Semiconductor Devices and Technology

Section — 02

Course :- EEE 410

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Answer to the Q. No — 01

(b)

$N_A = 5.7 \times 10^{15} / cm^3$

$N_D = 6.4 \times 10^{16} / cm^3$

$D_n = 23 \; cm^2/s$

$D_p = 14.5 \; cm^2/s$

$\tau_{no} = 7.45 \times 10^{-7} s$

$\tau_{po} = 3.35 \times 10^{-7} s.$

$A = 2.55 \times 10^{-3} \; cm^2$

$V_a = 0.69V$

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

$$\therefore J_n(-x_p) = \frac{e D_n n_{po}}{L_n}\left[\exp\left(\frac{eV_a}{kT}\right) - 1\right]$$

$$n_{po} = \frac{n_i^2}{N_A} = \frac{(1.5 \times 10^{10})^2}{5.7 \times 10^{15}}$$

$$= \frac{2.25 \times 10^{20}}{5.7 \times 10^{15}}$$

$$= 0.039473 \times 10^{6} / cm^3$$

$L_n^2 = D_n \tau_{n0} = 23 \times 7.45 \times 10^{-7}$

$= 1.7135 \times 10^{-5}\ cm^2$

$L_n = \sqrt{1.7135 \times 10^{-5}}$

$\Rightarrow L_n = 4.13944 \times 10^{-3}\ cm$

$I_n(-x_p) = \dfrac{e D_n n_{p0}}{L_n}\left[\exp\left(\dfrac{eV_a}{KT}\right) - 1\right]$

$= \dfrac{1.6 \times 10^{-19} \times 23 \times 0.039473 \times 10^{6}}{4.13944 \times 10^{-3}}\left[\exp\left(\dfrac{0.618}{0.025875}\right) - 1\right]$

$= (3.5091857 84 \times 10^{-11}) \times (2.358925 \times 10^{10} - 1)$

$= 0.8277\ A/cm^2$

$I_p(x_n) = I_p(-x_p) \times A$

$= 0.8277 \times 2.55 \times 10^{-3} = 2.1107 \times 10^{-3} A$

$J_p(x_n) = \dfrac{q D_p p_{n0}}{L_p}\left[\exp\left(\dfrac{qV_A}{KT}\right) - 1\right]$

$p_{n0}^2 = \dfrac{n_i^2}{N_D} = \dfrac{(1.5 \times 10^{10})^2}{6.4 \times 10^{16}}$

$= 3.5156 \times 10^{3}/cm^3$

$L_p^2 = D_p \tau_{p0} = 14.5 \times 3.35 \times 10^{-7} = 4.8575 \times 10^{-6}\ cm^2$

$L_p = \sqrt{4.8575 \times 10^{-6}} = 2.20397 \times 10^{-3}\ cm.$

3.

$$I_p(X_n) = \frac{1.6\times10^{-19}\times 14.5\times 3.5156\times10^{3}}{2.20397\times10^{-3}}\left[\exp\left(\frac{0.618}{0.025875}\right)-1\right]$$

$$= 0.08729 \text{ A/cm}^2$$

$$I_p(X_n) = I_p(X_n)\times A$$

$$= 0.08729\times 2.55\times10^{-3}$$

$$= 2.22605\times10^{-4}\text{ A.}$$

$$I = I_n(-X_p) + I_p(X_n)$$

$$\cancel{2.1107\times10^{-7}}$$

$$\Rightarrow I = 2.1107\times10^{-3} + 2.22605\times10^{-4}$$

$$\Rightarrow I = 2.33305\times10^{-3}\text{ A.}$$

(Ans).

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1.(a). In PN junction the electric field formed in the depletion region acts as a barrier. External energy must be applied to get the electrons to move across the barrier of the electric field. The potential difference required to move the electrons through the electric field is called barrier potential. Depends on the type of semiconductor material, amount of doping and temperature. In another terms, built-in voltage is simply the difference of the fermi levels in p- and n-type. When increase the temperature, the intrinsic carrier concentration increases. This pushes the fermi level closer to the intrinsic fermi level. Difference in fermi level in the ptype and ntype regions, the fermi level in each region moves closer to the middle of the gap and the built on potential is decreased after increasing the temperature.

Bandgap to decrease V_{bi} :- In a pn junction diode the built in voltage, evo is related to the energy band gap. the build in voltage is half the bandgap to the full bandgap.

Answer to the Q No - 02

Given that, $N_A = 3.5 \times 10^{16}/cm^3$
$n_i = 1.5 \times 10^{10}/cm^3$

(i) Bulk potential,

$$\varphi_B = \frac{KT}{q} \ln\left(\frac{N_A}{n_i}\right)$$

$$= 0.0259 \times \ln\left(\frac{3.5 \times 10^{16}}{1.5 \times 10^{10}}\right)$$

$$= 0.379 \text{ V.}$$

(ii) When the surface is inverting total surface band bonding, $\varphi_S = 2\varphi_B$

$$= (2 \times 0.379)$$

$$= 0.7505 \text{ V}$$

(iii) $\varphi_M = 4.25$ eV, $X = 4.01$ eV, $E_G = 1.12$ ev

$$V_{FB} = \varphi_m - \left(\chi + \frac{E_G}{2} + \varphi_B\right)$$

$$= 4.25 - \left(4.01 + \frac{1.12}{2} + 0.379\right)$$

$$= -0.699 \text{ ev.}$$

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(iv) Maximum depletion width,

$$W_{dm} = \sqrt{\frac{2 \varepsilon_s \phi_{s\,inv}}{q N_A}}$$

$$= \sqrt{\frac{2 \times 11.7 \times 8.85 \times 10^{-14} \times 0.7595}{1.6 \times 10^{-19} \times 3.5 \times 10^{16}}}$$

$$= 1.6759 \times 10^{-5}\ cm$$

$$= 0.1675\ \mu m.$$

(v) $t_{ox} = 8.6\ nm$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{8.85 \times 10^{-14} \times 3.9}{8.6 \times 10^{-9}}\ F/cm^2$$

$$= 4.0133 \times 10^{-5}\ F/cm^2$$

Threshold voltage,

$$V_T = V_{FB} + \phi_s + \frac{q N_A W_{dD}}{C_{ox}}$$

$$= -6.99 + 0.7595 + \frac{1.6 \times 10^{-19} \times 3.5 \times 10^{16} \times 1.6759 \times 10^{-5}}{4.0133 \times 10^{-5}}$$

$$= 0.628\ V$$

Answer to the Q NO — 03

3/ b) We know that,

For saturation,

$$I_{D(sat)} = \frac{W \mu_n C_{ox}}{2L} (V_{GS} - V_T)^2$$

for linear,

$$I_{D(sat)} = \mu C_{ox} \frac{W}{L} \left\{ (V_{gs} - V_T) V_{ds} - \frac{V_{ds}^2}{2} \right\}$$

(i) $V_{gs} = 0.22V$, $V_{ds} = 0.16V$, $t_{ox} = 8.5 nm$

$$V_{gs} - V_T = 0.22 - 0.38$$
$$= -0.16 < V_{DS}$$

It is ~~sat~~ saturation region.

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.9 \times 8.85 \times 10^{-14}}{8.5 \times 10^{-9}}$$
$$= 4.0605 \times 10^{-5} \; F/cm^2$$

$$I_{D(sat)} = \frac{11.8 \times 780 \times 4.0605 \times 10^{-5}}{2 \times 1.36} (0.22 - 0.38)^2$$

$$= 3.517 \times 10^{-3} \; A$$

(ii) $V_{gs} = 1.78\,V$, $V_{ds} = 0.72\,V$

$V_{gs} - V_T = 1.78 - 0.38 = 1.4 > V_{ds}$

So linear,

$$I_D(sat) = \mu_n C_{ox} \frac{W}{L}\left\{(V_{gs}-V_T)V_{ds} - \frac{V_{ds}^2}{2}\right\}$$

$$= \frac{780 \times 4.0605 \times 10^{-5} \times 11.8}{1.28}\left\{1.4 \times 0.72 - \frac{.72^2}{2}\right\}$$

$$= 0.02186\,A$$

(iii) $V_{gs} = 2.24\,V$, $V_{ds} = 2.55\,V$

$V_{gs} - V_T = 2.24 - 0.38 = 1.86 < V_{DS}$

Saturation region,

$$I_D(sat) = \frac{W \mu_n C_{ox}}{2L}(V_{gs} - V_T)^2$$

$$= \frac{11.8 \times 780 \times 4.0605 \times 10^{-5}}{2 \times 1.36}(\cancel{2.24})(1.86)^2$$

$$= 0.0475\,A$$

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3(a) For limitation in supply voltage V_T have to decrease.

For $I_{D(sat)}$ is increasing,

from equation,

$$I_{D(sat)} = \frac{W \mu_n C_{ox}}{2L}(V_{GS} - V_T)^2$$

So, oxide thickness needed lower and doping density needed higher from equation,

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$$

Oxide thickness t_{ox} is inverse relation ship with doping density. The channel mobility μ_n needed higher for achieving selected doping density

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