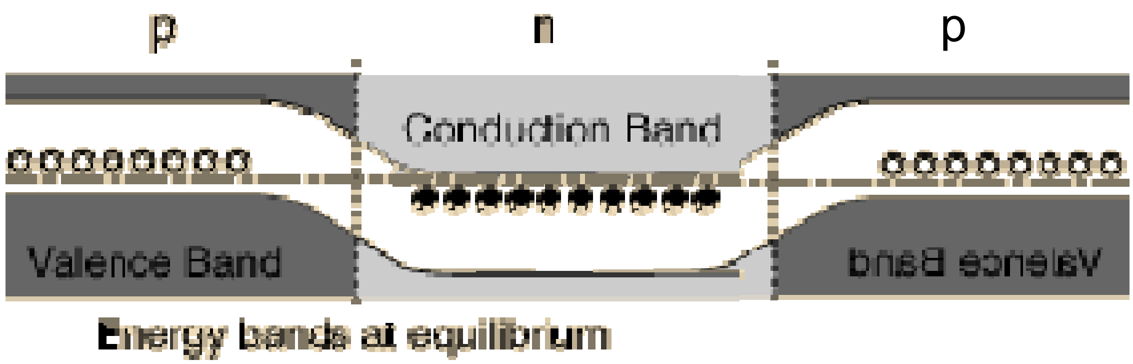
MSE 2002, Spring 2009
Homework Assignment 4, Due at start of class, Thursday, April 9
Answer Key

Solve Questions 18.5, 18.11, 18.21, 18.28, 18.30, 18.49, 18.56
AND solve the following additional questions:

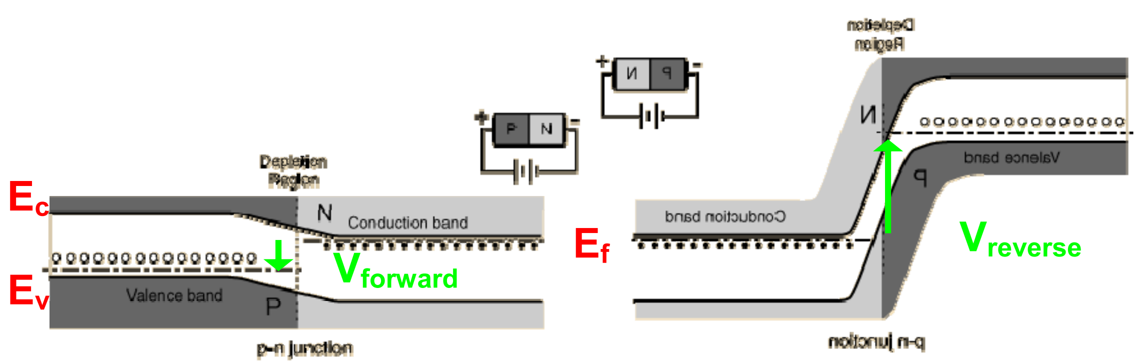
Problem I) Sketch the band diagram for a pnp transistor: **4 pts total**

a) at equilibrium **2 pts.**



b) with a forward bias applied at one edge (the left p-type edge) AND a reverse bias applied at the other edge (the right p-type edge) **2 pts.**

NOTE: As always, include Ec, Ev, and Ef in each diagram. Note the applied voltages as well (they may be equal or not, you choose, but make sure you identify which is which).



Problem II) Calculate the conductivity at 300K for: **4 pts, with 2 pts each for b, & d. a and c are not graded as similar to other questions elsewhere.**

Generally, must use conductivity equation:

$$\sigma = n|e|\mu_e + p|e|\mu_h = n_i|e|(\mu_e + \mu_h) = e^{-E_{gap}/kT}|e|(\mu_e + \mu_h)$$

a) an unspecified insulator with a bandgap of 6 V, an electron mobility of 0.1 m^2/(Volt*s), and a hole mobility of 0.02 m^2/(Volt*s)

*Since this is an insulator, use sigma= ni*e*(mue + muh), where ni is related to the gap energy/kT such that ni=exp(-Eg/kT).*

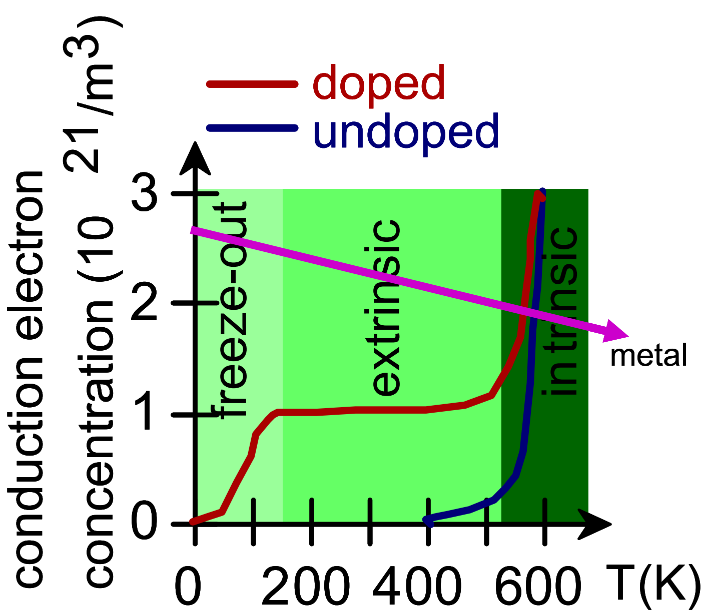
b) a Si wafer doped with 10^{24} Al atoms/m^3, (you may assume they are all ionized if you wish), a bandgap of 3 V, and conveniently the same electron and hole mobilities as the insulator in part a.

*Use sigma=p*e*muh. Thus, sigma is 3.2E3 per (Ohm*m) if units are accounted for correctly.*

c) a metal with 10^{29} e/m^3 and an electron mobility of 0.001 m^2/(Volt*s)

*Use sigma=n*e*mue. Thus, sigma is 1.6E7 per (Ohm*m).*

d) ALSO, sketch a plot of the relative conductivity for each of these samples as a function of temperature, all on the same graph (i.e. approximately which are greater at what temperatures)?



5) Not graded, but answers shown below.

18.5 (a) In order to compute the resistance of this aluminum wire it is necessary to employ Equations 18.2 and 18.4. Solving for the resistance in terms of the conductivity,

$$R = \frac{\rho l}{A} = \frac{l}{\sigma A} = \frac{l}{\sigma \pi \left(\frac{d}{2}\right)^2}$$

From Table 18.1, the conductivity of aluminum is 3.8 x 10^7 $(\Omega\text{-m})^{-1}$, and

$$R = \frac{l}{\sigma \pi \left(\frac{d}{2}\right)^2} = \frac{5 \text{ m}}{\left[3.8 \times 10^7 \ (\Omega - \text{m})^{-1}\right](\pi)\left(\frac{5 \times 10^{-3} \text{ m}}{2}\right)^2}$$

$$= 6.7 \times 10^{-3} \ \Omega$$

(b) If V = 0.04 V then, from Equation 18.1

$$I = \frac{V}{R} = \frac{0.04 \text{ V}}{6.7 \times 10^{-3} \ \Omega} = 6.0 \text{ A}$$

(c) The current density is just

$$J = \frac{I}{A} = \frac{I}{\pi \left(\frac{d}{2}\right)^2} = \frac{6.0 \text{ A}}{\pi \left(\frac{5 \times 10^{-3} \text{ m}}{2}\right)^2} = 3.06 \times 10^5 \text{ A/m}^2$$

(d) The electric field is just

$$E = \frac{V}{l} = \frac{0.04 \text{ V}}{5 \text{ m}} = 8.0 \times 10^{-3} \text{ V/m}$$

11) 4 points total. A) 1 pt for eq and 1 pt for value. B) 1 pt for density value (equation is from last term). C) 1 point for final value.

18.11 (a) The number of free electrons per cubic meter for aluminum at room temperature may be computed using Equation 18.8 as

$$n = \frac{\sigma}{|e|\,\mu_e}$$

$$= \frac{3.8 \text{ x } 10^7\ (\Omega - \text{m})^{-1}}{(1.602 \text{ x } 10^{-19}\ \text{C})(0.0012\ \text{m}^2/\text{V-s})}$$

$$= 1.98 \text{ x } 10^{29}\ \text{m}^{-3}$$

(b) In order to calculate the number of free electrons per aluminum atom, we must first determine the number of copper atoms per cubic meter, N_{Al}. From Equation 4.2 (and using the atomic weight and density values for Al found inside the front cover—viz. 26.98 g/mol and 2.71 g/cm^3)

$$N_{\text{Al}} = \frac{N_{\text{A}}\,\rho'}{A_{\text{Al}}}$$

$$= \frac{(6.023 \text{ x } 10^{23}\ \text{atoms/mol})(2.71\ \text{g/cm}^3)(10^6\ \text{cm}^3/\text{m}^3)}{26.98\ \text{g/mol}}$$

$$= 6.03 \text{ x } 10^{28}\ \text{m}^{-3}$$

(*Note*: in the above expression, density is represented by ρ' in order to avoid confusion with resistivity which is designated by ρ.) And, finally, the number of free electrons per aluminum atom is just n/N_{Al}

$$\frac{n}{N_{\text{Al}}} = \frac{1.98 \text{ x } 10^{29}\ \text{m}^{-3}}{6.03 \text{ x } 10^{28}\ \text{m}^{-3}} = 3.28$$

21) Not graded.

18.21 In this problem we are asked to compute the intrinsic carrier concentration for PbS at room temperature. Since the conductivity and both electron and hole mobilities are provided in the problem statement, all we need do is solve for n and p (i.e., n_i) using Equation 18.15. Thus,

$$n_i = \frac{\sigma}{|e|(\mu_e + \mu_h)}$$

$$= \frac{25\ (\Omega\text{ - m})^{-1}}{(1.602\ \text{x}\ 10^{-19}\ \text{C})(0.06\ +\ 0.02)\ \ \text{m}^2/\text{V - s}}$$

$$= 1.95\ \text{x}\ 10^{21}\ \text{m}^{-3}$$

28) 5 points total, 1 each.

18.28 Nitrogen will act as a donor in Si. Since it (N) is from group VA of the periodic table (Figure 2.6), and an N atom has one more valence electron than an Si atom.

Boron will act as an acceptor in Ge. Since it (B) is from group IIIA of the periodic table, a B atom has one less valence electron than a Ge atom.

Sulfur will act as a donor in InSb. Since S is from group VIA of the periodic table, it will substitute for Sb; also, an S atom has one more valence electron than an Sb atom.

Indium will act as a donor in CdS. Since In is from group IIIA of the periodic table, it will substitute for Cd; and, an In atom has one more valence electron than a Cd atom.

Arsenic will act as an acceptor in ZnTe. Since As is from group VA of the periodic table, it will substitute for Te; furthermore, an As atom has one less valence electron than a Te atom.

30) not graded (similar to additional problem II)

18.30 (a) This germanium material to which has been added 10^{24} m^{-3} As atoms is *n*-type since As is a donor in Ge. (Arsenic is from group VA of the periodic table--Ge is from group IVA.)

(b) Since this material is *n*-type extrinsic, Equation 18.16 is valid. Furthermore, each As atom will donate a single electron, or the electron concentration is equal to the As concentration since all of the As atoms are ionized at room temperature; that is $n = 10^{24}$ m^{-3}, and, as given in the problem statement, $\mu_e = 0.1$ m^2/V-s. Thus

$$\sigma = n|e|\mu_e$$

$$= (10^{24}\ \text{m}^{-3})(1.602\ \text{x}\ 10^{-19}\ \text{C})(0.1\ \text{m}^2/\text{V-s})$$

$$= 1.6\ \text{x}\ 10^{4}\ (\Omega\text{-m})^{-1}$$

49) 2 points total. 1 pt for eq, and 1 pt for value.

18.49 We want to compute the plate spacing of a parallel-plate capacitor as the dielectric constant is increased form 2.2 to 3.7, while maintaining the capacitance constant. Combining Equations 18.26 and 18.27 yields

$$C = \frac{\varepsilon_r \varepsilon_0 A}{l}$$

Now, let us use the subscripts 1 and 2 to denote the initial and final states, respectively. Since $C_1 = C_2$, then

$$\frac{\varepsilon_{r1}\varepsilon_0 A}{l_1} = \frac{\varepsilon_{r2}\varepsilon_0 A}{l_2}$$

And, solving for l_2

$$l_2 = \frac{\varepsilon_{r2} l_1}{\varepsilon_{r1}} = \frac{(3.7)(2\ \text{mm})}{2.2} = 3.36\ \text{mm}$$

56) 4 points total. A) Not graded. B) 1 pt for each of the 4 questions.

18.56 (a) For electronic polarization, the electric field causes a net displacement of the center of the negatively charged electron cloud relative to the positive nucleus. With ionic polarization, the cations and anions are displaced in opposite directions as a result of the application of an electric field. Orientation polarization is found in substances that possess permanent dipole moments; these dipole moments become aligned in the direction of the electric field.

(b) Only electronic polarization is to be found in gaseous argon; being an inert gas, its atoms will not be ionized nor possess permanent dipole moments.

Both electronic and ionic polarizations will be found in solid LiF, since it is strongly ionic. In all probability, no permanent dipole moments will be found in this material.

Both electronic and orientation polarizations are found in liquid H_2O. The H_2O molecules have permanent dipole moments that are easily oriented in the liquid state.

Only electronic polarization is to be found in solid Si; this material does not have molecules with permanent dipole moments, nor is it an ionic material.