489 Spring 2004 Homework 9

Due Monday, April 26, 2004

1. The compound InSb has parameters given in the text and a dielectric constant of 18. From this calculate (a) the donor binding energy, (b) donor state radius, and (c) an estimate of the concentration of donors above which the semiconductor becomes metallic, i.e., the added electrons have a finite conductivity at T=0.

2. A & M Problem 28-4. In your solution you may use the results of problem 5 in Set 1, which is equivalent to parts (a) and (b). Note that the difference from the simple Fermi distribution is due to the electron electron interactions which can be very important in defect states in semiconductors.

3. A p-n junction in equilibrium has a charge distribution in the depletion region as shown:

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                  - - -   + + +
                  - - -   + + +
         neutral  - - -   + + +  neutral
                  - - -   + + +
                  - - -   + + +

      p - type      depletion       n - type
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   The density of acceptors in the p side is N_A and the density of donors on the n side is N_D and the thickness of the depletion regions are d_n and d_p.
   (a) If $N_D = N_A = 10^{17} cm^{-3}$ find the total thickness of the depletion region $d = d_n + d_p$ for a junction in silicon. Assume a Si band gap and that the dopings are high enough that the valence band edge is near μ in the p region and the conduction band edge is near μ in the n region.
   (b) Find the thickness $d = d_n + d_p$ if a reverse bias voltage of 5.0 volts is applied.

4. Quantum wells can now be made with essentially arbitrary variation of the band edge with position, e.g., by gradual variations of the composition of the alloy (GaAl)As. One of the structures that has been made is a layer of very large extent in the x and y directions and has band edge which varies quadratically with position z, so that a conduction electron acts as if it is in a potential $V(z) = V_0 + Az^2$.
   (a) Find the quantized energies in this quantum well in terms of A and any other needed constants and parameters. (You may use the approximation that

the quadratic variation holds for all z, although this is clearly not correct since the maximum variation if from pure GaAs to pure AlAs.) Also assume the effective mass is that of an electron in GaAs, 0.066 me (given in Kittel).
(b) Evaluate the density of states for each sub-band in states per eV per unit area. (c) Draw a diagram of the density of states per unit energy per unit area as a function of energy over an energy range that includes several sub-bands. (d) In reality the potential V(z) saturates at a maximum value instead of increasing indefinitely as in our idealized potential $V(z) = V_0 + Az^2$. Without carrying out any calculations argue whether the quantized energy levels in the realistic potential are higher or lower than those calculated above for the idealized potential.

Suggested extra problems: DO NOT TURN IN.

1. An expression for the Hall constant of carriers in two bands is given by Eq. (12.73). The Hall effect is very useful in semiconductors, where the two bands often denote electrons of density n in the conduction band and holes of density p in the valence band. Using the fact that the magnetic field term in (12.73) is small if the resistance is high, show that (12.73) reduces to the simpler expression (which is given by Kittel (see problem 8-3)):

   $R_H = (1/ec)\frac{(p-n(\mu_e/\mu_h)^2)}{(p+n((\mu_e/\mu_h))^2}$

   where μ_e and μ_h are the electron and hole mobilities.

   Note on this problem: In Chapt. 12, A & M emphasize that if the carriers are in only one band and the H field is in the high field limit, the Hall effect measures the effective number of carriers independent of the scattering times τ. Here we have an illustration of the fact that in general we are not in the high limit and the carriers are from more than one band so that the Hall coefficient depends upon the τ's, i.e., the μ's. Only in the limit where one carrier dominates the conductivity is the Hall coefficient directly related to the density of that type of carrier.

2. Draw the energy diagram for the conduction and valence band edges in an n-p-n transistor as a function of position along a line perpendicular to the plane of the junctions for two cases: (a) in equilibrium and (b) with a voltage applied. Understand whether holes or electrons are being injected into the base region and in which direction is their motion in the applied voltage.