ECE 320 - Solution to Homework #2

Semiconductors, PN Junction, Diode VI Characteristics. Due Wednesday, September 5th, 2018

Semiconductors

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

As temperature goes up, more and more holes / electron pairs are created due to thermal energy. More charge carriers make the resistance less and less.

2) What doping do you need to make an 0603 resistor have a resistance of 1000 Ohms? The dimensions of an 0603 resistor are

L = 1.6mm, W = 0.8mm, H = 0.45mm

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

$$1000\Omega = \frac{\rho \cdot 0.16cm}{0.08cm \cdot 0.045cm}$$

$$\rho = 22.5\ \Omega \cdot cm$$

$$\sigma = \frac{1}{\rho} = 0.0444\ \frac{1}{\Omega \cdot cm}$$

$$\sigma = nq\mu$$

If doped with Boron (p-type)

$$\sigma = 0.0444 = n_p(1.6x10^{-19}C)(500)\frac{cm^2}{Vs}$$

$$n_p = 5.55 \cdot 10^{14}\ \frac{atoms}{cc}$$

If doped with Phosphorus (n-type)

$$\sigma = 0.0444 = n_n(1.6x10^{-19}C)(1300)\frac{cm^2}{Vs}$$

$$n_n = 2.13 \cdot 10^{14}\ \frac{atoms}{cc}$$

3) A thermistor has the following resistance - voltage relationship

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

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

- -70C (dry ice)
- 0C (freezing point of water)
- 100C (boiling point of water)

At -70C (203K)

$$R = 460k\Omega$$

At 0C (273K)

$$R = 3321\Omega$$

At 100C (373K)

$$R = 71.7\Omega$$

Thermistors are nice: they have a large change with temperature.

PN Junction

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

Answer 1: p to n you are using majority carriers so the resistance is small. n to p you are using minority carriers, so the resistance is large.

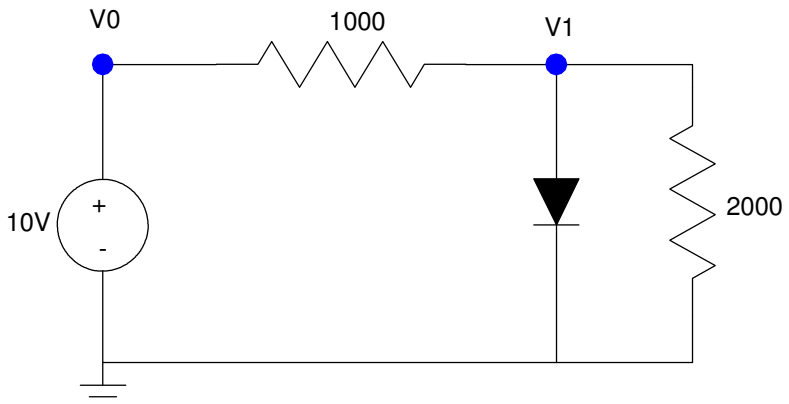
Answer 2: Applying voltage p to n results in the depletion zone be reduced in size. If reduced to zero, current flows. Applying voltage n to p just makes the depletion zone bigger.

Answer 3: If you have enough voltage to overcome the potential energy barrier (0.7V for silicon), current flows. If you don't, current doesn't (it doesn't have enough energy to overcome the potential energy barrier).

Diode VI Characteristics

Assume the VI characteristics for a diode are

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



Problem 5 & 6

5) Write the voltage node equations for the following circuit. Solve for V1

$$I_d = 10^{-8}\left(\exp\left(\frac{V_1}{0.052}\right) - 1\right) \qquad (1)$$

$$\left(\frac{V_1 - 10}{1000}\right) + I_d + \left(\frac{V_1}{1000}\right) = 0 \qquad (2)$$

Using *fminsearch()* in Matlab:

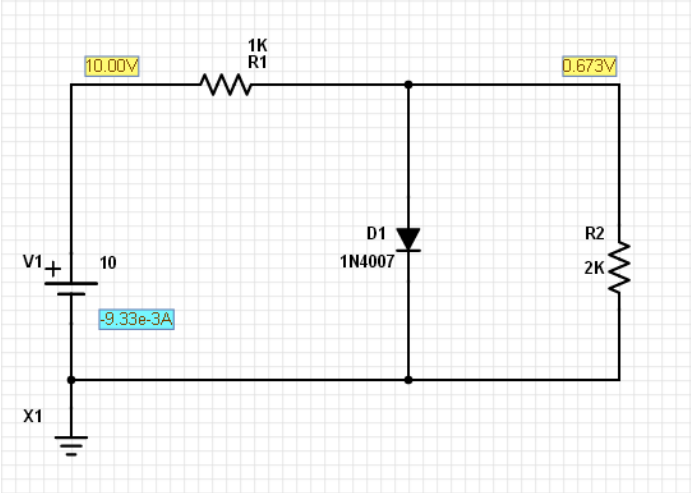
Create a function in Matlab:

```
function [ J ] = cost( z )
    V1 = z(1);
    Id = 1e-8 * exp( V1 / 0.052  -  1);
    e = (V1 - 10) / 1000 + Id + V1 / 2000;
    J = e^2;
    end
```

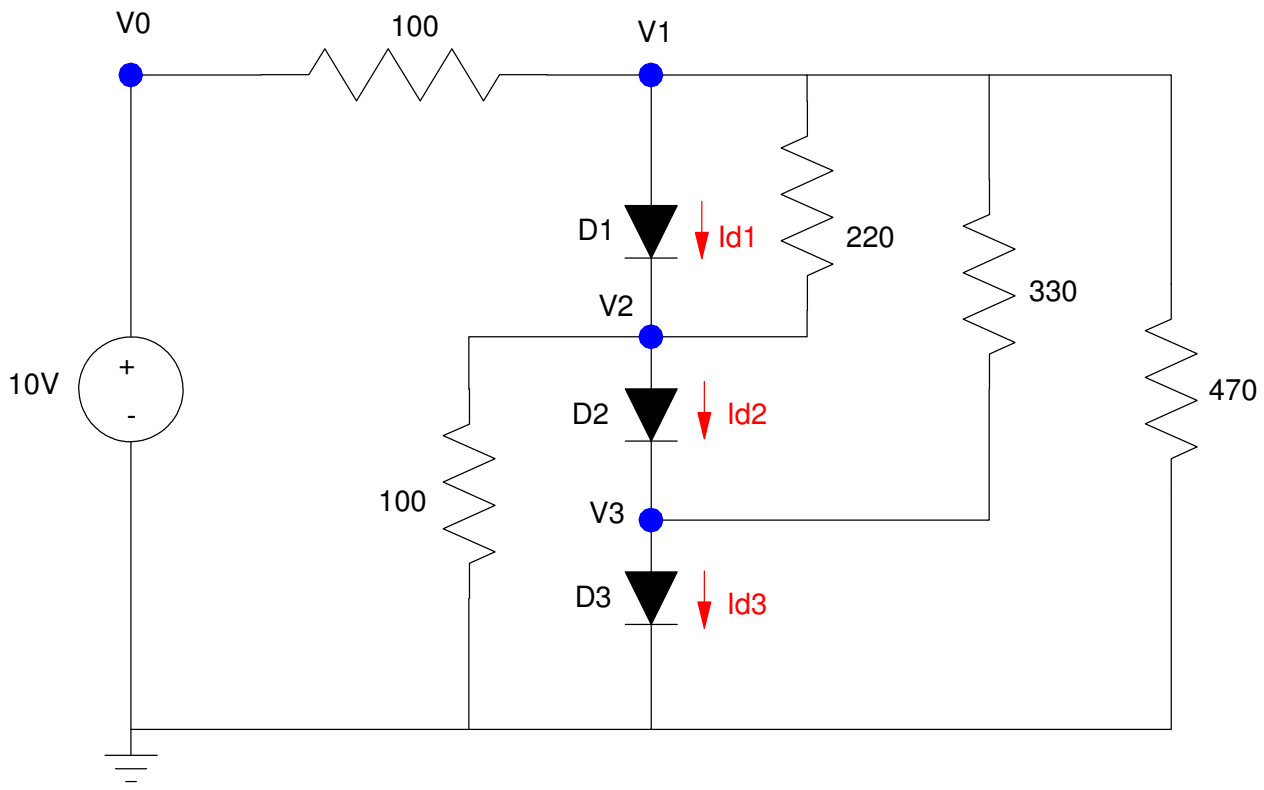
Solve using minesearch:

```
>> [V1, e] = fminsearch('cost',0.7)
V1 =   0.7641
e =  1.6873e-011
```

6) Check your answer in PartSim. (use Fairchild, Rectifier Diode, 1N4007)



Calculation	PartSim	Ideal Diode
0.7641V	0.673V	0.7V



Problem 7, 8, 9

7) Write the voltage node equations for the following circuit. Solve for V1, V2, and V3

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

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

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

$$\left(\frac{V_1 - 10}{100}\right) + I_{d1} + \left(\frac{V_1 - V_2}{220}\right) + \left(\frac{V_1 - V_3}{330}\right) + \left(\frac{V_1}{470}\right) = 0$$

$$-I_{d1} + I_{d2} + \left(\frac{V_2}{100}\right) + \left(\frac{V_2 - V_1}{220}\right) = 0$$

$$-I_{d2} + I_{d3} + \left(\frac{V_3 - V_1}{330}\right) = 0$$

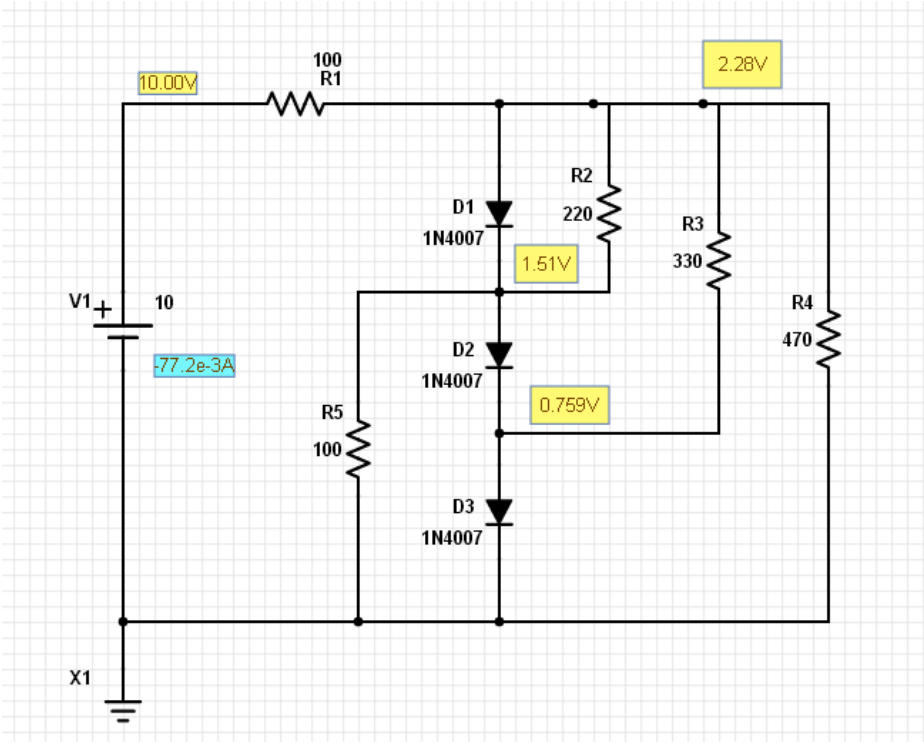
Create a function in Matlab to return the error in these equations

```
function [ J ] = cost( 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);

   e1 = (V1-10)/100 + Id1 + (V1-V2)/220 + (V1-V3)/330 + V1/470;
   e2 = -Id1 + Id2 + V2/100 + (V2-V1)/220;
   e3 = -Id2 + Id3 + (V1-V3)/330;

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

   end
```

Solve usin fminsearch()

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

V =

    2.5588    1.6953    0.8446


e =

  3.1233e-009
```

8) Check your results in PartSim. (use Fairchild, Rectifier Diode, 1N4007)



Lab

9) Build this circuit and measure the voltages V1, V2, and V3. Use a 4004 diode (in room 211)

	V1	V2	V3
Calculations	2.5588	1.6953	0.8446
PartSim	2.28	1.51	0.76
Lab	2.32	1.55	0.78
Ideal Diode	2	1.4	0.7