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1. b) A silicon pn junction at $T = 300K$ has the following parameters: $N_A = 2\times10^{15}\ cm^3$, $N_D = 5\times10^{16}\ cm^{-3}$, $D_n = 26\ cm^2/s$, $D_p = 16\ cm^2/s$, $\tau_{no} = 8.2\times10^{-7}s$ $\tau_{po} = 3.4\times10^{-7}s$. The cross sectional area is $A = 3.2\times10^{-3}\ cm^2$ and the forward bias voltage is $V_a = 0.6\ V$. Calculate the total current $I_{diode}(A)$ in the p-n junction diode. Value of n_i at $T = 300k$ is $1.5\times10^{10}\ cm^{-3}$.

Solve:

We know,

$$J_p(x_n) = \frac{eD_p P_{no}}{L_p}\left[\exp\left(\frac{qV_A}{KT}\right) - 1\right]$$

$$= \frac{1.6\times10^{-19}\times16\times4500}{3.2\times10^{-3}}\left[e^{\frac{0.6}{0.0259}} - 1\right]$$

$$= 0.015\ m/cm^2$$

$$P_{no} = \frac{n_i^2}{N_D} = \frac{(1.5\times10^{10})^2}{5\times10^{16}} = 4500\ cm^3$$

$$L_p^2 = D_p \times \tau_{po} = 16\times3.4\times10^{-7}$$

$$= 5.44\times10^{-6}$$

$$\therefore\ L_p = 2.332\times10^{-3}\ cm$$

$$J_n(-x_p) = \frac{e D_n n_{p_0}}{L_n}\left(\exp\frac{qV_A}{nT} - 1\right)$$

$$= \frac{1.6\times10^{-19} \times 26\times112500}{2.97\times10^{-3}}\left(\exp\frac{0.625}{0.0259} - 1\right)$$

$$= 1.57\times10^{-10}\left(1.11\times10^{10}\right)$$

$$= 1.744$$

$$L_n^2 = D_n \tau_{p_0} = 26 \times 3.4\times10^{-7}$$

$$= 8.84\times10^{-6}$$

$$\therefore \quad L_n = 2.97\times10^{-3} \quad cm$$

$$n_{p_0} = \frac{n_i^2}{N_A} = \frac{(1.5\times10^{10})^2}{2\times10^{15}} = 112500 \quad cm^3$$

$$J_{diode} = (0.015 + 1.744)$$

$$= 1.759 \quad A/cm^2$$

$$I = I_{diode} \times A = 1.759 \times 3.2\times10^{-3}$$

$$= 5.628\times10^{-3} \quad A.$$

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2\. c) For a p-substrate silicon MOS capacitor, at $T = 300K$, the substrate doping is $N_A = 1.3 \times 10^{16} / cm^3$.

i) What is bulk potential, φ_B ?

ii) At inversion condition what is φ_s ? (Hint: φ_s is total band bending at the surface)

iii) For $\varphi_m = 4.35\,eV$ and $\chi = 4.01\,eV$ (for silicon), what is the flatband voltage $V_{FB} = \varphi_{ms}$?

iv) Find the maximum depletion width $x_{dT}(\mu m)$ at the inversion condition of the surface. Value of n_i at $T = 300k$ is $1.5 \times 10^{10}\ cm^{-3}$.

Useful equations:

$$x_{dT} = \left(\frac{2 \epsilon_s \varphi_s}{q N_A}\right)^{1/2} \qquad \epsilon_s = 11.7\,\epsilon_0 \qquad \varphi_B = \frac{KT}{q} \ln\left(\frac{N_A}{n_i}\right)$$

Solve:

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

$N_A = 1.3 \times 10^{16}$

$n_i = 1.5 \times 10^{10}$

$$= 0.0259 \ln\left(\frac{1.3 \times 10^{16}}{1.5 \times 10^{10}}\right)$$

$$= 0.354\ V$$

ii)
$$\varphi_s = 2\varphi_B$$
$$= 2 \times 0.354\ V$$
$$= 0.708\ V$$

iii) $$V_{FB} = \frac{\varphi_m - \varphi_s}{q}$$

$$= \frac{(4.35 - 4.924)\cancel{e}V}{1\cancel{e}}$$

$$= -0.574 \text{ V}$$

Here,

$\varphi_m = 4.35 \text{ eV}$

$$\varphi_s = \chi_{Si} + \frac{E_g}{2} + \varphi_B$$

$$= 4.01 + \frac{1.12}{2} + 0.354$$

$$= 4.924 \text{ eV}$$

iv) $$x_{dT} = \left(\frac{2\varepsilon_s \varphi_s}{qN_A}\right)^{1/2}$$

$$= \left(\frac{2 \times 11.7 \times 8.854 \times 10^{-14} \times 0.708}{1.6 \times 10^{-19} \times 1.3 \times 10^{16}}\right)^{1/2}$$

$$= (7.067 \times 10^{-10})^{1/2} \text{ cm}$$

$$= 2.65 \times 10^{-5} \text{ cm}$$

$$= 0.265 \ \mu\text{m}.$$

Ans.

Here,

$\varepsilon_s = 11.7 \times 8.854 \times 10^{-14}$

$\varphi_s = 0.708 \text{ V}$

$N_A = 1.3 \times 10^{16} / \text{cm}^3$

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3. b) An ideal n-channel MOSFET has the following parameters $V_T = 0.4V$, $\mu_n = 740\ cm^2/V\text{-}s$, $t_{ox} = 10.9\ nm$, $W = 9\ \mu m$, and $L = 0.9\ \mu m$. Find the drain current I_{ds} for this MOSFET when

i) $V_{gs} = 0.2\ V$ and $V_{ds} = 0.15\ V$.

ii) $V_{gs} = 1.5\ V$ and $V_{ds} = 0.4\ V$.

iii) $V_{gs} = 1.8\ V$ and $V_{ds} = 2.2\ V$.

Make sure to apply the above bias conditions to determine cut off, linear case and saturation case for calculation of drain current

Useful equations:

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

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

Solution:

(I) $V_{gs} < V_T$

So, channel is no cut off $\therefore I_{ds} = 0A$

(II)

$V_{gs} - V_T = 1.5 - 0.4 = 1.1\ V > V_{ds} = 0.5\ V$

$\therefore$ Linear region of operation

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

$$= 740 \times 3.18 \times 10^{-7} \times \frac{9}{0.9} \times \left\{ (1.1)(0.4) - \frac{0.4^2}{2} \right\}$$

$$= 8.46 \times 10^{-4}$$

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

$$= \frac{3.9 \times 8.89 \times 10^{-14}}{10.9 \times 10^{-7}}$$

$$= 3.18 \times 10^{-7}\ F/cm^2$$

(iii) $V_{gs} - V_T = 1.8 - 0.4$

$= 1.4 < V_{ds} = 2.2 \text{ v}$

$\therefore$ Saturation case

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

$$= 740 \times 3.18 \times 10^{-7} \times \frac{9}{0.9} \times \frac{(1.4)^2}{2}$$

$$= 2.306 \times 10^{-3} \text{ A} \quad \text{(saturation)}$$

Ans.

Last class.

For an n-channel enhancement mode silicon MOSFET at $T = 300\,K$, dopping $N_A = 2\times10^{16}/cm^3$ and oxide thickness $t_{ox} = 9\,nm$. Find the threshold voltage of the device. If $L = 0.95\ \mu m$ and $W = 7\mu m$. mreobility $\mu_m = 900 \frac{cm^2}{V\text{-}s}$. what is the value of drain current I_{ds}. Assume metal gate with $\varphi_m = 4.22\ ev$

(i) $V_{gs} < V_T$

(ii) $V_{gs} = 0.8\,V$ and $V_{ds} = 0.2\,V$

(iii) $V_{gs} = 1.8\,V$ and $V_{ds} = 2.2\,V$

Solution:

$$V_T = V_{FB} + 2\varphi_B + \frac{\sqrt{2q\epsilon_s 2\varphi_B N_A}}{C_{ox}}$$

$$\varphi_B = \frac{KT}{2} \ln\left(\frac{N_A}{n_i}\right)$$

$$= 0.0259 \ln\left(\frac{2\times10^{16}}{1.5\times10^{10}}\right)$$

$$= 0.365\ V$$

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

$$= 4.22 - \left(4.01 + \frac{1.12}{2} + 0.365\right)$$

$$= -0.715\ V$$

$$V_T = -0.715 + (2\times 0.365) + \frac{\sqrt{2\times 1.6\times 10^{-19}\times 11.7\times 8.854\times 10^{-14}\times 2\times 0.365\times 2\times 10^{16}}}{3.84\times 10^{-7}}$$

$= 0.196\ v$

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

$$= \frac{3.9\times 8.854\times 10^{-14}}{9\times 10^{-7}}$$

$= 3.84\times 10^{-7}\ F/cm^2$

(i) $V_x < 0.196\ v$

no cut off. no. φx

$I_{ds} = 0$

(ii) $V_{gs} = 0.8\ v > V_T = 0.196\ v$

$V_g - V_T = 0.8 - 0.196$

$= 0.604\ v$

$V_{gs} - V_T > V_{ds} = 0.2$

Lineare on mode

$$I_{ds} = \mu_m C_{ox} \frac{W}{L}\left[V_{gs} - V_T - \frac{V_{ds}}{2}\right] V_{ds}$$

$$= 900\times 3.84\times 10^{-7}\times \frac{7}{0.95}\times\left[0.8 - 0.196 - \frac{0.2}{2}\right]0.2$$

$= 2.37\times 10^{-4}\ A$

$= 0.257\ mA$