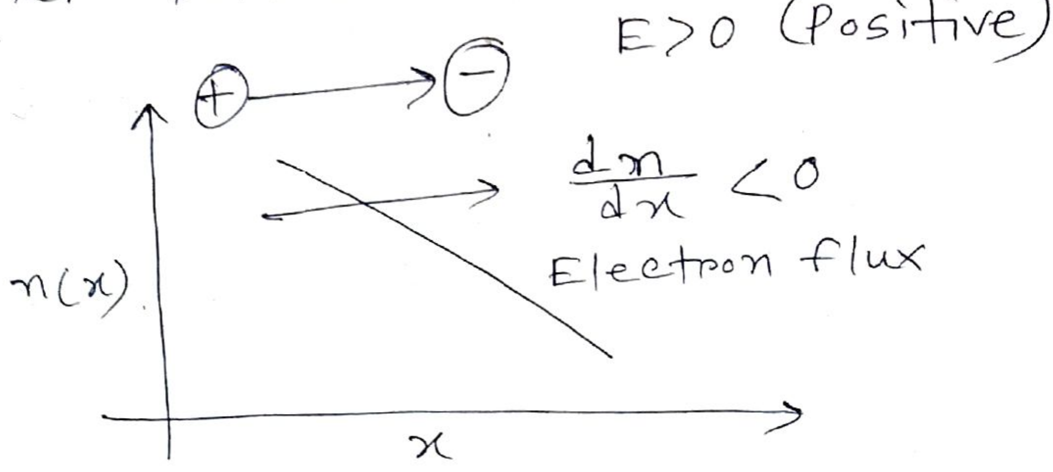
4.8.19

Final Starts

Carrier Diffusion:



$E_x = ?$

Example 5.5 :
From slide

$x = 0$

$E_x(x=0) = 25.9 \frac{V}{cm}$

$x = 1\ \mu m$
$= 10^{-4}\ cm$

$$E_x = -\frac{KT}{q} \frac{1}{N_D(x)} \frac{dN_D(x)}{dx}$$

$N_D(x) = 10^{16} - 10^{19} \cdot x$

$N_D(x = 10^{-4}\ cm) = 10^{16} - 10^{19} \times 10^{-4}$
$= 9 \times 10^{15} / cm^3$

$$E_x = -0.0259 \frac{1}{9 \times 10^{15}} (-10^{19})$$

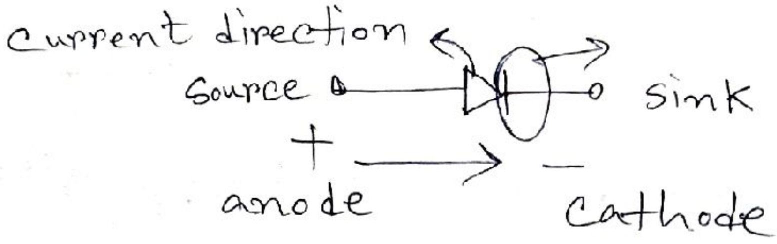
$$= 28.78 \frac{V}{cm}$$

(Ans)

$$\frac{KT}{q} = \text{Thermal Voltage}$$

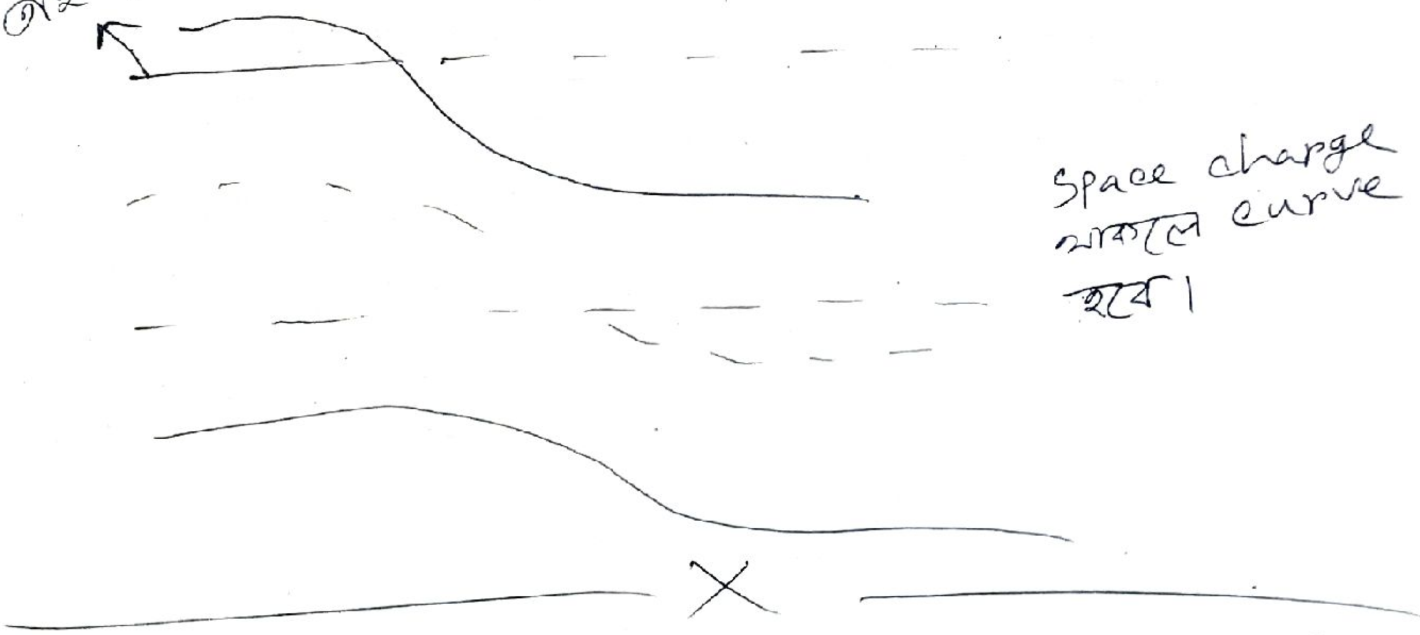
18-8-19

The pn Junction



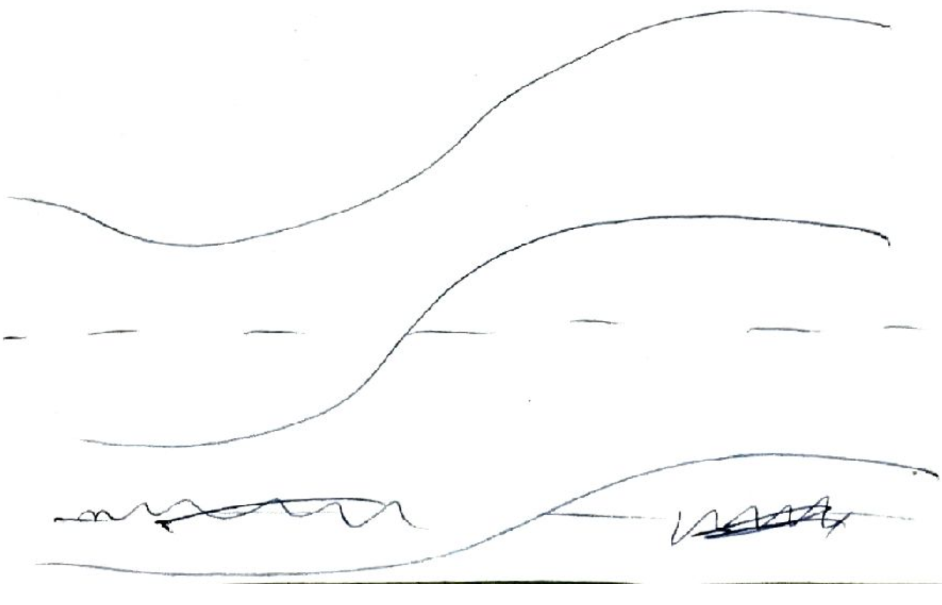
electron flux কিভাবে force কে oppose করছে

space charge নাই তাই flat



space charge থাকলে curve হবে।

np হলে এমন হবে



$$W = \left\{ \frac{2 \varepsilon_x V_{bi}}{e} \left[\frac{N_a + N_d}{N_a N_d} \right] \right\}^{\frac{1}{2}}$$

doping related

bariation বাড়লে depression width বাড়বে

20.8.19

Math: Calculate V_{bi}, x_n, x_p, w and E_{max} for a silicon pn junction diode at zero bias and T=300K for doping concentration of (a) $N_A = 2\times10^{17}/cm^3$, $N_D = 10^{16}/cm^3$, $\varepsilon_{Si}=11.7$

(a) $$V_{bi} = \frac{KT}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

$$= \frac{8.625\times10^{-5}\ eV/K \times 300K}{1e} \ln\left(\frac{2\times10^{17}\times10^{16}}{(1.5\times10^{10})^2}\right)$$

$$= 0.7715 = 0.772V$$

$$x_n = \sqrt{\frac{2\times11.7\times8.854\times10^{-14}\times \cancel{10}\times0.772}{1.6\times10^{-19}} \times\left(\frac{2\times10^{17}}{10^{16}}\right)\times\left(\frac{1}{2\times10^{17}+10^{16}}\right)}$$

$$x_n = \sqrt{\frac{2\varepsilon_s V_{bi}}{q}\frac{N_A}{N_D}\left(\frac{1}{N_A+N_D}\right)}$$

$$= 3.086\times10^{-5} cm \quad (1\mu m = 10^{-4} cm)$$

$$= 0.3086\ \mu m$$

x_p: charge neutrality:

$$N_D x_n = N_A x_p$$

$$x_p = \frac{N_D}{N_A} x_n$$

$$= \frac{10^{16}}{2 \times 10^{17}} \times 0.3086\,\mu m$$

$$= 0.0154\,\mu m$$

$$W = x_n + x_p$$

$$= 0.3086 + 0.0154\,\mu m$$

$$= 0.324\,\mu m$$

$$E = \frac{-qN_A}{\varepsilon_s}(x + x_p)$$

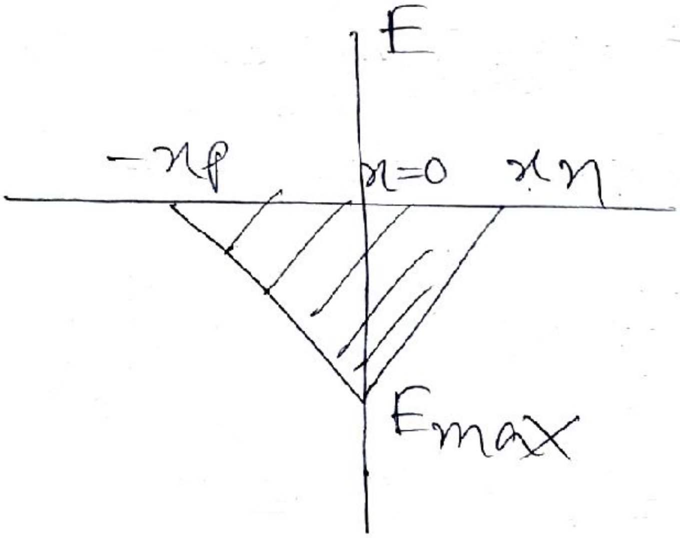
$$|E_{max}| = E|_{x=0} = \left| -\frac{qN_A}{\varepsilon_s} x_p \right|$$

$$= \frac{qN_A}{\varepsilon_s} x_p$$

$$E_{max} = \frac{1.6\times10^{-19}\times2\times10^{17}}{11.7\times8.854\times10^{-14}}\times0.0154\times10^{-4}$$

যেহেতু μm এ ছিল তাই

$$= 4.76\times10^{4}\ \frac{V}{cm}$$



$$\frac{1}{2}E_{max}\cdot W = V_{bi}$$

$$E_{max} = \frac{2V_{bi}}{W}$$

$$= \frac{2\times0.772}{0.324\times10^{-4}}\ \frac{V}{cm}$$

$$= 4.765\times10^{4}\ \frac{V}{cm}$$

(Finish)

Math: A Silicon p-n junction diode at $T = 300K$ has the following Parameters:
$N_A = 5\times 10^{16}/cm^3$, $N_D = 10^{16}/cm^3$, $D_n = 25\,\frac{cm^2}{s}$, $D_p = 10\,\frac{cm^2}{s}$, $\tau_{n0} = 5\times 10^{-7} s$, $\tau_{p0} = 10^{-7} s$.
Cross sectional area $A = 10^{-3}\ cm^2$. Forward bias voltage $= 0.625$ V. (i) calculate minority carrier diffusion current for electron, (ii) for hole and (iii) total current.

$$J_n(-x_p) = \frac{q D_n n_{p0}}{L_n}\left[\exp\left(\frac{qV_A}{KT}\right) - 1\right]$$

$$n_{p0} = \frac{n_i^2}{N_A} = \frac{(1.5\times 10^{10})^2}{5\times 10^{16}} = 4.5\times 10^{3}/cm^3$$

$$L_n^2 = D_n \tau_{n0} = 25\times 5\times 10^{-7}\ cm^2$$

$$L_n = 3.535\times 10^{-3}\ cm$$

$$J_n(-x_p) = \frac{1.6\times10^{-19}\times25\times4.5\times10^{3}}{3.535\times10^{-3}}\times$$

$$\left[\exp\left(\frac{0.625}{0.0259}\right)-1\right]$$

$$= 0.1538\ \frac{A}{cm^2}$$

(i) $I_n(-x_p) = J_n(-x_p)\times A$

$= 0.1538\times10^{-3}\,A$

$= 0.1538\ mA$

(ii) $J_p(x_n) = \frac{qD_p\,P_{n_0}}{L_p}\left[\exp\left(\frac{qV_A}{KT}\right)-1\right]$

$P_{n_0} = \frac{n_i^2}{N_D} = \frac{(1.5\times10^{10})^2}{10^{16}}$

$= 2.25\times10^{4}/cm^3$

$L_p^2 = D_p\tau_{p_0} = 10\times10^{-7} = 10^{-6}\,cm^2$

$L_p = 10^{-3}\,cm$

$$J_p(x_n) = \frac{1.6\times10^{-19}\times10\times2.25\times10^{4}}{10^{-3}}\left(\exp\left(\frac{0.625}{0.0259}\right)-1\right)$$

$$= 1.087\ \frac{A}{cm^2}$$

$$I_p(x_n) = J_p(x_n)\times A$$

$$= 1.087\times10^{-3}\,A$$

$$= 1.087\ mA$$

(iii) $I = I_n(-x_p) + I_p(x_n)$

$$= 0.1538 + 1.087\ mA$$

$$= 1.241\ mA$$

(Finish)

Math: For a P-substrate n-mos silicon capacitor, suppose $\phi_N = 4.18$ eV. The doping of the substrate $N_A = 4\times10^{16}/cm^3$ at $T = 300K$ and oxide thickness $= 8.8$ um. Find

(ia) V_{FB}

(ii) Total surface band banding ψ_s at invention.

(iii) Total depletion width at invension (depletion width maximum)

(iv) Threshold voltage.

$$V_{FB} = \overset{\text{given}}{\phi_{M}} - \phi_S$$

$$\phi_S = \chi_{Si} + \frac{E_g}{2} + \phi_B$$

$$\cancel{\phi_g =} \quad \phi_B = \frac{KT}{q} \ln\left(\frac{N_A}{n_i}\right)$$

$$= 0.0259 \ln\left(\frac{1 \times 10^{16}}{1.5 \times 10^{10}}\right)$$

$$= 0.383\,V$$

$$\phi_S = \chi_{Si} + \frac{E_g}{2} + \phi_B$$

Si এর জন্য জানা আছে

$$= 4.01 \left(\frac{eV}{e}\right) + \frac{1.12}{2} + 0.383$$

$$= 4.953\,V$$

(i) $$V_{FB} = 4.18\left(\frac{eV}{1e}\right) - 4.953$$

$$= -0.773\,V$$

(ii) $\Psi_S = 2\phi_B$

$= 2 \times .383$

$= .766\ V$

(iii) $W_d\ (max) = \sqrt{\dfrac{2\varepsilon_S \phi_S\ (in\ V)}{q N_A}}$

$W_d\ (max) = \sqrt{\dfrac{2 \times 11.7 \times 8.854 \times 10^{-14} \times 0.766}{1.6 \times 10^{-19} \times 4 \times 10^{16}}}$

$= 1.575 \times 10^{-5}\ cm = 0.158\ \mu m$

(iv) $Q_{dep}\ (max)$

$= q N_A W_d\ (max)$

$C_{ox} = \dfrac{\varepsilon_{ox}}{t_{ox}} = \dfrac{3.9 \times 8.854 \times 10^{-14}}{8.8 \times 10^{-7}}$

$= 3.924 \times 10^{-7}\ F/cm^2$

$V_4 = V_T$ (threshold voltage)

$= V_{FB} + \psi_S(inv) + \dfrac{qN_A W_d(max)}{C_{ox}}$

$= -0.773 + 0.766 + \dfrac{1.6 \times 10^{-19} \times 4 \times 10^{16} \times 1.375 \times 10^{-5}}{3.924 \times 10^{-7}}$

$= 0.249 \cong 0.25V$

(finish)

g_m (trans conductance) $= \frac{\partial I_{ds}}{\partial V_{gs}}$

g_d (output conductance) $= \frac{\partial I_{ds}}{\partial V_{ds}}$

Math: For a n-channel enhancement mode silicon mosfet, suppose,

$N_A = 1.8 \times 10^{16}/cm^3$, $t_{ox} = 9.5\,nm$,

$L = 0.95\,\mu m$, $W = 8.5\,\mu m$. At $t = 300K$,

assume, metal gate with $\phi_m = 4.25\,ev$.

$\mu_n = 910\,\frac{cm^2}{V\text{-}s}$

calculate (a) V_t of the device

(b) $V_G = 0.1V$, what is I_{ds}?

(c) $V_G = 0.8V$, and $V_{ds} = 0.15V$, what is I_{ds}?

(d) $V_n = 1.3V$, $V_{ds} = 2V$, what is I_{ds}?

(i) V_T calculation,

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

$$= 0.0259 \ln\left(\frac{1.8\times10^{16}}{1.5\times10^{10}}\right)$$

$$= 0.363V$$

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

$$= 4.35 - \left(4.01 + \frac{1.12}{2} + 0.363\right)$$

$$= -0.683V$$

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

$$= \frac{3.9\times8.854\times10^{-14}}{9.5\times10^{-7}} \; F/cm^2$$

$$= 3.63\times10^{-7} \; F/cm^2$$

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

$$= -0.683 + (2\times0.363) + \frac{\sqrt{2\times1.6\times10^{-19}\times11.7\times8.854\times10^{-14}\times2\times0.363\times1.8\times10^{16}}}{3.63\times10^{-7}}$$

$= 0.224V$

(ii) $V_{in} = 0.1V < V_T$

$\theta_4 \approx 0$ or negligible

$I_{ds} = 0$ or negligible (cut off)

(iii) $V_{ds} - V_T = 0.8 - 0.22$

$= 0.58V > V_{ds} (0.15V)$

linear region

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

$$= 910 \times 3.63 \times 10^{-7} \times \frac{8.5}{0.95} \left[0.58 - \frac{0.15}{2} \right] \times 0.15$$

$= 2.24 \times 10^{-4} A$

$= 0.224 mA$

(iv) $V_{GS} = 1.5V$

$V_{GS} - V_T = 1.5 - 0.22 = 1.28$

$V_{DS} = 2V > V_{GS} - V_T$

saturation region

$V_{ds}(sat) = 1.28V = V_{GS} - V_T$

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

$$= 910 \times 3.63 \times 10^{-7} \times \frac{8.5}{0.95} \times \frac{(1.28)^2}{2}$$

$$= 2.42 \times 10^{-3} A$$

$$= 2.42 mA$$

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linear এর চেয়ে saturaএর value বেশি হবে, তবে হলে ভুল হয়েছে math টা