UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Electrical Engineering and Computer Sciences

EE 130 / EE 230A — Prof. Liu
Spring 2013

Homework Assignment #2

Due at the beginning of class on Thursday, 9/12/13

Problem 1: Semiconductor doping

a) Explain why boron (B) is preferred over indium (In) as the dopant species to achieve highly conductive p-type silicon.
b) At very high temperatures (*e.g.* >1000^{o}C), the conductivity of silicon is not significantly affected by moderate doping (N_A or N_D less than 10^{18}/cm^3), *i.e.* it is an intrinsic semiconductor. Explain why this is the case.

Problem 2: Electron and hole concentrations

Calculate the electron density (n) and hole density (p) in the following samples:

a) Silicon doped with 10^{15} cm^{-3} boron atoms, at room temperature (T = 300 K).
b) Silicon doped with 10^{15} cm^{-3} boron atoms and 10^{17} cm^{-3} arsenic atoms, at room temperature.
c) Silicon doped with 10^{15} cm^{-3} boron atoms and 10^{17} cm^{-3} arsenic atoms, at T = 1000 K.

Problem 3: Carrier distributions

The "density of states" describes the energy distribution of states (number of states per unit volume per unit energy) within a band. For energies close to the band edges E_c and E_v, the density of states at an energy E in the conduction band and valence band of Si are given by $g_c(E)$ and $g_v(E)$, respectively:

$$g_c(E) = \frac{m_n^* \sqrt{2m_n^*(E - E_c)}}{\pi^2 \hbar^3} \qquad \text{for } E \geq E_c$$

$$g_v(E) = \frac{m_p^* \sqrt{2m_p^*(E_v - E)}}{\pi^2 \hbar^3} \qquad \text{for } E \leq E_v$$

where m_n* and m_p* are the density of states effective mass for electrons and holes, respectively. (m_n*=1.08m_o and m_p*=0.81m_o for Si at 300K.) In thermal equilibrium, the probability that a state at energy E is occupied is given by the Fermi function:

$$f(E) = \frac{1}{1 + e^{(E - E_F)/kT}}$$

where E_F is the Fermi level. Thus, the distribution of electrons within the conduction band is given by $n(E)=f(E)\times g_c(E)$, and the distribution of holes within the valence band is given by $p(E)=[1-f(E)]\times g_v(E)$. Consider a Si sample in thermal equilibrium at T = 300K, with E_F located 3kT below E_c:

a) Compute and plot n(E). At what energy (relative to E_c) does $n(E)$ exhibit a peak?
b) Show qualitatively (with a simple sketch) how $n(E)$ changes with increasing temperature. You may assume that $g_c(E)$ does not change with temperature.

Problem 4: Energy band diagram

Consider a Si sample maintained under equilibrium conditions, doped with Phosphorus to a concentration 10^{16} cm^{-3}:

a) For T = 300K, draw the energy band diagram for this sample, indicating the values of ($E_c - E_F$) and ($E_F - E_i$) to within 0.01 eV.
b) For T = 600K, draw the energy band diagram for this sample, indicating the values of ($E_c - E_F$) and ($E_F - E_i$) to within 0.01 eV. Remember that N_c and N_v are temperature dependent. Also, E_G is dependent on temperature: for silicon, $E_G = 1.205 - 2.8\times10^{-4}(T)$ for T > 300K.
Provide a qualitative explanation for the relative shift in Fermi level.