ECE321 – Electronics I

Lecture 5: Physics of Semiconductor MOSFETs

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Review of Last Lecture

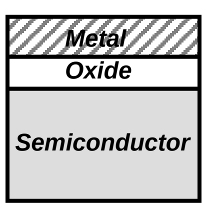
- More on Depletion Region
- Reverse Biased PN Junction
- Forward Biased PN Junction

Today's Lecture

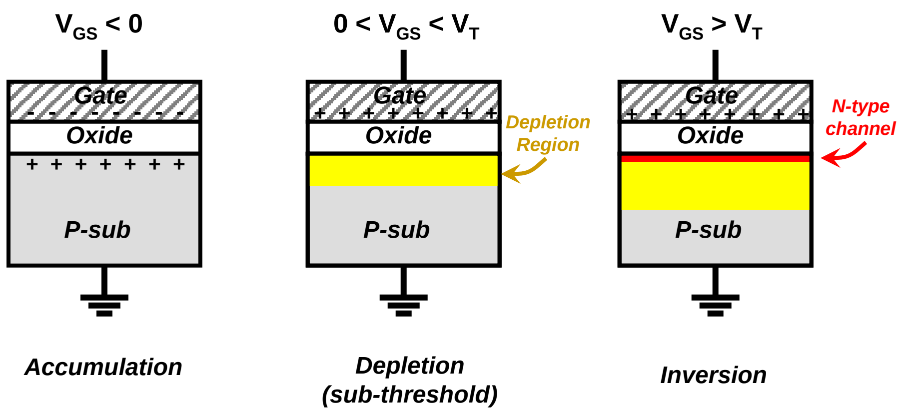
- Basic MOS Transistor
- MOSFET Operations
- Cutoff, Linear, and Saturation Regions in MOSFET
- NMOS and PMOS Structures

MOS Structure

- MOS (Metal-Oxide-Semiconductor) is the base of modern semiconductor industry.
- The top conductor, originally was metal but it became polysilicon and now is metal again. Why?
- The insulator has been silicon dioxide (SiO_2) for a long period of time, but now is a high-k dielectric material, such as hafnium dioxide (HfO_2 with k of 25-30). Why?
- The semiconductor has been, and most probably will be, silicon for a long time.



Depletion Region in MOS



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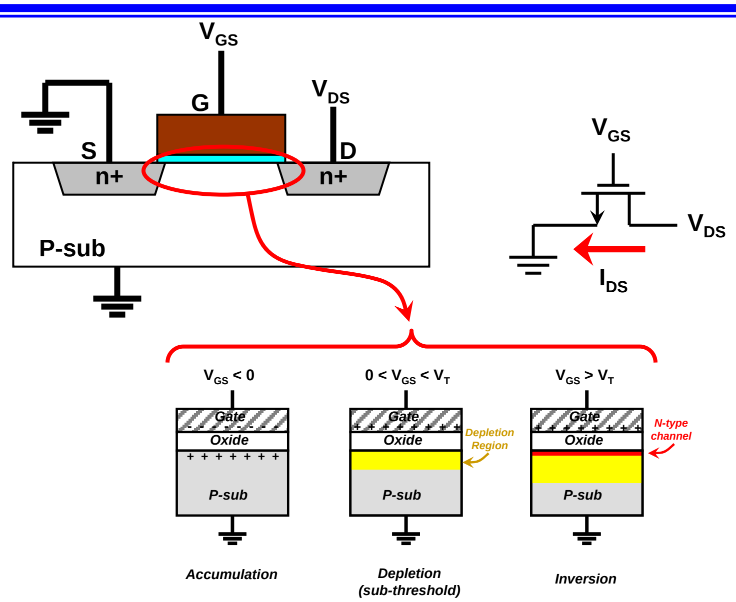
MOS Field Effect Transistor (MOSFET)



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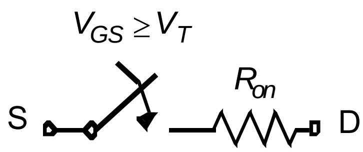
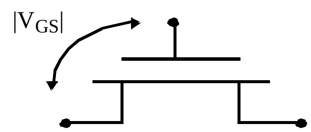
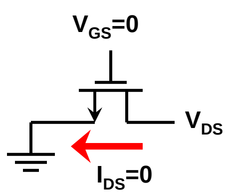
What is a Transistor?

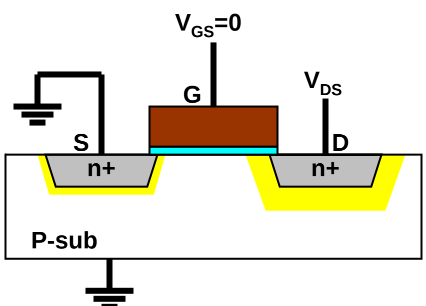
A Switch! ⟷ An MOS Transistor

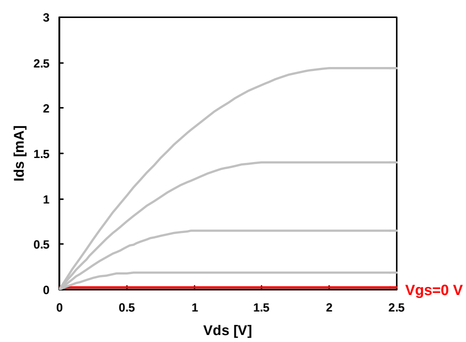




Cutoff Region



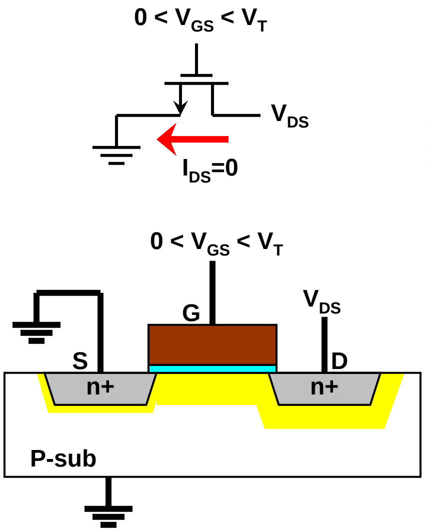


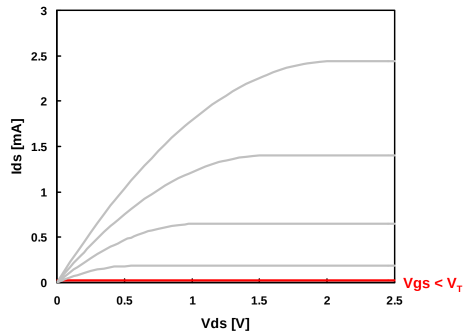


When: $V_{GS} = 0$

$I_{DS} = 0$

Depletion Region





When: $V_{GS} < V_T$

$I_{DS} = 0$

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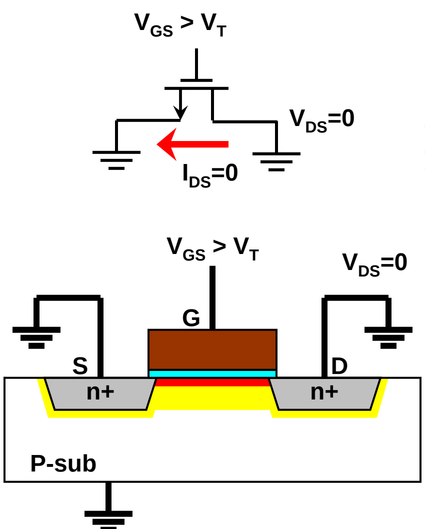
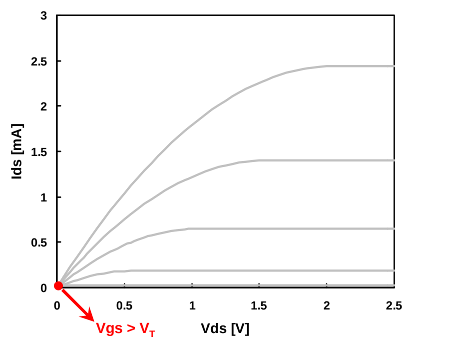
Inversion Region





When: $V_{DS} = 0$

$I_{DS} = 0$

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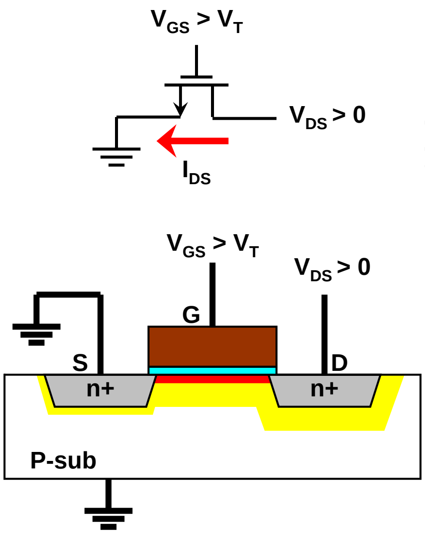
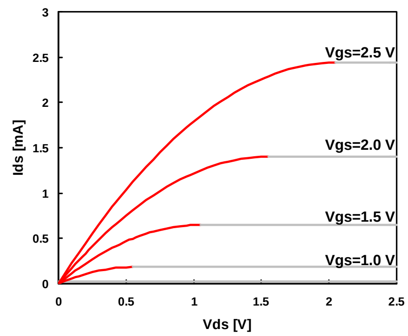
Linear Region (inversion)

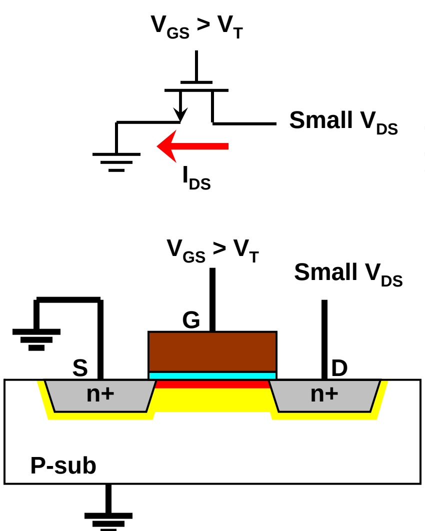


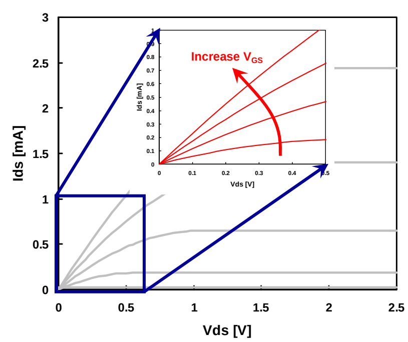


When: $V_{DS} < V_{GS} - V_T$

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

Ohmic Region (inversion)

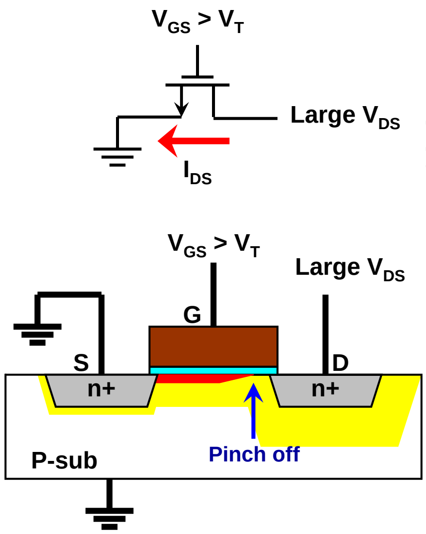


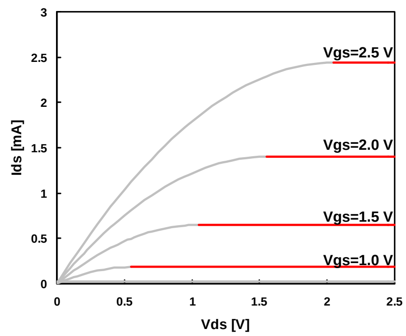


For small V_{DS} **:**

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

Saturation Region (inversion)





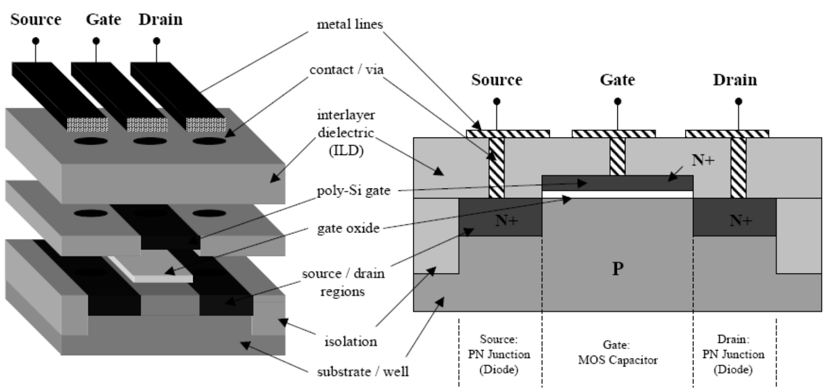
When: $V_{DS} > V_{GS} - V_T$

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

$$I'_{DS} = I_{DS}(1 + \lambda V_{DS})$$

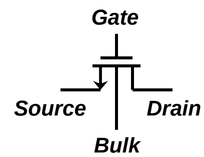
MOSFET Top & Cross Section View

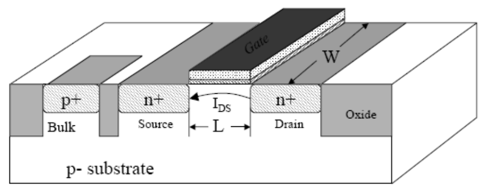
Metal **O**xide **S**emiconductor **F**ield **E**ffect **T**ransistor



NMOS Device Cross-Section

- I_{DS} is Defined as "from Drain to Source" Current
  - Majority carriers are electrons
  - NMOS device conducts when "gate-to-source" voltage is positive
- I_{DS} is as a function of:
  - Channel width (W)
  - Inverse of channel length (1/L)
  - Gate-to-source potential (V_{GS})





PMOS Device Cross-Section

- Complement of NMOS
- Built inside an N-well implant in substrate
- Majority carriers are holes, not electrons
- Conducts when gate-source voltage is negative