0.7263
8b) Ideal Diode Solution	2.1000 V	1.4000 V	0.7000 V
9) Simulation (CircuitLab)	2.054 V	1.379 V	0.7043 V
10) Lab (experimental)	2.07 V	1.41 V	0.686 V