ENG2210
Electronic Circuits

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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 Objectives

- 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.

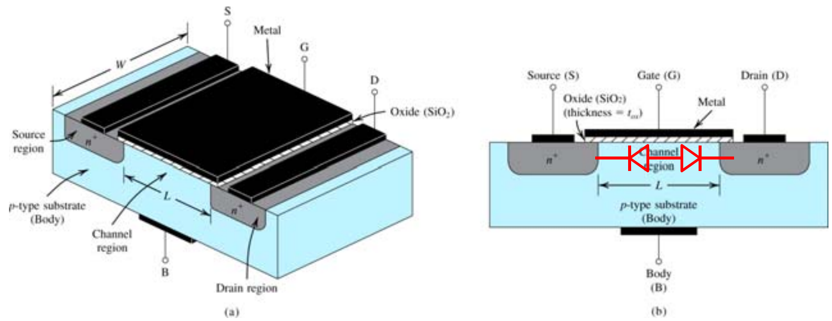
MOSFET– Metal Oxide Semiconductor Field Effect Transistor

- 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 –

MOSFET

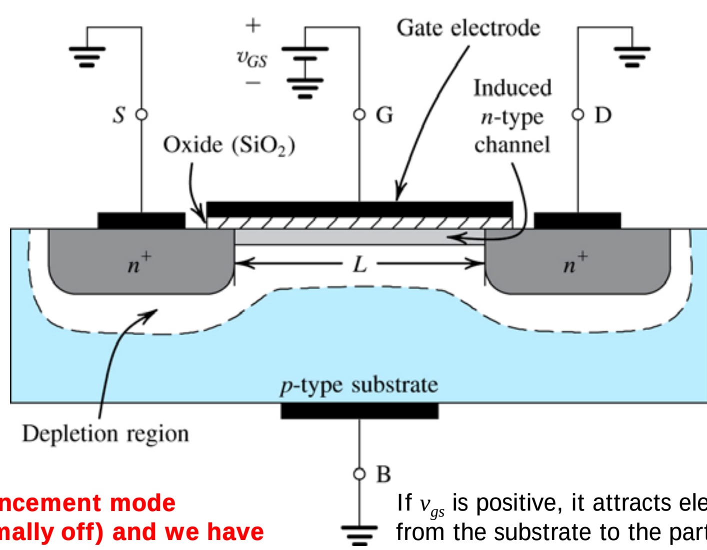
- This is not a course on semiconductor (nor this is a physics course). However, understanding how the device work is very important.

Gate is isolated (SiO2) no current from gate



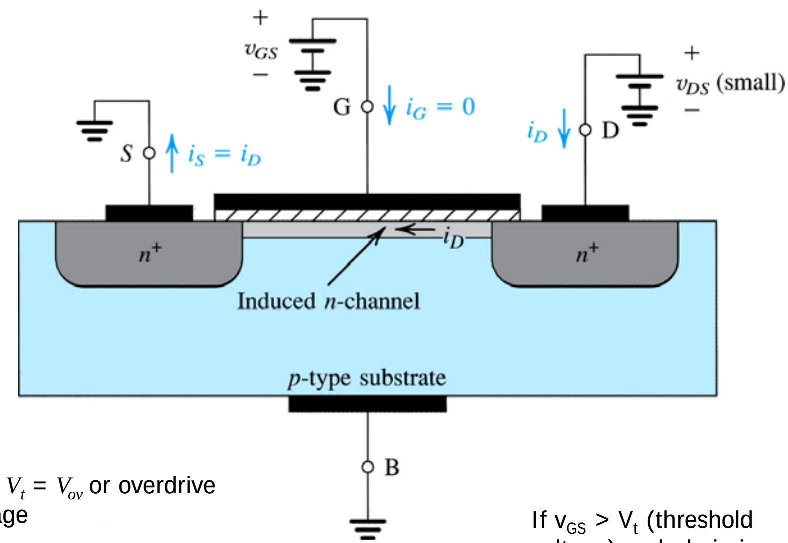
No current can flow between source and drain

Usually body contact is connected to the source



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

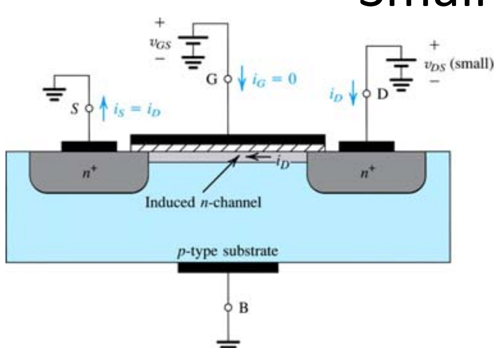
If v_{gs} is positive, it attracts electrons from the substrate to the part of the substrate next to the SiO2 creating a channel



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

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

Small v_{DS}



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

$$\frac{Q}{\text{Unit length}} = C_{ox} W v_{ov}$$

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

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

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

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

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

Small v_{DS}

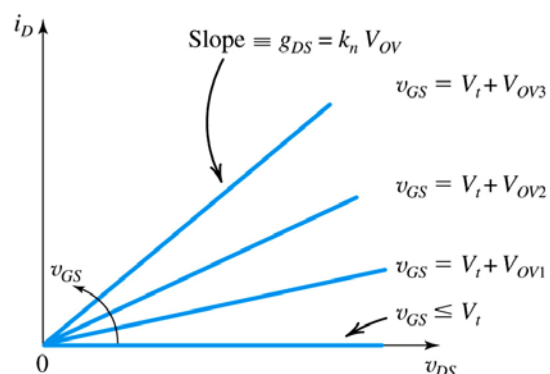
$$i_D = \left[(\mu_n C_{ox}) \left(\frac{W}{L} \right) V_{ov} \right] v_{DS}$$

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

Not Small v_{DS}

- As v_{DS} increases we can not assume a constant voltage between the gate and any point along the channel.
- The voltage at one end of the channel is 0, while at the other end is v_{DS}

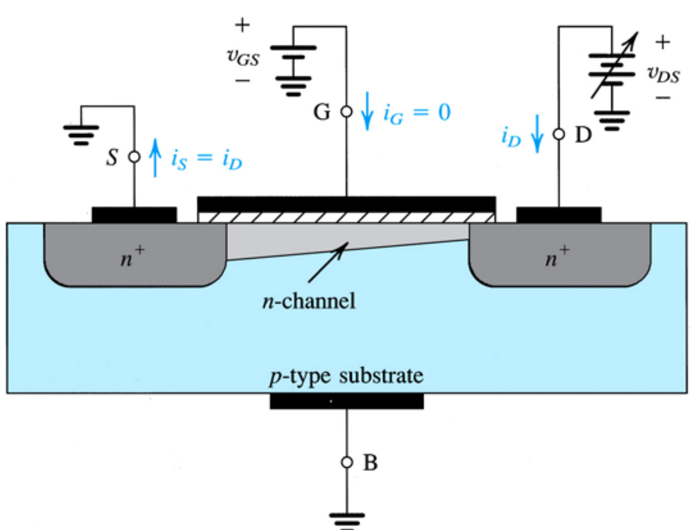


Figure 5.5 Operation of the enhancement NMOS transistor as v_{DS} is increased. The induced channel acquires a tapered shape, and its resistance increases as v_{DS} is increased. Here, v_{GS} is kept constant at a value > V_t; $v_{GS} = V_t + V_{OV}$.

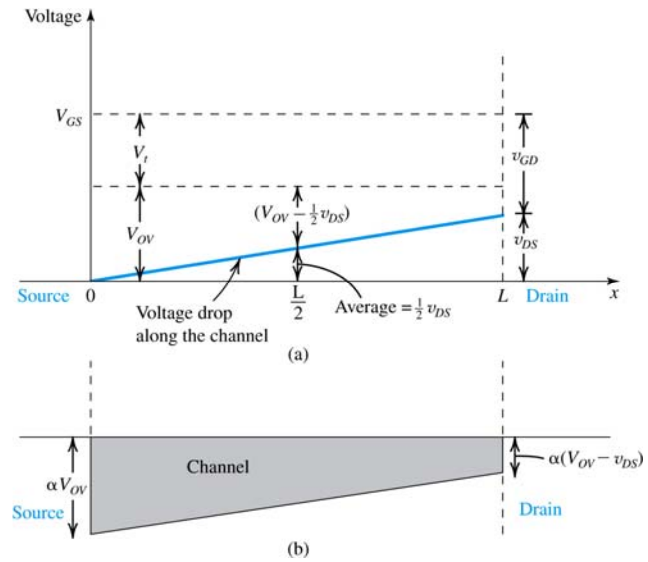


Figure 5.6(a) For a MOSFET with $v_{GS} = V_t + V_{OV}$, application of v_{DS} causes the voltage drop along the channel to vary linearly, with an average value of $\frac{1}{2} v_{DS}$ at the midpoint. Since $v_{GD} > V_t$, the channel still exists at the drain end. **(b)** The channel shape corresponding to the situation in (a). While the depth of the channel at the source end is still proportional to V_{OV}, that at the drain end is proporational to $(V_{OV} - v_{DS})$.

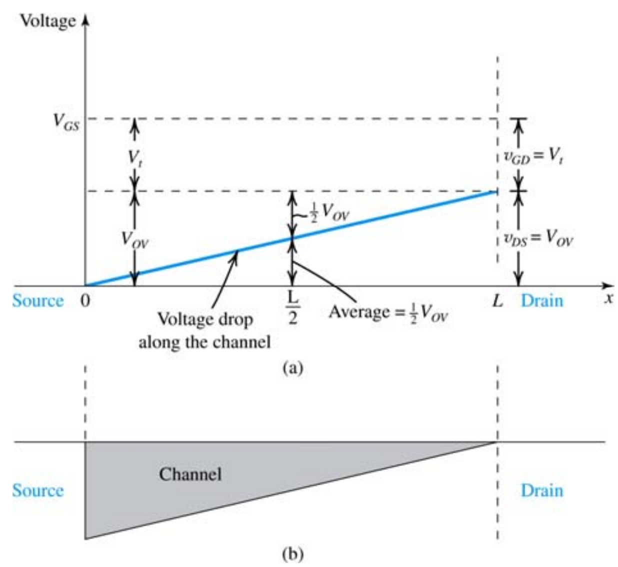
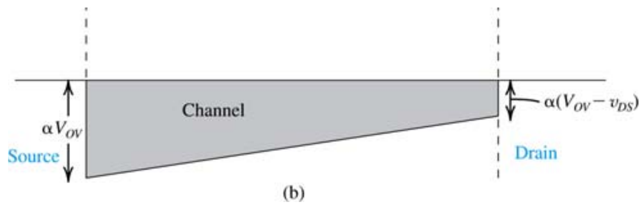


Figure 5.8 Operation of MOSFET with $v_{GS} = V_t + V_{OV}$, as v_{DS} is increased to V_{OV}. At the drain end, v_{GD} decreases to V_t and the channel depth at the drain end reduces to zero (pinch off). At this point, the MOSFET enters the saturation mode of operation. Further increasing v_{DS} (beyond $V_{DSat} = V_{OV}$) has no effect on the channel shape and i_D remains constant.



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

$$i_D = \left[(\mu_n C_{ox}) \left(\frac{W}{L} \right) \left(V_{ov} - \frac{1}{2} v_{DS} \right) \right] v_{DS}$$

$$i_D = \left[k_n' \left(\frac{W}{L} \right) \left(V_{ov} - \frac{1}{2} v_{DS} \right) \right] v_{DS}$$

As v_{DS} increases the resistance increases and the current does not continue to grow with the same rate

$$v_{DS} >= V_{ov}$$

- As V_{DS} grows, the channel pinches off.
- When $v_{DS} = V_{ov}$ the channel depth is zero
- Increasing v_{DS} beyond that has no effect.
- The drain current saturates (saturation region)
- Electrons can still go through the depletion region

$$i_D = \frac{1}{2} k_n' \left(\frac{W}{L} \right) V_{ov}^2$$

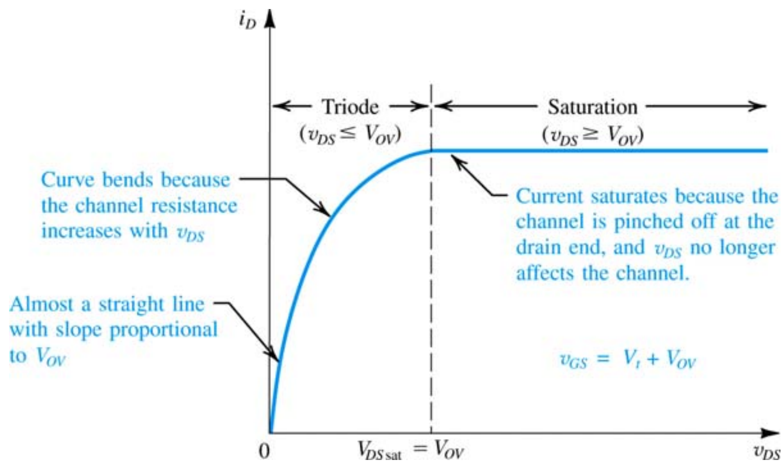


Figure 5.7 The drain current i_D versus the drain-to-source voltage v_{DS} for an enhancement-type NMOS transistor operated with $v_{GS} = V_t + V_{OV}$.

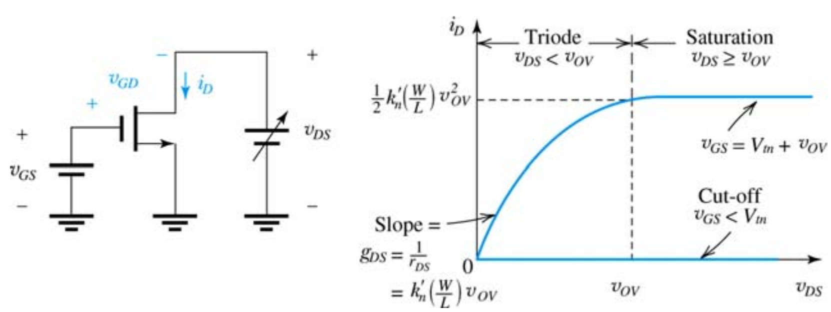


Table 5.1 Regions of Operation of the Enhancement NMOS Transistor

NMOS

Cut-off

$v_{GS} < V_{tn}$

Saturation

$v_{GS} > V_t$

$v_{DS} > v_{GS} - V_t$

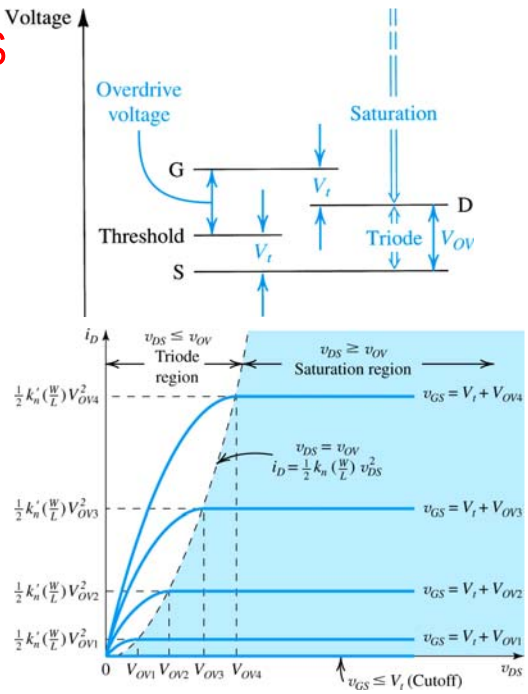
$v_D - v_s > v_G - v_s - V_t$

$v_{GD} < V_t$

Triode

$v_{DS} < v_{OV}$

$v_{GD} > V_t$



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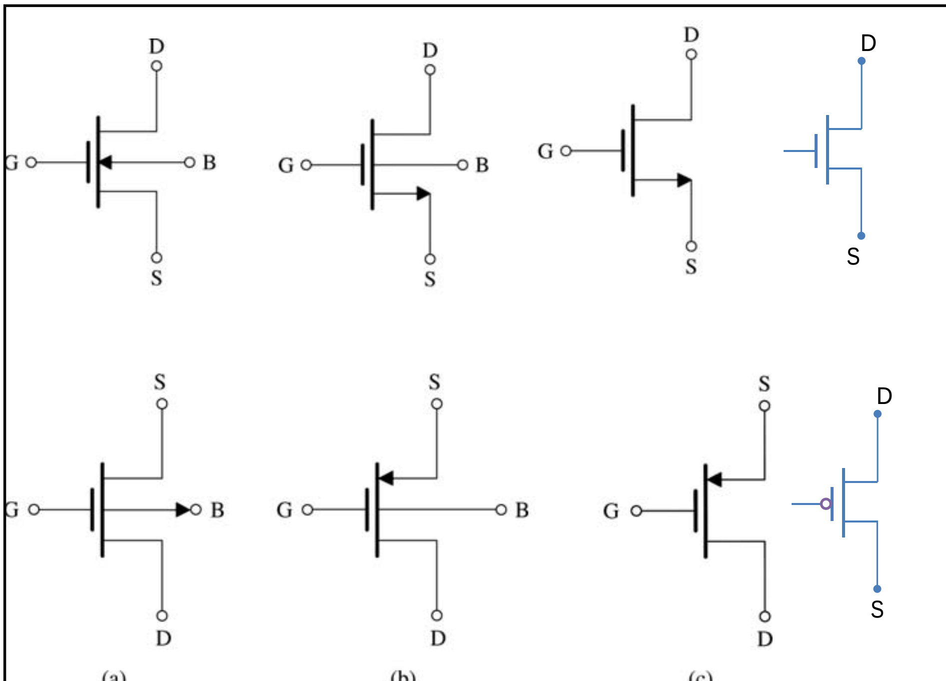

Microelectronic Circuits, Sixth Edition Sedra/Smith