Homework #2 - EE 482

due 10/16/02

1. 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.

2. (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.

3. The occupation probability of an donor energy level is given by

$$f(E_d) = \left(1 + \frac{1}{2}\exp\frac{E_d - E_f}{kT}\right)^{-1}.$$

   (a) Using the Boltzmann approximation for the conduction band occupation, show that the fraction of ionized impurities depends on temperature according to

$$\frac{n}{N_d} = \frac{\left\{-\frac{N_c}{N_d} + \left[\left(\frac{N_c}{N_d}\right)^2 + 8\frac{N_c}{N_d}\exp\frac{E_c - E_d}{kT}\right]^{1/2}\right\}}{\left(4\exp\frac{E_c - E_d}{kT}\right)}.$$

   (b) Sketch n/N_d as a function of $(E_c - E_d)/kT$ for $N_c/N_d = 10^2$.

   (c) For $N_d = 10^{16}\mathrm{cm}^{-3}$ of phosphorus in silicon ($E_c - E_d = 0.045\,\mathrm{eV}$), what percentage of impurity ions are ionized at 50K and 300K?

   (d) If $N_d = 10^{18}\mathrm{cm}^{-3}$, what percentage of phosphorus ions are ionized at 50K and 300K? Comment on the difference between the answers in (c) and (d).

4. Problem 4.58 in text (page 152). Assume that the density of defects is $10^{16}\mathrm{cm}^{-3}$.