Lec 14: MOSFETs

$\Rightarrow$ $$\boxed{V_G = \phi_s + \gamma\sqrt{\phi_s}} = 2\phi_f + \gamma\sqrt{2\phi_f}$$

V_G ↑ Gate voltage.

ϕ_s ↑ Surface potential

$\rightarrow \frac{\Delta E_2}{q} = \frac{\Delta E_1}{q}$

Strong inversion

$$\Delta E_2 = KT \ln \frac{N_D}{n_i} = q\phi_f$$

$$\phi_s = \frac{1}{q}(\Delta E_2 + \Delta E_1) = \overbrace{\frac{2}{q}\Delta E_2}^{2\phi_f} = \frac{2KT}{q}\ln\frac{N_D}{n_i}$$

$$\Rightarrow V'_{T_0} = \overbrace{\frac{2KT}{q}\ln\frac{N_D}{n_i}}^{2\phi_f} + \gamma\sqrt{\underbrace{\frac{2KT}{q}\ln\frac{N_D}{n_i}}_{2\phi_f}}$$

$$\phi_f = \frac{KT}{q}\ln\left(\frac{N_D}{n_i}\right)$$

> Correction factors

① $\phi_{ms} = q(\Phi_m - \Phi_s) \longrightarrow$ Offset applied to get to flat band response.

② $\frac{Q_{ss}}{C_{ox}}$ is an additional voltage due to charges trapped at $S_i - Ox$ interface.

$$V_{FB} = \phi_{ms} - \frac{Q_{ss}}{C_{ox}} - \frac{Q_I}{C_{ox}}$$

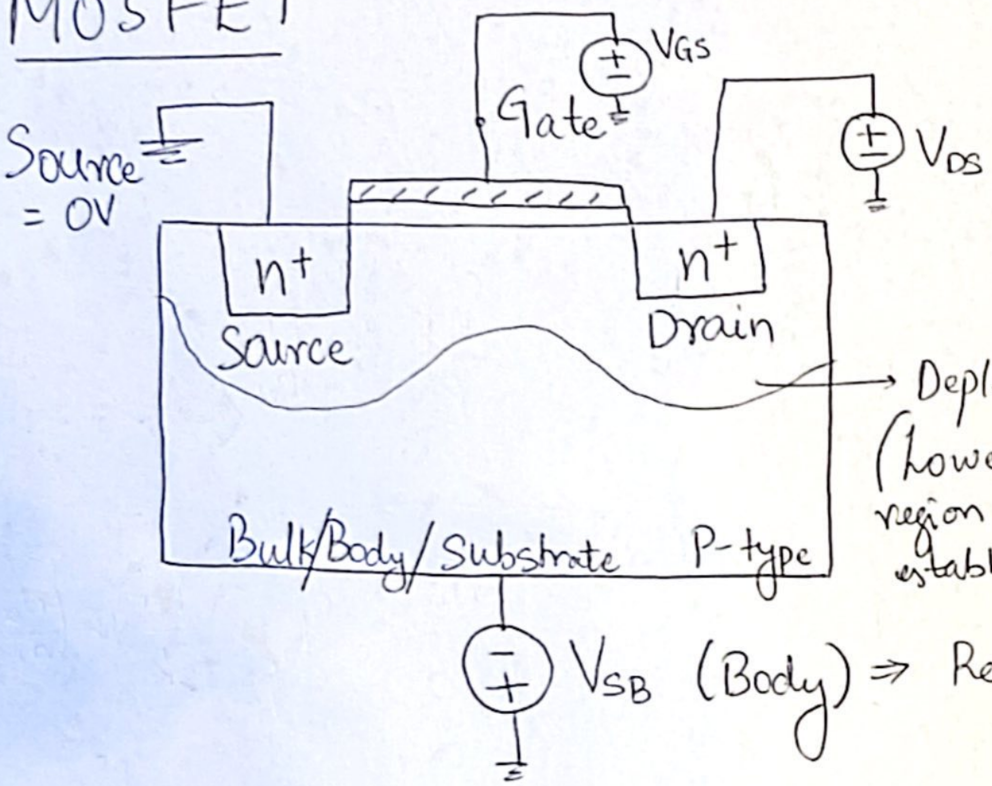
(Q_I → implantation charge.)

is the "flat band voltage" which needs to applied to get to a flat band.

$$\boxed{V_{TO} = V_{FB} + 2\phi_f + \gamma\sqrt{2\phi_f}}$$ ⇒ Threshold voltage

Voltage applied to reach strong inversion

MOSFET



Depletion region.
(Lower V_{SB} ⇒ larger depletion region ⇒ need more V_G to establish the channel).

V_{SB} (Body) ⇒ Reverse bias p-n junctions.

> The n^+ wells (charge supply since highly doped) now acts as a large source & sink of minority carriers to enable faster "Strong inversion".

> Note a fourth "body terminal". This voltage changes the size of the depletion region. Therefore both V_{GS} & V_{SB} control the surface charge distribution.

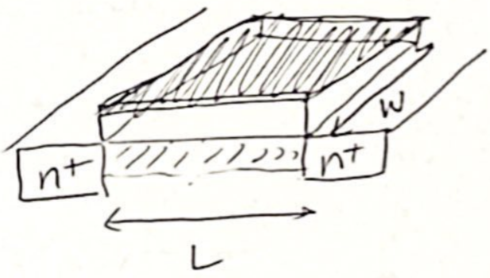
Recall,

$$V_{T\emptyset} = \underbrace{V_{FB}}_{\text{constant to account for assumptions}} + \underbrace{2\phi_f}_{\text{Definition of Strong inversion}} + \gamma\sqrt{2\phi_f + V_{SB}}$$

- V_{FB}: constant to account for assumptions
- $2\phi_f$ (SC): Definition of Strong inversion
- $\gamma\sqrt{2\phi_f + V_{SB}}$ (oxide) ← Body Effect.
- V_{SB} ~~is applied~~ appears across the oxide ⇒ Square root dependance.

Current - Voltage Relationship (Assume V_{DS} is small).

> Total charge in channel



~~$q_{ch} = W \cdot L \cdot Q_{inv}$ → total charge per unit height~~

$$q_{ch} = C \cdot (V_{GS} - V_{th}) \rightarrow \text{(ignoring changes stored during weak inversion.)}$$

$$= C_{ox} \cdot W \cdot L \cdot (V_{GS} - V_{th}).$$

> Avg. time for electron to go from Source to drain

$$\tau_F = \frac{L}{v_d} = \frac{L}{\mu_n E} = \frac{L}{\mu_n \cdot \frac{V_{DS}}{L}} = \frac{L^2}{\mu_n V_{DS}}.$$

- v_d: drift velocity
- μ_n: mobility of e^-

$$\Rightarrow \quad I_D = \frac{q_{ch}}{\tau_F} = \frac{WL\,C_{ox}(V_{GS}-V_T)}{\frac{L^2}{\mu_n V_{DS}}}$$

Equivalent to Saturation in BJT

↑

Triode (aka linear) ⇐

$$\boxed{I_D = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T) V_{DS}}$$

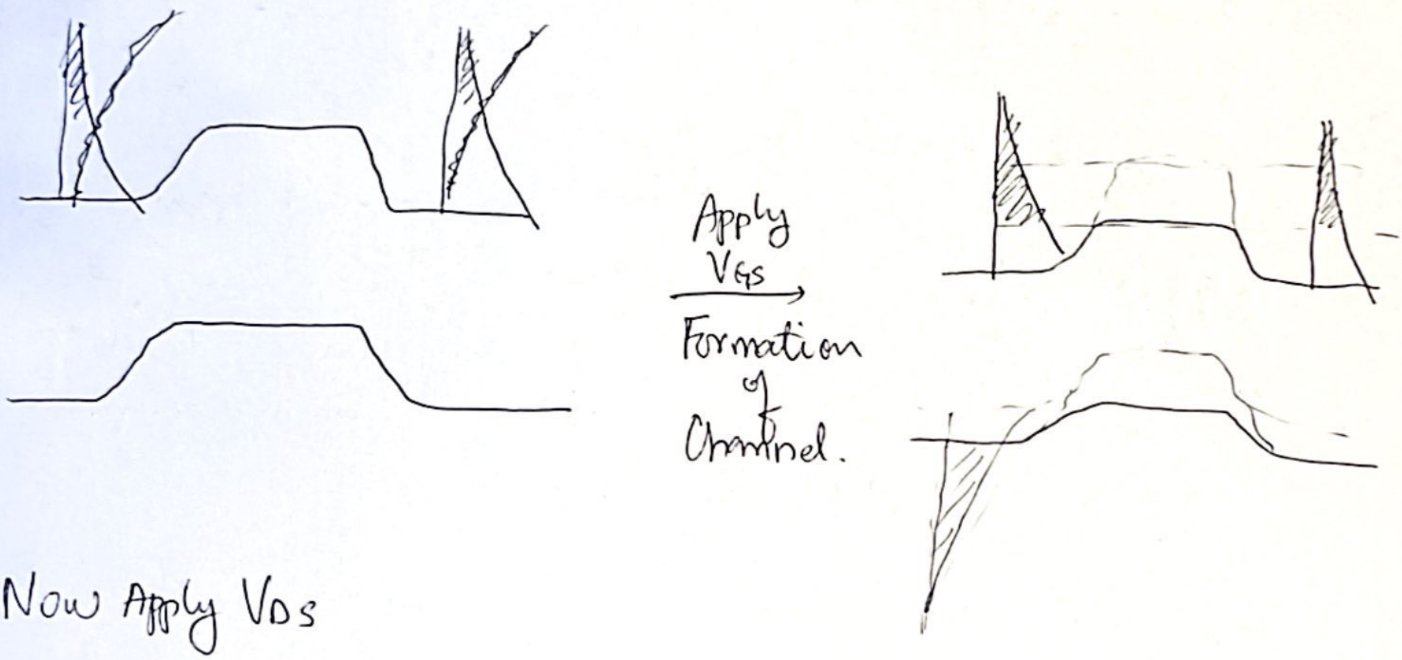
V_{GS} large V_{DS} small

for small V_{DS}.

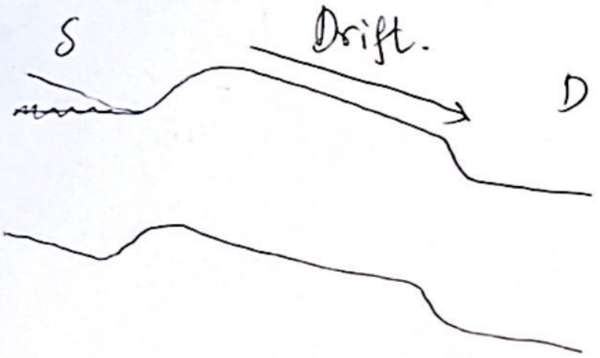
→ "Trans Resistor"

(Not a real resistor ⇒ not due to constant conductivity).

Energy Band Picture



Now Apply V_{DS}



> I_D is therefore a drift current.