Homework 2: Introduction to Semiconductors (II)

(Due on 03/29 in Class)

1. (Average kinetic energy of electrons at conduction band) (30pts)
   (a) Establish a general expression (involving integrals) for the average kinetic energy, \(<K.E.>\), of the conduction band electrons in a semiconductor. (15 pts)
   (b) Taking the semiconductor to be nondegenerate, simplify your general \(<K.E.>\) expression to obtain a closed-form result. (15 pts)

   Hint:
   \[
   \frac{1}{2} \int_0^\infty \frac{\kappa^{3/2}}{1 + \exp(\kappa - \kappa_c)} d\kappa \approx e^{\kappa_c} \quad \text{if} \quad \kappa_c \leq -3 \quad \text{or} \quad E_C - E_F \geq 3kT
   \]

2. (Carriers in compensational doping) (30 pts)
   For a semiconductor piece with both \(N_D=10^{16}\) cm\(^{-3}\) and \(N_A=10^{15}\) cm\(^{-3}\) everywhere in equilibrium, we have \(n_i=1.5\times10^{10}\) cm\(^{-3}\) at \(T=300K\). The approximate electron mobility \(\mu_n=1000\) cm\(^2\)/Vs and hole mobility \(\mu_p=400\) cm\(^2\)/Vs in the low-doping situation.
   (a) Use the nondegenerate approximation to estimate the electron and hole concentrations. (6 pts)
   (b) Use the nondegenerate approximation to estimate the position of the Fermi level with respect to \(E_C\) and \(E_V\). (8 pts)
   (c) What is the resistivity of the semiconductor? When we use the mobility calibrated from singly-doped semiconductor pieces (doped only with \(N_D\) or \(N_A\)), do we overestimate or underestimate the resistivity? Briefly explain. (8 pts)
   (d) Draw the band diagram in steady state, and when there is a 0.5V bias applied across the resistor of 1\(\mu\)m length. What is the gradient of the Fermi level here? (8 pts)

3. (Practice with Band Diagrams) (40 pts)
   A Si sample at 300K has band diagram as sketched below:
(a) Is the semiconductor under equilibrium at every point? Explain briefly. (5 pts)

(b) If there is only one type of dopant at x=b, what is its doping level? What is its type? (5 pts)

(c) Sketch the electric field (F) in the semiconductors (x=0 to x=b). (5 pts)

(d) Sketch the net charge density from x=0 to x=b. (5 pts)

(e) Is the semiconductor degenerate at any point? If so, where? (5 pts)

(f) Determine the numerical values of n and p at x=0, x=a and x=b. (5 pts)

(g) A hole at x=b with a kinetic energy of kT moves from x=b to x=0 without loss of energy (ballistic motion without scattering). What is its kinetic energy at x=0? (5 pts)

(h) For a dopant with an energy level of $E_{\text{gap}}/3$ below the conduction band, estimate its ionization percentage at x=b and at x=0. (5 pts)