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) \(5 \times 10^{16}\) cm\(^{-3}\) phosphorus atoms.
(b) \(10^{18}\) cm\(^{-3}\) boron atoms and \(5 \times 10^{17}\) 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 \(N_d = 10^{18}\) 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 \(T^{3/2}\) and account for the change in band-gap with temperature.

5. A silicon wafer is doped with \(10^{17}\) cm\(^{-3}\) of manganese, which has a donor level 0.53eV below the conduction band. (\(E_g = 1.12\)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 \(10^{17}\) cm\(^{-3}\) of manganese and \(2 \times 10^{17}\) cm\(^{-3}\) of arsenic.
(c) Repeat for a sample with \(10^{17}\) cm\(^{-3}\) of manganese and \(2 \times 10^{17}\) cm\(^{-3}\) of boron.