02/08/19

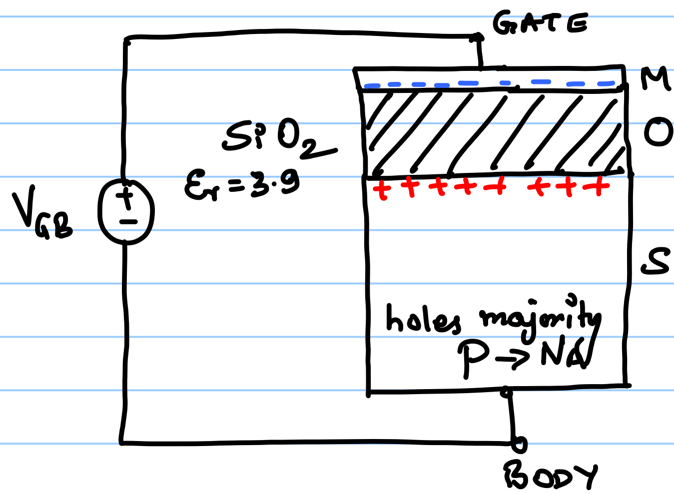
# EE5311

## MODULE 1: THE TRANSISTOR

1) LAW OF MASS ACTION: $np = n_i^2$
2) MAWELL BOLTZMAN LAW: $n_1/n_2 = e^{(q\psi_{12}/kT)}$ $\quad \overset{1}{n_1} \leftarrow \psi_{12} \rightarrow \overset{2}{n_2}$
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

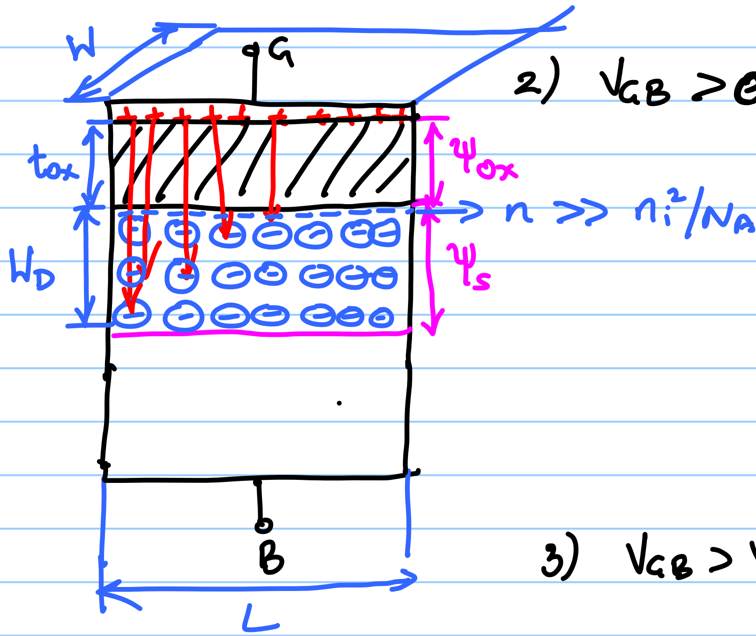



$N_A \to$ BORON CONC $10^{15}/cm^3$

$p = N_A$
$n = n_i^2/N_A$

1) $V_{GB} < 0 \rightarrow$ ACCUMULATION

2) $V_{GB} > 0$




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

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

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

$\downarrow$

PINNED $\longrightarrow$ 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.

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

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

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

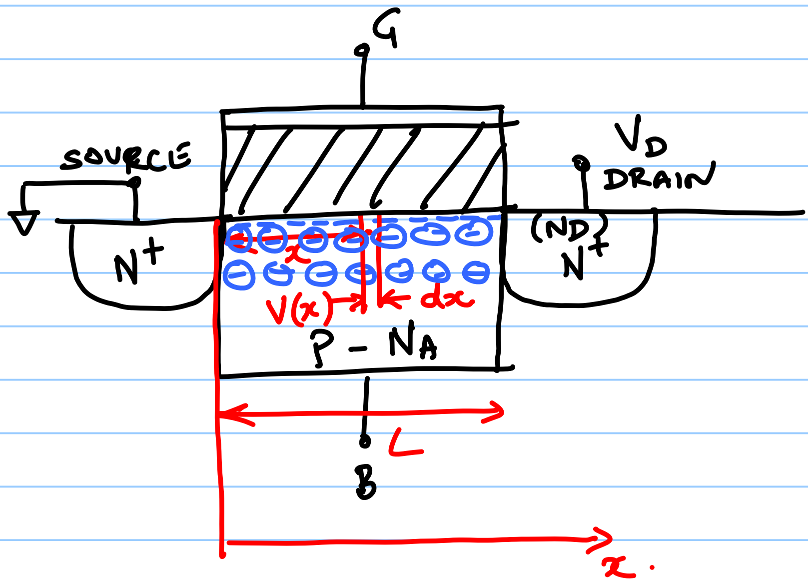
$$\Rightarrow \quad Q_D = \sqrt{2\varepsilon_{si}|\psi_s| q N_A}$$

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

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

$$V_{TH} = 2\psi_s - \frac{1}{C_{ox}'} \cdot \sqrt{2\underbrace{\varepsilon_{si}}_{\varepsilon_{r,si}\,\varepsilon_0}|\psi_s| q N_A}$$

## MOS TRANSISTOR




$N^+ \rightarrow$ N-TYPE SEMI COND WITH LARGE DOPING ( $N_D \sim 10^{17} - 10^{19} /cm^3$ )

$V(0) = 0$

$V(L) = V_D$.

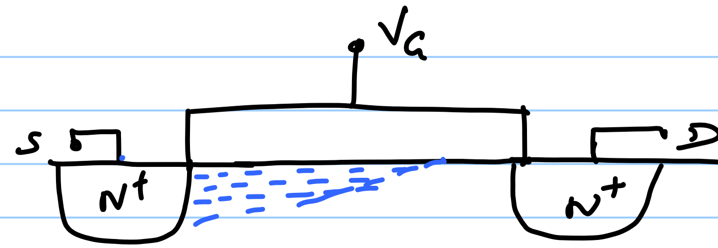
$Q_I = -C_{ox}(V_G - V_T - V)$

$dQ_I' = Q_I W dx$.

$$I_D \leftarrow \frac{dQ_I'}{dt} = -C_{ox}(V_G - V_T - V) \cdot W \frac{dx}{dt}.$$

$\frac{dx}{dt} \rightarrow v_d$ (drift velocity)

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




$$v_d = \mu_n E$$

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

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

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

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

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

Drain $(V_G - V_T - V_D)$

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

$$V_{GS} - V_T - V_{DS} \geq 0$$

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

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