Homework #2 - EE 482

due 1/18/11 (Tuesday due to MLK holiday)

1. Sketch the Fermi-Dirac distribution and appropriate forms of the Maxwell-Boltzmann approximation versus energy on a common set of axes. How far must the energy be above the Fermi level at 300K for the appropriate M-B approximation to result in an error of less than 3% in the occupation probability? How far below? Repeat for probability of being empty (1-p_{occ}).

2. The outer occupied energy band in a crystal with N atoms per unit volume is described by

$$E = E_0 + \frac{\hbar^2(k-k_0)^2}{2m^*}$$

and the band contains one electron per atom.

   (a) Is this material an insulator, a metal or a semiconductor? Explain.

   (b) Give an expression for $E_f - E_0$ at 0K in terms of m^*? (Hint the Fermi-Dirac distribution has a particularly simple form at 0K).

3. Find the equilibrium electron and hole concentrations and the location of the Fermi level for **germanium** at 27°C if the germanium contains the following concentrations of shallow dopant atoms:

   (a) $5 \times 10^{16}\,\mathrm{cm}^{-3}$ phosphorus atoms.

   (b) $10^{18}\,\mathrm{cm}^{-3}$ boron atoms and $5 \times 10^{17}\,\mathrm{cm}^{-3}$ phosphorus atoms.

   Calculate the resistivity for these two samples.

4. (a) Express the Fermi level relative to the intrinsic Fermi level as a function of doping, temperature and intrinsic carrier concentration in a n^- (lightly-doped n-type) semiconductor if n_i cannot be neglected relative to $N_d - N_a$.

   (b) If a silicon wafer is doped with $N_d = 10^{18}\,\mathrm{cm}^{-3}$ of arsenic atoms, calculate the position of the Fermi level E_f and carrier concentrations at 750°C. Note: You can get n_i vs. T from plot in the notes. Alternatively, to use equation, N_c and N_v vary with temperature so use N_c, N_v proportional to $T^{\frac{3}{2}}$ and account for the change in band-gap with temperature.

5. A silicon wafer is doped with $10^{17}\mathrm{cm}^{-3}$ of manganese, which has a donor level 0.53eV below the conduction band. ($E_g = 1.12\mathrm{eV}$)

   (a) Determine the Fermi level relative to the conduction band and the carrier concentrations in this sample at 300K.

   (b) Repeat for a sample with $10^{17}\mathrm{cm}^{-3}$ of manganese and $2 \times 10^{17}\mathrm{cm}^{-3}$ of arsenic.

   (c) Repeat for a sample with $10^{17}\mathrm{cm}^{-3}$ of manganese and $2 \times 10^{17}\mathrm{cm}^{-3}$ of boron.