ECEN 325
Electronics

MOS Field-Effect Transistors

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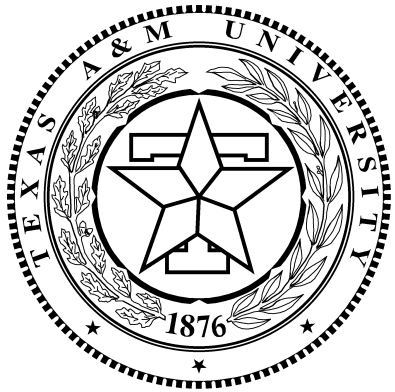
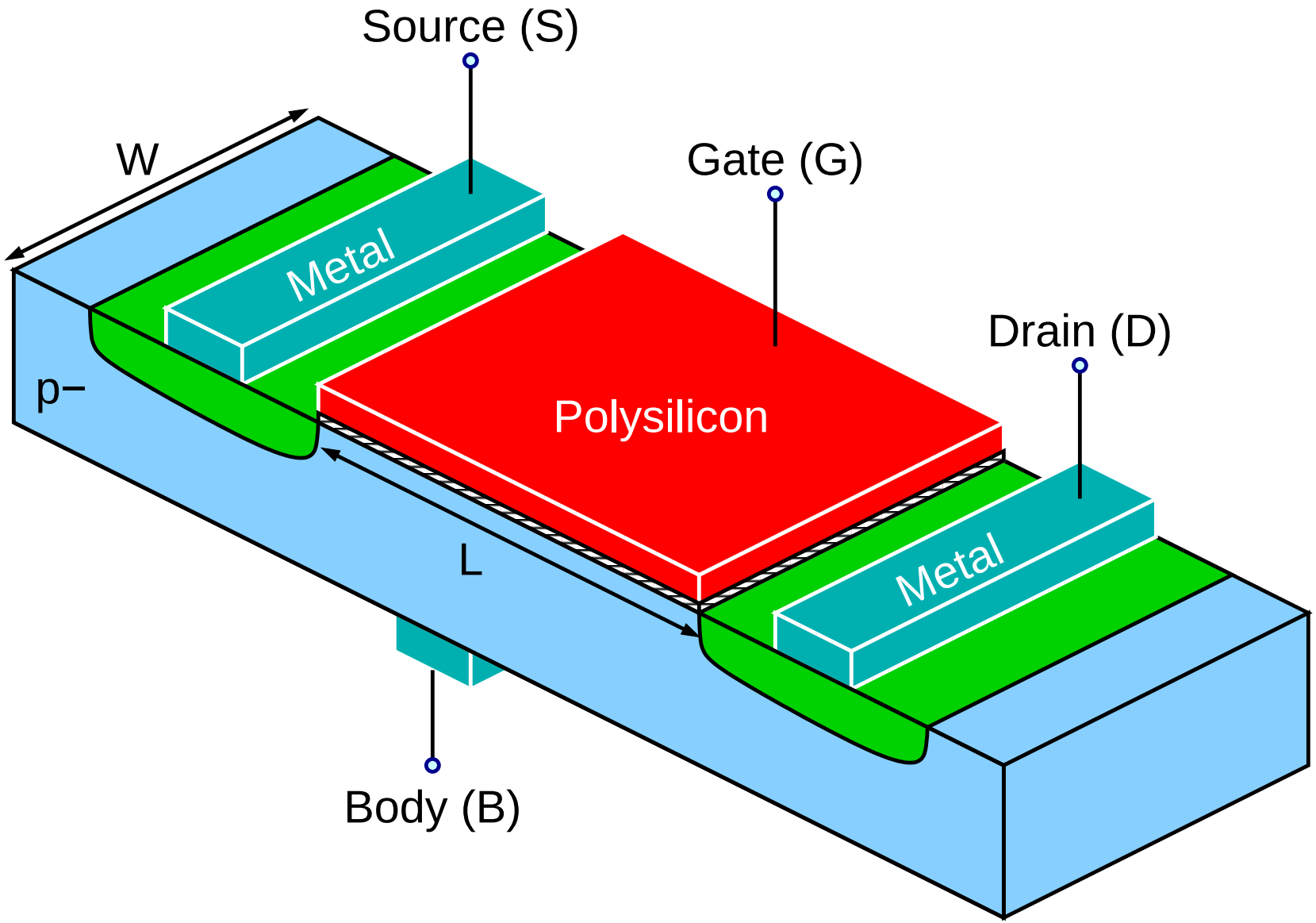
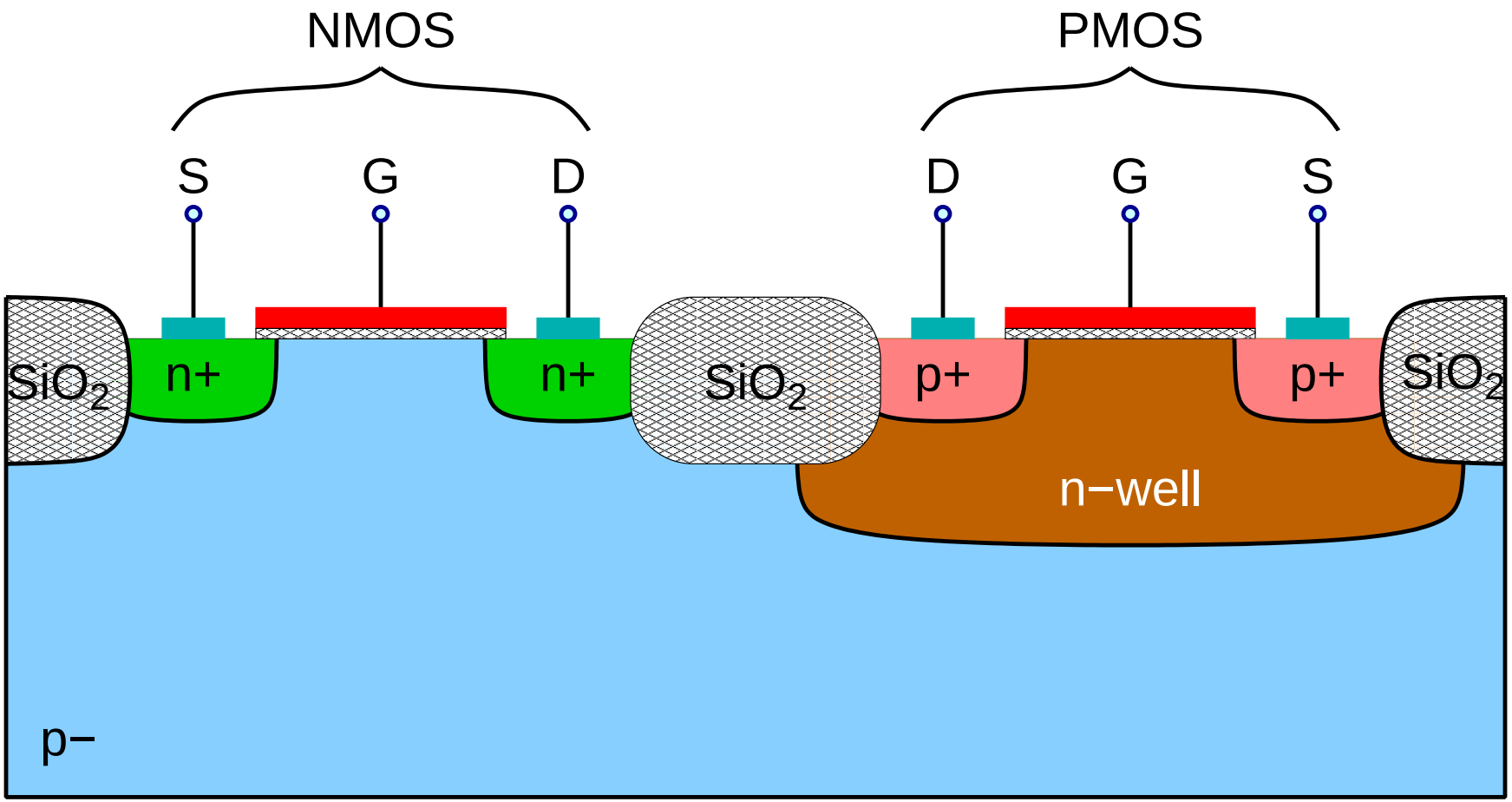


NMOS Physical Structure



CMOS Physical Structure

Cross-section



ELEN - 325

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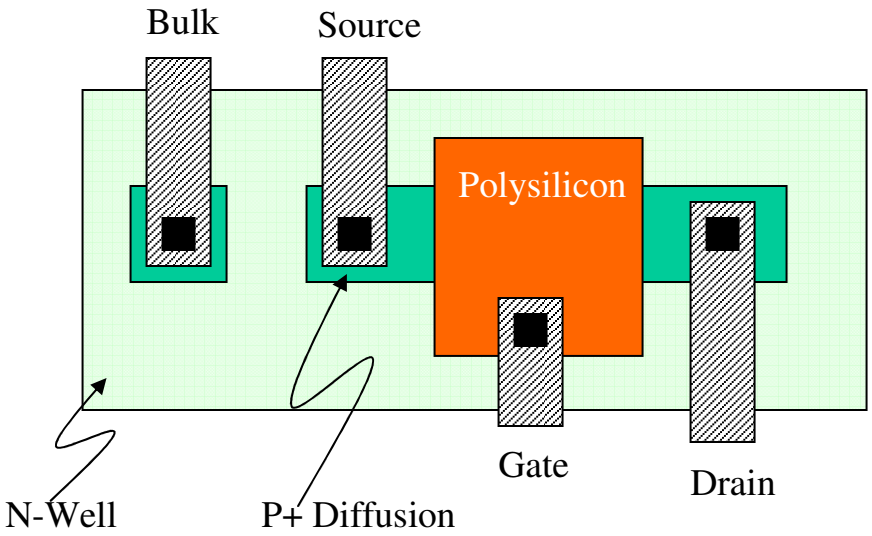
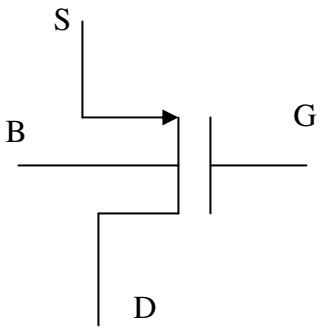
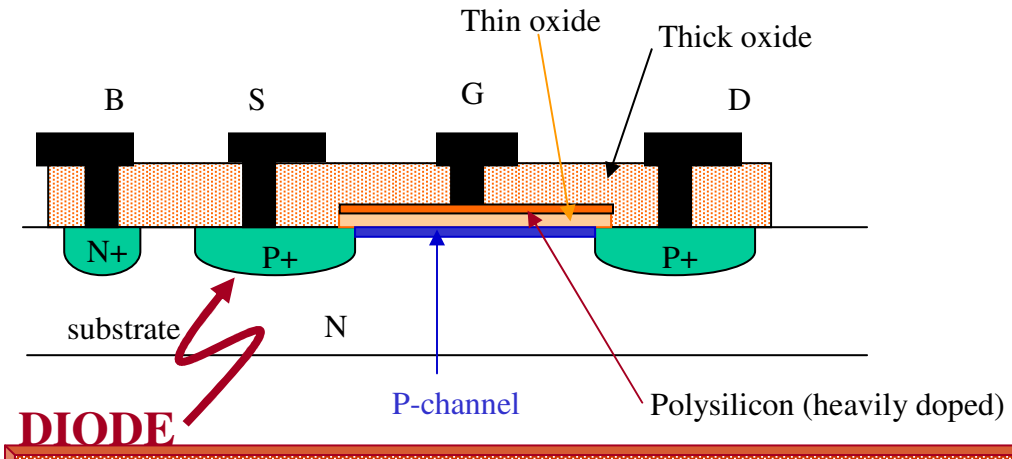
P-MOS Transistor



P-type transistor



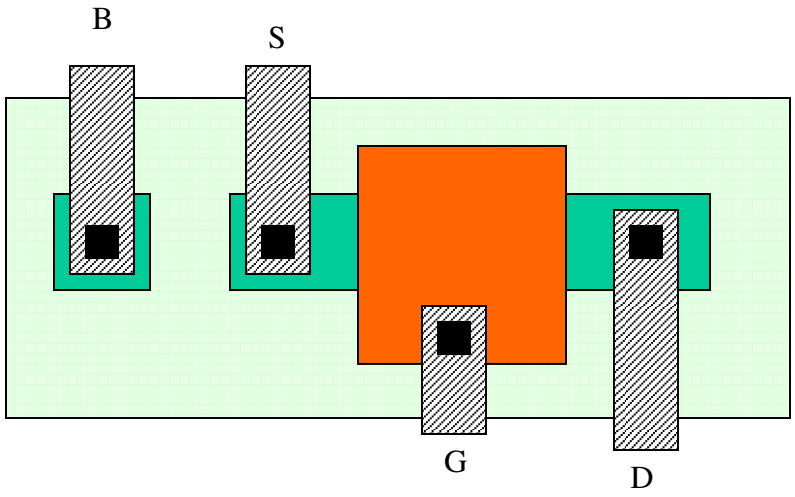


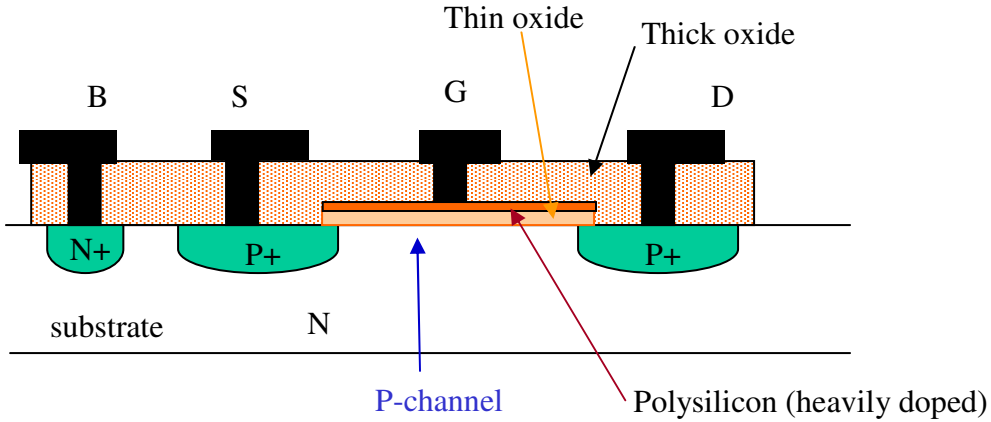
DIODE

Basic elements:

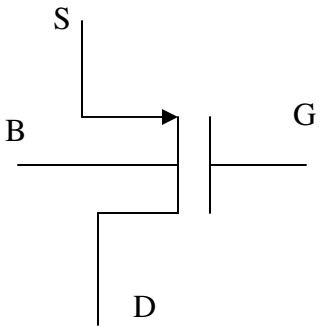
Diffusions + Oxidations + Polysilicon

P-MOS Transistor





P-type transistor



BASIC IDEA:

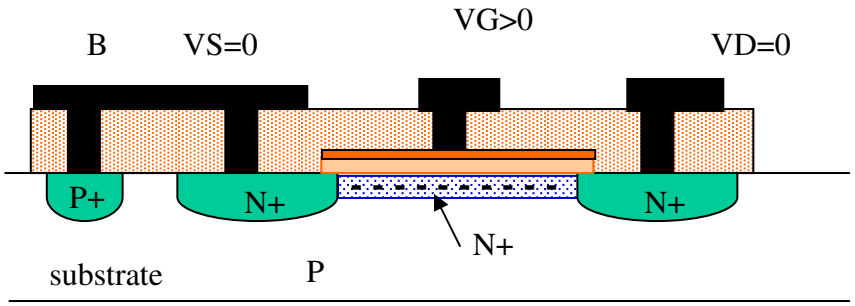
DRAIN-SORCE CURRENT IS CONTROLLED BY THE GATE.

The system is "isolated" if the diodes are biased in reverse using the Bulk terminal.

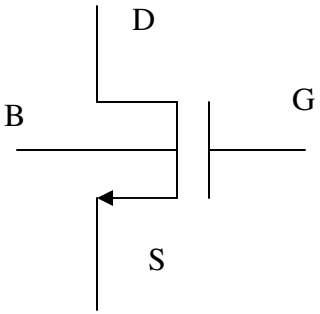
N-MOS Transistor

Inversion: channel is created

D-S current is zero

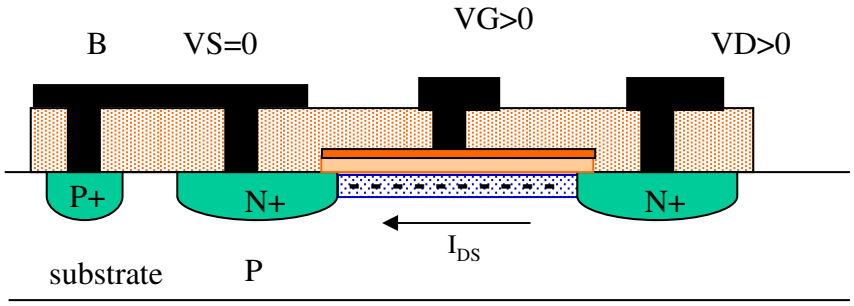


N-type transistor



Inversion: Channel connects D and S

D-S current is possible



Under this condition, there are 3 possible applications:

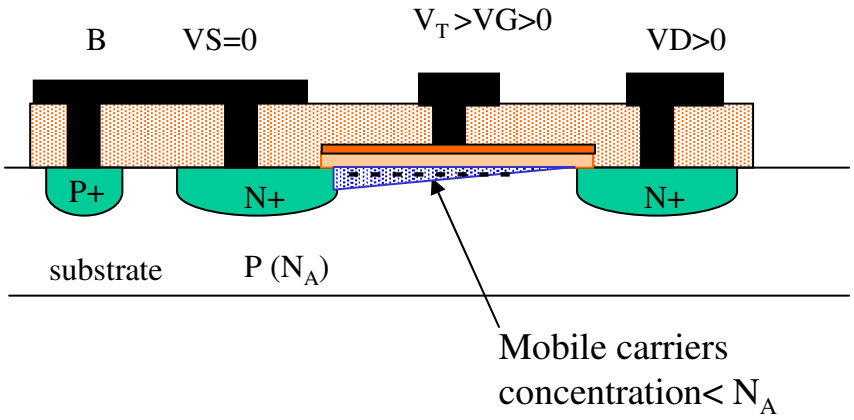
Subthreshold (extremely low-voltage low-power applications)

Linear region (voltage controlled resistor)

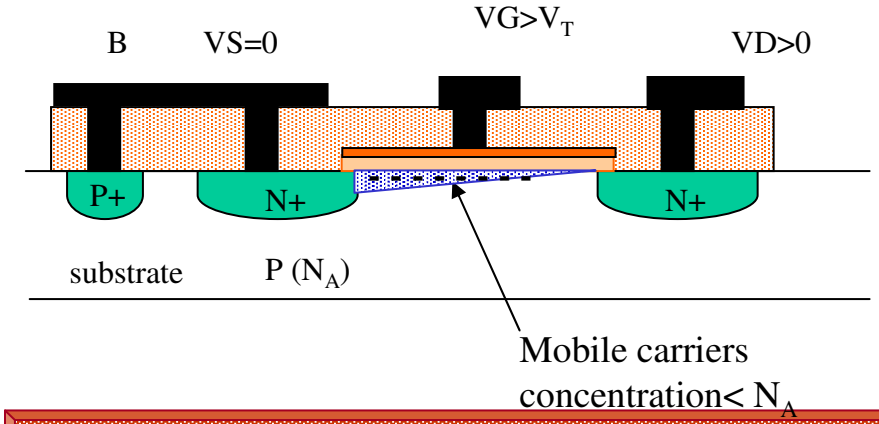
Saturation region (Amplifiers)

MOS Transistor

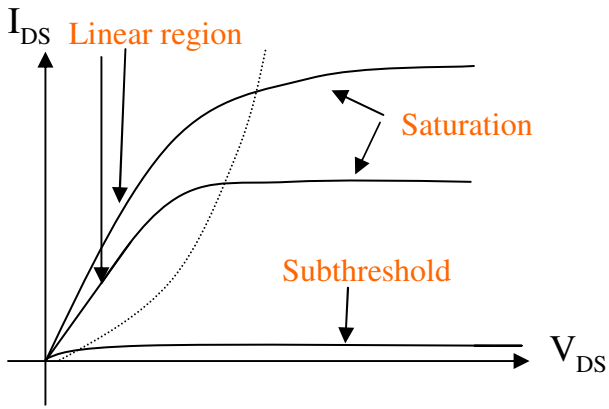
Subthreshold (weak inversion)



Saturation (Strong inversion)



N-type transistor



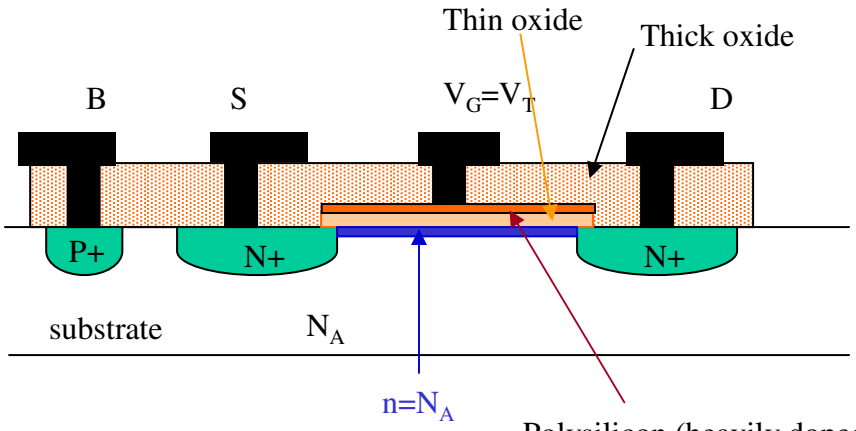
Subthreshold (extremely low-voltage low-power applications)

Linear region (voltage controlled resistor, linear OTA's, multipliers)

Saturation region (Amplifiers)

MOS Transistor

STRONG INVERSION : BODY EFFECTS



$$V_T = VT0 + \gamma\sqrt{\phi_{j0}} - \gamma\left[\sqrt{\phi_{j0}} - \sqrt{\phi_{j0} - V_{Channel-B}}\right]$$

$$\gamma = \frac{\sqrt{2q\varepsilon_{si}N_{Bulk}}}{C_{OX}}$$

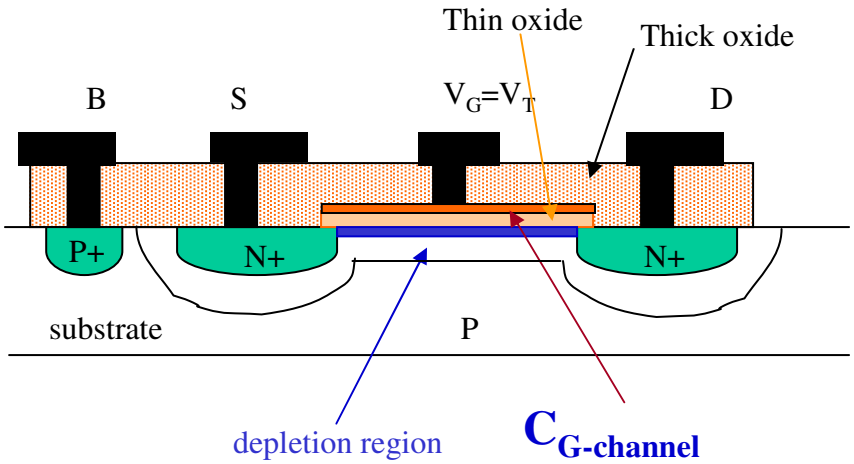
γ = BODY FACTOR

Threshold voltage:

Voltage needed at the gate to create an inversion layer such that the number of carriers in the channel equals the bulk concentration (~10^{17}-10^{18} electrons /cm^3)

MOS Transistor

Two control capacitors: $C_{G\text{-}channel}$ and $C_{B\text{-}channel}$



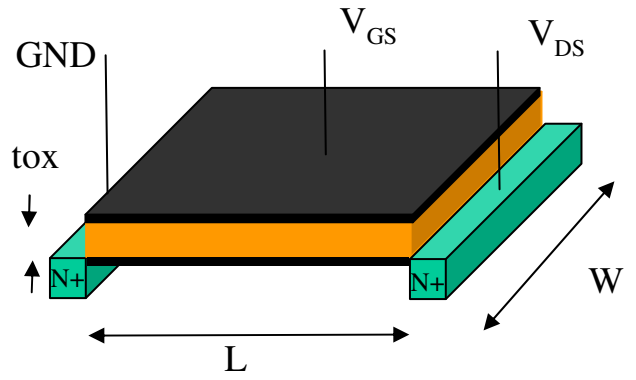
$C_{G\text{-}channel}$

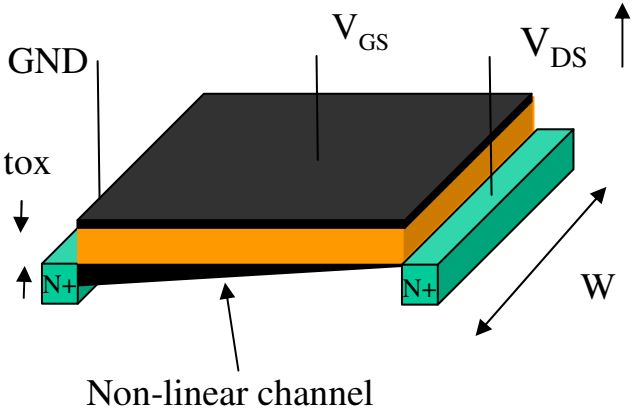
- Voltage independent
- Its value depends of the gate area
- Gate-channel resistance is extremely large

Channel substrate capacitance:

- Voltage dependent (ε_{si}/t_{si}) and non-linear
- Depends of the gate area
- Depends of the square root of the bulk doping

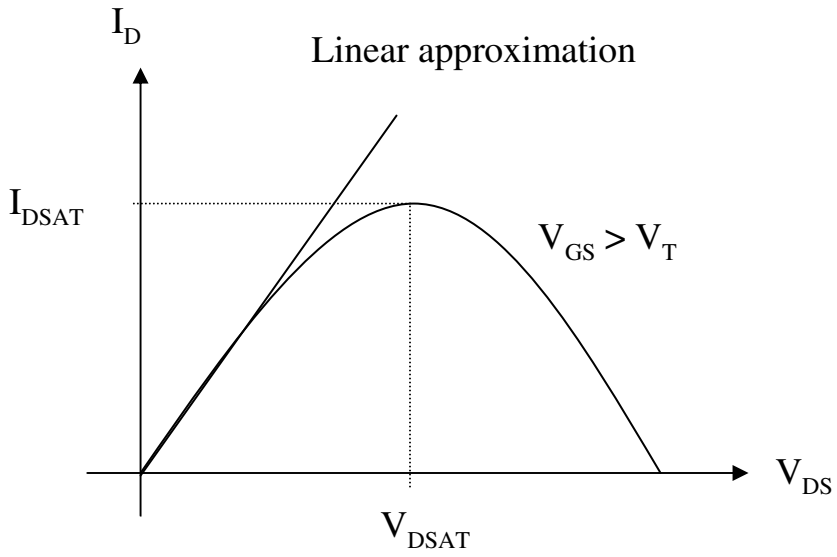
MOS Equations in **Linear Region**



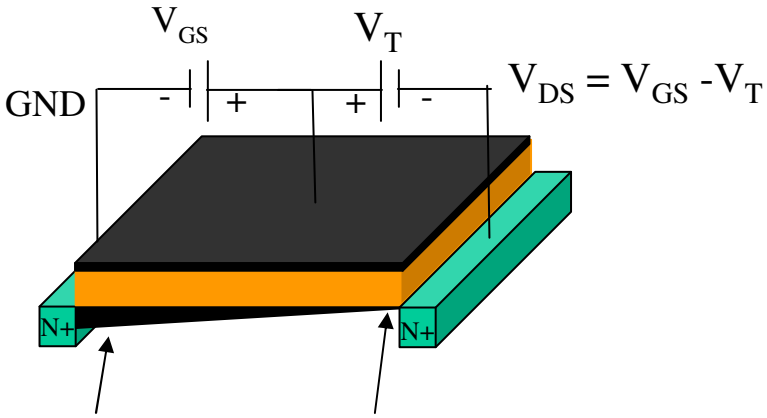


Drain current: Expression used in SPICE level 1

$$I_D = \frac{W}{L}\mu_n C_{OX}\left(V_{GS} - V_T - 0.5V_{DS}\right)V_{DS}$$



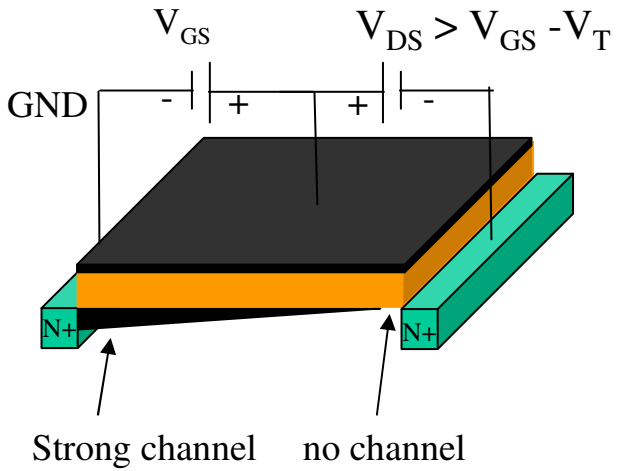
MOS Equations in **Saturation and Linear Region**



Under these conditions → current is highest

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

SATURATION REGION ($V_{DS} > V_{GS} - V_T$)



Carriers are attracted to the drain, and swept in the region where channel is incomplete (why??)

Current is till given by $I_D = \frac{W}{2L}\mu_n C_{OX}(V_{GS} - V_T)^2$

or

$$I_{DSAT} = \frac{W}{2L}\mu_n C_{OX}(V_{DSAT})^2$$

SPICE level 1

MOS MODEL: Fundamental equations

- **Drain current, Triode region**

$$i_D=\mu C_{OX}\frac{W}{L_{eff}}[V_{GS}-V_T-0.5V_{DS}]V_{DS}$$

- **Drain Current, Saturation region**

$$i_D=\frac{\mu C_{OX}}{2}\ \frac{W}{L_{eff}}\ [V_{GS}-V_T]^2[1+\lambda V_{DS}]$$

- **Threshold voltage (zero bias)**

$$V_{T0}=V_{FB}+2\phi_F+\gamma\sqrt{2\phi_F}$$

- **Threshold voltage**

$$V_T=V_{T0}+\gamma\left[\sqrt{2\phi_F+V_{SB}}-\sqrt{2\phi_F}\right]$$

- **KP (Spice Model)**

$$KP=\mu C_{OX}$$

MOS MODEL: Some values frequently used

- **KP**
  - **N-MOS 10^{-4} A/V**
  - **P-MOS $0.3*10^{-4}$ A/V**
- **VT0**
  - **N-MOS 0.7V**
  - **P-MOS 1V**
- **Vearly**
  - **N-MOS 10 V/um**
  - **P-MOS 15 V/um**