MN-1
August 2017 QE

1. For 3D crystalline silicon, constant electron energy surfaces are ellipsoids that can be characterized by a longitudinal $m^*_l = 0.98m_0$ and a transversal $m^*_t = 0.19m_0$ effective mass. Depending on which properties of silicon need to be evaluated, the definitions of a density-of-state effective mass m_{de} or conductivity effective mass m_{ce} are appropriate.

a) Express m_{de} and m_{ce} for silicon in terms of m^*_l and m^*_t and indicate which one is greater. **[10pts]**

b) Determine the three-dimensional (3D) density of states $N_{3D}(E)$ close to the bottom of the conduction band (E_C) for an isotropic energy dispersion:

$$E - E_C = \frac{\hbar^2 k^2}{2m_{de}} \quad (E>E_C)!$$

($k^2=k_x^2+k_y^2+k_z^2$ -- do not forget the spin degeneracy) **[20pts]**

c) Once the 3D crystalline silicon is used to build a transistor, frequently a two-dimensional (2D) inversion layer can be formed by means of a gate at the surface.

Determine the two-dimensional (2D) density of states $N_{2D}(E)$ close to the bottom of the conduction band (E_C) for an energy dispersion:

$$E - E_C = \frac{\hbar^2 k^2}{2m_{de}} \quad (E>E_C)!$$

($k^2=k_x^2+k_y^2$ -- do not forget the spin degeneracy) **[20pts]**

d) Assume that the 2D system from question 1c) is a non-degenerate semiconductor. Determine the electron concentration "n" in the conduction band as a function of temperature (T). Use a proper approximation for the Fermi Distribution $f = \frac{1}{1+e^{(E-E_F)/k_BT}}$ for $E - E_F \gg k_BT$.

If you did not solve 1c), assume that $N_{2D}(E)$=A=constant! **[20pts]**

e) What concentration N_D of As donors must be used to make the conductivity of crystalline silicon 10^8 times larger than the intrinsic conductivity at room temperature? Assume donors are fully ionized. It is known that the carrier concentration of intrinsic Si is $n_i \approx 10^{10}/cm^3$ at room temperature. In your calculations, neglect acceptor impurities and assume that the electron and hole mobility are identical. Also assume that the mobility is not affected by the doping procedure. **[10pts]**

2. The work function ϕ_s of a semiconductor is the difference in energy between an electron at rest in vacuum and an electron at the Fermi level E_F in the semiconductor. If a metal with work function ϕ_m is used to make contact with the semiconductor, band diagrams showing the conduction (E_C) and valence band edges (E_V) can be used to illustrate the band bending at the semiconductor-to-metal interface.

a) Assume degenerate silicon with $E_F = Ec$. Draw band diagrams before and after the metal is in contact with the semiconductor for two cases:
   i) $\phi_m < \phi_s$ and
   ii) $\phi_m > \phi_s$.
   You must indicate E_F, E_c, E_v, ϕ_m and ϕ_s and the amount of band bending clearly in your graphs. **[20pts]**