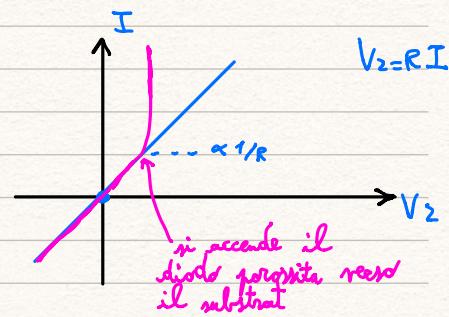
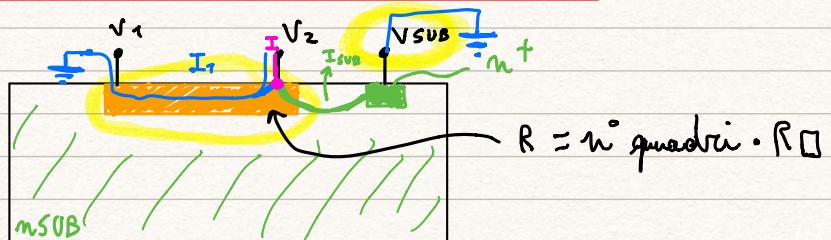


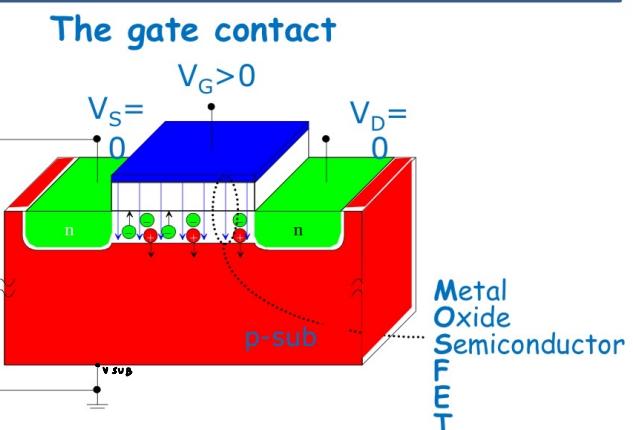
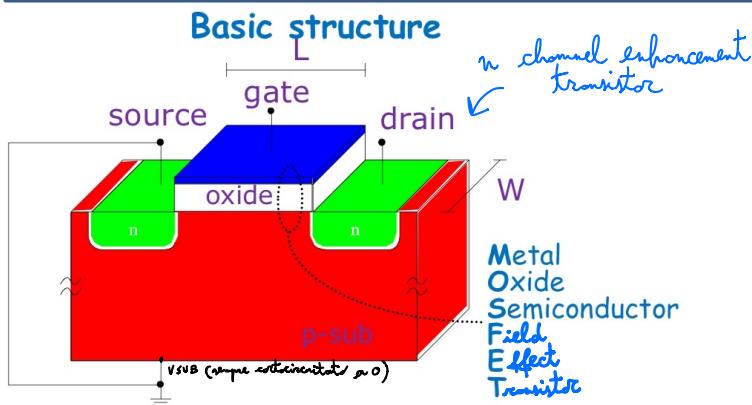
I TRANSISTORI MOS:

EFFETTO DELLA POLARIZZAZIONE DEL SUBSTRATO SULLA CARATTERISTICA

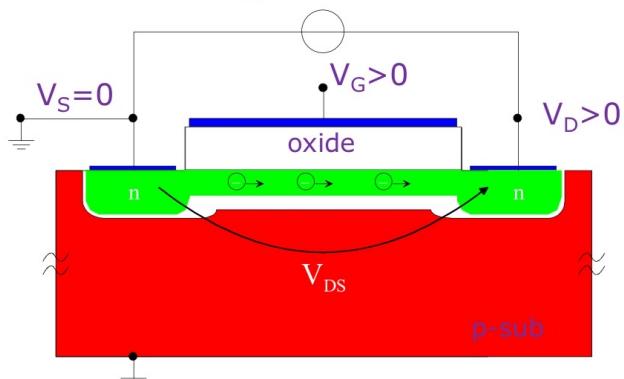
IV DI UN RESISTORE INTEGRATO:



MOSFET operating principle - I

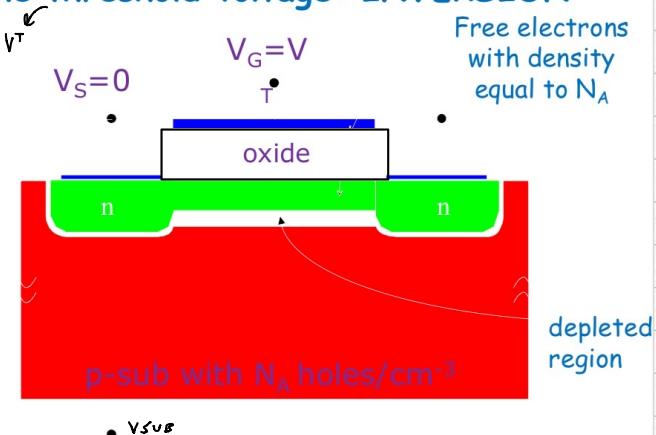


The conducting channel is formed ...

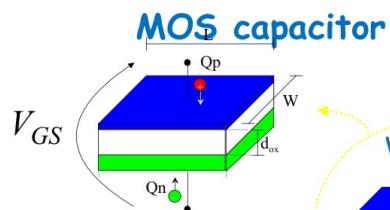


current can flow between D and S!

The threshold voltage: INVERSION



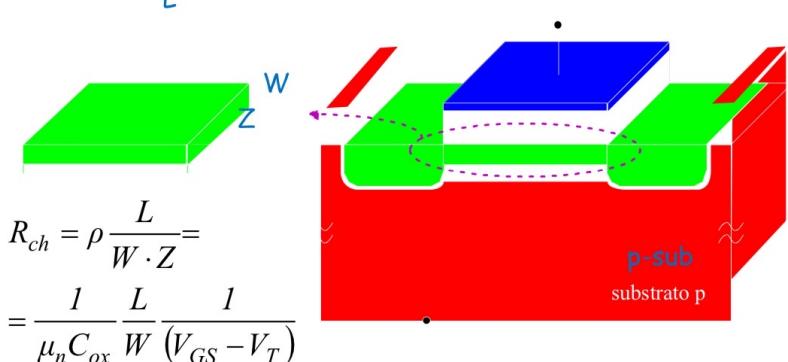
MOSFET operating principle - II



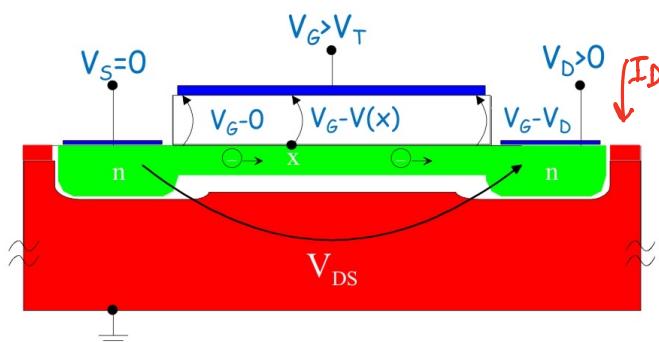
$$C_{gate} = C_{ox} = \frac{\epsilon_{ox}}{d_{ox}} WL$$

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

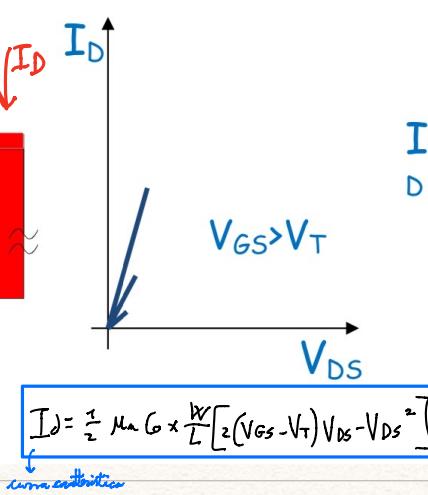
Channel resistance



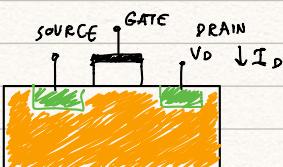
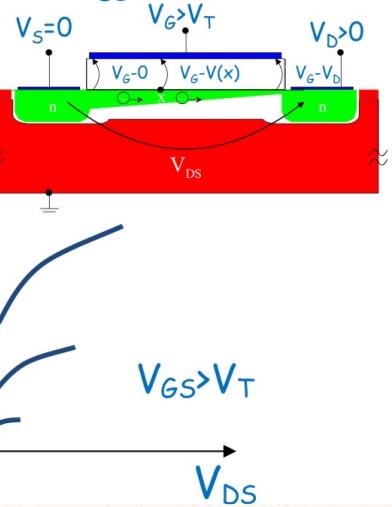
MOS as variable resistor: OHMIC region



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



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

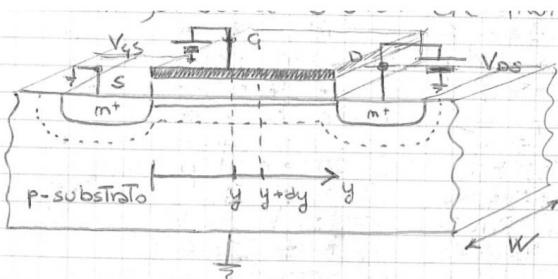
I_D = corrente DC entrante nel morsetto di drain

$$\left. \begin{aligned} V_{DS} &= V_D - V_S \\ V_{GS} &= V_G - V_S \\ V_{GD} &= V_G - V_D \end{aligned} \right\} \text{differenze di potenziale}$$

"depletion" = transistor che cercano 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 unitaria per unità di area nel canale è pari a:

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

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

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

Quindi la ceduta di tensione sarà data da:

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

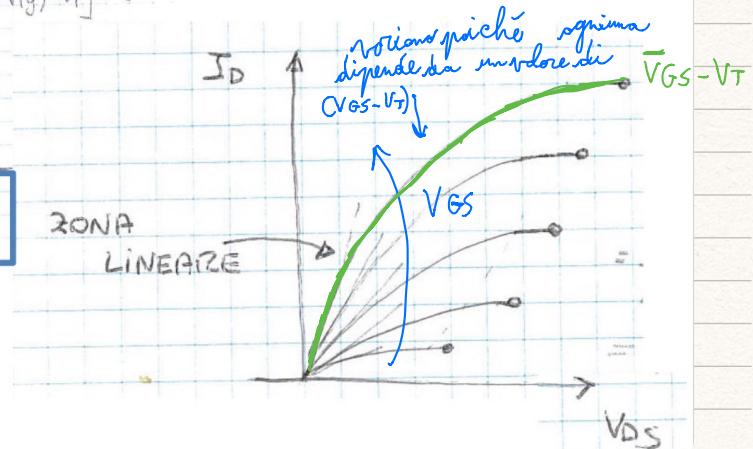
Se riportiamo le variabili ed integriamo:

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

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

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

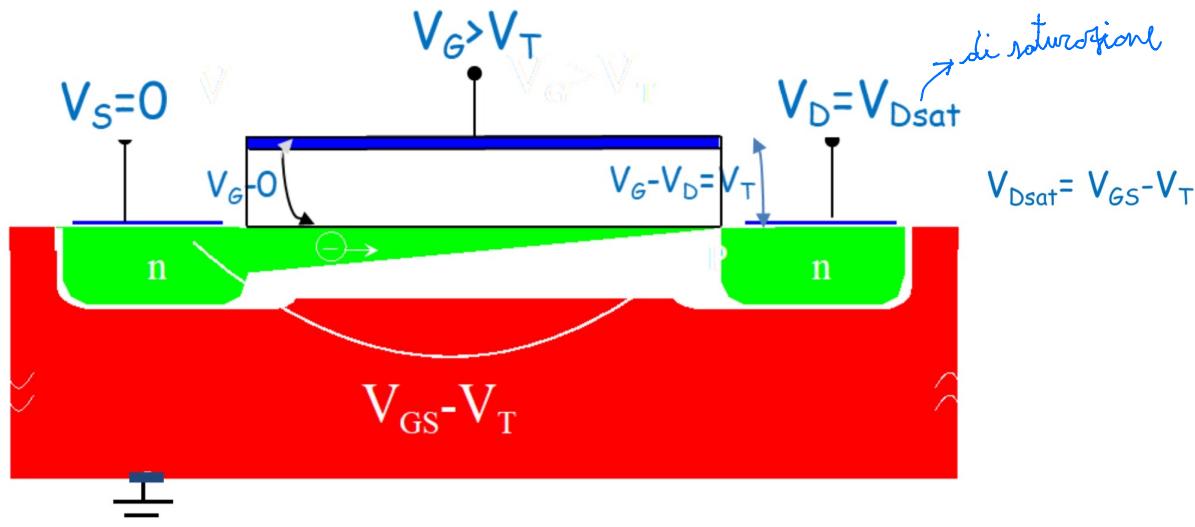
$$V_{GD} = V_T$$



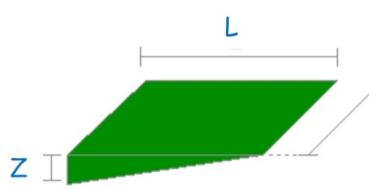
La concentrazione di elettroni nel canale si offra se $V_{GD} = V_T$.

MOSFET operating principle - XI

Channel pinch-off: saturation region



MOSFET operating principle - XII

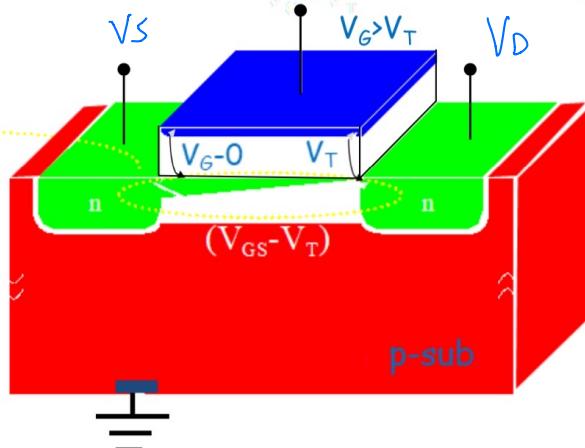


$$R_{sat} = 2 \cdot R_{ch}$$

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

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

Current at pinch-off voltage



$$I_D = \frac{(V_{GS} - V_T)}{R_{sat}} =$$

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

(nella che deriva dall'andante)

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

Drain Current in Triode Region

zona ohmica

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

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

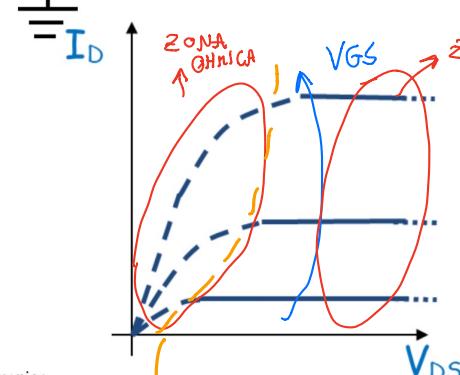
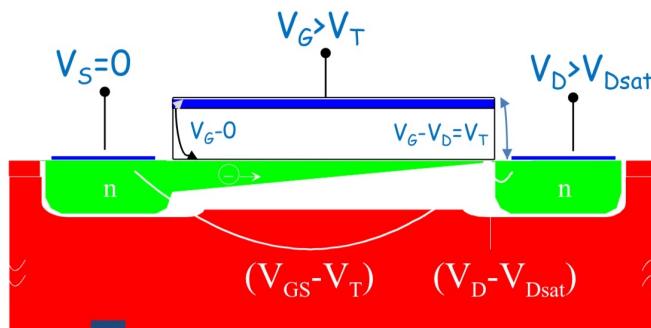
Drain Current in Saturation region



C. Guazzoni, Fondamenti di Elettronica

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

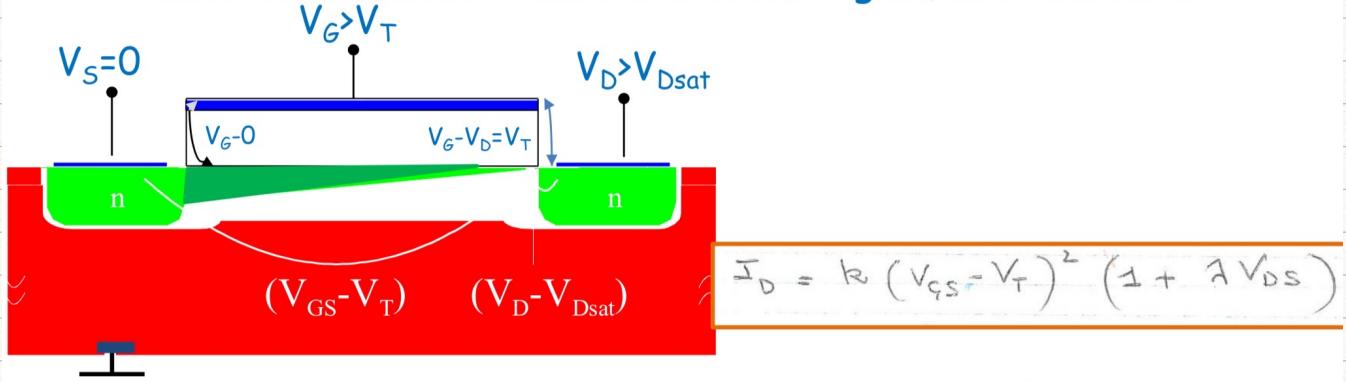


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Il luogo dei punti che separa le due zone è lungo una curva parabolica

MOSFET operating principle - XIV

MOS as transistor: SATURATION region, real vs. ideal



λ : channel-length modulation parameter

V_A : Early voltage (< 0)

effetto early



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