02/08/19

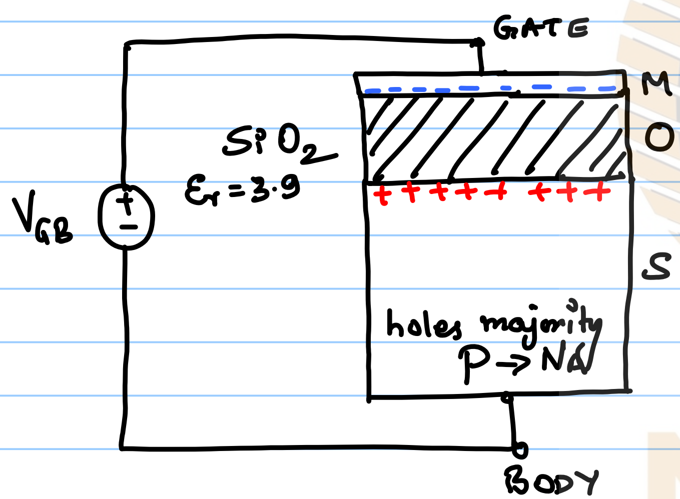
EE5311

MODULE 1: THE TRANSISTOR

1) LAW OF MASS ACTION: $np = n_i^2$
2) MAXWELL BOLTZMAN LAW: $n_1/n_2 = e^{(q\psi_{12}/kT)}$ ① $n_1 \xleftarrow{\psi_{12}} \xrightarrow{} n_2$ ②
3) $W_N N_D = W_P N_A \Rightarrow N_D \gg N_A \Rightarrow W_P \gg W_n$

MOS CAPACITOR

MOS → METAL OXIDE SEMICONDUCTOR



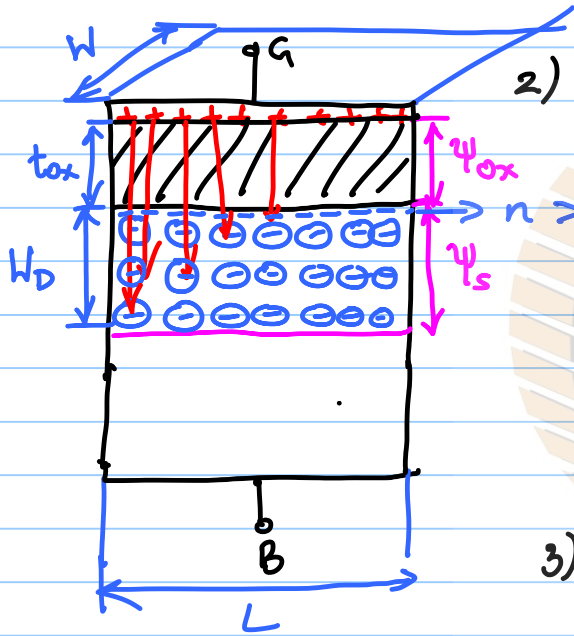
$N_A \to$ BORON CONC $10^{15}/cm^3$

$p = N_A$

$n = n_i^2 / N_A$

1) $V_{GB} < 0$ → ACCUMULATION

2) $V_{GB} > 0$



2) $V_{GB} > 0 \longrightarrow$ DEPLETION

$$n_s = n_B e^{\frac{q\psi_s}{KT}}$$

$$\psi_s = \frac{KT}{q} \ln\left(\frac{n_s}{n_B}\right)$$

PINNED $\rightarrow$ when $n_s = N_A$

3) $V_{GB} > V_{TH} \longrightarrow$ INVERSION

$$\psi_s = \frac{KT}{q} \ln\left(\frac{N_A}{n_i^2/N_A}\right) = 2\frac{KT}{q} \ln\left(\frac{N_A}{n_i^2}\right)$$

$$\boxed{\psi_s = 2\frac{KT}{q} \ln\left(\frac{N_A}{n_i^2}\right)}$$

$V_{TH} \rightarrow$ THRESHOLD VOLTAGE $\rightarrow$ GATE POTENTIAL NEEDED TO "INVERT" THE SURFACE

$$V_{GB} = \psi_s + \psi_{ox}$$

$$\psi_{ox} = -\frac{(Q_D' + Q_I')}{C_{ox}'}.$$

$$C_{ox}' = \frac{\varepsilon_r \varepsilon_0 WL}{t_{ox}} \rightarrow C_{ox} = \frac{\varepsilon_r \varepsilon_0}{t_{ox}}$$

$Q_D', Q_I' \rightarrow$ charge $\qquad Q_D, Q_I \rightarrow$ charge per unit area.

$$Q_D' = q \cdot N_A \cdot (WL \cdot W_D)$$

$$W_D = \sqrt{\frac{2\varepsilon_{si}|\psi_s|}{qN_A}} \Rightarrow Q_D' = qN_A\left(WL \cdot \sqrt{\frac{2\varepsilon_{si}|\psi_s|}{qN_A}}\right)$$

$$\Rightarrow \quad Q_D' = \left(\sqrt{2\varepsilon_{si}|\psi_s| q N_A}\right) WL$$

$$\Rightarrow \quad Q_D = \sqrt{2\varepsilon_{si}|\psi_s| q N_A}$$

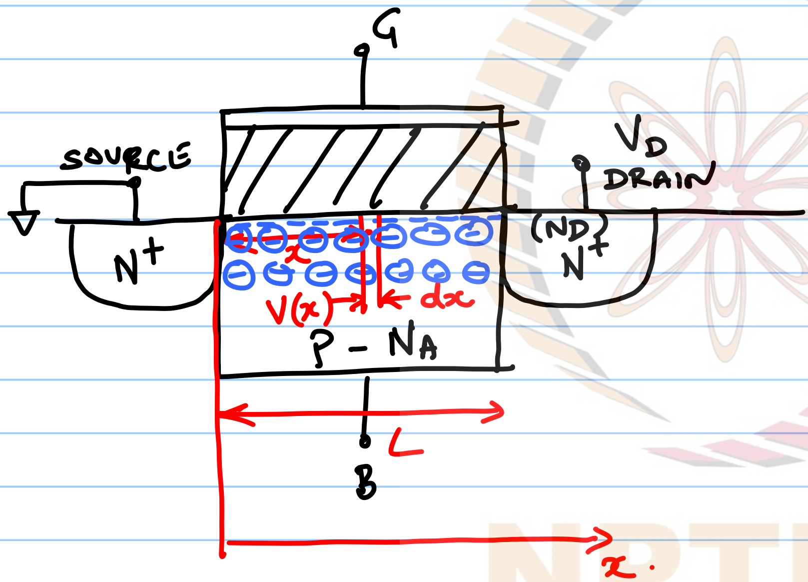
$$V_{GB} = \left(\psi_s - \frac{Q_D'}{C_{ox}'}\right) - \frac{Q_I'}{C_{ox}'}$$

$$Q_I' = -C_{ox}' \left(V_{GB} - V_{TH}\right)$$

$$V_{TH} = \psi_s - \frac{1}{C_{ox}'} \cdot \sqrt{\underset{\downarrow}{2\varepsilon_{si}}|\psi_s| q N_A}$$

$\varepsilon_{r,si} \varepsilon_0$.

MOS TRANSISTOR



$N^+ \rightarrow$ N-TYPE SEMI COND WITH LARGE DOPING ($N_D \sim 10^{17} - 10^{18}/cm^3$)

$V(0) = 0$

$V(L) = V_D.$

$$Q_I = -C_{ox}(V_G - V_T - V)$$

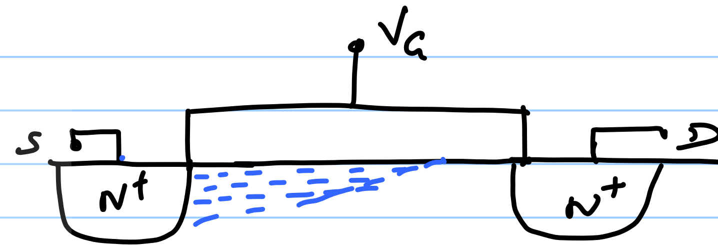
$$dQ_I' = Q_I W dx.$$

$$I_D \leftarrow \frac{dQ_I'}{dt} = -C_{ox}(V_G - V_T - V) \cdot W \underbrace{\frac{dx}{dt}}_{v_d \text{ (drift velocity)}}.$$

$$\therefore \quad I_D = -C_{ox}(V_G - V_T - V)\, v_d \cdot W$$

$$v_d = \mu_n E$$

$$= -\mu_n \frac{dV}{dx}$$



$$\therefore \quad \int_0^L I_D\,dx = \int_0^{V_D} +\mu_n C_{ox} W \,(V_G - V_T - V)\,dV$$

$$\therefore \quad I_D \cdot L = \mu_n C_{ox} W \left[(V_G - V_T)V_D - \frac{V_D^2}{2}\right]$$

$$\therefore \quad I_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2}\right] \longrightarrow \text{LINEAR}$$

$V_{DS} \uparrow$ at the source $(V_G - V_T) \rightarrow$ inversion

Drain $(V_G - V_T - V_D)$

$$I_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS}-V_T)(V_{GS}-V_T) - \frac{(V_{GS}-V_T)^2}{2}\right]$$

$$V_{GS}-V_T-V_{DS} > 0$$

$$V_{DS} \leq V_{GS}-V_T$$

$$= \frac{1}{2}\mu_n C_{ox} \frac{W}{L}(V_{GS}-V_T)^2 \longrightarrow \text{SATURATION}$$