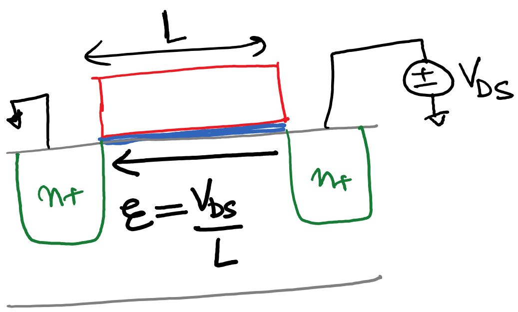
ECE 445 - Lecture 12

Monday, February 25, 2019 8:04 AM



$$\mathcal{E} = \frac{V_{DS}}{L}$$

$L \downarrow$ & $V_{DS} = $ const

$\mathcal{E} \uparrow$

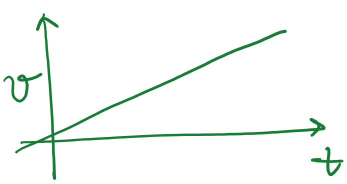
Drift velocity:

Vacuum

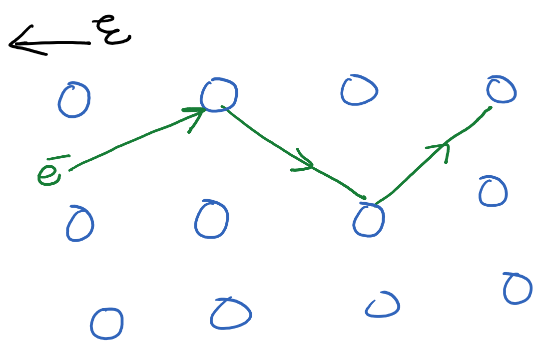
$\mathcal{E}$

$\bar{e}$ $F = q\mathcal{E}$

$$a = \frac{q\mathcal{E}}{m_e}$$



In a semiconductor Xtal



* carriers travel with a constant velocity
  ↳ drift velocity due to collisions with the crystal lattice

Drift velocity:

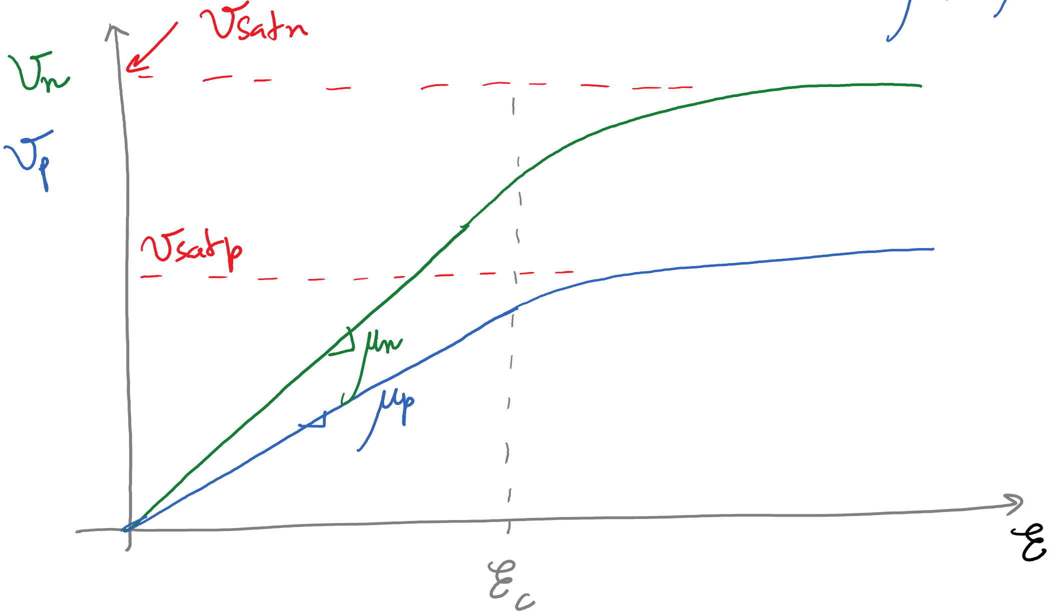
$$v_n \propto \mathcal{E}$$

$$\Rightarrow v_n = \mu_n \mathcal{E} \longrightarrow \text{electron mobility}$$

$$v_p = \mu_p \mathcal{E} \longrightarrow \text{hole mobility}$$

μ_n & μ_p are properties of the semiconductor material

$\Rightarrow \mu_p < \mu_n$ as holes are heavier



* Beyond a critical electric field ($\mathcal{E}_c$), drift velocities start to saturate with increase in $\mathcal{E}$.

↳ velocity saturation

↳ hot carriers

$$v = \begin{cases} \dfrac{\mu \mathcal{E}}{1 + \left(\dfrac{\mathcal{E}}{\mathcal{E}_c}\right)}, & \mathcal{E} < \mathcal{E}_c \end{cases}$$

$$v = \begin{cases} \dfrac{\mu \mathcal{E}}{1 + \left(\dfrac{\mathcal{E}}{\mathcal{E}_c}\right)}, \\ v_{sat}, & \mathcal{E} > \mathcal{E}_c \end{cases}$$

* In velocity saturation regime, the 'mobility' model is no longer true
  ↳ we need revised I-V equations

* While deriving MOSFET 'I_D' equation, we had a step

$$I_D = \mu_n W \cdot C_{ox}' \cdot \left(\frac{dV(y)}{dy}\right) \left[V_{GS} - V_{THN} - V(y)\right] \longrightarrow Eq^n\ 6.29$$

$$\mathcal{E} \triangleq \frac{dV(y)}{dy}$$

$$\mu_n \triangleq \frac{v_{sat}}{\mathcal{E}} = \frac{v_{sat}}{\frac{dV(y)}{dy}}$$

$$= \frac{v_{sat}}{\left(\frac{dV(y)}{dy}\right)} \cdot W C_{ox}' \cdot \left(\frac{dV(y)}{dy}\right) \cdot \left[V_{GS} - V_{THN} - V(y)\right].$$

$\Rightarrow$

$$I_D = W \cdot v_{sat} \cdot C_{ox}' \left(V_{GS} - V_{THN} - V_{DS,sat}\right)$$

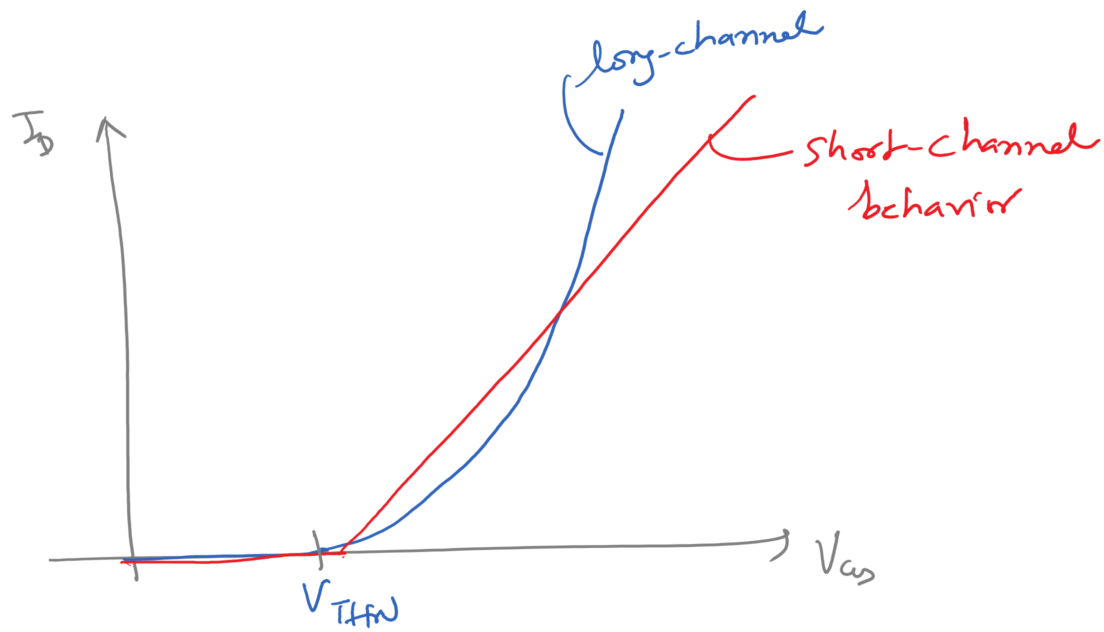
↳ $= V_{GS} - V_{THN}$

* Short-channel Equation " "

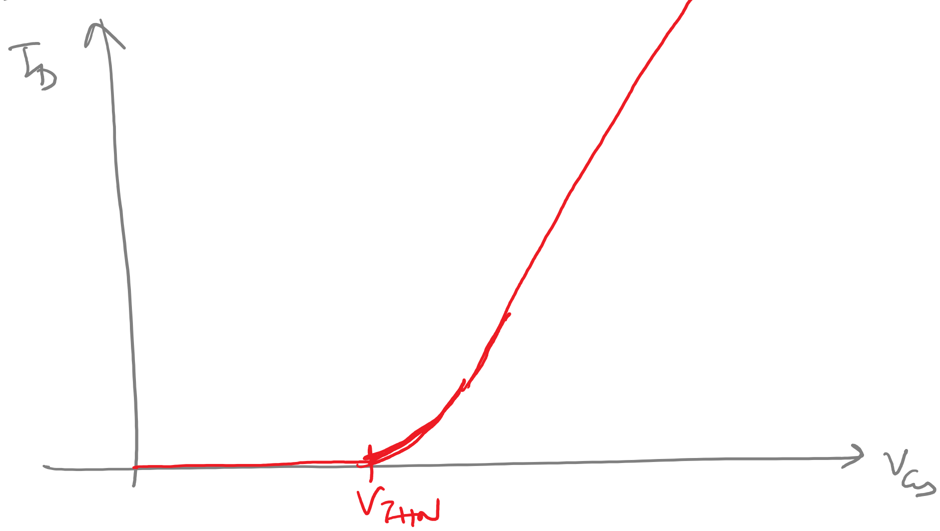
* No longer dependent upon "L"
* characteristics are linear than square-law

$I_D = W \cdot I_{drive}$ ← drive current

↳ $I_{drive} = v_{sat} C_{ox}' (V_{GS} - V_{THN} - V_{DS,sat})$



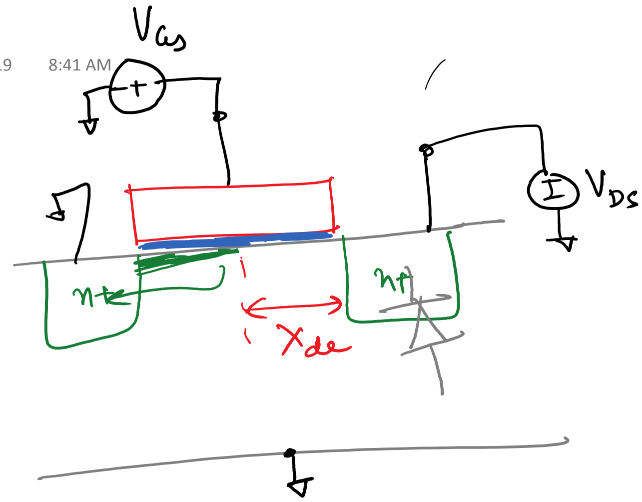
In reality



α

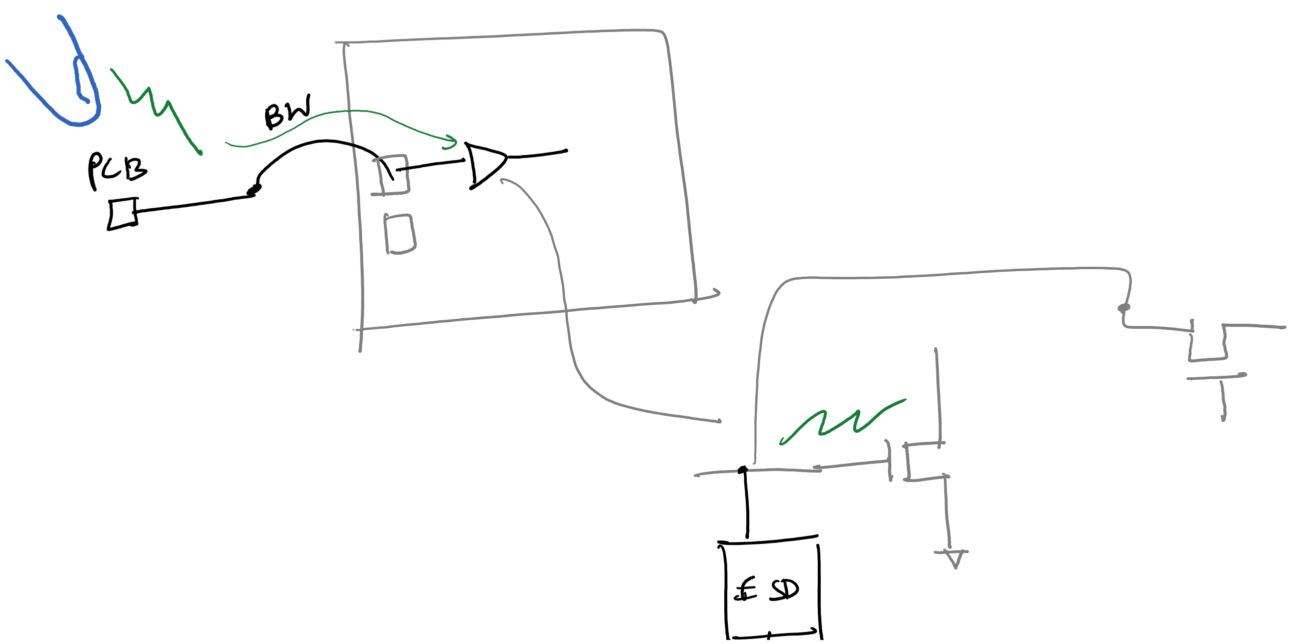
* $I_D \propto W \cdot (V_{GS} - V_{THN} - V_{DS,sat})^{\alpha}$

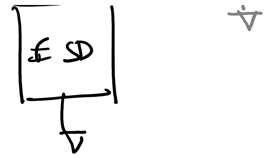
$1 < \alpha < 2$

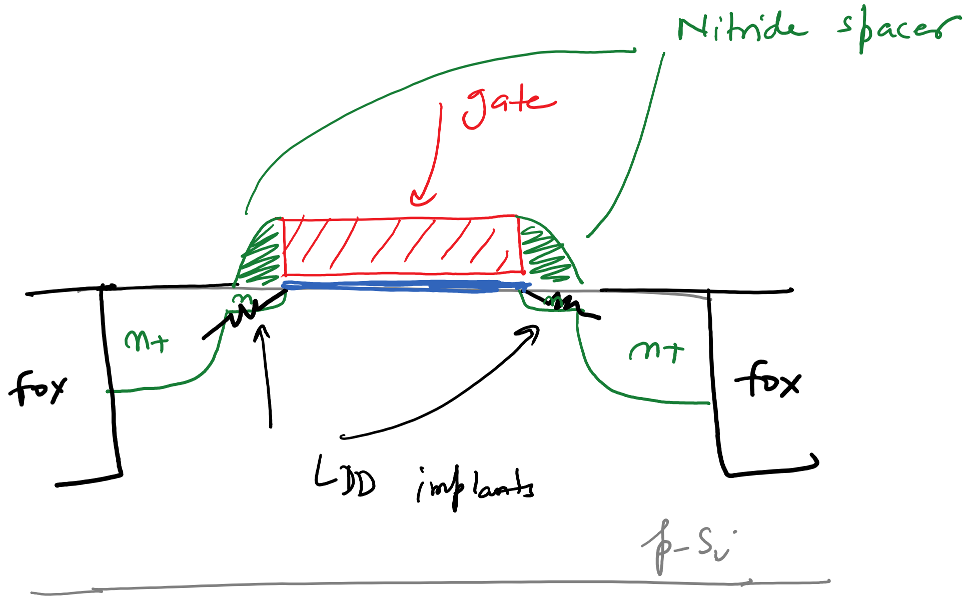


$0 \leq V_{GS}, V_{DS} \leq V_{DD}$

- What limits V_{DD}?
- Gate oxide breakdown $\simeq t_{ox} \cong 10\text{Å}$
- Drain junction breakdown
  - ↳ large current can flow
- If depletion layer extends from Drain to source
  - ↳ large current can flow
    - ↳ punch through







LDD ⇒ Lightly doped drain

↳ LDD implants (n-doping) provides a resistive buffer between channel and higher-doped drain/source region.

↳ reduce hot carrier generation as the 'E' across the channel is reduced.

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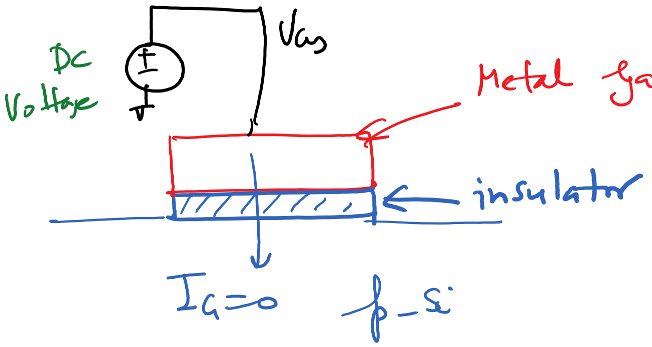
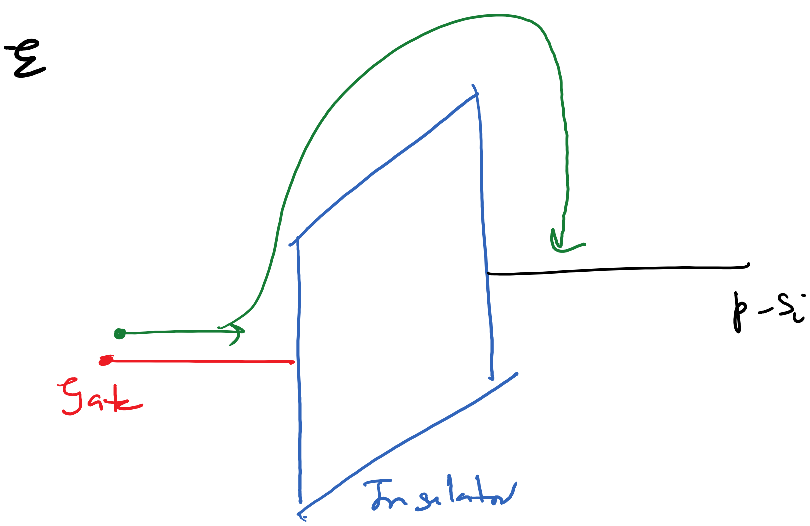
Tunnelling

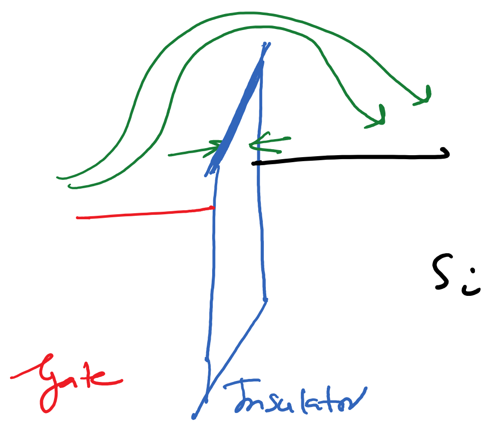




Energy band diagram

"Quantum mechanical phenomenon"

Tunnel



Fowler Nordheim Tunneling (FNT)

→ Gate Leakage current

↑ Gate leakage

↳ instead of t_{ox} ↓ E_{ox} ↑

↳ high-K gate stack

Hafnium Oxide

↳ $K > 10$