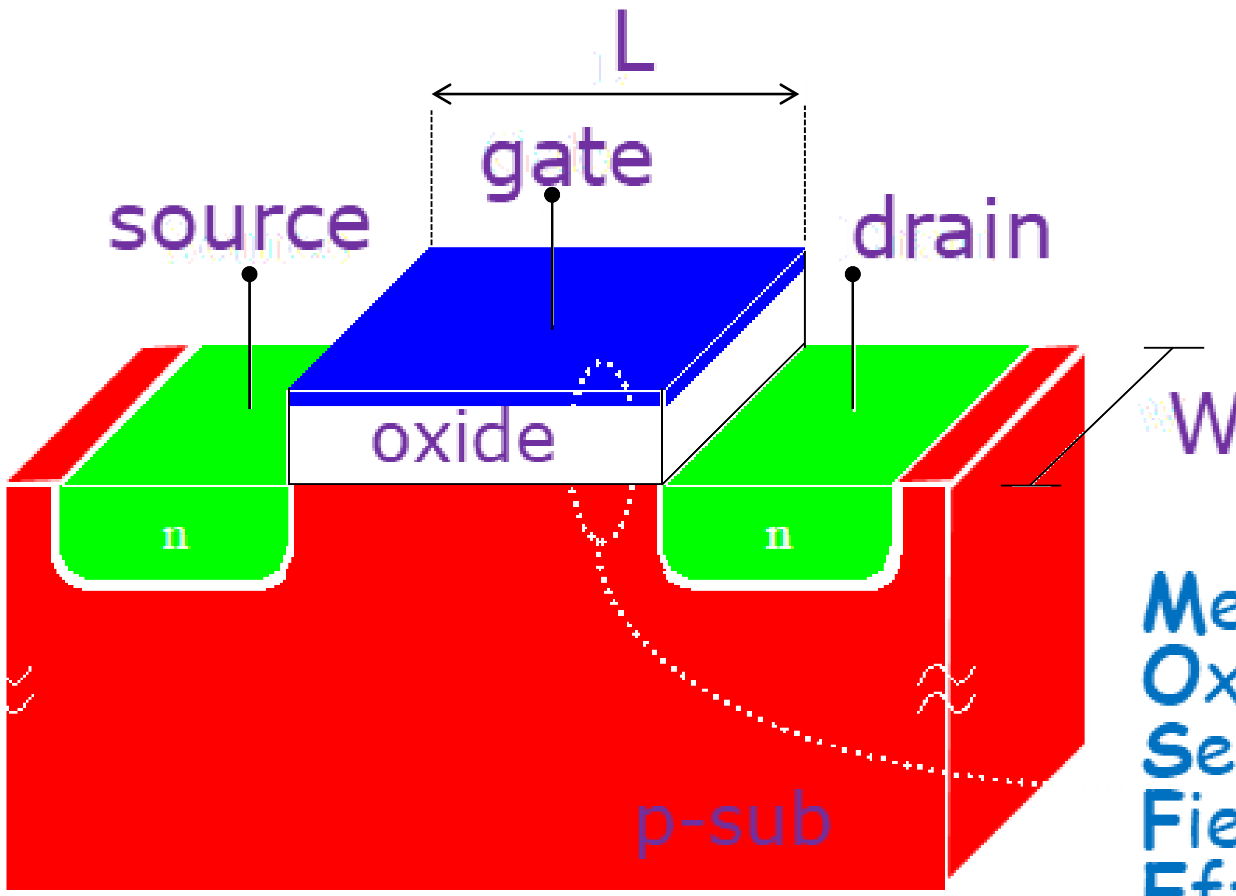
MOSFET operating principle – I

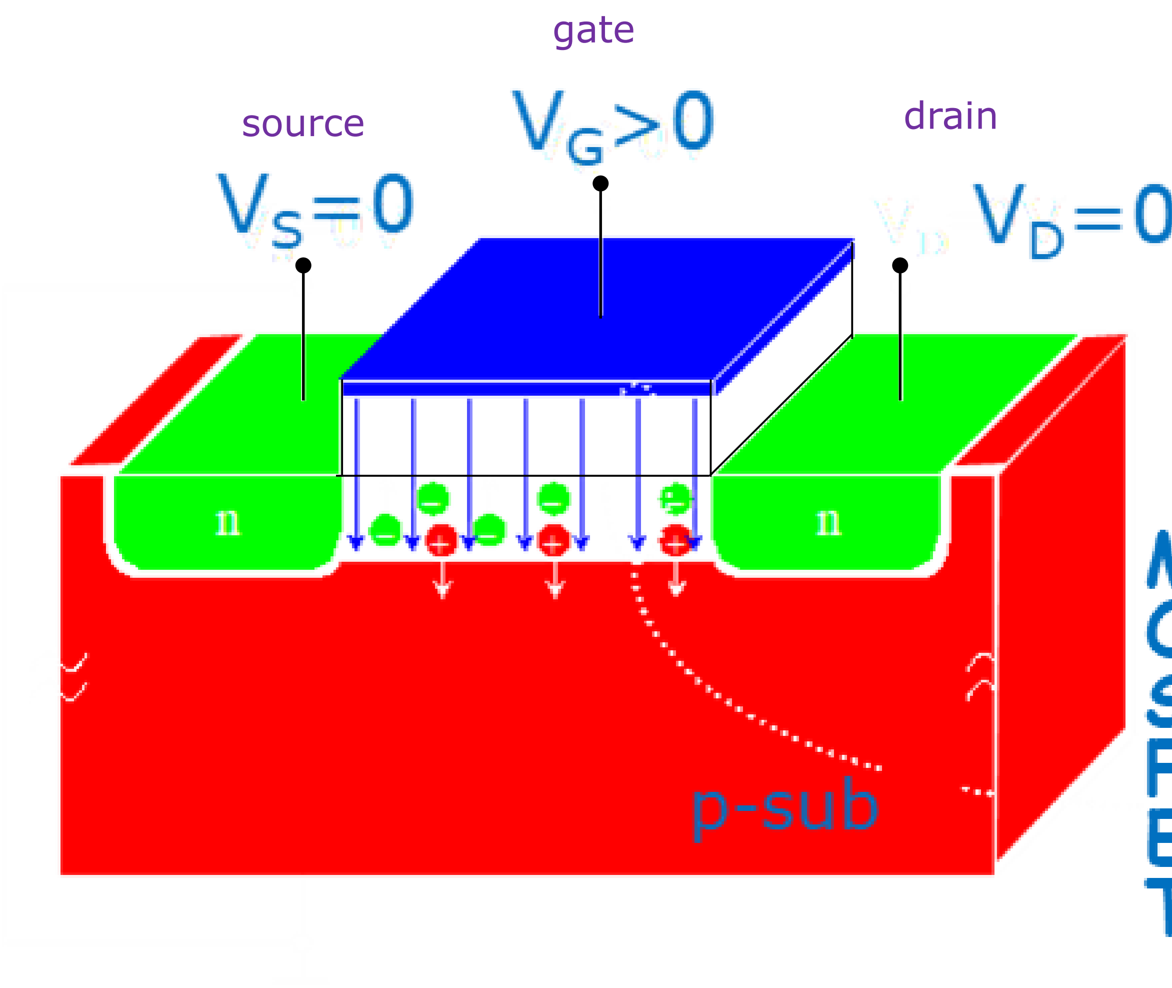
Basic structure of an n-channel enhancement MOS transistor



Metal
Oxide
Semiconductor
Field
Effect
Transistor

MOSFET operating principle - II

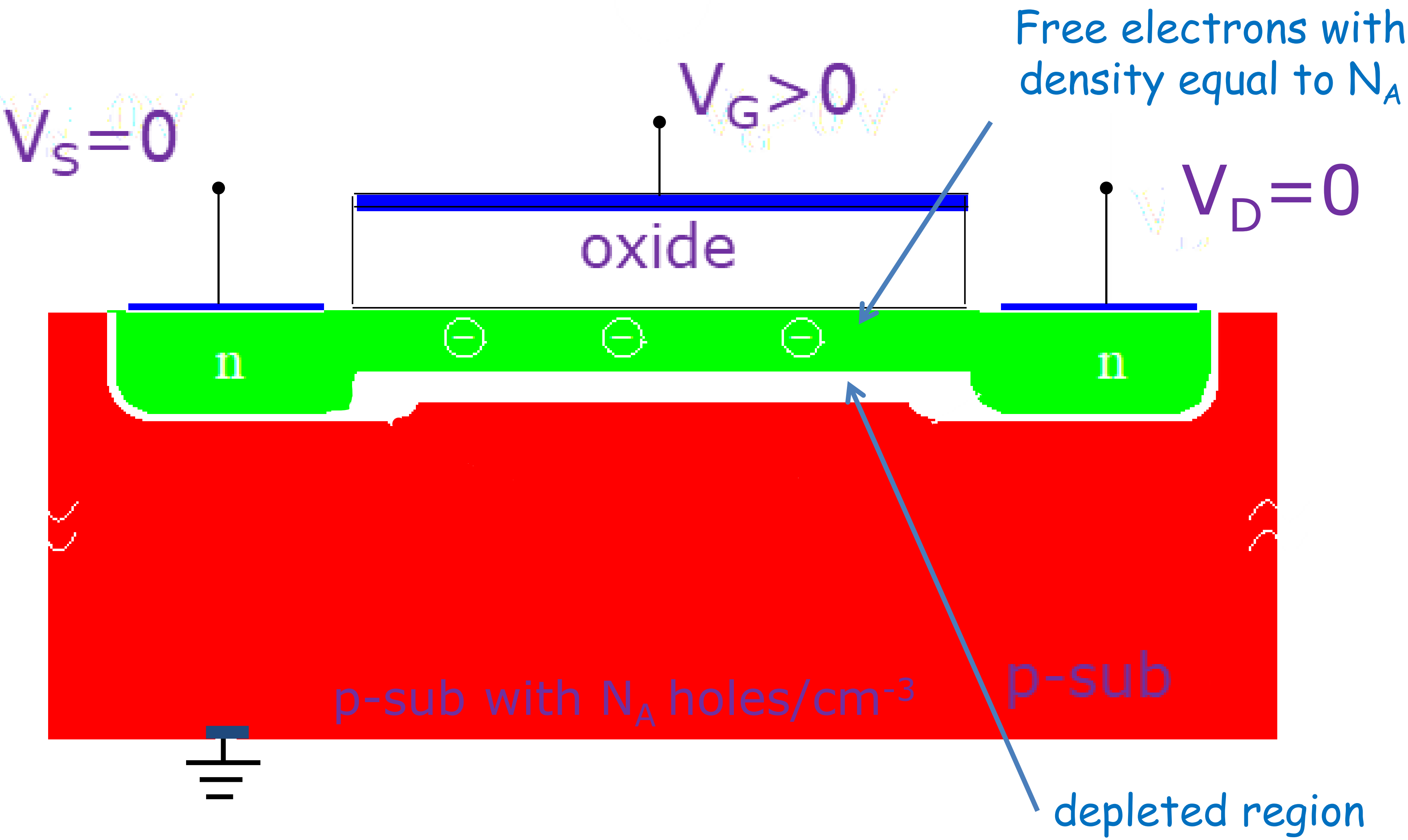
The gate contact



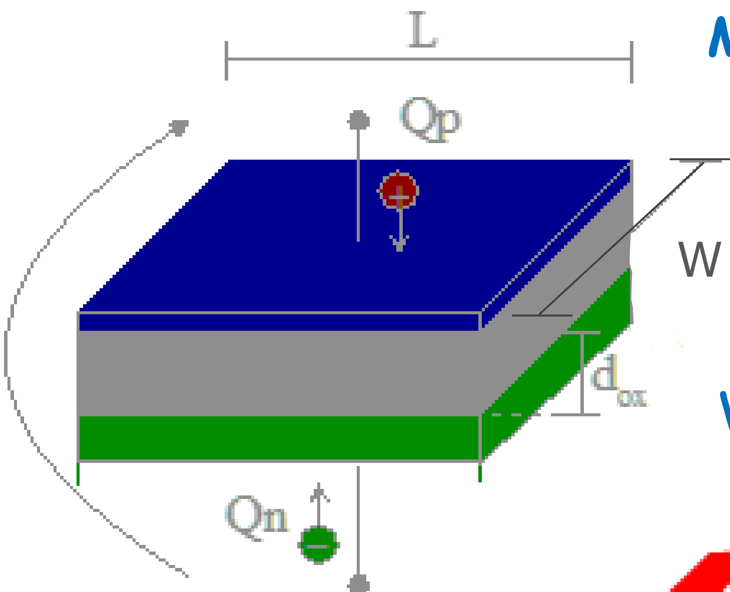
Metal
Oxide
Semiconductor
Field
Effect
Transistor

MOSFET operating principle – III

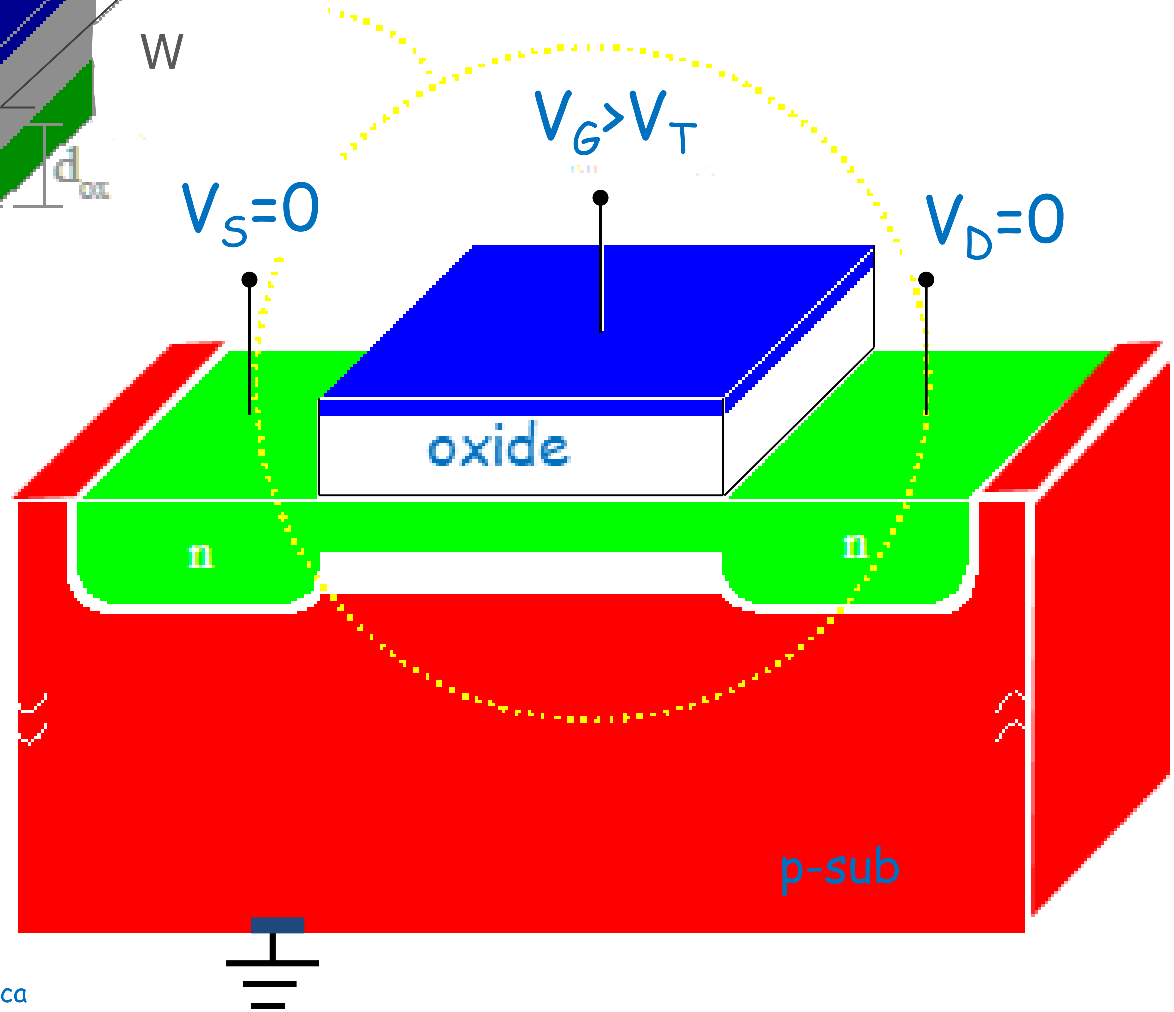
The threshold voltage: INVERSION



MOSFET operating principle – IV



MOS capacitor



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

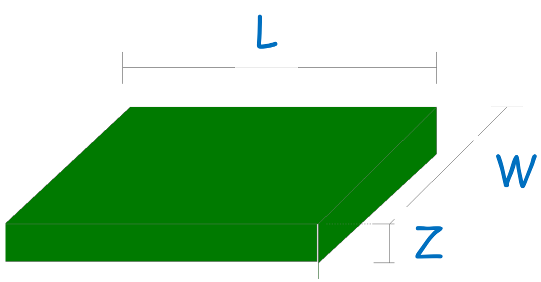
$$Q_n = C_{ox}\left(V_{GS} - V_T\right)$$

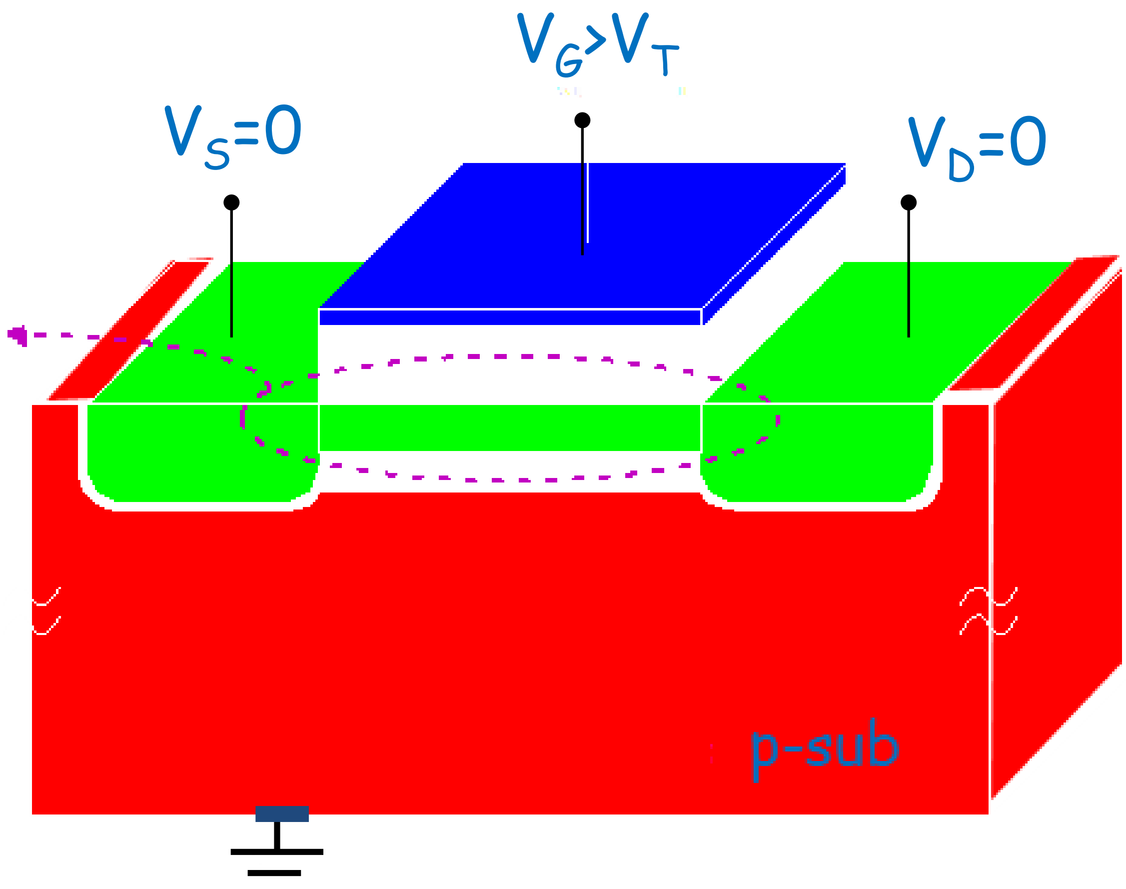
MOSFET operating principle – V

Channel resistance

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

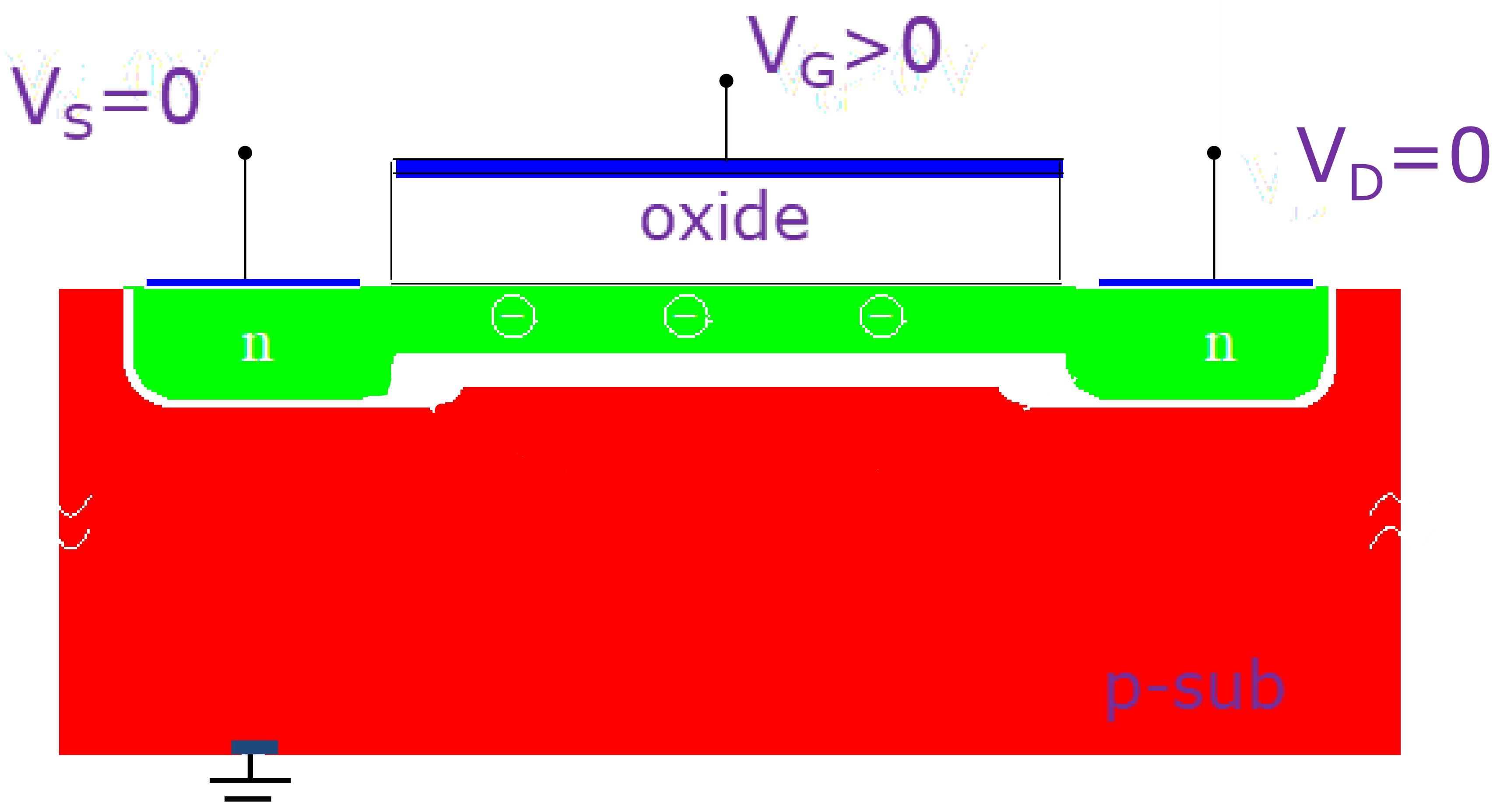
$$= \frac{1}{\mu_n C_{ox}} \frac{L}{W} \frac{1}{(V_{GS} - V_T)}$$





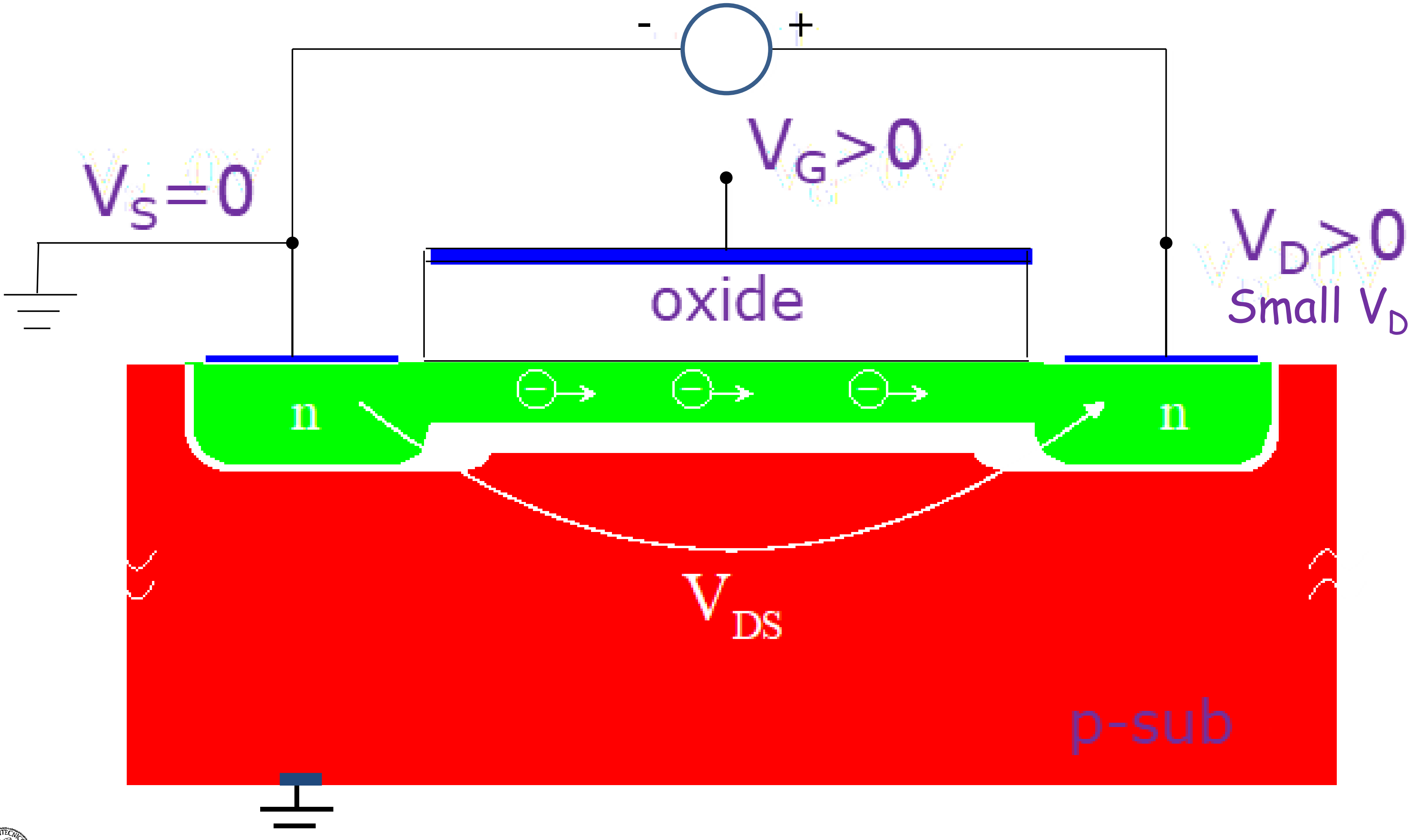
MOSFET operating principle - IV

The conducting channel is formed …



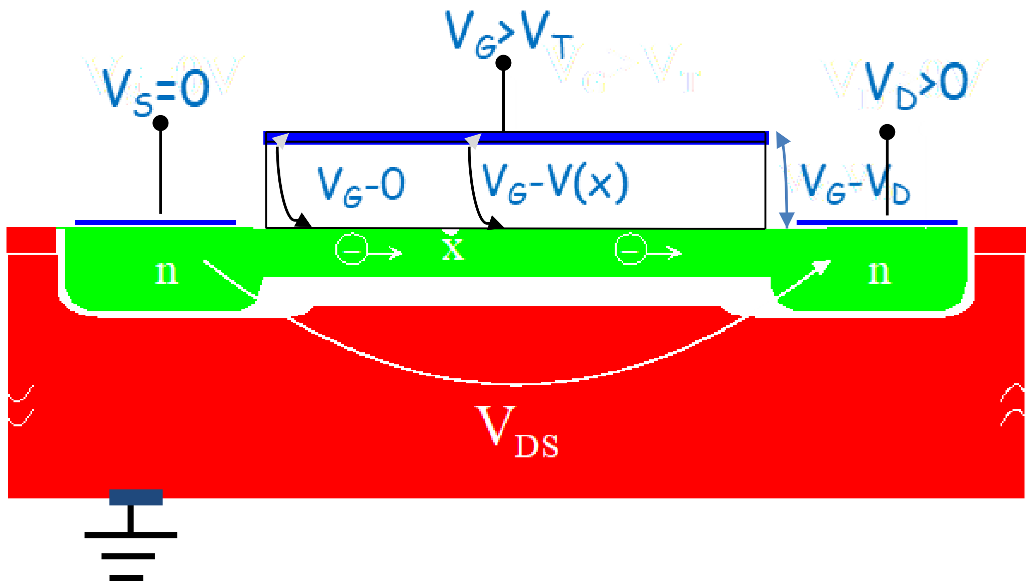
MOSFET operating principle – V

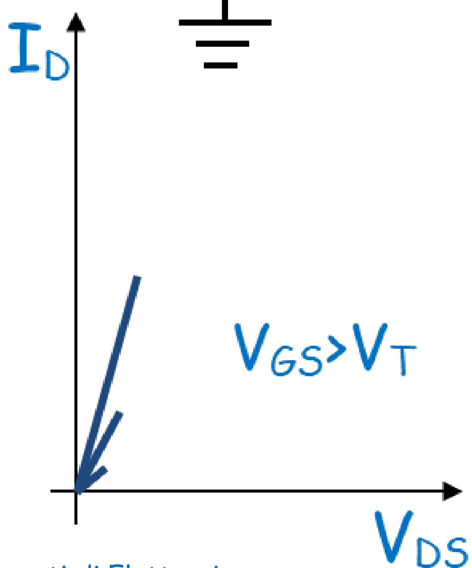
… current can flow between Drain and Source!



MOSFET operating principle - VIII

MOS as variable resistor: OHMIC region

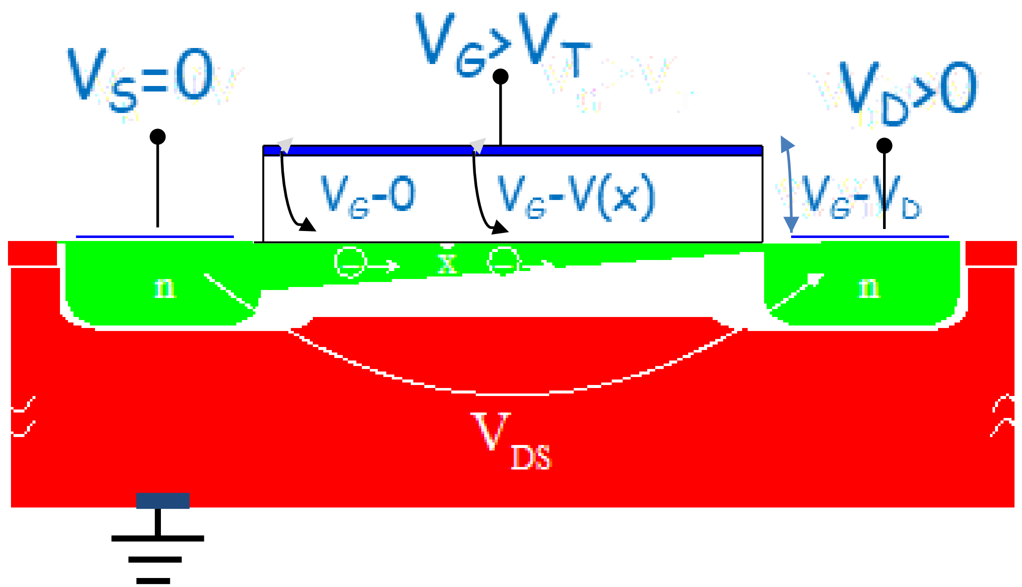


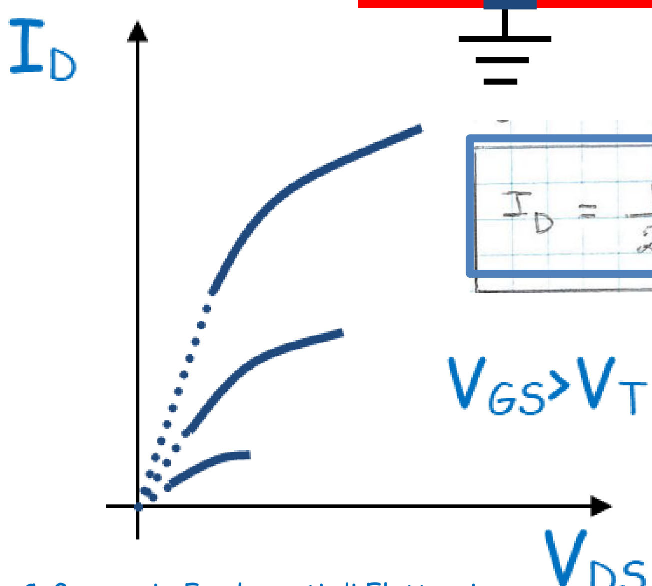


$$I_D = \frac{V_{DS}}{R_{ch}} = \mu_n C_{ox} \frac{W}{L}\left(V_{GS} - V_T\right)$$

MOSFET operating principle – IX

MOS as variable resistor: as V_{DS} increases …



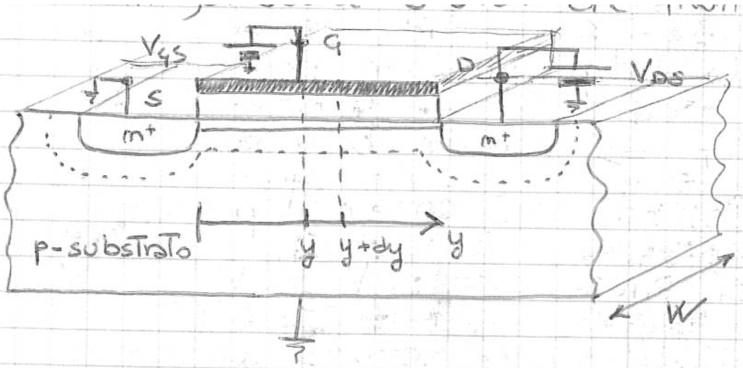


$$I_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L}\left[2\left(V_{GS}-V_T\right)V_{DS} - V_{DS}^2\right]$$

CURVA CARATTERISTICA MOSFET IN ZONA OHMICA

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 indotta 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 sarà data da:

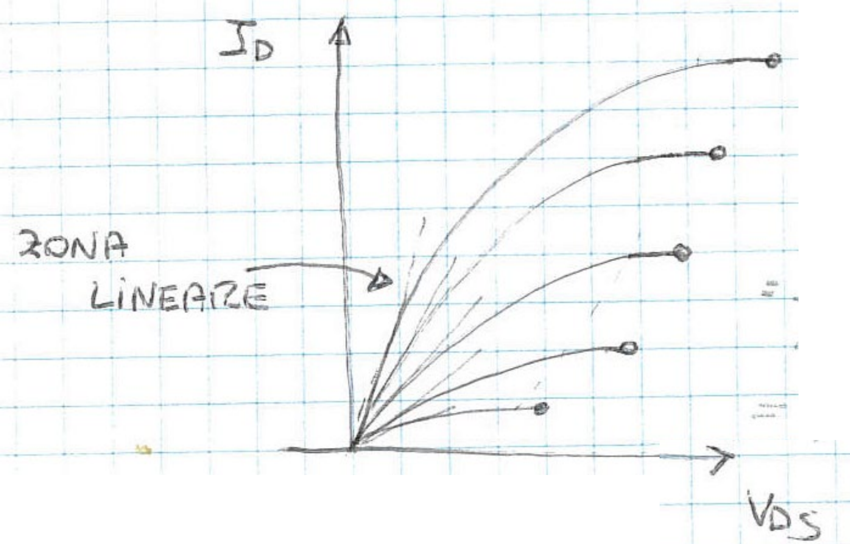
$$dV = I_D \cdot dR = \frac{I_D}{W \cdot \mu_n \cdot q(y)}\, dy = \frac{I_D}{W \cdot \mu_n\, C_{ox}\left[V_{GS} - V(y) - V_T\right]}\, dy$$

Se separiamo le variabili ed integriamo:

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

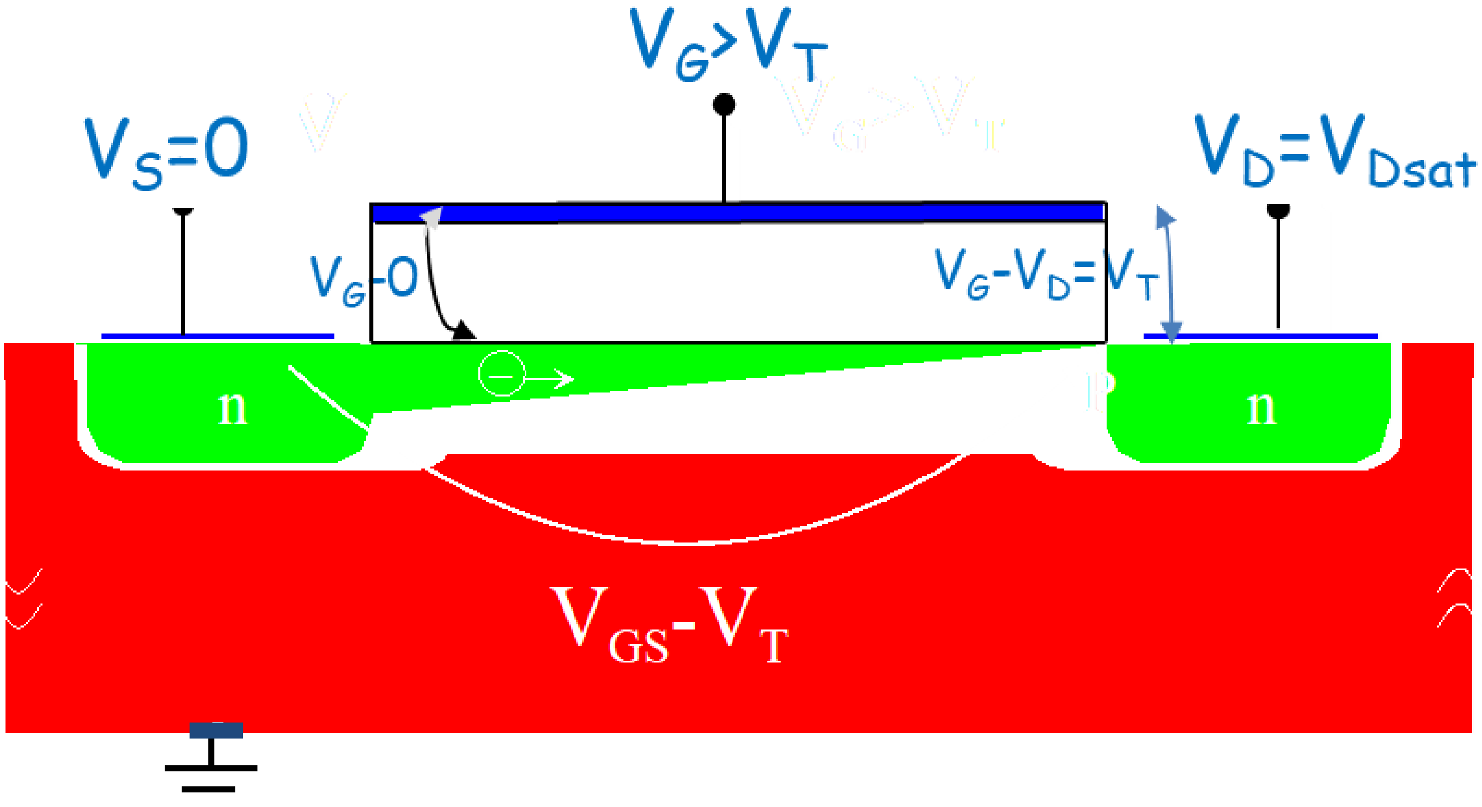
$\Downarrow$

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



MOSFET operating principle - XI

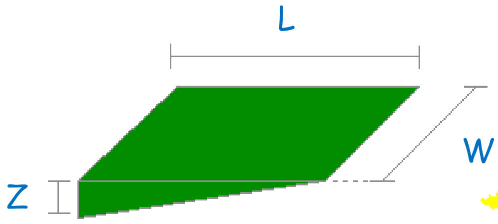
Channel pinch-off: saturation region



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

MOSFET operating principle – XII

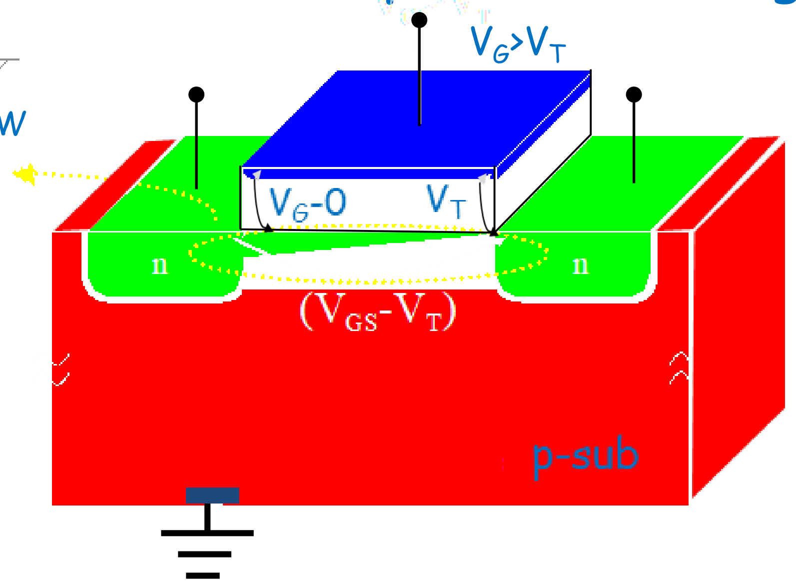
Current at pinch-off voltage



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

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

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



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

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

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

Drain Current in Triode Region

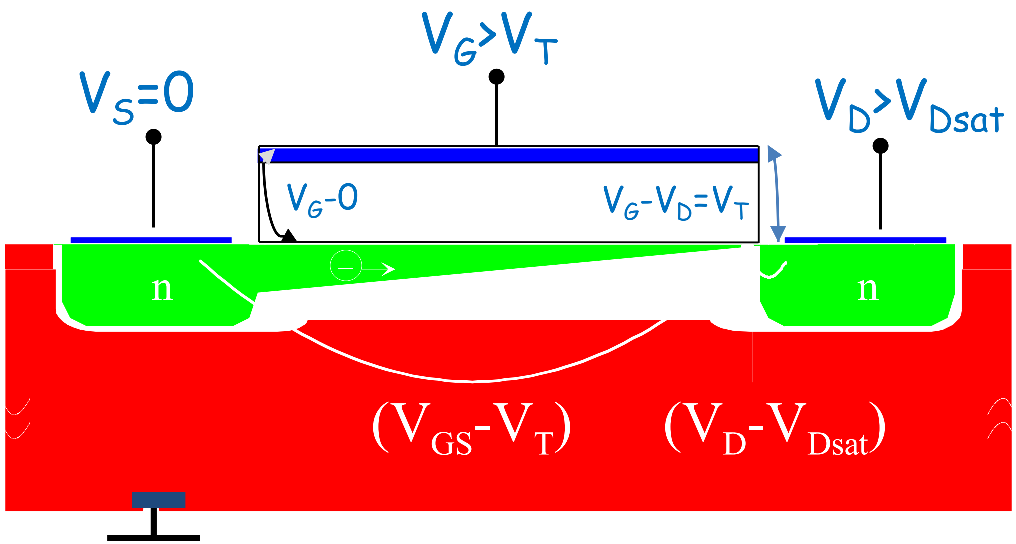
$$V_{DS} = V_{GS} - V_T$$

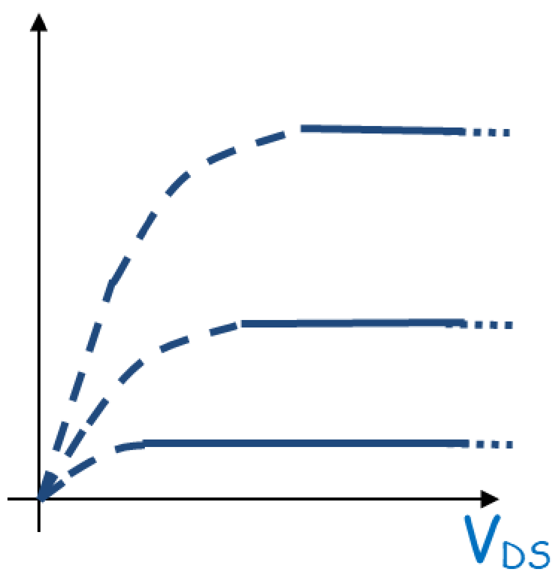
$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2$$

Drain Current in Saturation region

MOSFET operating principle - XIII

MOS as transistor: SATURATION region

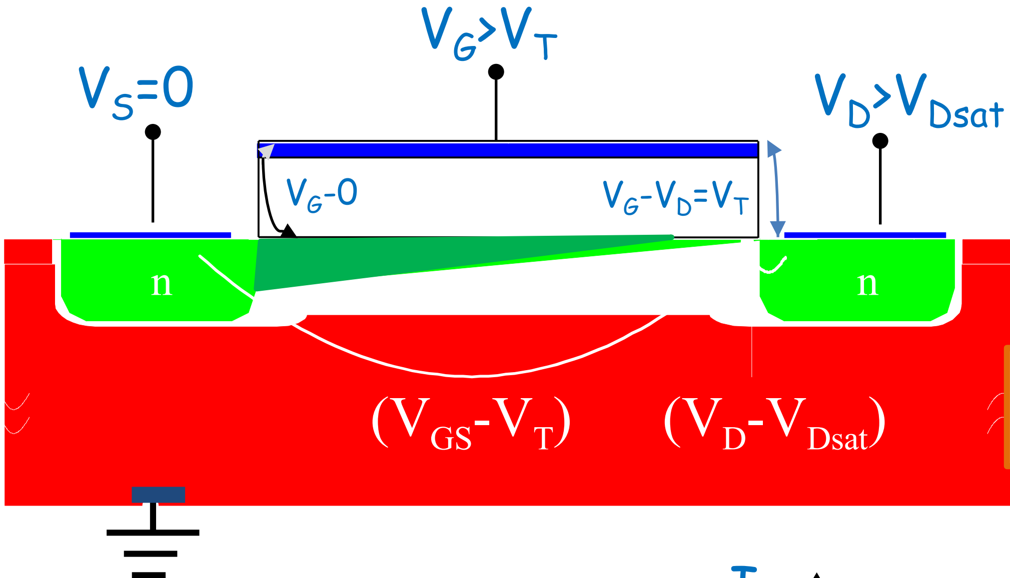




$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS} - V_T)^2$$

MOSFET operating principle - XIV

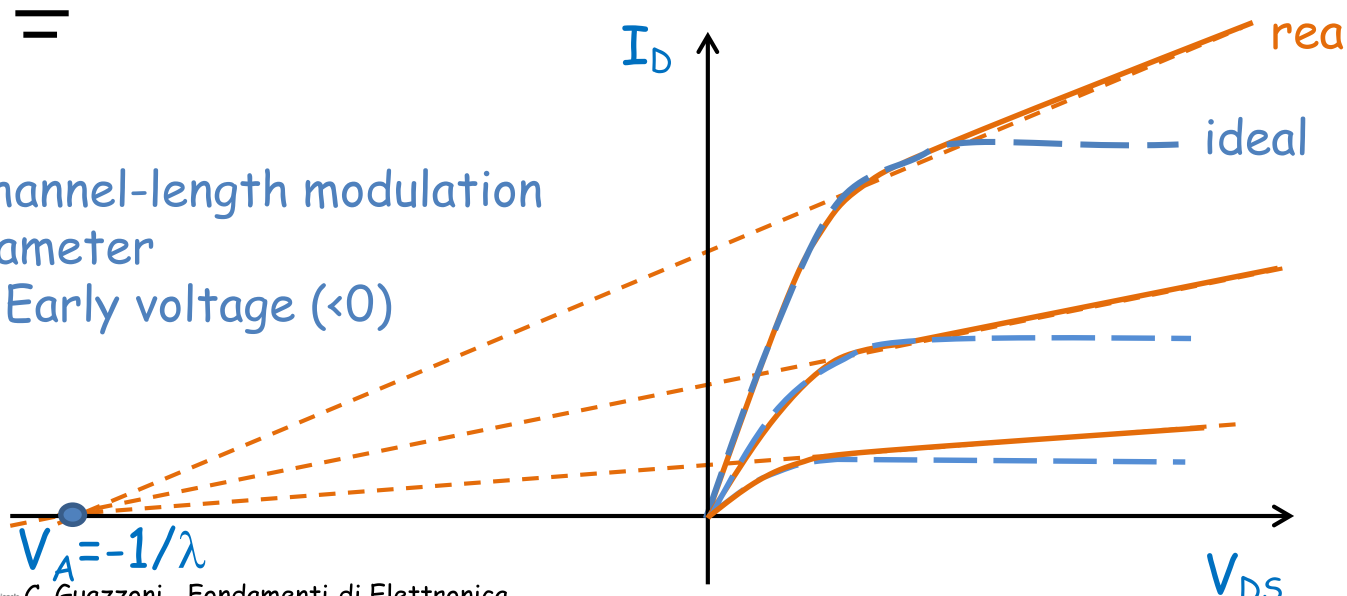
MOS as transistor: SATURATION region, real vs. ideal



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

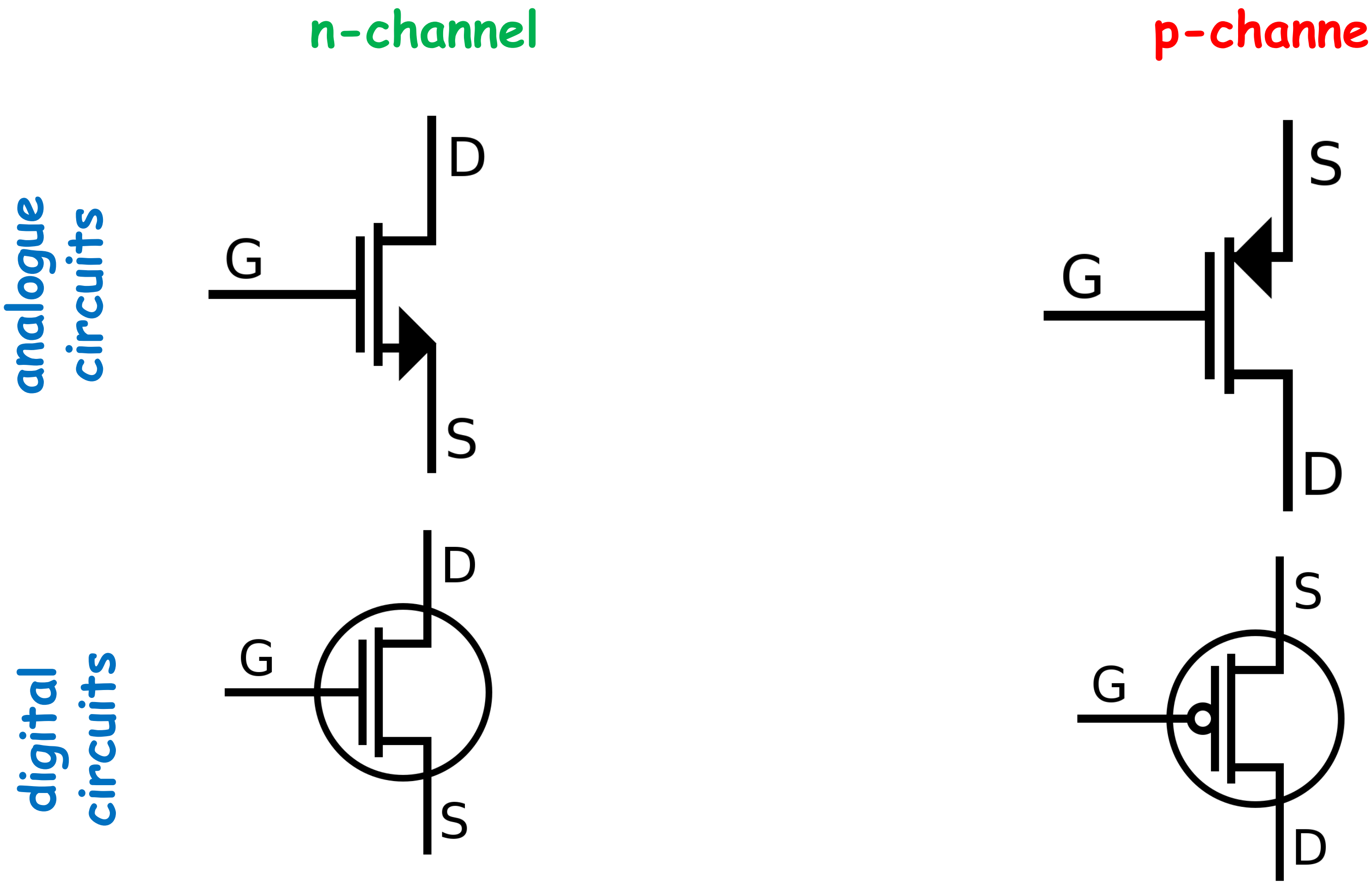
λ: channel-length modulation parameter

V_A: Early voltage (<0)



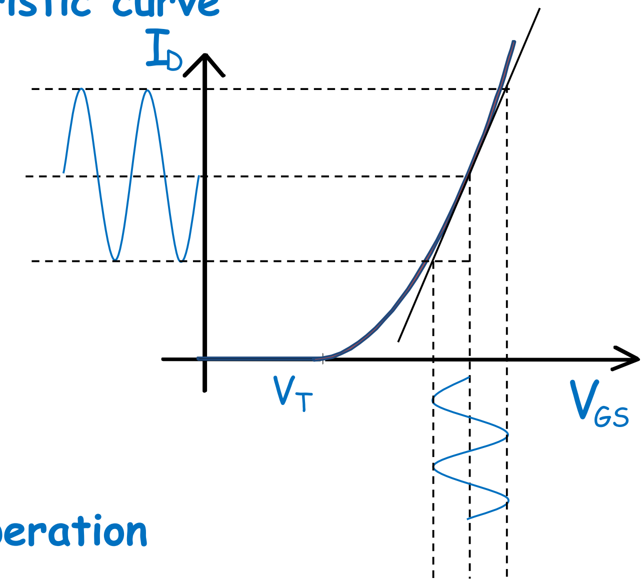
MOSFET operating principle - XIII

MOS circuit symbols



MOSFET operating principle – IV

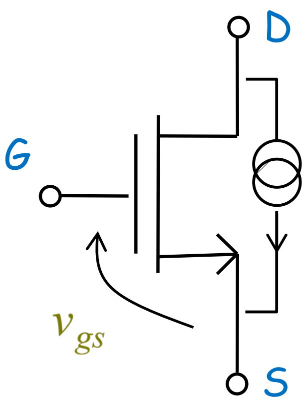
Transcharacteristic curve



Transconductance

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

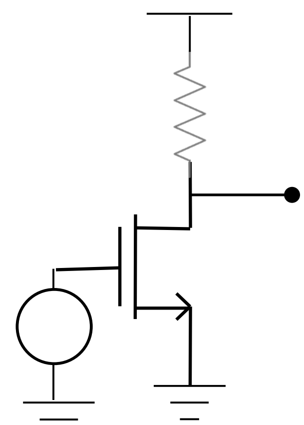
Small signal operation



Small signal condition:

$$v_{gs} << 2 \cdot (V_{GS} - V_T)$$

Basic amplifier configuration (Common source)



Voltage gain:

$$A_v = \frac{v_{out}}{v_{in}} = -g_m R_L$$