ECE 320 - Homework #2

Semiconductors, PN Junction. Due Monday, September 9th

Semiconductors

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

As temperature goes up, you get more thermal electron / hole pairs (i.e. conductors).

As the number of conductors increases, the resistance decreases.

2) What doping of Boron (p-type) do you need to make an 0805 resistor have a resistance of 7500 Ohms? The dimensions of an 0805 resistor are

L = 2.0mm, W = 1.25mm, H = 0.95mm

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

$$7500\Omega = \left(\frac{\rho \cdot 0.2cm}{(0.125cm)(0.095cm)}\right)$$

$$\rho = 445.3125\ \Omega \cdot cm$$

$$\sigma = \frac{1}{\rho} = 0.0022\ \frac{1}{\Omega \cdot cm} = qp\mu_p$$

$$0.0022 = (1.6 \cdot 10^{-19}C)(p)(500)$$

$$\boxed{p = 2.807 \cdot 10^{13}\ \frac{\text{atoms}}{\text{cc}}}$$

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

- +41.1C (hottest day in Fargo - July 1988)
- -37.2C (coldest day in Fargo - January 1977)
- +6.2C (average temperature in Fargo in 2018)

Kelvin = Celsius + 273

- **41.1C: 510.85 Ohms**
- **-37.2C: 31,709 Ohms**
- **+6.2C 2,416.6 Ohms**

Note: One nice feature of thermistors is the high sensitivity: there is a large change in resistance when the temperature changes.

PN Junction

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

Any of the following explanations are OK

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).

5) The voltage across a forward-biased diode is

$$V_d = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

Plot the voltage vs. temperature from -40C to +40C for a diode with doping

$$N_A = N_D = 10^{18}\ \frac{\text{atoms}}{cc}$$

Assume $V_T = 0.052V$

From the lecture notes,

$$n_i^2 = A_o T^3 e^{-E_G'/kT}$$

$$A_0 = 2.51 \cdot 10^{31}$$

$$E_G = 1.2 - 0.00036T \qquad \text{eV}$$

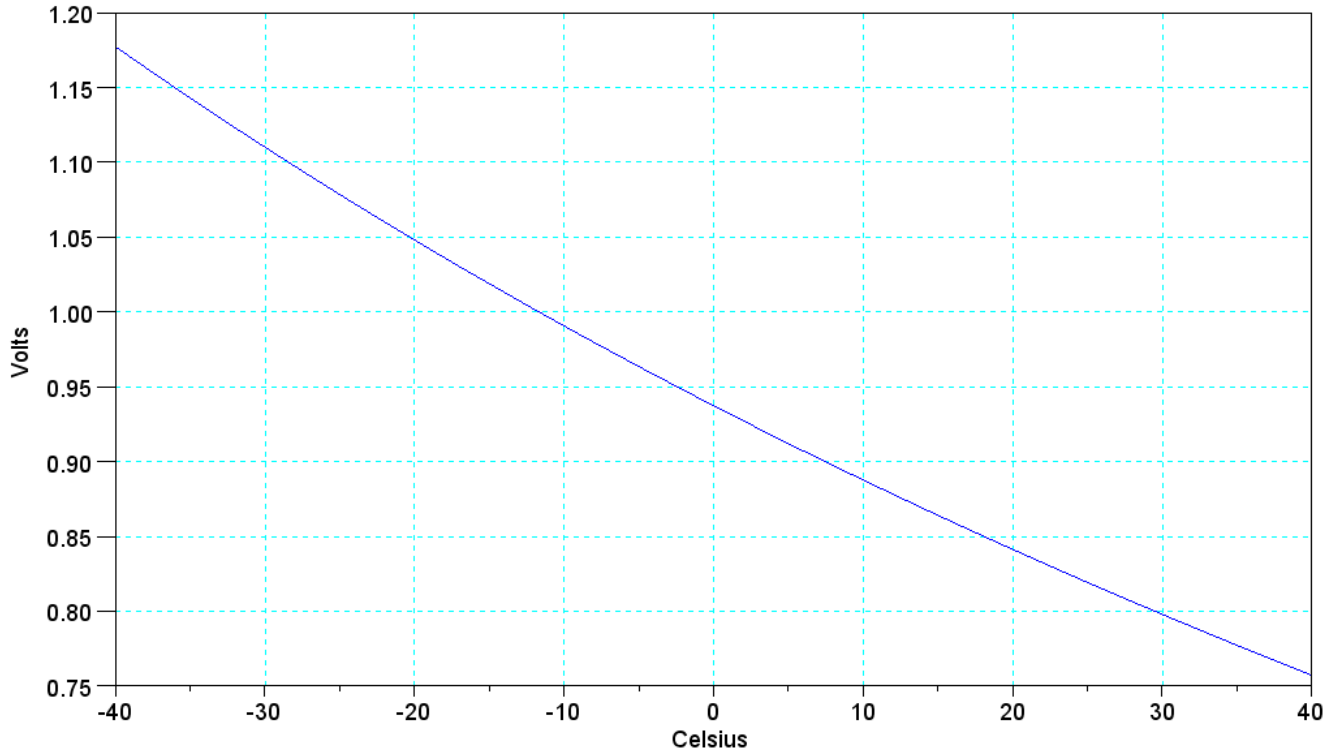
$$k = 8.617343 \times 10^{-5}\ \frac{eV}{K}$$

In Matlab:

```
C = [-40:40]';
T = C + 273;
Ao = 2.36e33;
Eg = 1.2 - 0.00036*T;
k = 8.617343e-5;
ni = sqrt(  Ao * (T.^3) .* exp(-Eg ./ (k*T) ) );
Vt = 0.026;

Vd = Vt * log( Na * Nd ./ (ni .^ 2) );

plot(C, Vd);
xlabel('Celsius');
ylabel('Volts');
```



Voltage across a diode with Na = Nd = 1e18 atoms / cc