Semiconductor Physics　Final exam (Chapter 3.4-5)

Department of materials science and engineering, National United University Jun. 19, 2023　13:00 – 15:00

(A) Select the correct answer from the list (45%)

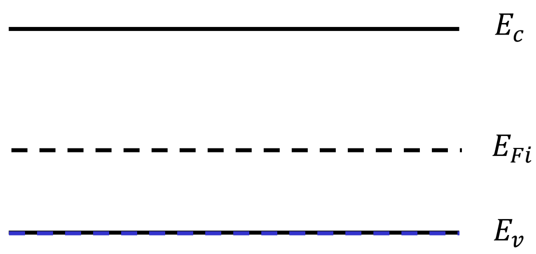
1. At T= 300 K, 1 kT is equal to (a) 0.0026 eV (b) 0.026 eV (c) 0.26 eV (d) 2.6 eV (e) 26 eV
2. Which of the following is not true for the semiconductor? (a) At $T = 0$ K, all of the valence electrons are in the valence band. (b) At $T = 0$ K, there is no electron in the conduction band. (c) At $T = 0$ K, semiconductor is an insulator. (d) Holes move faster than electrons. (e) The effective mass takes into account the particle mass and also takes into account the effect of the internal forces.
3. The probability of a state being occupied at $E = E_F$ is (a) 0 (b) 1/e (c) 1/2 (d) 1/π (e) 1
4. About the density of states for free electrons, which of the following statement is not true? (a) The density of states is a function of energy (b) The density of states decreases with increasing energy (c) The density of states is typically a large number ranging from 10^{18} to 10^{22} $\left(\frac{\text{states}}{\text{cm}^3}\right)$ between 0 and 1 eV (d) The density of states is usually less than the density of atoms in the semiconductor crystal (e) The unit of density of states is states per unit energy per unit volume $\left(\frac{\text{states}}{\text{cm}^3\cdot\text{eV}}\right)$
5. In a p-type material the Fermi level is 0.3 eV above the valence band. The concentration of accepter atoms is increased. The new position of Fermi level is likely to be (a) 0.5 eV above the valence band. (b) 0.2 eV above the valence band. (c) Below the valence band. (d) Above the conduction band. (e) None of the above
6. What happens to the free electrons when an electric field is applied? (a) They move randomly and collide with each other (b) They move in the direction of the field (c) They remain stable (d) They move in the direction opposite to that of the field (e) They are going to find the holes
7. $E_F = (E_C + E_V)/2$, this represents the Fermi energy level of which of the following? (a) Extrinsic semiconductor (b) N-type semiconductor (c) P-type semiconductor (d) Intrinsic semiconductor (e) none of the above
8. A semiconductor that contains both donors and acceptors in the same semiconductor region is called (a) intrinsic semiconductor (b) extrinsic semiconductor (c) degenerated semiconductor (d) compensated semiconductor (e) III-V semiconductor
9. The carrier effective mass in a particular semiconductor has the relation $m_p^* = 10m_n^*$. The position of the intrinsic Fermi level with respect to the center of the bandgap at $T = 300$ K is (a) 44.7 meV (b) -44.7 meV (c) 12.8 meV (d) -12.8 meV (e) 0 meV
10. Two scattering mechanisms are present in a particular semiconductor material. If only the first scattering mechanism were present, the mobility would be $\mu_1 = 200\ \text{cm}^2/\text{V}\cdot\text{s}$, and if only the second scattering mechanism were present, the mobility would be $\mu_2 = 200\ \text{cm}^2/\text{V}\cdot\text{s}$. When two scattering mechanisms exist at the same time, the net mobility is (a) $50\ \text{cm}^2/\text{V}\cdot\text{s}$ (b) $100\ \text{cm}^2/\text{V}\cdot\text{s}$ (c) $150\ \text{cm}^2/\text{V}\cdot\text{s}$ (d) $400\ \text{cm}^2/\text{V}\cdot\text{s}$ (e) $600\ \text{cm}^2/\text{V}\cdot\text{s}$.
11. Which of the following statement is incorrect? (a) The drift velocity of electron is typically higher than the thermal velocity. (b) The resistivity is inversely proportional to the mean time between collisions. (c) Both electrons and holes in semiconductors contribute to the conductivity. (d) The response of an electron in a crystal is not the same as that of a free electron. (e) The conductivity of semiconductors is a function of temperature.
12. A uniform silver wire has a resistivity of 1.54×10^{-18} ohm/m at room temperature. For an electric field along the wire of 1 V/cm. Compute the mobility, assuming that there are 5.8×10^{28} conduction electrons/m³. (a) $1.54\ \text{m}^2/\text{V}\cdot\text{s}$ (b) $6.9973\ \text{m}^2/\text{V}\cdot\text{s}$ (c) $6.9973 \times 10^{-3}\ \text{m}^2/\text{V}\cdot\text{s}$ (d) $0.69973\ \text{m}^2/\text{V}\cdot\text{s}$ (e) $6.9973 \times 10^{3}\ \text{m}^2/\text{V}\cdot\text{s}$
13. Calculate the drift velocity of the free electrons with mobility of $3.5 \times 10^{-3}\ \text{m}^2/\text{V}\cdot\text{s}$ in copper for an electric field strength of 0.5 V/m.
(a) 3.5 m/s (b) 1.75×10^3 m/s (c) 11.5 m/s (d) 1.75×10^{-3} m/s (e) 1.75 m/s
14. Which method can be used to distinguish between the two types of carriers? (a) Hall effect (b) Rayleigh method (c) Doppler effect (d) Fermi effect (e) Photoelectric effect
15. The intrinsic carrier density at room temperature in Ge is $2.37 \times 10^{19}\ /\text{m}^3$. If the electron and hole mobilities are 0.38 and 0.18 m²/ V · s, respectively. Calculate its resistivity. (a) 0.18 Ω · m (b) 0.460 Ω · m (c) 0.4587 Ω · m (d) 0.709 Ω · m (e) 1.418 Ω · m

(B) Answer the following questions (55%)

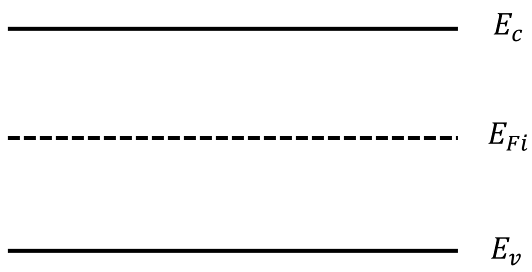
16. Calculate the temperature at which there is a 10^{-8} probability that an energy state 0.6 eV above the Fermi energy level is occupied by an electron. (6%)

17. Silicon atoms, at a concentration of $7 \times 10^{15}\ \text{cm}^{-3}$, are added to gallium arsenide. Assume that the silicon atoms act as fully ionized dopant atoms and that 10 percent of the concentration added replace gallium atoms and 90 percent replace arsenic atoms. Let $T = 300$ K. (a) Determine the donor and acceptor concentrations. (2%) (b) Is the material n type or p type? (2%) (c) Calculate the electron and hole concentrations. (2%) (d) Determine the position of the Fermi level with respect to E_{Fi}. (2%) (The intrinsic carrier concentration of GaAS is $1.8 \times 10^6\ \text{cm}^{-3}$ at 300 K)

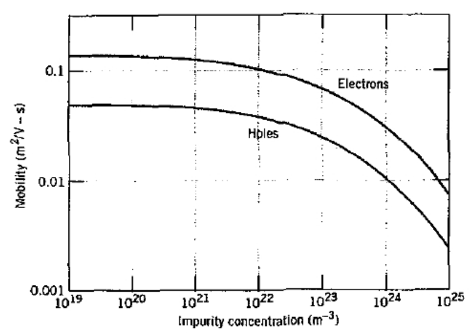
18. Silicon atoms, at a concentration of $5 \times 10^{14}\ \mathrm{cm^{-3}}$, are added to gallium arsenide. Assume that the silicon atoms act as fully ionized dopant atoms and that 8 percent of the concentration added replace gallium atoms and 92 percent replace arsenic atoms. Let $T = 300$ K, $n_i = 1.8 \times 10^{6}\ \mathrm{cm^{-3}}$ for gallium arsenide. (a) Determine the donor and acceptor concentrations. (2%) (b) Is the material n type or p type? (2%) (c) Calculate the electron and hole concentrations. (4%) (d) Determine the position of the Fermi level with respect to E_{Fi}, and plot the Fermi-level position in the band diagram shown below. The bandgap is 1.42 eV. (4%)



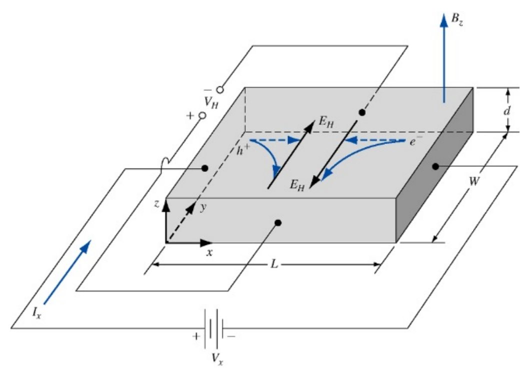
19. Silicon at $T = 300$ K is doped with boron atoms such that the concentration of holes is $p_0 = 1 \times 10^{16}\ \mathrm{cm^{-3}}$. (a) Find $E_F - E_v$. (2%) (b) Plot the Fermi-level position in the band diagram shown below (2%) (c) Calculate n_0. (2%) (d) Which carrier is the minority carrier? (2%)



20. For silicon, dependence of room temperature electron and hole mobilities (logarithmic scale) on dopant concentration (logarithmic scale) is shown in the following diagram. To high-purity silicon is added $10^{23}\ \mathrm{m^{-3}}$ arsenic atoms. (a) Is this material n-type or p-type? (2%) (b) Calculate the room-temperature electrical conductivity of this material. (4%)



21. A semiconductor Hall device has the following geometry: $d = 25$ μm, $W = 0.6$ cm, and $L = 0.6$ cm. The following parameters are measured: $I_x = 0.5$ mA, $V_x = 1$ V, $V_H = 5.0$ mV, and $B_z = 0.20$ tesla. (a) Is the semiconductor p-type or n-type? (2%) (b) Determine the majority carrier concentration (3%), and (c) majority carrier mobility. (3%)



22. Consider an n-type semiconductor at $T = 300$ K in thermal equilibrium (no current). Assume that the donor concentrations varies as $N_d(x) = N_{d0}e^{-2x/L}$ over the range $0 \le x \le L$, where $N_{d0} = 4 \times 10^{15}\ \mathrm{cm^{-3}}$ and $L = 10$ μm. (a) Determine the electric field as a function of x for $0 \le x \le L$. (4%) (b) Calculate the potential difference between $x = 0$ and $x = L$. (with the potential at $x = 0$ being positive with respect to that at $x = L$). (3%)