



Roll No:

Name:

Indian Institute of Information Technology, Design and Manufacturing, Kancheepuram

Mid Semester Examination, Jul - Nov 2024

Course Code: EC2000

Course Title: Solid State Electronic Devices

Date of Examination: 01/10/2024

Category: Core

Duration: 1 hour 30 minutes (3.30 -5.00 PM)

Max. Marks: 25 marks

Answer the following:

(5x1 = 5 marks)

Note: Give explanation for your correct choice

1. Diamond lattice can be considered as a combination of two FCC lattice displaced along the body diagonal by one quarter of its length. There are eight atoms per unit cell. The packing fraction of the diamond structure is

(a) 0.48 (b) 0.74 (c) 0.34 (d) 0.68

$$\text{Solution: } P \cdot F = \frac{n_{\text{eff}} \times \frac{4\pi}{3} r^3}{V}$$

$$\text{Where, } n_{\text{eff}} = 8, V = a^3 \text{ and } \frac{\sqrt{3}a}{4} = 2r \Rightarrow a = \frac{8r}{\sqrt{3}}$$

$$\therefore P \cdot F = \frac{8 \times \frac{4\pi}{3} r^3}{\left(\frac{8r}{\sqrt{3}}\right)^3} = \frac{\sqrt{3}\pi}{16} = 0.34.$$

2. In a crystalline solid, the energy band structure (E- k relation) for an electron of mass m is given by. The effective mass of the electron in the crystal is

(a) m (b) $\frac{2}{3}m$ (c) $\frac{m}{2}$ (d) 2m

$$\text{Solution: The expression of effective mass of electron in solid is } m^* = \frac{\hbar^2}{d^2 E / dk^2}$$

$$\frac{dE}{dk} = \frac{\hbar^2}{2m}(4k-3) \Rightarrow \frac{d^2 E}{dk^2} = \frac{\hbar^2}{2m}(4) = \frac{2\hbar^2}{m} \Rightarrow m^* = \frac{m}{2}$$

3. Calculate the mean free time of an electron having a mobility of $1000 \times 10^{-4} \text{ m}^2/\text{V-s}$ at 300 K; Assume $m_n = 0.26 m_0$ in these calculations ($m_0 = 9.109 \times 10^{-31} \text{ kg}$)

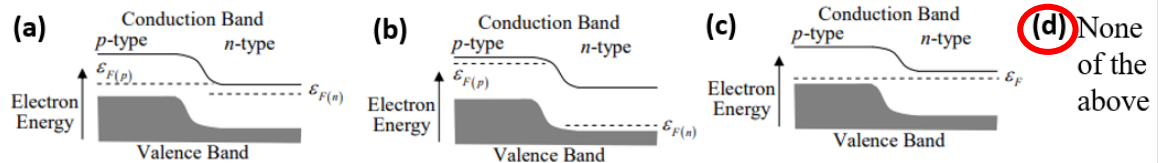
(a) 1.45 μs (b) 0.148 ps (c) 1.5 fs (d) 1.48 ns

SOLUTION From Eq. 3, the mean free time is given by

$$\tau_e = \frac{m_n \mu_n}{q} = \frac{(0.26 \times 0.91 \times 10^{-30} \text{ kg}) \times (1000 \times 10^{-4} \text{ m}^2/\text{V-s})}{1.6 \times 10^{-19} \text{ C}}$$

$$= 1.48 \times 10^{-13} \text{ s} = 0.148 \text{ ps.}$$

4. For a forward biased p-n junction diode, which one of the following energy-band diagrams is correct (ϵ_F is the Fermi energy)?



5. In a pn junction, dopant concentration on the p-side is higher than that on the n-side. Which of the following statements is (are) correct, when the junction is at zero bias?

- (a) The width of the depletion layer is larger on the n-side.
 (b) At thermal equilibrium the Fermi energy is higher on the p-side.
 (c) In the depletion region, number of negative charges per unit area on the p-side is equal to number of positive charges per unit area on the n-side
 (d) The value of the built-in potential barrier depends on the dopant concentration.

Answer the following:

(5x4 = 20 marks)

6. A p-type silicon sample has parameters $L = 0.2 \text{ cm}$, $W = 10^{-2} \text{ cm}$, and $d = 8 \times 10^{-4} \text{ cm}$. The semiconductor parameters are $p = 10^{16} \text{ cm}^{-3}$ and $\mu_p = 320 \text{ cm}^2/\text{V-s}$. For $V_x = 10 \text{ V}$ and $B_z = 500 \text{ gauss} = 5 \times 10^{-2} \text{ tesla}$, determine I_x and V_H . (Formula -1 mark, correct ans-1 mark)

From Equation (5.59),

$$I_x = \frac{(\mu_p)(epV_xWd)}{L}$$

$$= \frac{(320)(1.6 \times 10^{-19})(10^{16})(10)(10^{-2})(8 \times 10^{-4})}{0.2}$$

$$I_x = 2.048 \times 10^{-4} \text{ A}$$

$$\text{or } I_x = 0.2048 \text{ mA}$$

From Equation (5.53),

$$V_H = \frac{I_x B_z}{epd} = \frac{(2.048 \times 10^{-4})(5 \times 10^{-2})}{(1.6 \times 10^{-19})(10^{22})(8 \times 10^{-6})}$$

$$= 8 \times 10^{-4} \text{ V}$$

$$\text{or } V_H = 0.80 \text{ mV}$$

7. Minority carriers (holes) are injected into a homogeneous n-type semiconductor sample at one point. An electric field of 50 V/cm is applied across the sample, and the field moves these minority carriers a distance of 1 cm in 100 μ s. Find the diffusivity of the minority carriers. (v_p -1 mark, μ_p -1 mark, D_p – 2 marks)

$$v_p = \frac{1 \text{ cm}}{100 \times 10^{-6} \text{ s}} = 10^4 \text{ cm/s};$$

$$\mu_p = \frac{v_p}{\mathcal{E}} = \frac{10^4}{50} = 200 \text{ cm}^2/\text{V}\cdot\text{s};$$

$$D_p = \frac{kT}{q} \mu_p = 0.0259 \times 200 = 5.18 \text{ cm}^2/\text{s}.$$

8. Impurity concentrations of $N_d = 3 \times 10^{15} \text{ cm}^{-3}$ and $N_a = 10^{16} \text{ cm}^{-3}$ are added to silicon at $T = 300 \text{ K}$. Excess carriers are generated in the semiconductor such that the steady-state excess carrier concentrations are $\delta n = \delta p = 4 \times 10^{14} \text{ cm}^{-3}$. (a) Determine the thermal-equilibrium Fermi level with respect to the intrinsic Fermi level. (b) Find E_{Fn} and E_{Fp} with respect to E_{Fi} . ($p_0=n_0=0.5$ mark each, $E_{Fi}-E_F=1$ mark, $E_{Fi}-E_{Fp}=E_{Fn}-E_{Fi}=1$ mark)

$p_o = N_a - N_d = 10^{16} - 3 \times 10^{15}$ $= 7 \times 10^{15} \text{ cm}^{-3}$ $n_o = \frac{n_i^2}{p_o} = \frac{(1.5 \times 10^{10})^2}{7 \times 10^{15}} = 3.214 \times 10^4 \text{ cm}^{-3}$ <p>(a) In thermal equilibrium,</p> $E_{Fi} - E_F = kT \ln \left(\frac{p_o}{n_i} \right)$ $= (0.0259) \ln \left(\frac{7 \times 10^{15}}{1.5 \times 10^{10}} \right)$ $= 0.33808 \text{ eV}$	<p>(b) Quasi-Fermi levels,</p> $E_{Fi} - E_{Fp} = kT \ln \left(\frac{p_o + \delta p}{n_i} \right)$ $= (0.0259) \ln \left(\frac{7 \times 10^{15} + 4 \times 10^{14}}{1.5 \times 10^{10}} \right)$ $= 0.33952 \text{ eV}$ $E_{Fn} - E_{Fi} = kT \ln \left(\frac{n_o + \delta n}{n_i} \right)$ $= (0.0259) \ln \left(\frac{3.214 \times 10^4 + 4 \times 10^{14}}{1.5 \times 10^{10}} \right)$ $= 0.26395 \text{ eV}$
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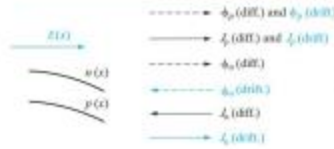
9. Discuss and derive the relation between diffusion coefficient and mobility in a non-uniformly doped semiconductor. (correct formula and step by step derivation $E(x)=1$ mark, $J_p(x)=1$ mark, derivation of $E(x)$ from $J_p(x)=1$ mark, final equation =1 mark)

Einstein relation

$$J_n(x) = q\mu_n n(x) \mathcal{E}(x) + qD_n \frac{dn(x)}{dx}$$

drift diffusion

$$J_p(x) = q\mu_p p(x) \mathcal{E}(x) - qD_p \frac{dp(x)}{dx}$$



- If an electric field is present in addition to the carrier gradient, the current densities will each have a drift component and a diffusion component.
- An electric field is assumed to be in the x-direction, along with carrier distributions $n(x)$ and $p(x)$, which decrease with increasing x and diffusion takes place in the $+x$ -direction.
- The resulting electron and hole diffusion currents [$J_n(\text{diff.})$ and $J_p(\text{diff.})$] are in opposite directions.
- Holes drift in the direction of the electric field [$\Phi_p(\text{drift})$], whereas electrons drift in the opposite direction because of their negative charge.
- The resulting drift current is in the $+x$ -direction in each case.

- The electrostatic potential $V(x)$ varies in the opposite direction, since it is defined in terms of positive charges and is therefore related to the electron potential energy $E(x)$ displayed in the figure by $V(x) = E(x)/(-q)$

$$\mathcal{E}(x) = -\frac{dV(x)}{dx}$$

$$\mathcal{E}(x) = -\frac{dV(x)}{dx} = -\frac{d}{dx} \left[\frac{E_i}{(-q)} \right] = \frac{1}{q} \frac{dE_i}{dx}$$

At equilibrium, no net current flows in a semiconductor. Thus any fluctuation which would begin a diffusion current also sets up an electric field which redistributes carriers by drift.

$$J_p(x) = q\mu_p p(x) \mathcal{E}(x) - qD_p \frac{dp(x)}{dx}$$

So assume $J_p(x)=0$, then find $\mathcal{E}(x)$

$$\mathcal{E}(x) = \frac{D_p}{\mu_p} \frac{1}{p(x)} \frac{dp(x)}{dx}$$

We know that $p_0 = n_i e^{(E_i - E_f)/kT}$

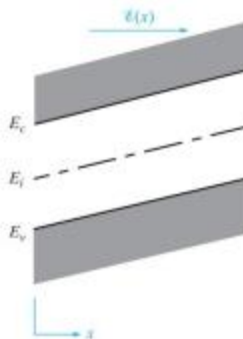
Upon substituting the above equation for $p(x)$, we get

$$\mathcal{E}(x) = \frac{D_p}{\mu_p} \frac{1}{kT} \left(\frac{dE_i}{dx} - \frac{dE_f}{dx} \right)$$

The equilibrium Fermi level does not vary with x ,

$$\text{We know that } \mathcal{E}(x) = \frac{1}{q} \frac{dE_i}{dx}$$

$$\frac{D}{\mu} = \frac{kT}{q}$$



10. Calculate V_{bi} , x_n , x_p , W , and $|E_{max}|$ for a silicon pn junction at zero bias and $T = 300$ K for doping concentrations of $N_a = 2 \times 10^{17} \text{ cm}^{-3}$, $N_d = 10^{16} \text{ cm}^{-3}$. ($V_{bi} = x_n = x_p = |E_{max}|$ 1 mark each, correct formula = 0.5 mark and ans = 0.5 mark)

$$(a) \quad V_{bi} = (0.0259) \ln \left[\frac{(2 \times 10^{17})(10^{16})}{(1.5 \times 10^{10})^2} \right]$$

$$= 0.772 \text{ V}$$

$$x_n = \left\{ \frac{2 \epsilon_s (V_{bi})}{e} \left(\frac{N_a}{N_d} \right) \left(\frac{1}{N_a + N_d} \right) \right\}^{1/2}$$

$$= \left\{ \frac{2(11.7)(8.85 \times 10^{-14})(0.7722)}{1.6 \times 10^{-19}} \right.$$

$$\left. \times \left(\frac{2 \times 10^{17}}{10^{16}} \right) \left(\frac{1}{2 \times 10^{17} + 10^{16}} \right) \right\}^{1/2}$$

$$= 3.085 \times 10^{-5} \text{ cm}$$

$$\text{or } x_n = 0.3085 \text{ } \mu\text{m}$$

$$x_p = \left\{ \frac{2 \epsilon_s (V_{bi})}{e} \left(\frac{N_d}{N_a} \right) \left(\frac{1}{N_a + N_d} \right) \right\}^{1/2}$$

$$= \left\{ \frac{2(11.7)(8.85 \times 10^{-14})(0.7722)}{1.6 \times 10^{-19}} \right.$$

$$\left. \times \left(\frac{10^{16}}{2 \times 10^{17}} \right) \left(\frac{1}{2 \times 10^{17} + 10^{16}} \right) \right\}^{1/2}$$

$$= 1.54 \times 10^{-6} \text{ cm}$$

$$\text{or } x_p = 0.0154 \text{ } \mu\text{m}$$

$$W = \left\{ \frac{2 \epsilon_s (V_{bi})}{e} \left(\frac{N_a + N_d}{N_a N_d} \right) \right\}^{1/2}$$

$$= \left\{ \frac{2(11.7)(8.85 \times 10^{-14})(0.7722)}{1.6 \times 10^{-19}} \right.$$

$$\left. \times \left[\frac{2 \times 10^{17} + 10^{16}}{(2 \times 10^{17})(10^{16})} \right] \right\}^{1/2}$$

$$= 3.240 \times 10^{-5} \text{ cm}$$

$$\text{or } W = 0.3240 \text{ } \mu\text{m}$$

$$|E_{\max}| = \frac{e N_d x_n}{\epsilon_s}$$

$$= \frac{(1.6 \times 10^{-19})(10^{16})(0.3085 \times 10^{-4})}{(11.7)(8.85 \times 10^{-14})}$$

$$= 4.77 \times 10^4 \text{ V/cm}$$