EMSE314--Fall 2003--Homework 5--Name: ___________________

Issued: Nov. 03, Due: Nov. 10

Explain how answers were obtained. Give appropriate units for all numerical answers.

Problem 1—"Metal-metal contact" (10 pts)

Between two metals in electrical contact, a thin layer of metal oxide sometimes forms. If the layer is about 5nm thick, it is insulating to small voltage (<~1V). Conduction will occur across the oxide (without damaging or otherwise altering the oxide layer) if the voltage is higher (>~2V) or if the oxide is thinner (~1nm).

a). Identify the quantum mechanical phenomenon that is responsible for these effects.

b). Explain the importance of the applied voltage and the thickness of the oxide in this phenomenon.

Problem 2— "temperature dependence of conductivity" (15 pts)

An *n*-type Si sample has been doped with 10^{15} phosphorus atoms/cm^3. The donor energy level for P in Si is 0.045 eV below the conduction band edge energy.

a). Calculate the room temperature conductivity of the sample.

b). Estimate the temperature above which the sample behaves as if intrinsic.

c). Estimate to within 20% the lowest temperature above which all the donors are ionized.

d). Sketch schematically the dependence of the electron concentration in the conduction band on the temperature as ***log(n)*** versus ***1/T***, and mark the various important regions and critical temperatures. For each region draw an energy band diagram that clearly shows from where the electrons are excited into the conduction band.

e). Sketch schematically the dependence of the conductivity on the temperature as ***log(σ)*** versus ***1/T*** and mark the various critical temperatures and other relevant information.

Problem 3—"Schottky & ohmic contact" (13 pts)

Consider an n-type Si sample doped with 10^6 donors/cm^3. The length L is 100 μm; the cross-section area A is 10 $\mu m \times 10$ μm. The two ends of the sample are labeled as B and C. The electron affinity (χ) of Si is 4.01 eV and work function Φ of four potential metals for contacts at B and C are list in the following table.

Work function in eV			
Cs	**Li**	**Al**	**Au**
1.8	2.5	4.25	5.1

a). Ideally, which metals will result in a Schottky contact?

b). Ideally, which metals will result in an ohmic contact?

c). Sketch the *I-V* characteristics when both B and C are ohmic contacts.
What is the relationship between *I* and *V*?

d). Sketch the *I-V* characteristics when B is ohmic and C is a Schottky junction.
What is the relationship between *I* and *V*?

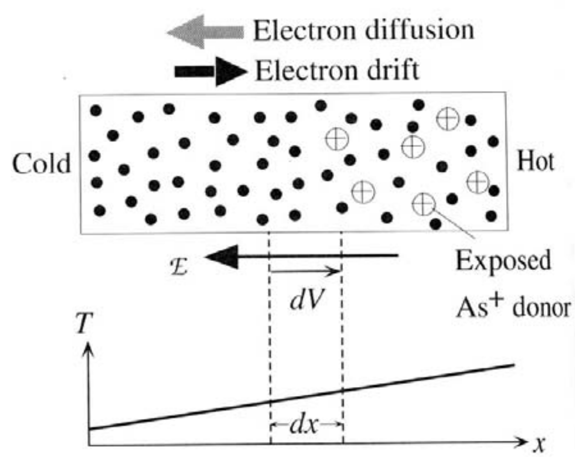
e). Sketch the *I-V* characteristics when both B and C are Schottky contacts.
What is the relationship between *I* and *V*?

Problem 4—"thermal drift in semiconductor devices" (12 pts)

Consider an *n*-type semiconductor that has a temperature gradient across it. The right end is hot and the left end is cold, as depicted in *Figure HW5-4*. There are more energetic electrons in the hot region than in the cold region. Consequently, electron diffusion occurs from hot to cold regions, which immediately exposes positively charged donors in the hot region and therefore builds up an internal field and a built-in voltage, as shown in *Figure HW5-4*. Eventually an equilibrium is reached when the diffusion of electrons is balanced by their drift driven by the built-in field. The net current must be zero. The Seebeck coefficient (or thermoelectric power) S measures this effect in terms of the voltage developed as a result of an applied temperature gradient as

$$S = \frac{dV}{dT}$$

Figure HW5-4 In the presence of a temperature gradient, there is an internal field and a voltage difference.
The Seebeck coefficient is defined as dV/dT, the potential difference per unit temperature difference.



a). How is the Seebeck effect in a *p*-type semiconductor different than that for an *n*-type semiconductor when both are placed in the same temperature gradient in *Figure HW5-4*? Recall that the sign of the Seebeck coefficient is the polarity of the voltage at the cold end with respect to the hot end (see Section 4.8.2 in the textbook)

b). Given that for an n-type semiconductor,

$$S_n = -\frac{k}{e}\left[2 + \frac{(E_c - E_F)}{kT}\right] \qquad \textit{Seebeck coefficient for } n-\textit{type semiconductor}$$

what are typical magnitudes for S_n in Si doped with 10^{14} and 10^{16} donors cm^{-3}? What is the significance of S_n at the semiconductor device level?