Lecture10: MOSFET

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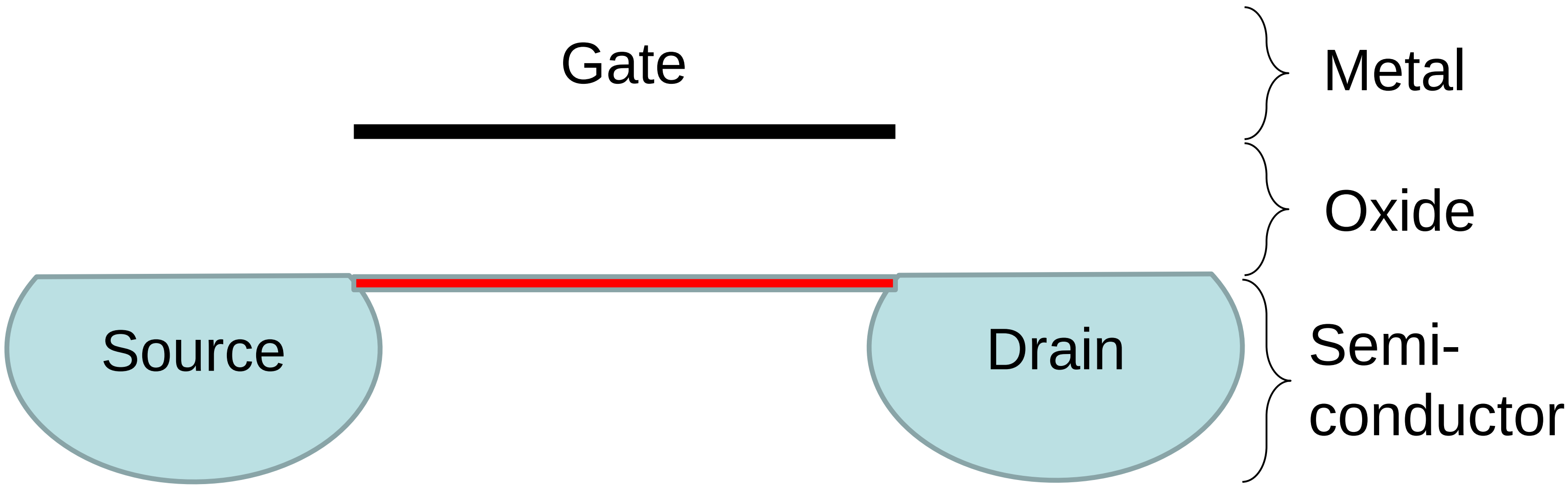
MOS? MOSFET?

- MOS (Metal-Oxide-Semiconductor)
  - By changing the gate voltage, the charge density can be controlled.
- MOSFET (MOS Field-Effect Transistor)
  - Current conduction



Its operation

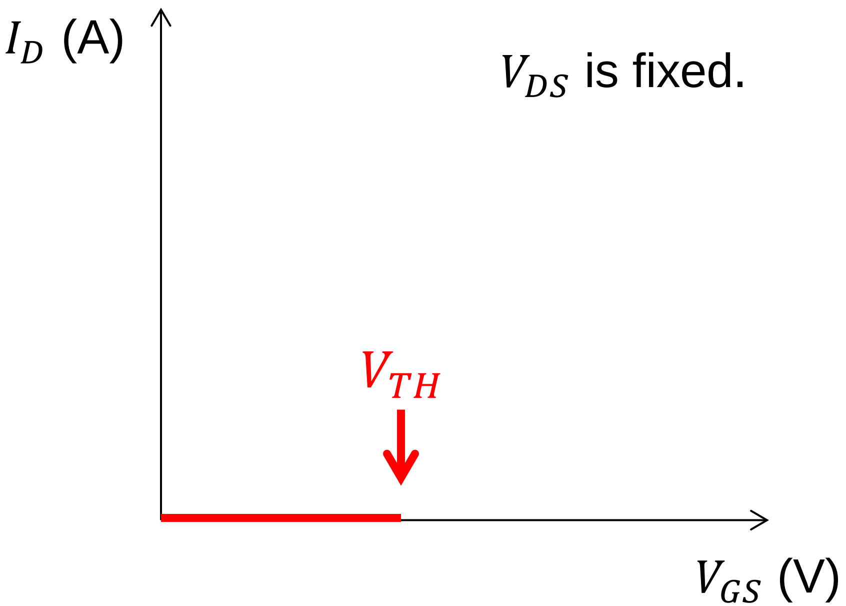
- The MOSFET has three terminals.
  - Source, drain, and gate
  - We always have

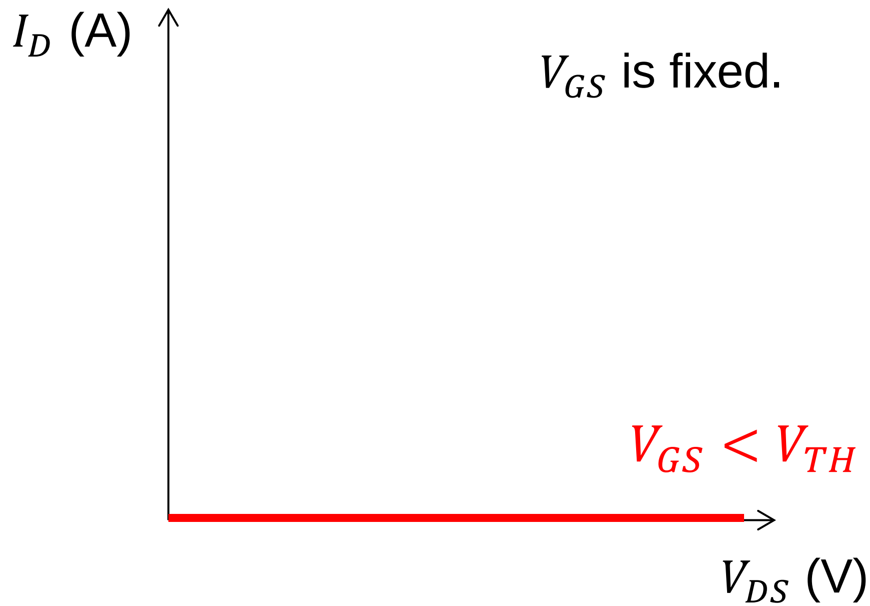
$$I_S(t) + I_D(t) + I_G(t) = 0.$$

- At low frequencies, the gate current is zero.
  - Source current + drain current = 0, $I_S + I_D = 0$
  - Source is regarded as the reference contact.
  - Gate voltage (V_{GS}) and drain voltage (V_{DS}) are variables.
- We are interested with $I_D(V_{GS}, V_{DS})$.

IV characteristics

- We will draw the two graphs.
  - $I_D(V_{GS})$ with fixed V_{DS} & $I_D(V_{DS})$ with fixed V_{GS}





Drain current

- It is easy to guess that
  - When $V_{GS} < V_{TH}$, no drain current is allowed.

$$I_D = 0$$

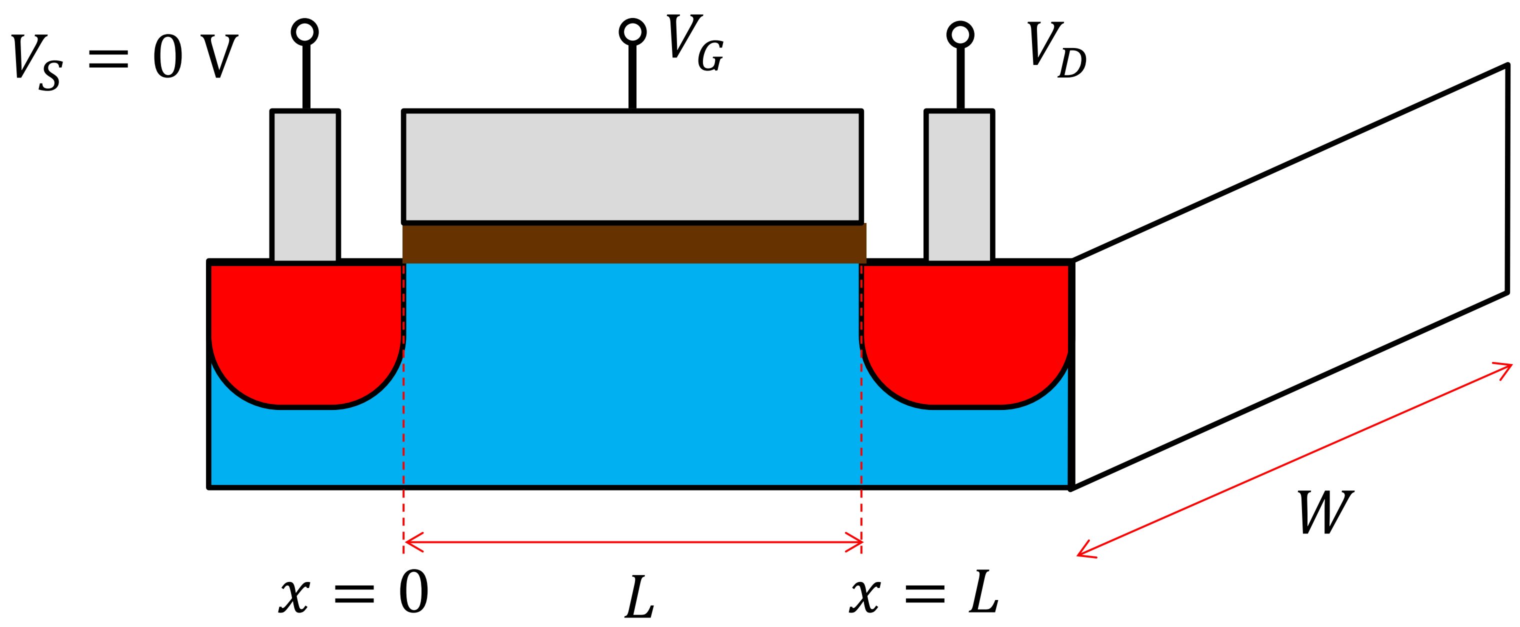
  - When $V_{GS} > V_{TH}$,

$$I_D \propto C_{ox}(V_{GS} - V_{TH})$$

- In this lecture, we derive an appropriate expression for I_D.

Device structure

- Two-dimensional cross-section
  - "Potential" can be dependent on the position, $V(x)$.



Derivation of IV (1)

- Drain current
  - Q_{elec} is the electron charge density *per unit length*.
  - It follows

$$Q_{elec} = WC_{ox}[V_G - V(x) - V_{TH}] \qquad \text{(Razavi 6.3)}$$

  - At a certain position of x, the current is given by

$$I(x) = Q_{elec}(x)\, v(x) \qquad \text{(Razavi 6.4)}$$

  - Also v is the electron velocity.

$$v = -\mu_n E = +\mu_n \frac{dV}{dx} \qquad \text{(Razavi 6.5 and 6.6)}$$

Derivation of IV (2)

- Drain current (Continued)
  - It is easy to understand that $I_D = I(x)$. The drain current is

$$I_D = WC_{ox}[V_G - V(x) - V_{TH}]\mu_n \frac{dV}{dx} \qquad \text{(Razavi 6.7)}$$

  - Simply re-arranging,

$$I_D dx = \mu_n C_{ox} W[V_G - V(x) - V_{TH}]dV$$

  - When integrated,

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

Derivation of IV (3)

- Graph ($I_D - V_{DS}$)
  - Is it acceptable?