ECE 320 - Solution to Homework #2

Semiconductors, PN Junction, Diode VI Characteristics. Due Wednesday, September 6th, 2017

Semiconductors

Problem 1) What is the difference between n-type, p-type, and intrinsic silicon?

- **n-type:** The number of electrons is much greater than the number of holes
- **p-type:** The number of holes is much greater than the number of electrons
- **intrinsic:** Undoped silicon. The number of holes is about the same as the number of electrons.

2) An 0805 resistor is made out of silicon with dimensions

- Width & height: 1.25mm x 1.25mm
- Length: 2mm

What does the doping level need to be to make this a 1k resistor using Boron (p-type semiconductor)?

The resistance is

$$R = \left(\frac{\rho L}{A}\right)$$

$$1000\Omega = \left(\frac{\rho(0.2cm)}{(0.125cm)(0.125cm)}\right)$$

$$\rho = 78.125\ \Omega\ cm$$

The conductivity is

$$\sigma = \frac{1}{\rho} = 0.0128\frac{1}{\Omega\ cm}$$

$$\sigma = q \cdot (n_p \mu_p + n_n \mu_n)$$

Since this is doped p-type, the number of electrons is essentially zero

$$\sigma = q \cdot n_p \cdot \mu_p$$

$$0.0128\ \Omega\ cm = (1.6 \cdot 10^{-19} C) \cdot n_p \cdot \left(500\frac{cm^2}{Vs}\right)$$

$$n_p = 1.60 \cdot 10^{14}$$

You need a doping of 1.6e14 Boron atoms / cc

PN Junction

Problem 3) If Vin = +3V, will current flow in the following circuit? Why?

Yes, current will flow.

- You are using majority carriers in the p and n regions, resulting in a low resistance
- Vin is large enough to reduce the deplation zone to zero, allowing current to flow
- Vin is large enough to overcome the potential energy barrier (0.7V for silicon)

Any of these answers are acceptable.

Problem 4) If Vin = -3V, will current flow in the following circuit? Why?

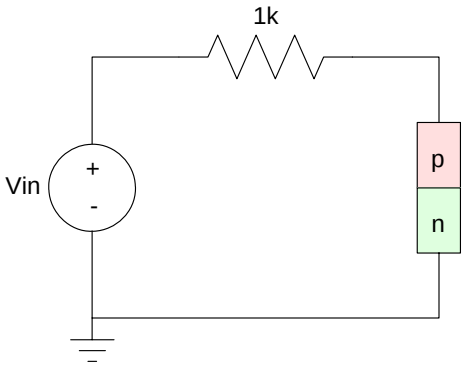
Yes, current will flow but it will be very small

- You are using minority carriers in the p and n regions, resulting in a very high resistance (but not infinite)

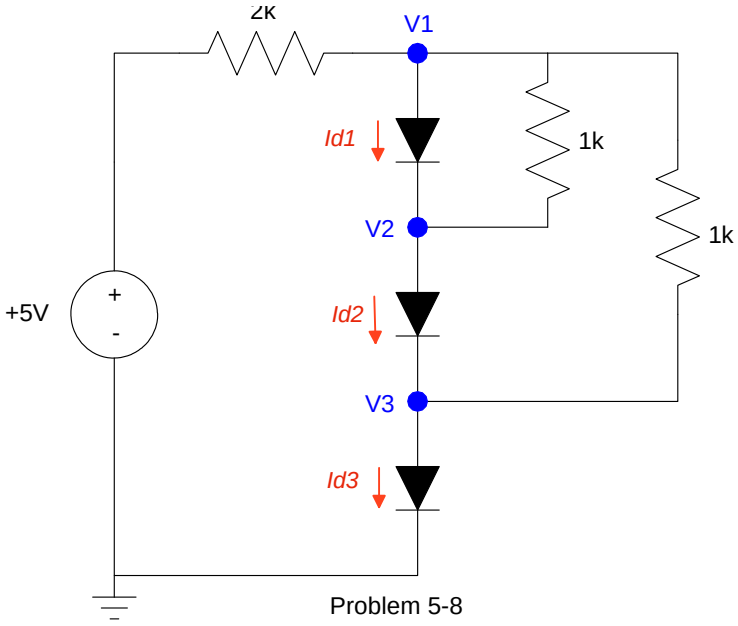
No, current will not flow

- You are using minority carriers in the p and n regions, resulting in a very high resistance
- Vin increases the size of the deplation zone, blocking current flow
- Vin increases the potential energy barrier, blocking current flow

Any of these answers are acceptable.



Problem 3 & 4



Problem 5-8

Diode VI Characteristics

Assume the VI characteristics for a diode are:

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

Problem 5) Write the voltage node equations for the following circuit

Start with the current through each diode

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

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

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

Now write the node equations

$$\left(\frac{V_1 - 5}{2000}\right) + I_{d1} + \left(\frac{V_1 - V_2}{1000}\right) + \left(\frac{V_1 - V_3}{1000}\right) = 0$$

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

$$-I_{d2} + I_{d3} + \left(\frac{V_3 - V_1}{1000}\right) = 0$$

Problem 6) Solve for V1, V2, and V3 (hint: use Matlab and fminsearch())

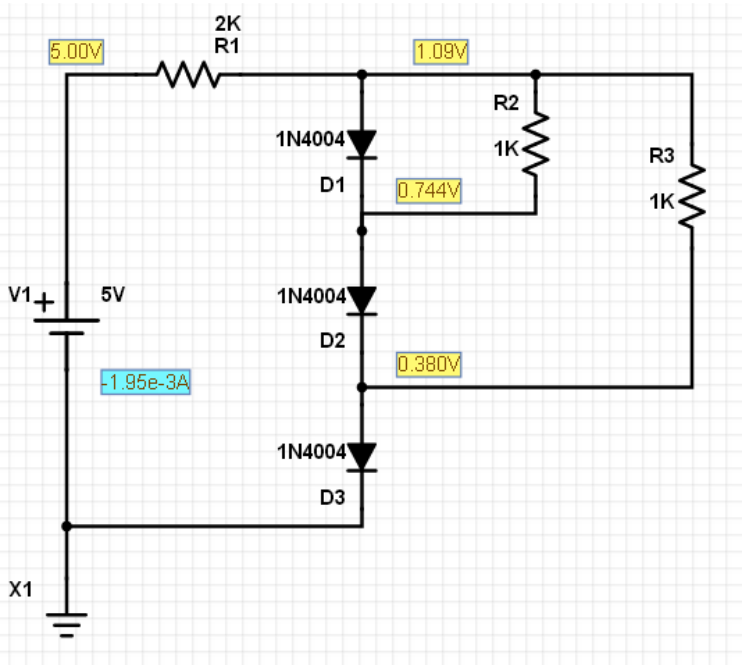
Create an m-file for these equations. Guess V1, V2, V3 and return the sum squared error

```
function [ J ] = diode1( 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 = (V1-5)/2000 + Id1 + (V1-V2)/1000 + (V1-V3)/1000;
   e2 = -Id1 + Id2 + (V2 - V1)/1000;
   e3 = -Id2 + Id3 + (V3 - V1)/1000;

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

end
```

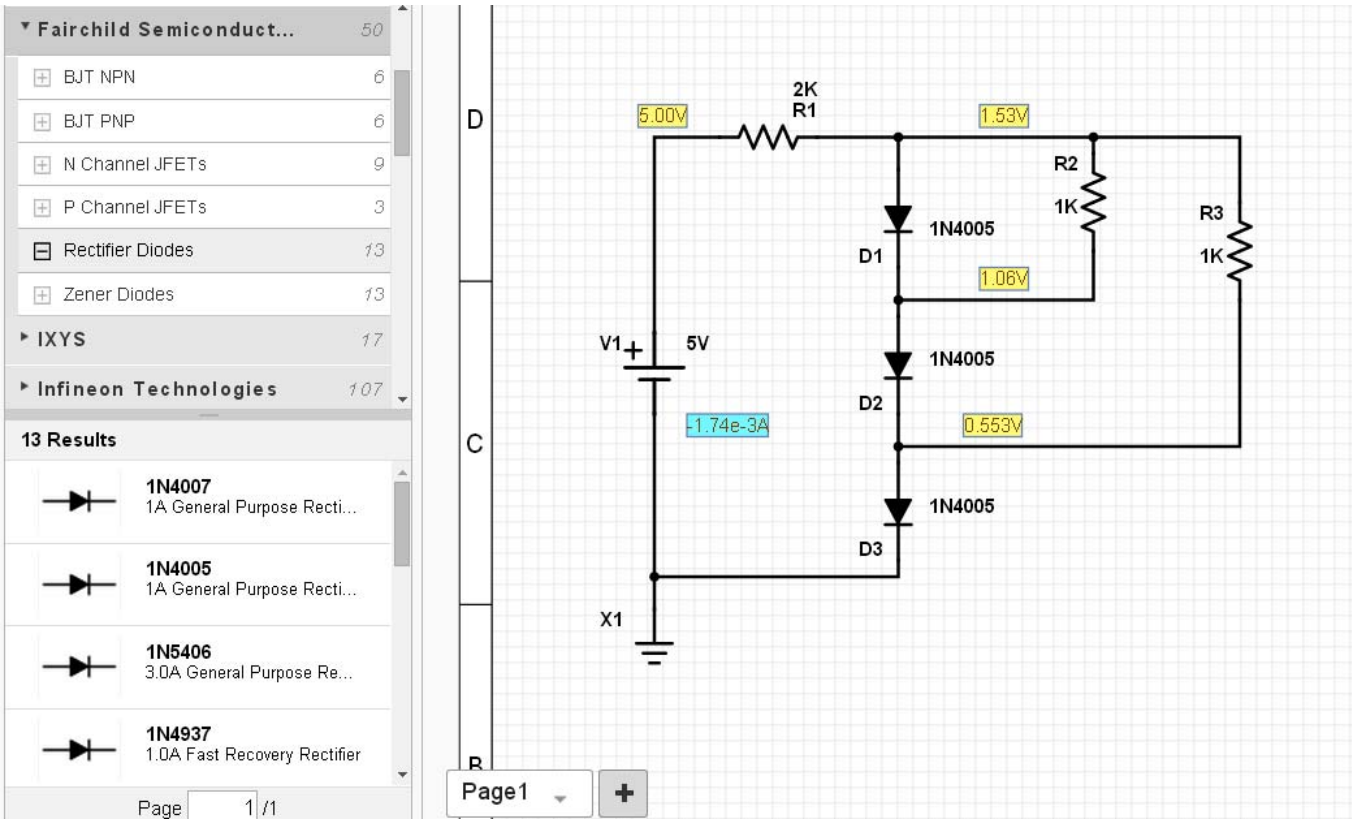
```
>> V = fminsearch('diode1',[3,2,1])

    V1      V2      V3
  1.6831  1.1971  0.6250
```

Problem 7) Check your answers in PartSim (or similar program)

The default diode (1004) is a Germanium diode (0.3V drop)

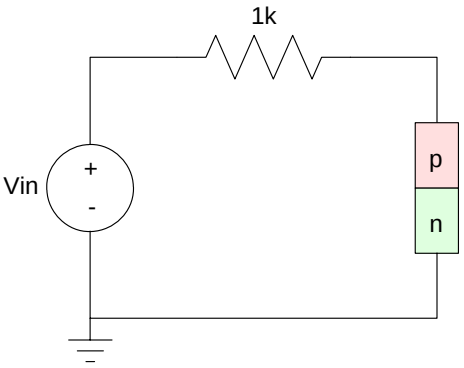


Fairchild 1n4005 is a Silicon diode (about 0.7V drop)

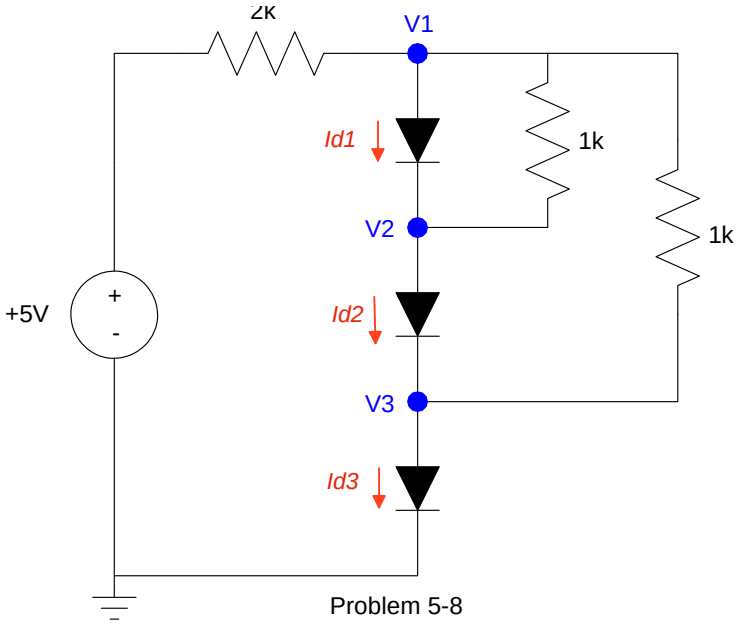


Lab:

Problem 8) Build the diode circuit below and check your calculations



Problem 3 & 4



Problem 5-8

Summary:

	Analysis Matlab - Problem 6	Test PartSim - Problem 7	Validation Lab - Problem 8
V1	1.6831	1.53V	1.46V
V2	1.1971	1.06V	1.00V
V3	0.6250	0.553V	0.52V