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

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

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

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

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

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

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

3. Calculate the mean free time of an electron having a mobility of 1000 x 10^{-4} m²/V-s at 300 K; Assume $m_n = 0.26\ m_o$ in these calculations ($m_o = 9.109 \times 10^{-31}$ kg)

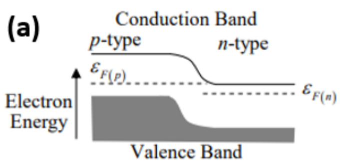
   (a) 1.45 μs **(b) 0.148 ps** **(c)** 1.5 fs **(d)** 1.48 ns

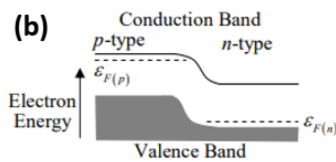
SOLUTION From Eq. 3, the mean free time is given by

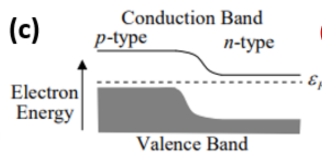
$$\tau_e = \frac{m_n \mu_n}{q} = \frac{(0.26 \times 0.91 \times 10^{-30} \text{ kg}) \times (1000 \times 10^{-4} \text{ m}^2/\text{V-s})}{1.6 \times 10^{-19} \text{ C}}$$

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

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)?

(a)


(b)


(c)


(d) None of the above

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 cm, W = 10^{-2} cm, and d = 8 x 10^{-4} cm. The semiconductor parameters are p = 10^{16} cm^{-3} and μ_p = 320 cm^2/V-s. For V_x = 10 V and B_z = 500 gauss = 5 x 10^{-2} tesla, determine I_x and V_H. (Formula -1 mark, correct ans-1 mark)

From Equation (5.59),

$$I_x = \frac{(\mu_p)(epV_x Wd)}{L}$$

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

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

or $I_x = 0.2048$ mA

From Equation (5.53),

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

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

or $V_H = 0.80$ 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 μs. Find the diffusivity of the minority carriers.(v$_p$-1 mark, μ$_p$-1 mark, D$_p$ – 2 marks)

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

$$\mu_p = \frac{\upsilon_p}{\mathscr{E}} = \frac{10^4}{50} = 200 \quad \text{cm}^2/\text{V-s;}$$

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

8. Impurity concentrations of N$_d$ = 3 x 10^{15} cm^{-3} and N$_a$ = 10^{16} cm^{-3} are added to silicon at T = 300 K. Excess carriers are generated in the semiconductor such that the steady-state excess carrier concentrations are δn = δp = 4 x 10^{14} 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)

$$p_o = N_a - N_d = 10^{16} - 3\times10^{15}$$
$$= 7\times10^{15}\ \text{cm}^{-3}$$
$$n_o = \frac{n_i^2}{p_o} = \frac{(1.5\times10^{10})^2}{7\times10^{15}} = 3.214\times10^4\ \text{cm}^{-3}$$

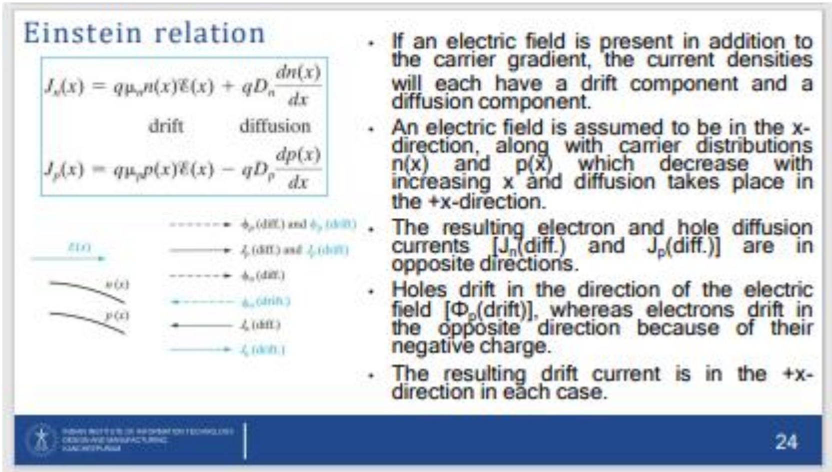
(a) In thermal equilibrium,

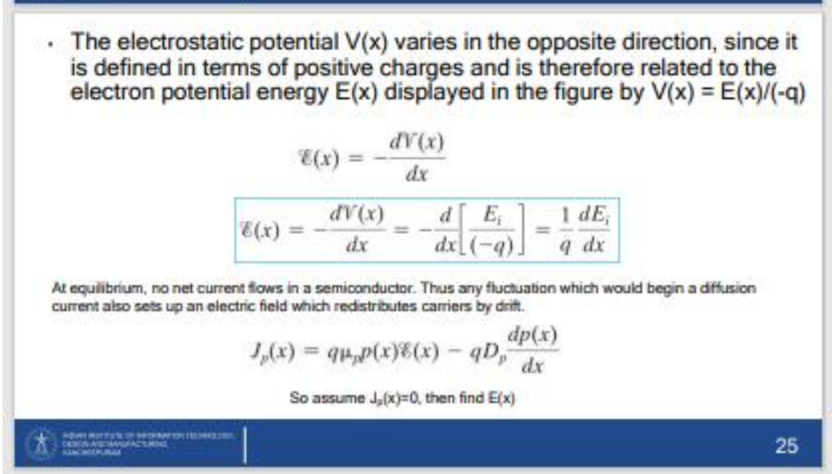
$$E_{Fi} - E_F = kT\ln\left(\frac{p_o}{n_i}\right)$$
$$= (0.0259)\ln\left(\frac{7\times10^{15}}{1.5\times10^{10}}\right)$$
$$= 0.33808\ \text{eV}$$

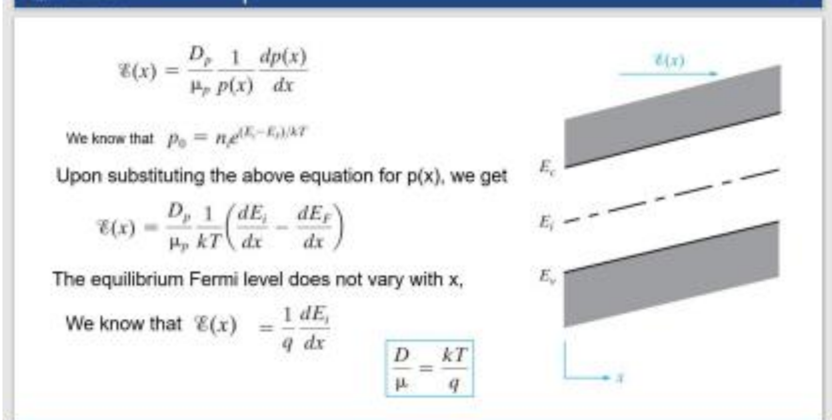
(b) Quasi-Fermi levels,

$$E_{Fi} - E_{Fp} = kT\ln\left(\frac{p_o + \delta p}{n_i}\right)$$
$$= (0.0259)\ln\left(\frac{7\times10^{15} + 4\times10^{14}}{1.5\times10^{10}}\right)$$
$$= 0.33952\ \text{eV}$$
$$E_{Fn} - E_{Fi} = kT\ln\left(\frac{n_o + \delta n}{n_i}\right)$$
$$= (0.0259)\ln\left(\frac{3.214\times10^4 + 4\times10^{14}}{1.5\times10^{10}}\right)$$
$$= 0.26395\ \text{eV}$$

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)=1mark, J$_p$(x)=1 mark, derivation of E(x) from J$_p$(x)=1 mark, final equation =1mark)







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 $N_a = 2 \times 10^{17}$ cm^{-3}, $N_d = 10^{16}$ cm^{-3}. (V_{bi} = x_n = x_p= $|E_{max}|$=1 mark each, correct formula =0.5 mark and ans = 0.5 mark)

(a) $V_{bi} = (0.0259)\ln\left[\frac{(2\times10^{17})(10^{16})}{(1.5\times10^{10})^2}\right]$

$= 0.772$ V

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

$$= \left\{\frac{2(11.7)(8.85\times10^{-14})(0.7722)}{1.6\times10^{-19}}\right.$$

$$\left.\times\left(\frac{2\times10^{17}}{10^{16}}\right)\left(\frac{1}{2\times10^{17}+10^{16}}\right)\right\}^{1/2}$$

$= 3.085\times10^{-5}$ cm

or $x_n = 0.3085\ \mu$m

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

$$= \left\{\frac{2(11.7)(8.85\times10^{-14})(0.7722)}{1.6\times10^{-19}}\right.$$

$$\left.\times\left(\frac{10^{16}}{2\times10^{17}}\right)\left(\frac{1}{2\times10^{17}+10^{16}}\right)\right\}^{1/2}$$

$= 1.54\times10^{-6}$ cm

or $x_p = 0.0154\ \mu$m

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

$$= \left\{\frac{2(11.7)(8.85\times10^{-14})(0.7722)}{1.6\times10^{-19}}\right.$$

$$\left.\times\left[\frac{2\times10^{17}+10^{16}}{(2\times10^{17})(10^{16})}\right]\right\}^{1/2}$$

$= 3.240\times10^{-5}$ cm

or $W = 0.3240\ \mu$m

$$|E_{max}| = \frac{eN_dx_n}{\in_s}$$

$$= \frac{(1.6\times10^{-19})(10^{16})(0.3085\times10^{-4})}{(11.7)(8.85\times10^{-14})}$$

$= 4.77\times10^{4}$ V/cm