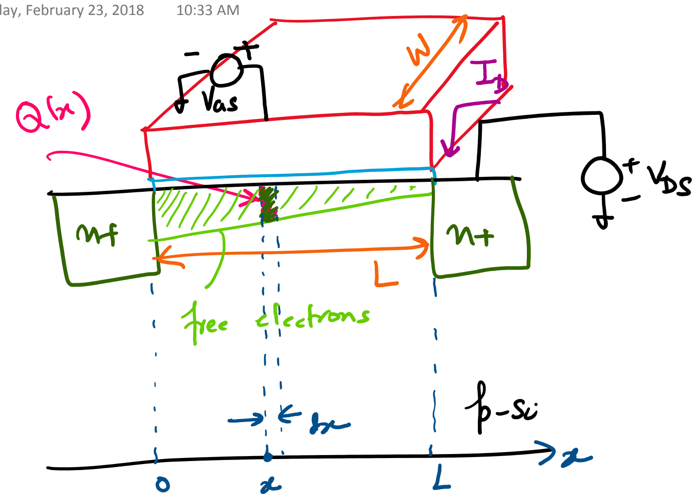
Lecture 17

Friday, February 23, 2018 10:33 AM



$V_{DS,sat} = V_{GS} - V_{THN}$

↳ pinch-off occurs

↑ onset of Saturation region

1-D model

channel charge density ⇒ charge due to free electrons per unit length

$$Q_{total} = \underbrace{Area}_{W \cdot L} \cdot C'_{ox} (V_{GS} - V_{THN})$$

C'_{ox} → Cap per unit area

$$C'_{ox} = \frac{\varepsilon_0 \varepsilon_{ox}}{t_{ox}}$$

ε_{ox} → 4

t_{ox} → Gox thickness

charge density (per unit length)

$$Q = \frac{Q_{total}}{L} = W C'_{ox} (V_{GS} - V_{THN}) \longrightarrow ①$$

$$\Rightarrow Q(x) = W C'_{ox} [V_{GS} - V_{THN} - V(x)] \longrightarrow ②$$

charge is flowing due to Drift

↳ v

$$\left(i = \frac{dQ}{dt} \right.$$

$$v = \mu E$$

$$I = Qv \longrightarrow ③$$

If the carriers move with velocity 'v' then the enclosed charge moves with

$$I = \frac{d}{dt} \left(Q(x)\, dx \right)$$

$$v = \mu_n E$$

$$= \mu_n \left[\frac{dV(x)}{dx} \right] \longrightarrow ④$$

$= \mu_n \left[\frac{dV(x)}{dx} \right] \longrightarrow (4)$

$I = \frac{d}{dt}\left(Q(x)\, dx \right)$

$= Q(x) \cdot \frac{dx}{dt}$

$= Q(x)\, v$

from (2), (3) & (4) we get

$$I_D = W C'_{ox} \left[V_{GS} - V(x) - V_{THN} \right] \mu_n \frac{dV(x)}{dx} \longrightarrow (5)$$

$$I_D \int_{x=0}^{L} dx = \mu_n W C'_{ox} \int_{V(x)=0}^{V(x)=V_{DS}} \left[V_{GS} - V(x) - V_{THN} \right] dV(x)$$

$$\boxed{I_D = \mu_n C'_{ox} \frac{W}{L} \left[(V_{GS} - V_{THN}) V_{DS} - \frac{V_{DS}^2}{2} \right]}$$

TRIODE

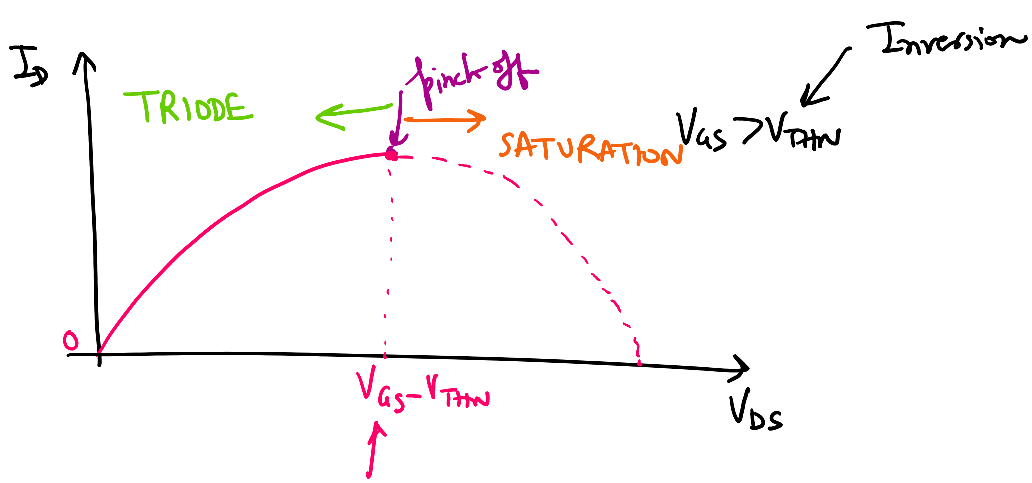
$C'_{ox} \in$ Gox Cap p.u. Area

$\hookrightarrow C_{ox}$

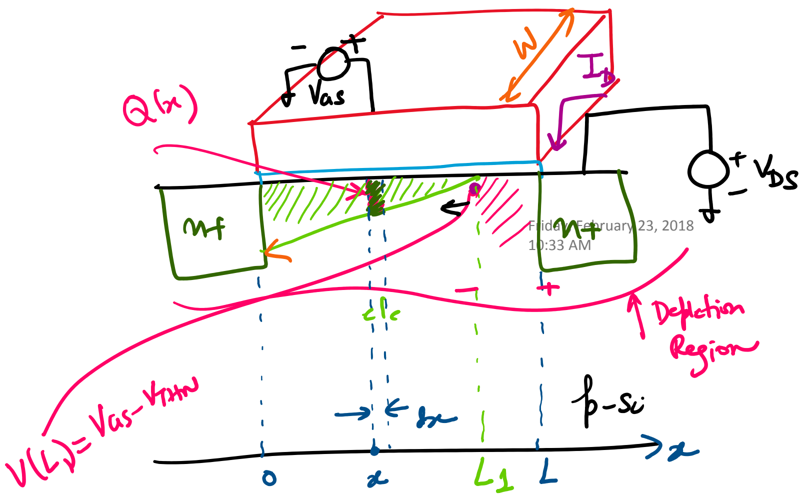
$I_D \propto \mu_n$ (mobility)

$\propto C'_{ox}$

$\propto \frac{W}{L} \in$ Aspect ratio or "sizing" of the MOSFET



Recall that pinch-off occured at $V_{DS} = V_{GS} - V_{THN}$



for $V_{DS} > V_{DS,sat}$
$\downarrow$
$= V_{GS} - V_{THN}$

further increase in V_{DS} simply shifts the pinchoff point towards the source

$\Rightarrow$ integration must be done from $x=0$ to $x=L_1$

$$\int_{x=0}^{x=L_1} I_D\, dx = \int_{V(x)=0}^{V(x)=V_{GS}-V_{THN}} \mu_n C_{ox}' W \left[V_{GS} - V_{THN} - V(x)\right] \cdot dV(x)$$

$\leftarrow$ beyond pinchoff, Voltage drop across channel is $(V_{GS} - V_{THN})$ even if we increase V_{DS}!

$$\boxed{I_D = \frac{1}{2}\mu_n C_{ox}' \frac{W}{L}\left(V_{GS} - V_{THN}\right)^2} \rightarrow \text{SATURATION}$$

for long-L devices

$L_1 \simeq L$

Long-channel Equation for Saturation region

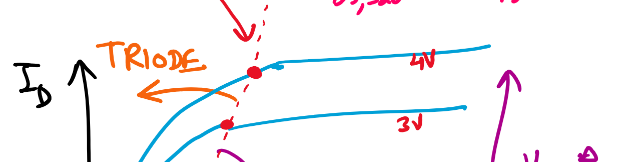
Cutoff

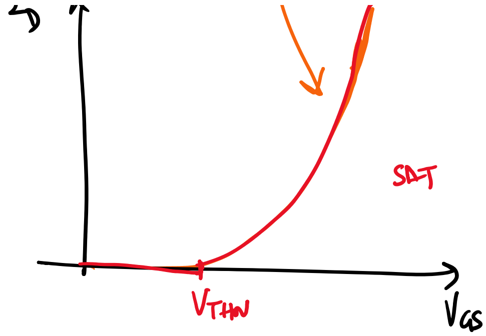
$$I_D = \begin{cases} \sim 0, & V_{GS} < V_{THN} \\ \mu_n C_{ox}' \frac{W}{L}\left[(V_{GS} - V_{THN})V_{DS} - \frac{V_{DS}^2}{2}\right], & V_{DS} < V_{DS,sat} \\ \frac{1}{2}\mu_n C_{ox}' \frac{W}{L}\left(V_{GS} - V_{THN}\right)^2, & V_{DS} \geq V_{DS,sat} \end{cases}$$

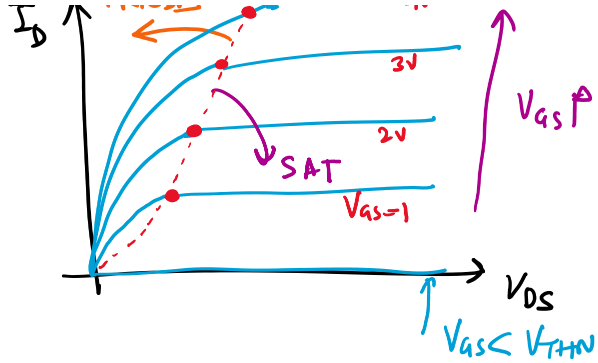
$V_{DS} < V_{DS,sat} \rightarrow$ TRIODE
$V_{GS} > V_{THN}$
$V_{DS} \geq V_{DS,sat} \rightarrow$ SATURATION

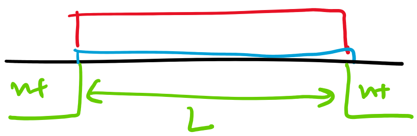
$V_{GS} - V_{THN}$

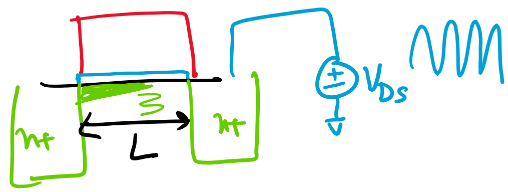
$V_{DS,sat} = V_{GS} - V_{THN}$









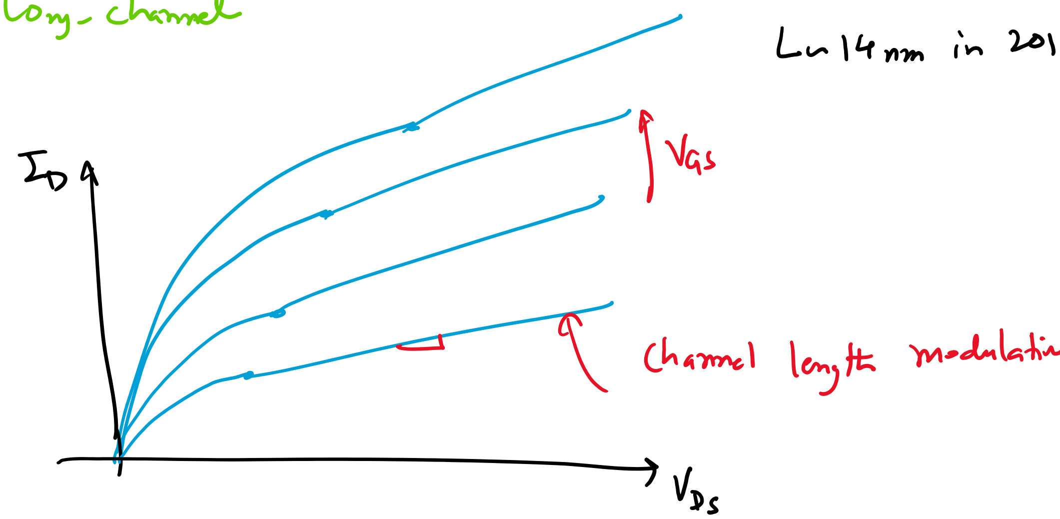


$L \geq 1\,\mu m$

Long-channel

Short-channel

$L \sim 14\,nm$ in 2018



In Saturation:

$$I_D = \frac{1}{2}\mu_n C_{ox}' \frac{W}{L}\left(V_{GS}-V_{THN}\right)^2 \left(1+\lambda V_{DS}\right)$$