CHAPTER 5

MOS Field-Effect Transistors (MOSFETs)

Disclaimer: Most of the slides are skeletons that will be filled/modified in the lecture. Please do not assume that you can know the material just by reading the slides.

Chapter Objective

- Learn the physical structure of the MOSFET and how it works.
- How to analyze circuits that contains MOSFET.
- How to obtain linear amplification from a nonlinear MOSFET.
- The three basic ways for connecting a MOSFET to construct amplifiers.
- Practical circuits for MOSFET.

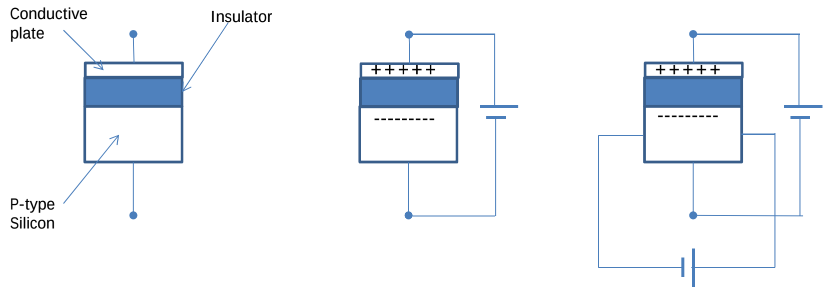
MOSFET: Metal Oxide Semiconductor Field Effect Transistor

- Transistors (3 terminal devices) diodes are 2 terminal devices – more complicated.
- One terminal usually control the current between the other two terminals.
- Used in digital and analog circuits
- Mainly MOSFET and BJT (vast majority of IC's are MOSFET)
  - Smaller
  - Loss power than BJT – very important –

- This is not a course on semiconductor (nor this is a physics course). However, understanding how the device work is very important.

CMOS

Not a real device, just to explain the idea



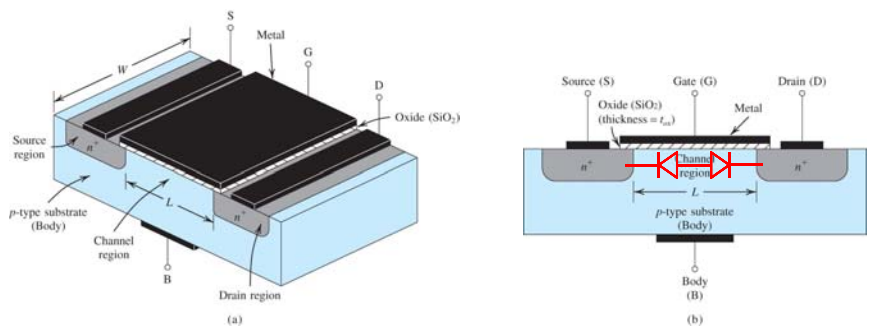


Figure 5.1 Physical structure of the enhancement-type NMOS transistor: **(a)** perspective view; **(b)** cross section. Typically L = 0.03 μm to 1 μm, W = 0.05 μm to 100 μm, and the thickness of the oxide layer (t_{ox}) is in the range of 1 to 10 nm.

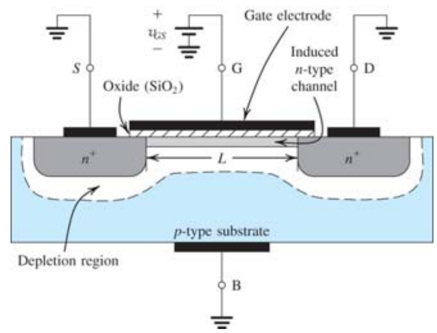


Figure 5.2 The enhancement-type NMOS transistor with a positive voltage applied to the gate. An *n* channel is induced at the top of the substrate beneath the gate.

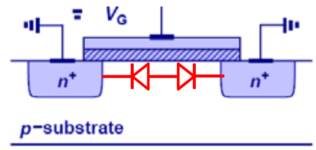
Enhancement mode (normally off) and we have to enhance it to be ON

If v_{gs} is positive, it attracts electrons from the substrate to the part of the substrate next to the SiO2 creating a channel

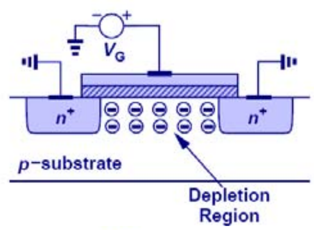
MOSFET Operation

- We start by explaining how things work, then we use mathematics to derive equations.
- Start with n-MOS

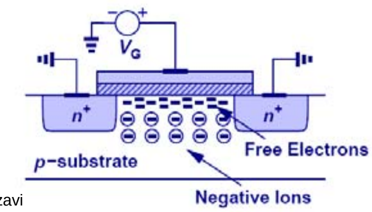
V_G=0, because of the back-to-back diodes, no current flows from source to destination



V_G>0, Holes are repelled by the positive gate voltage and leaving behind negative ions forming a depletion region



As V_G increases (Threshold voltage), Electrons are attracted to the surface forming a channel where current **might** flow



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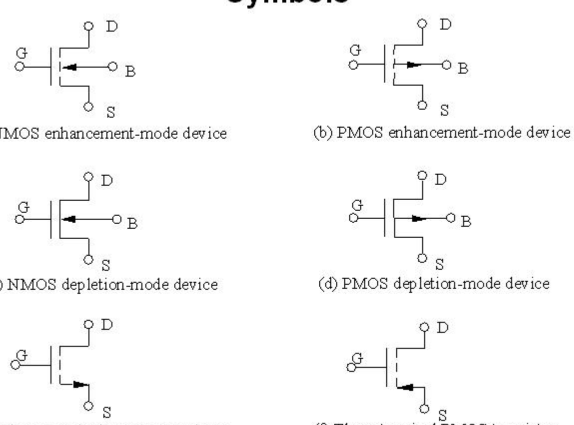
IEEE Standard MOS Transistor Circuit Symbols



(a) NMOS enhancement-mode device

(b) PMOS enhancement-mode device

(c) NMOS depletion-mode device

(d) PMOS depletion-mode device

(e) Three-terminal NMOS transistor

(f) Three-terminal PMOS transistor

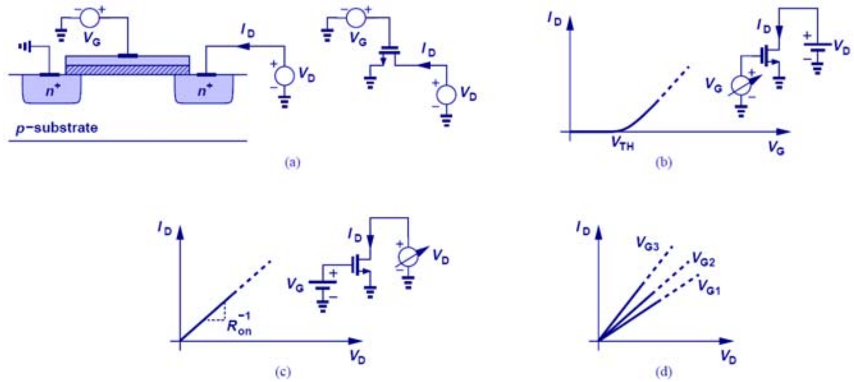
Transistors

MES Institute of Microelectronic Systems

11

Source: http://people.seas.harvard.edu/~jones/es154/

NMOS Characteristics



- We can vary V_G and keeping V_D constant
- Or vary V_D and keeping V_G constant

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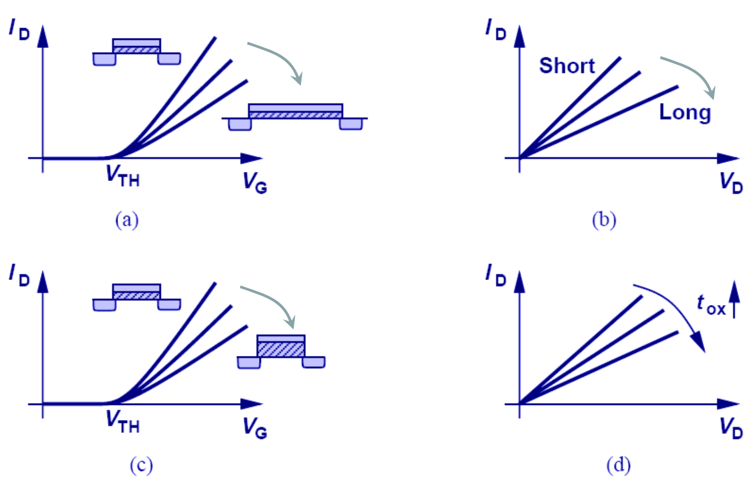
Effect of *L* and t_{ox}



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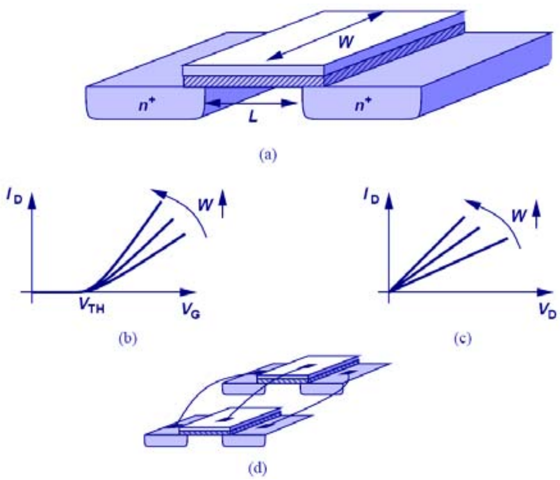
Effect of *W*



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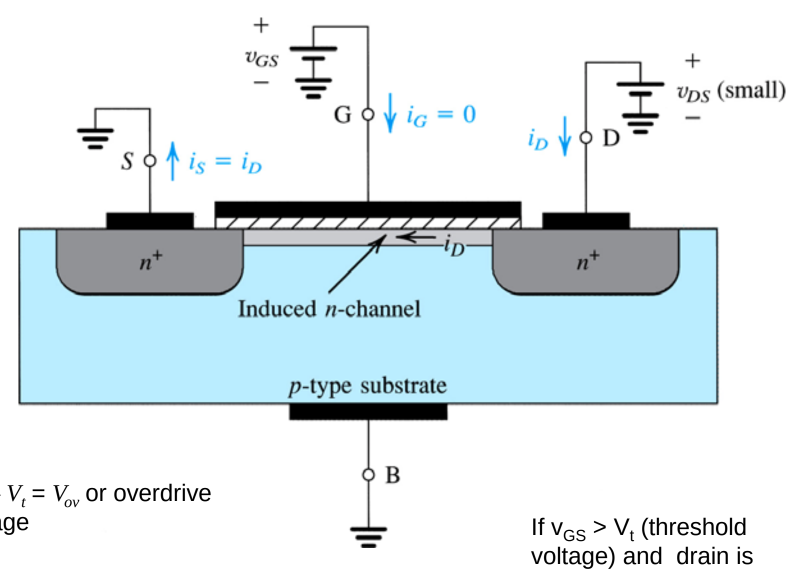
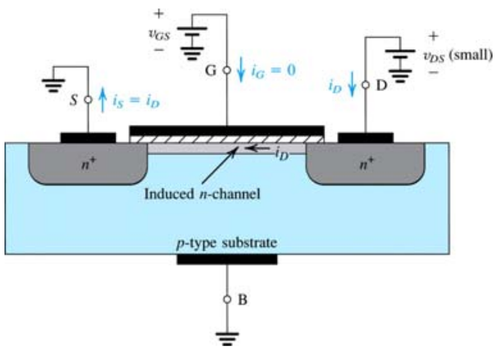


$v_{GS} - V_t = V_{ov}$ or overdrive voltage

If $v_{GS} > V_t$ (threshold voltage) and drain is positive, then current i_D can flow

Microelectronic Circuits, Sixth Edition Sedra/Smith

Small v_{DS}



$$\frac{Q}{\text{Unit length}} = \frac{CV}{L} = \frac{(\varepsilon_{ox} A / t_{ox})V}{L}$$

$$\frac{Q}{\text{Unit length}} = C_{ox} W v_{ov}\ , \quad C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$$

$$|E| = \frac{v_{DS}}{L}$$

$$\text{Electron drift velocity} = \mu_n |E| = \mu_n \frac{v_{DS}}{L}$$

$$i_D = \frac{Q}{\text{Unit length}} \times speed$$

$$i_D = C_{ox}\ W\ V_{ov} \times \mu_n \frac{v_{DS}}{L}$$

$$i_D = \left[(\mu_n C_{ox}) \left(\frac{W}{L} \right) V_{ov} \right] v_{DS}$$

Small v_{DS}

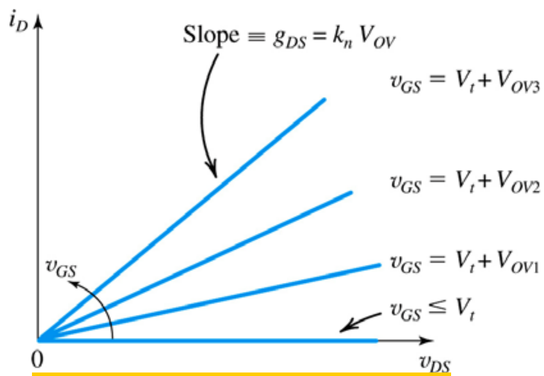
$$i_D = \left[(\mu_n C_{ox}) \left(\frac{W}{L} \right) V_{ov} \right] v_{DS}$$

Conductance

$$g_{DS} = (\mu_n C_{ox}) \left(\frac{W}{L} \right) V_{ov}$$

$$r_{DS} = \frac{1}{(\mu_n C_{ox}) \left(\frac{W}{L} \right) V_{ov}}$$

Linear resistance



$$i_D = \left[(\mu_n C_{ox}) \left(\frac{W}{L} \right) V_{ov} \right] V_{DS}$$

Determined by the process technology=K_n'

Transistor Aspect Ratio

Overdrive voltage

K_n