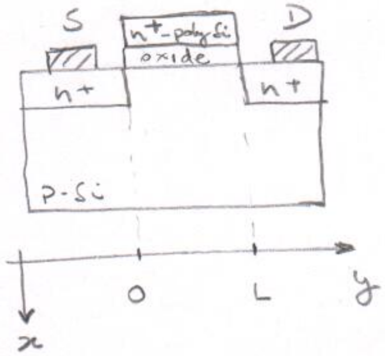
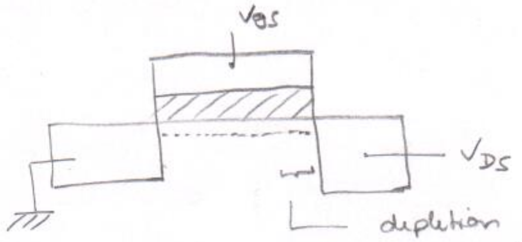
Cours 22

Ideal MOSFET :



1) $V_{GS} < V_t$. no inversion : $I_D = 0$

2) $V_{GS} > V_t$ = inversion



depletion on the drain side in saturation

a) $\underline{V_{DS} = 0}$ $\Rightarrow$ $I_D = 0$

no electric field $\Rightarrow$ no current

b) $\underline{V_{DS} > 0 \quad \text{but small}}$ $\Rightarrow$ I_D varies linearly with V_{DS}

Linear regime

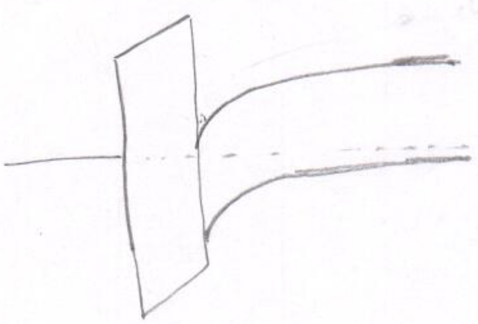
c) $V_{DS} > 0$ but large such as

$$V_{GS} - V_{DS} < V_T$$

or $\qquad V_{GD} < V_T \qquad \Rightarrow$ Saturation regime

We want to calculate the current:

1st order : consider device under inversion



electrons are confined in between the oxide and semiconductor

$\Rightarrow$ electrostatic potential forms a <u>well</u> for electrons

sheet charge approximation :

$$n_s(y) = \int_0^\infty n(x,y)\, dx \qquad [cm^{-2}]$$

then, the current can be written:

$C \cdot [cm^{-2}] \times cm \times cm/s = A$

$J = q \cdot v_{e_y} \cdot n_s \Rightarrow I = - \underbrace{q \cdot n_s(y)}_{Q_s \text{ : sheet charge density}} \cdot W \cdot v_{e_y}(y)$

for small enough $\vec{E}$:

- $v_{e_y}(y) = \mu \cdot E_y(y)$

- $V(y) = \underbrace{\phi_s(y)}_{\text{surface potential at } y} - \underbrace{\phi_s(y=0)}_{\text{source located at } y=0}$

- $E_y(y) = - \dfrac{\partial V(y)}{\partial y}$

But in MOS under inversion: $Q_s = - C_{ox} \cdot (V_{GS} - V_T)$

$\Rightarrow$ this is the charge density at the source-end.

For the rest of the channel:

$$Q_s(y) = - C_{ox} \cdot \left(V_{GS} - V_T - V(y) \right)$$

Let's come back to the current:

$$I_e = - Q_s(y) \cdot W \cdot \mu \cdot E_y(y) = - I_{Drain}$$

$$= - C_{ox} \cdot (V_{GS} - V_T - V(y)) \cdot W \cdot \mu \cdot \frac{\partial V(y)}{\partial y}$$

thus:

$$\boxed{I_D = C_{ox} \cdot W \cdot \mu \cdot \left(V_{GS} - V_T - V(y) \right) \cdot \frac{\partial V(y)}{\partial y}}$$

1) <u>cut-off</u>:

$$\begin{cases} V_{GS} < V_T \\ V_{DS} \geq 0 \end{cases} \Rightarrow \text{no inversion layer}$$

2) <u>Linear</u>

$$\begin{cases} V_{GS} > V_T \\ V_{GD} > V_T \end{cases}$$

$$I_{DS} \uparrow \quad \text{if}: \begin{cases} V_{GS} \uparrow \Rightarrow Q_s \uparrow \\ V_{DS} \uparrow \Rightarrow E_y \uparrow \end{cases}$$ similar to a triode vacuum tube

separate variables:

$$\int_0^L I_e \, dy = \int_0^{V_{DS}} -W \cdot \mu \cdot C_{ox} \cdot (V_{GS} - V_T - V) \, dV \qquad \begin{matrix} y=0 & V=0 \\ y=L & V=V_{DS} \end{matrix}$$

$$I_e \cdot L = -W \cdot \mu \cdot C_{ox} \cdot \left[(V_{GS} - V_T) \cdot V_{DS} - \frac{V_{DS}^2}{2} \right]$$

$$\therefore \boxed{I_D = \frac{W \cdot \mu \cdot C_{ox}}{L} \cdot \left[(V_{GS} - V_T) \cdot V_{DS} - \frac{V_{DS}^2}{2} \right]}$$

Point with less charges: <u>$y = L$</u>

$$Q_i(y=L) = -C_{ox} (V_{GS} - V_T - V_{DS})$$

thus: $V_{DS} < V_{GS} - V_T \Rightarrow V_{GD} > V_T$ to be in linear <u>region</u>.