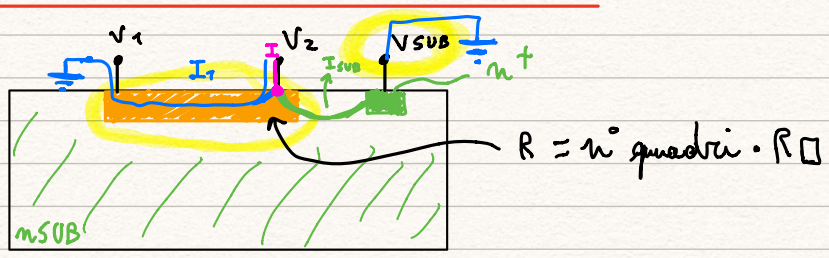
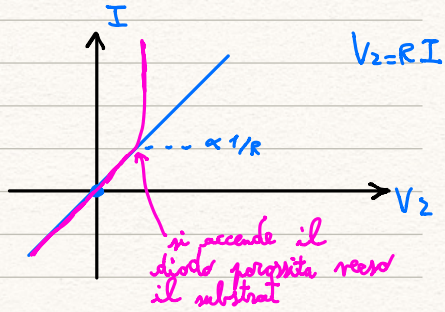
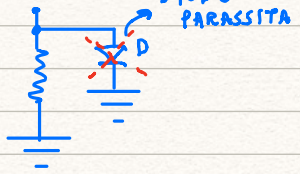
I TRANSISTORI MOS:

EFFETTO DELLA POLARIZZAZIONE DEL SUBSTRATO SULLA CARATTERISTICA IV DI UN RESISTORE INTEGRATO:





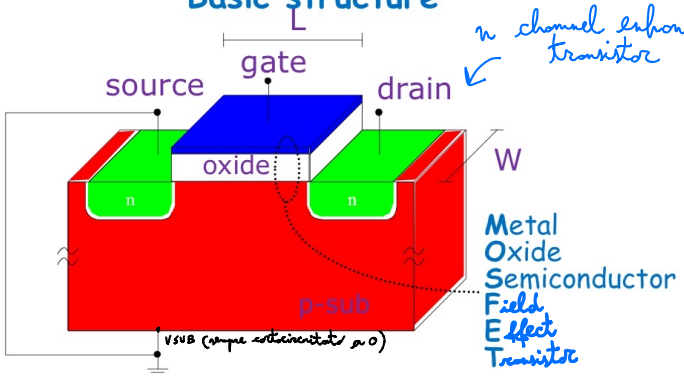


n - SUB polarizzato V_{SUB} > tensioni in gioco

p - SUB polarizzato

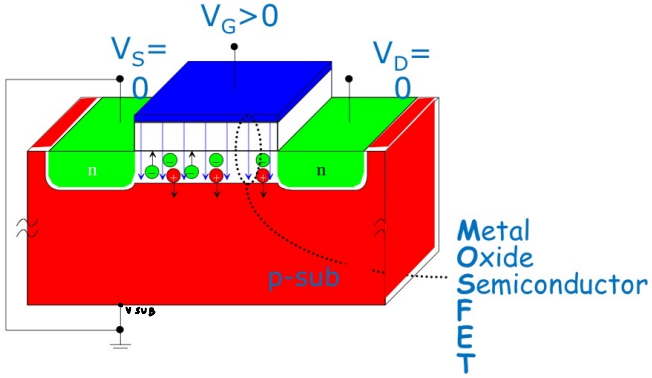
MOSFET operating principle - I

Basic structure

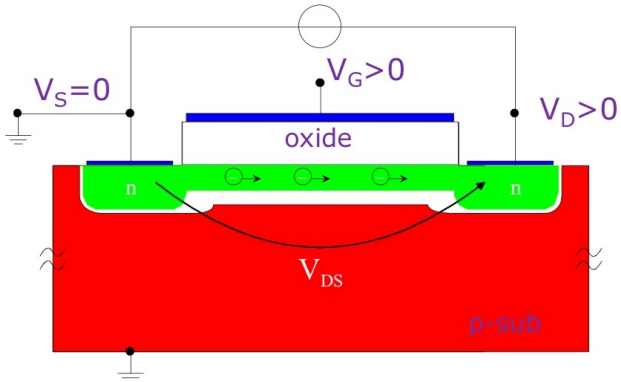


n channel enhancement transistor

The gate contact

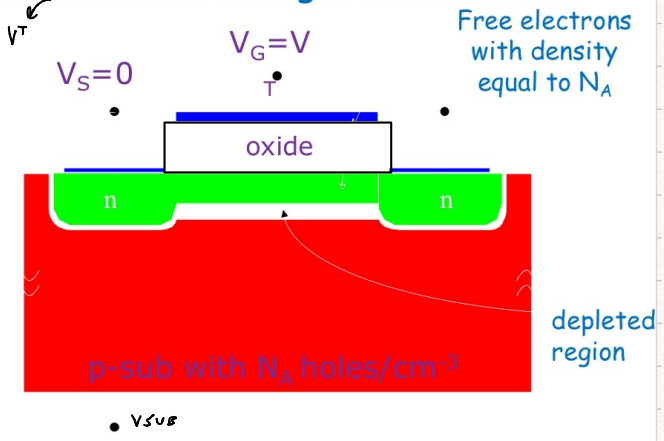


The conducting channel is formed ...



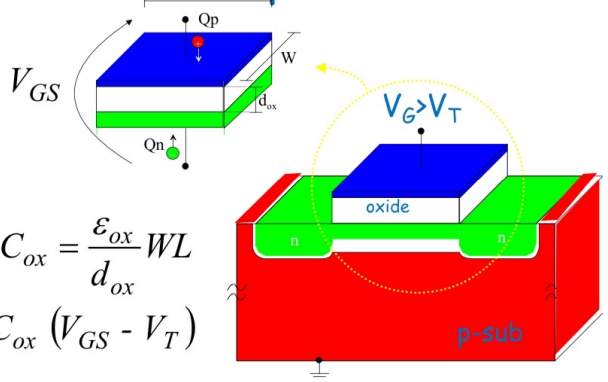
current can flow between D and S!

The threshold voltage: INVERSION



MOSFET operating principle – II

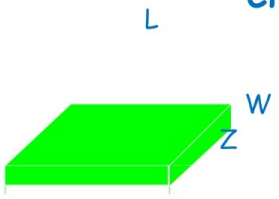
MOS capacitor



$$C_{gate} = C_{ox} = \frac{\varepsilon_{ox}}{d_{ox}} WL$$

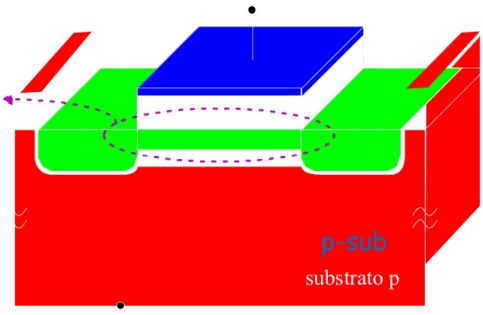
$$Q_n = C_{ox}\left(V_{GS} - V_T\right)$$

Channel resistance

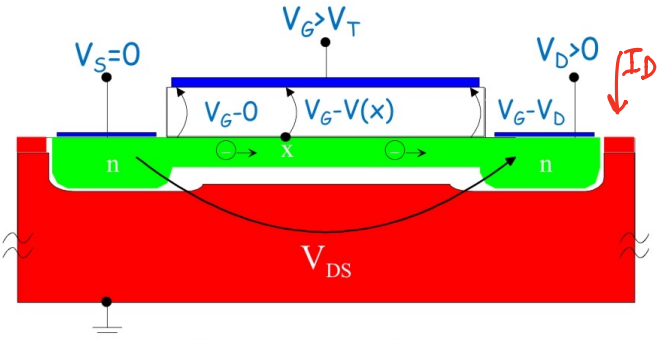


$$R_{ch} = \rho \frac{L}{W \cdot Z} =$$

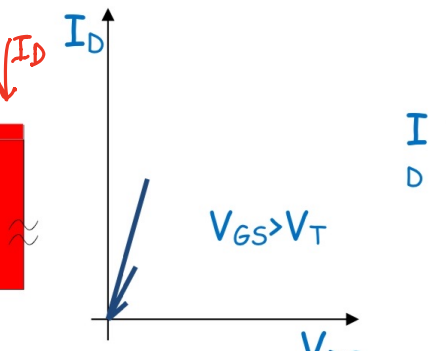
$$= \frac{1}{\mu_n C_{ox}} \frac{L}{W} \frac{1}{(V_{GS} - V_T)}$$



MOS as variable resistor: OHMIC region



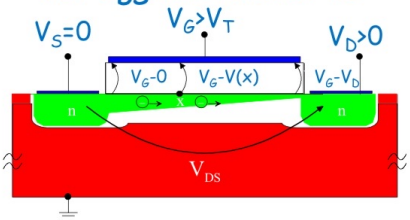
$$I_D = \frac{V_{DS}}{R_{ch}} = \mu_n C_{ox} \frac{W}{L}\left(V_{GS} - V_T\right)$$

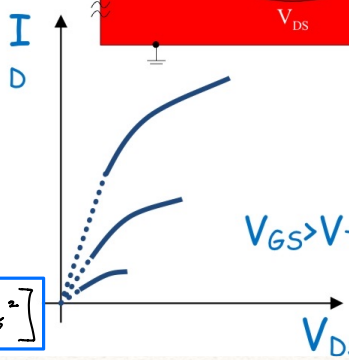


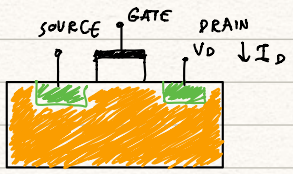
$I_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L}\left[2(V_{GS} - V_T)V_{DS} - V_{DS}^2\right]$

curva caratteristica

as V_{DS} increases …







TENSIONE DC al terminale di DRAIN

V_D

V_S = tensione DC al terminale di source

V_G = tensione DC al terminale di gate

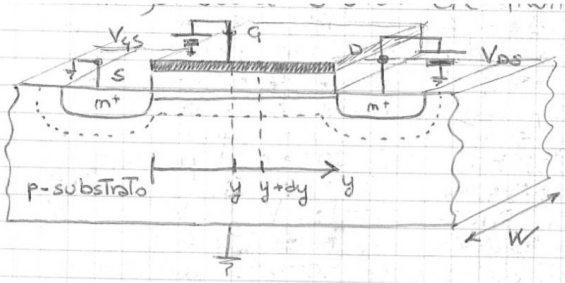
I_D = corrente DC entrante nel morsetto di drain

$V_{DS} = V_D - V_S$
$V_{GS} = V_G - V_S$
$V_{GD} = V_G - V_D$
} differenze di potenziale

"depletion" = transistor che cercavano di ridurre la popolazione di elettroni liberi tramite una differenza di potenziale. Opposti agli enhancement transistor, sono ora inutilizzati.

MOSFET operating principle – X

Gradual Channel approximation



Sia $V(y)$ la tensione ad un generico punto y nel canale rispetto al source tenuto a massa, allora la carica inotta per unità di area nel canale è pari a:

$$q(y) = C_{ox}\left[V_{GS} - V(y) - V_T\right]$$

e la resistenza dR di un tratto di canale è data da:

$$dR = \frac{dy}{W \cdot \mu_n \cdot q(y)}$$

Quindi la caduta di tensione dV è data da:

$$dV = I_D \cdot dR = \frac{I_D}{W \cdot \mu_n \cdot q(y)}\,dy = \frac{I_D}{W \mu_n C_{ox}\left[V_{GS} - V(y) - V_T\right]}\,dy$$

Se separiamo le variabili ed integriamo:

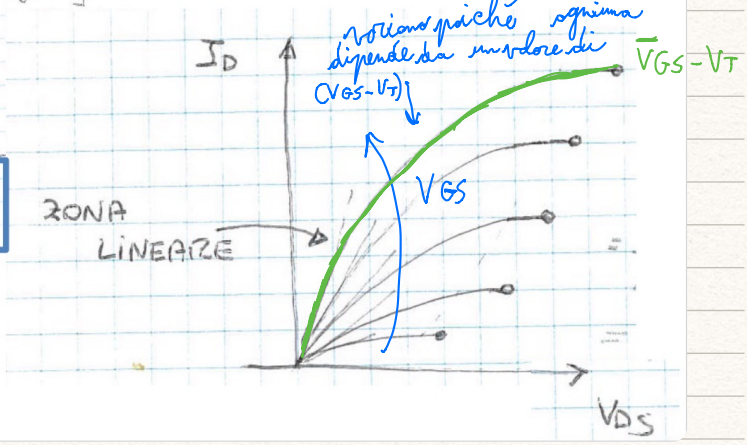
$$\int_0^L I_D \cdot dy = \int_0^{V_{DS}} W \mu_n C_{ox}\left[V_{GS} - V - V_T\right] dV$$

$$\Downarrow$$

$$\boxed{I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left[2\left(V_{GS} - V_T\right)V_{DS} - V_{DS}^2\right]}$$

$V_{DS} = V_{GS} - V_T \longrightarrow V_D = V_G - V_T$

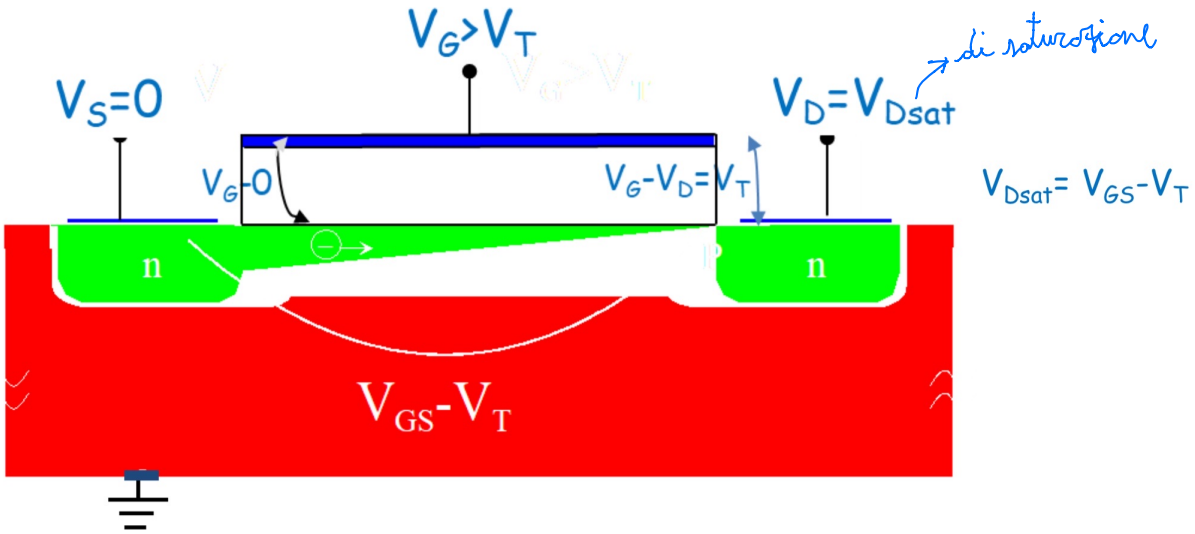
$V_{GD} = V_T$



La concentrazione di elettroni nel canale si annulla se $V_{GD} = V_T$.

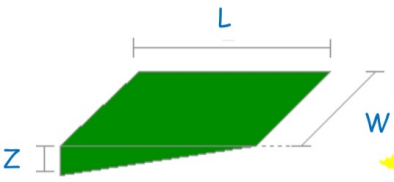
MOSFET operating principle – XI

Channel pinch-off: saturation region



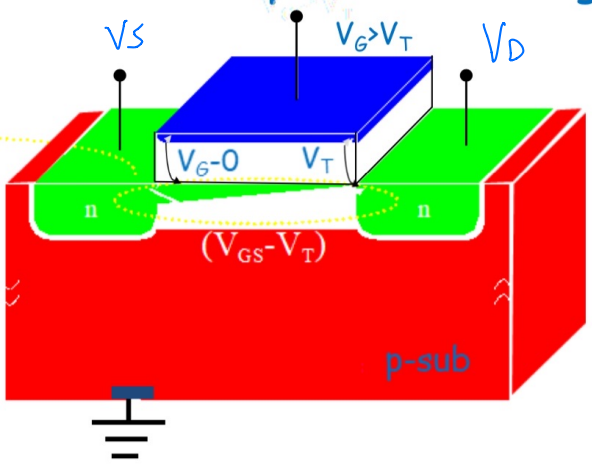
MOSFET operating principle - XII

Current at pinch-off voltage



$$R_{sat} = 2 \cdot R_{ch}$$

$$R_{ch} = \rho \frac{L}{W \cdot Z} = \frac{1}{\mu_n C_{ox}} \frac{L}{W} \frac{1}{(V_{GS} - V_T)}$$



$$I_D = \frac{(V_{GS} - V_T)}{R_{sat}} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2$$

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} \left[2 (V_{GS} - V_T) V_{DS} - V_{DS}^2 \right]$$

(nome che deriva dalla ondata)

Drain Current in Triode Region

ZONA OHMICA

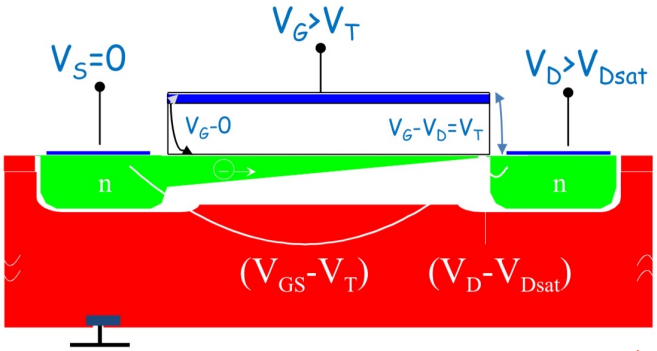
$$V_{DS} = V_{GS} - V_T$$

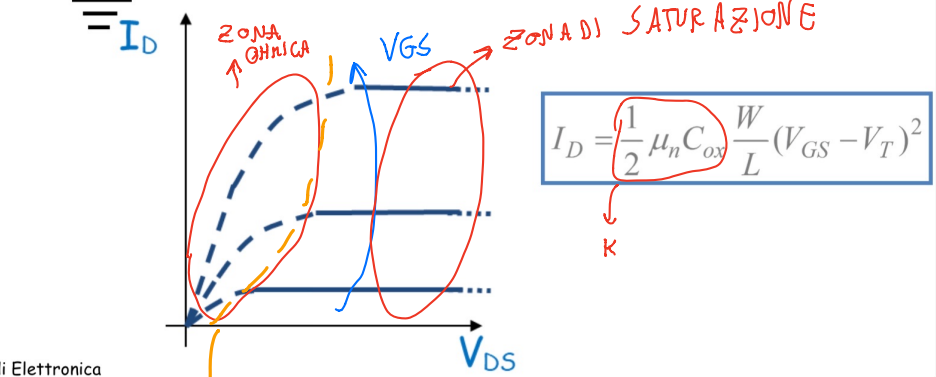
$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2$$

Drain Current in Saturation region

MOSFET operating principle - XIII

MOS as transistor: SATURATION region





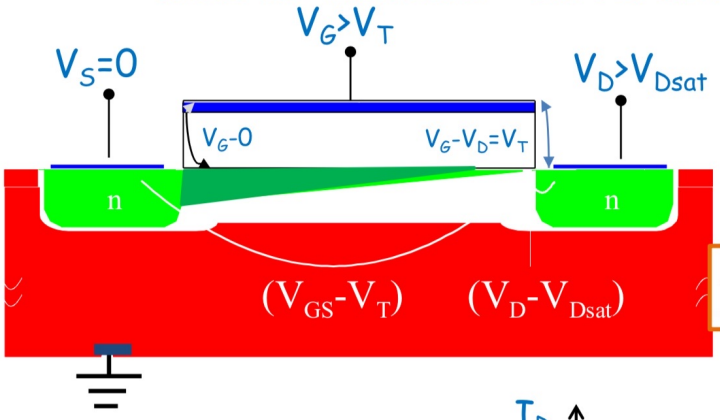
$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2$$

K

Il luogo dei punti che separa le due zone è una curva parabolica

MOSFET operating principle – XIV

MOS as transistor: SATURATION region, real vs. ideal



$$I_D = k\,(V_{GS}-V_T)^2\,(1+\lambda V_{DS})$$

λ:channel-length modulation parameter

V_A: Early voltage (<0)

effetto early