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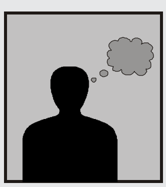
Workbook 2025



Detailed Explanations of Try Yourself *Questions*

Electronics Engineering

Electronic Devices and Circuits

MADE EASY PUBLICATIONS

1 Basics of Semiconductor Physics

Detailed Explanation of Try Yourself Questions

T1. Sol.

$$J_n = qD_n\frac{dn}{dx} = q\times D_n\times\left(\frac{-10^{16}\times(2x)}{L}\right) = -64\ \text{A/m}^2$$

T2. Sol.

Here E_i is not exactly as in the middle of the gap because the density of states N_C and N_V are different.

$$N_C\cdot e^{-\frac{E_C-E_i}{kT}} = \sqrt{N_C N_V}\,e^{-E_g/2kT} = n_i$$

$$e^{-\frac{E_C-E_i+E_g/2}{kT}} = \sqrt{\frac{N_V}{N_C}} = \left(\frac{m_p^*}{m_n^*}\right)^{3/4}$$

$$\frac{E_g}{2}-(E_C+E_i) = kT\cdot\frac{3}{4}\cdot ln\left(\frac{m_p^*}{m_n^*}\right) = 0.0259\cdot\frac{3}{4}ln\left(\frac{0.56}{1.1}\right) = -0.013\ \text{eV}$$

So E_i is about $\frac{kT}{2}$ below the centre of the band gap.

T3. (b)

Given the probability of state being empty is 0.9258

i.e. $1-f(E) = 0.9258$

The energy level being occupied by electron is $f(E)$

$\therefore$ $f(E) = 1-0.9258 = 0.0742$

$$f(E) = \frac{1}{1+e^{\left(\frac{E-E_F}{kT}\right)}}$$

$$0.0742 = \frac{1}{1+e^{\left(\frac{E-E_F}{kT}\right)}}$$

$$1+e^{\left(\frac{E-E_F}{kT}\right)} = 13.477$$

$$\frac{E-E_F}{kT} = 2.523$$

$$\therefore \quad E - E_F \approx 2.52\,\text{kT}$$

$$E = E_F + 2.52\,\text{kT}$$

The energy level 2.52 kT above the Fermi energy is occupied by electron with probability 0.0742.

T4. Sol.

The diffusion current density is defined as

$$J_n = qD_n \frac{dn}{dx}$$

substituting the given values, we get

$$0.09 = (1.6\times 10^{-19})\times 25\left(\frac{4\times 10^{14} - n(0)}{0.010-0}\right)$$

$$\frac{0.09\times 0.010}{1.6\times 10^{-19}\times 25} = 4\times 10^{14} - n(0)$$

$$n(0) = 1.75\times 10^{14}\ \text{cm}^{-3}$$

T5. (c)

Intrinsic carrier concentration in semiconductor is given by

$$n_i = \sqrt{N_C N_V}\exp[-E_g/2kT]$$

Given the bandgap energy

$$E_{gA} = 1.21\ \text{eV};\quad E_{gB} = 2.4\ \text{eV}$$

The ratio of intrinsic carrier concentration of semiconductor B to semiconductor A is obtained as,

$$\frac{n_{iB}}{n_{iA}} = \frac{\sqrt{N_C N_V}\exp[-E_{gB}/2kT]}{\sqrt{N_C N_V}\exp[-E_{gA}/2kT]}$$

$$= \exp[-(E_{gB}-E_{gA})/2kT]$$

$$= \exp\left[\frac{-(2.4-1.21)\ \text{eV}}{2\times 0.026\ \text{eV}}\right]$$

$$\frac{n_{iB}}{n_{iA}} = 1.152\times 10^{-10}$$

T6. Sol.

(i) Minimum conductivity, $\sigma_{min} = 2qn_i\sqrt{\mu_n \mu_p}$

$$\sigma_{min} = 2\times 1.6\times 10^{-19}\times 3.6\times 10^{12}\sqrt{7500\times 300}$$

$$\sigma_{min} = 1.728\times 10^{-3}\ \mho/\text{cm}$$

(ii) We know that,

The conductivity of semiconductor,

$$\sigma = n_q\mu_n + pq\mu_p \quad \text{...(i)}$$

By mass action law, $p = \dfrac{n_i^2}{n}$ ...(ii)

$\therefore$ $\sigma = nq\mu_n + \dfrac{n_i^2}{n}q\mu_p$

For minimum conductivity,

$$\frac{d\sigma}{dn} = 0$$

$$\frac{d\sigma}{dn} = q\mu_n + \left(-\frac{1}{n^2}\right)n_i^2 q\mu_p$$

$$0 = q\mu_n - \frac{1}{n^2}n_i^2 q\mu_p$$

$$\frac{n_i^2}{n^2} = \frac{\mu_n}{\mu_p} \Rightarrow n = n_i\sqrt{\frac{\mu_p}{\mu_n}}$$

Similarly, $p = n_i\sqrt{\dfrac{\mu_n}{\mu_p}}$

$\therefore$ $n = 3.6\times 10^{12}\sqrt{\dfrac{7500}{300}} = 1.8\times 10^{13}\ \text{cm}^{-3}$

From equations (i) and (ii),

$$p = 3.6\times 10^{12}\sqrt{\frac{300}{7500}} = 7.2\times 10^{11}\ \text{cm}^{-3}$$

(iii) Minimum conductivity, $\sigma_{min} = n_i\sqrt{\dfrac{\mu_p}{\mu_n}}q\mu_n + n_i\sqrt{\dfrac{\mu_n}{\mu_p}}q\mu_p$

$$\sigma_{min} = n_i q\left[\sqrt{\mu_p\mu_n} + \sqrt{\mu_p\mu_n}\right]$$

$$\sigma_{min} = 2n_i q\sqrt{\mu_p\mu_n}\ \mho/\text{cm}$$

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2 Junctions

Detailed Explanation of Try Yourself Questions

T1. Sol.

$$I = qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)(e^{qV/kT} - 1) = I_o(e^{qV/kT} - 1)$$

$$p_n = \frac{n_i^2}{n_n} = \frac{(1.5\times 10^{10})^2}{10^{15}} = 2.25\times 10^5\,\text{cm}^{-3}$$

$$n_p = \frac{n_i^2}{p_p} = \frac{(1.5\times 10^{10})^2}{10^{17}} = 2.25\times 10^3\,\text{cm}^{-3}$$

For minority carriers,

$$D_p = \frac{kT}{q}\mu_p = 0.0259\times 450 = 11.66\ \text{cm}^2\text{/s on the } n \text{ side}$$

$$D_n = \frac{kT}{q}\mu_n = 0.0259\times 700 = 18.13\ \text{cm}^2\text{/s on the } p \text{ side}$$

$$L_p = \sqrt{D_p\tau_p} = \sqrt{11.66\times 10\times 10^{-6}} = 1.08\times 10^{-2}\ \text{cm}$$

$$L_n = \sqrt{D_n\tau_n} = \sqrt{18.13\times 0.1\times 10^{-6}} = 1.35\times 10^{-3}\ \text{cm}$$

$$I_o = qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)$$

$$= 1.6\times 10^{-19}\times 0.0001\left(\frac{11.66}{0.0108}2.25\times 10^5 + \frac{18.13}{0.00135}2.25\times 10^3\right)$$

$$= 4.370\times 10^{-15}\ \text{A}$$

$I = I_o(e^{0.5/0.0259} - 1) \approx 1.058\times 10^{-6}$ A in forward bias.

$I = -I_o = -4.37\times 10^{-15}$ A in reverse bias.

T2. Sol.

Built in voltage, with no. external voltage applied the voltage (V_0) across the p-n junction is given by

$$V_o = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

$$V_o = 25\,\text{mV} \ln\left(\frac{10^{17}\times 10^{16}}{\left(1.5\times 10^{0}\right)^2}\right)$$

$\Rightarrow$ 25×29.12 mV

$V_o \Rightarrow 728$ mV

width of the depletion region.

$$W_{\text{dep}} = x_n + x_p = \sqrt{\frac{2\varepsilon_0}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)V_0} = 0.32\text{mm} \quad \ldots(i)$$

$$\frac{x_n}{x_p} = \frac{N_A}{N_D} = \frac{10^{17}}{10^{16}} = 10 \quad \ldots(ii)$$

$$x_n = 10\,x_p$$

By solving equation (i) and (ii)

$$x_p = 0.03\ \mu\text{m and } x_n = 0.29\ \mu\text{m}$$

T3. (a)

For P^+N junction diode

$$N_A >> N_D \quad \text{(or)} \quad \frac{1}{N_A} << \frac{1}{N_D}$$

$$W = \sqrt{\frac{2\varepsilon_s}{q}\left[\frac{1}{N_A}+\frac{1}{N_D}\right]V_{bi}}$$

$$W = \sqrt{\frac{2\varepsilon_s}{q}\cdot\frac{1}{N_D}\cdot V_{bi}}$$

$$\because \quad \frac{1}{N_A} << \frac{1}{N_D}$$

$$W = \sqrt{\frac{2\times 1.04\times 10^{-12}}{1.6\times 10^{-19}}\times\frac{1}{3\times 10^{16}}\times 0.75}$$

$$\because \quad \varepsilon_{si} = 1.04\times 10^{-10}\ \text{F/m} = 1.04\times 10^{-12}\ \text{F/cm}$$

$$W = 1.802\times 10^{-5}\ \text{cm}$$

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3 Optoelectronic Devices

Detailed Explanation of Try Yourself Questions

T1. (b)

Given photocurrent density J_L = 10 mA/cm^2
The open circuit voltage of solarcell is

$$V_{oc} = V_t \, ln\left(1+\frac{I_L}{I_S}\right)$$

or

$$V_{oc} = V_t \, ln\left(1+\frac{J_L}{J_S}\right)$$

$$J_S = qn_i^2\left[\frac{D_n}{L_n N_a}+\frac{D_p}{L_p N_d}\right]$$

where $n_i = 1.5 \times 10^{10}/\text{cm}^3$

$$L_n = \sqrt{D_n \tau_{n0}} = \sqrt{25\times 5\times 10^{-7}} = 35.4 \ \mu\text{m}$$

$$L_p = \sqrt{D_p \tau_{p0}} = \sqrt{10\times 10^{-7}} = 10 \ \mu\text{m}$$

$$J_S = (1.6\times 10^{-19})\times(1.5\times 10^{10})^2 \times\left\{\frac{25}{(35.4\times 10^{-4})(5\times 10^{18})}+\frac{10}{(10\times 10^{-4})(10^{16})}\right\}$$

$\therefore$ $$J_S = 3.6 \times 10^{-11} \text{ A/cm}^2$$

since the solar intensity is increased by 10 times

$\Rightarrow$ $$J_L = 10 \times 10 \text{ mA/cm}^2 = 100 \text{ mA/cm}^2$$

Given temperature remains constant hence the reverse saturation current density also constant.

$\therefore$ $$J_S = 3.6 \times 10^{-11} \text{ A/cm}^2$$

$\therefore$ The open-circuit voltage is

$$V_{OC} = (0.026) \, ln\left(1+\frac{100\times 10^{-3}}{3.6\times 10^{-11}}\right)$$

$\therefore$ $$V_{OC} = 0.565 \text{ V}$$

T2. Sol.

(i) Entire junction is uniformly illuminated

$$I_{SC} = I_L = Aq(W + L_n + L_p)\, G_L$$

$$V_o = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right) = 0.026 \ln\left(\frac{10^{16} \times 10^{15}}{(1.5 \times 10^{10})^2}\right)$$

$$= 0.6374 \text{ Volt}$$

$$W = \sqrt{\frac{2\epsilon_{si} V_o}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)} = \sqrt{\frac{2 \times 11.7 \times 8.85 \times 10^{-14} \times 0.6374}{1.6 \times 10^{-19}}\left(\frac{1}{10^{15}} + \frac{1}{10^{16}}\right)}$$

$$W = 95.26 \times 10^{-6} \text{ cm}$$

$$L_n = \sqrt{D_n \tau_n} = \sqrt{25 \times 10^{-6}} = 5 \times 10^{-3} \text{ cm}$$

$$L_p = \sqrt{D_p \tau_p} = \sqrt{10 \times 5 \times 10^{-7}} = 2.236 \times 10^{-3} \text{ cm}$$

(ii) Short circuit current

$$I_{SC} = 5 \times 1.6 \times 10^{-19}\,(95.26 \times 10^{-6} + 5 \times 10^{-3} + 2.236 \times 10^{-3})$$

$$I_{SC} = 4000(0.00733) = 29.32 \text{ Amp.}$$

(iii)

$$I_o(\text{dark current}) = Aq\frac{D_p}{L_p}\frac{n_i^2}{N_D} + Aq\frac{D_n}{L_n}\frac{n_i^2}{N_A}$$

$$= Aqn_i^2\left(\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right)$$

$$= 5 \times 1.6 \times 10^{-19} \times (1.5 \times 10^{10})^2 \left[\frac{10}{2.236 \times 10^{-3} \times 10^{15}} + \frac{25}{5 \times 10^{-3} \times 10^{16}}\right]$$

$$= 895.0089 \times 10^{-12} \text{ Amp}$$

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5 Field Effect Transistor

Detailed Explanation of Try Yourself Questions

T1. Sol.

Since $V_{DS} > V_{GS}$, MOSFET is in saturation region

$$I_{dsat} = \frac{\mu_n C_{ox}}{2}\frac{W}{L}(V_{GS} - V_T)^2 (1 + \lambda V_{ds})$$

$$100\ \mu A = k(2 - V_T)^2 (1 + 3\lambda)$$

$$110\ \mu A = k(2 - V_T)^2 (1 + 5\lambda)$$

$$\frac{100}{110} = \frac{1+3\lambda}{1+5\lambda}$$

$$\lambda = 0.0588\ V^{-1}$$

T2. (c)

T3. (d)

n = new concentration of electrons at the surface

n_0 = equilibrium concentration of electrons

$$n_0 = \frac{n_i^2}{p_0} \approx \frac{n_i^2}{N_A} = 1.8 \times 10^5\ \text{cm}^{-3}$$

$$n = n_0 e^{\Psi/V_t};\quad V_t = \frac{kT}{q},\quad \Psi = \text{surface potential}$$

$$\Psi = \frac{kT}{q} ln\left(\frac{n}{n_0}\right) = 0.026\ ln\left(\frac{3 \times 10^{10}}{1.8}\right) \approx 0.612\ V$$

T4. (b)

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