Introduction to CMOS VLSI Design

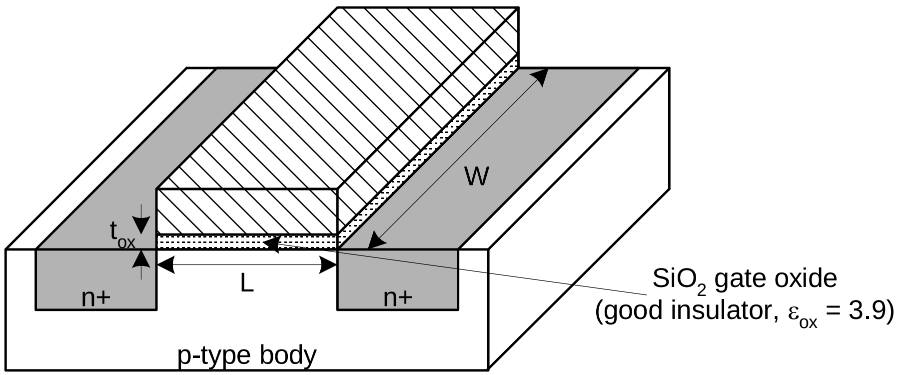
CMOS Transistor Theory

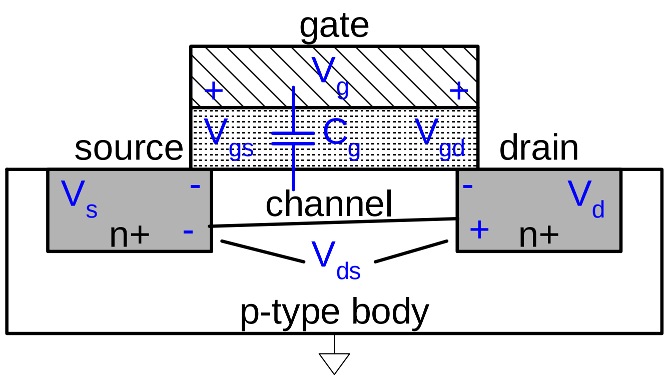
I-V Characteristics

- In Linear region, I_{ds} depends on
  - – How much charge is in the channel?
  - – How fast is the charge moving?

Channel Charge

- MOS structure looks like parallel plate capacitor while operating in inversion
  - Gate – oxide – channel
- $Q_{channel}$ =





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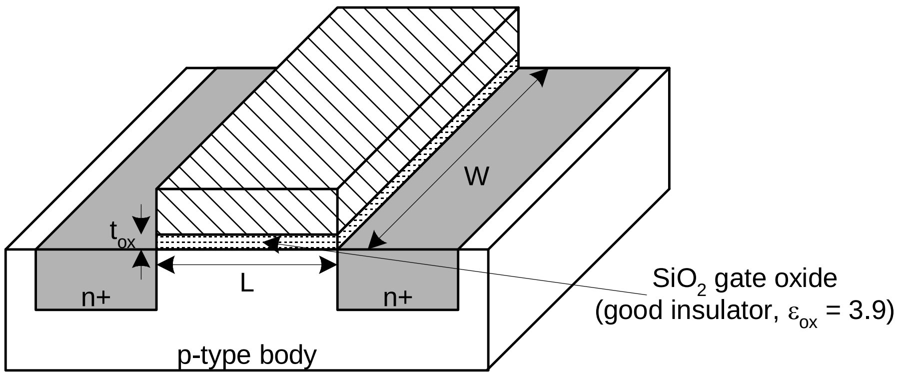

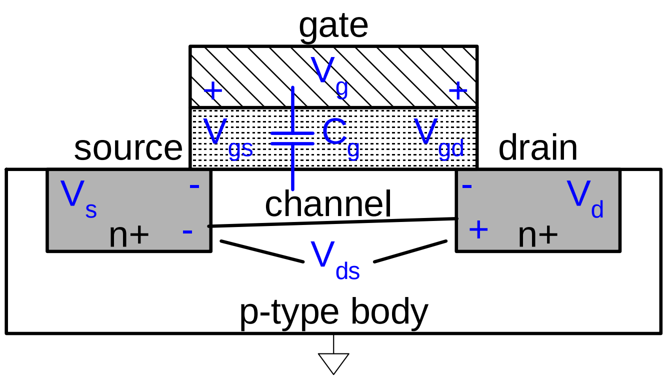

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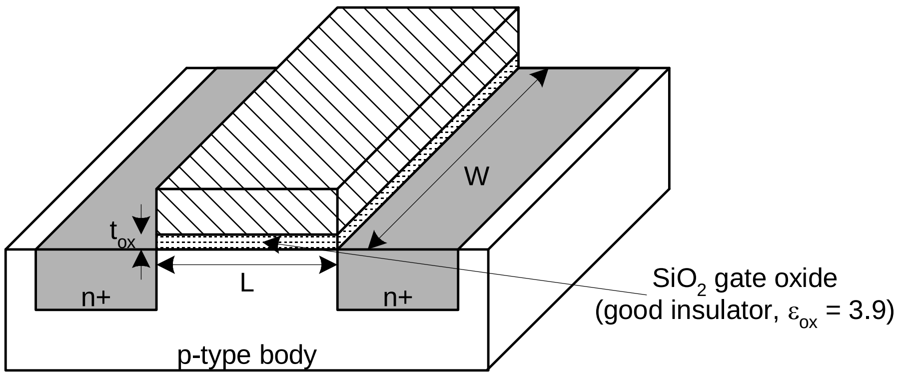
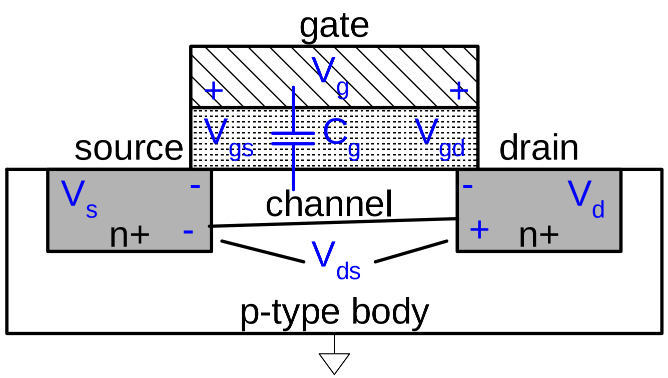
- V =





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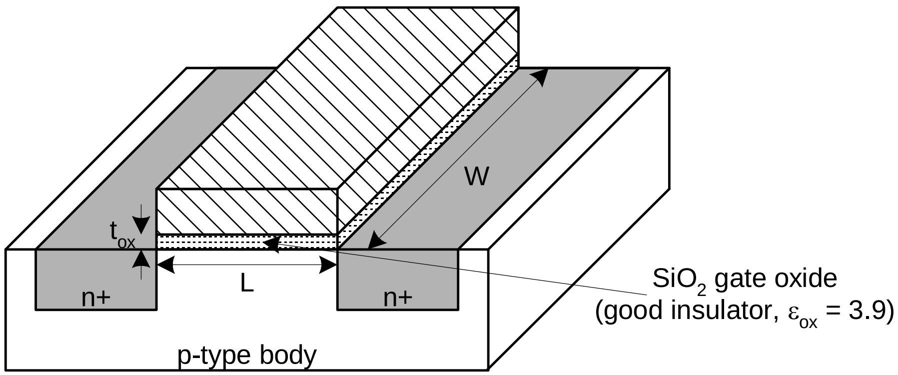
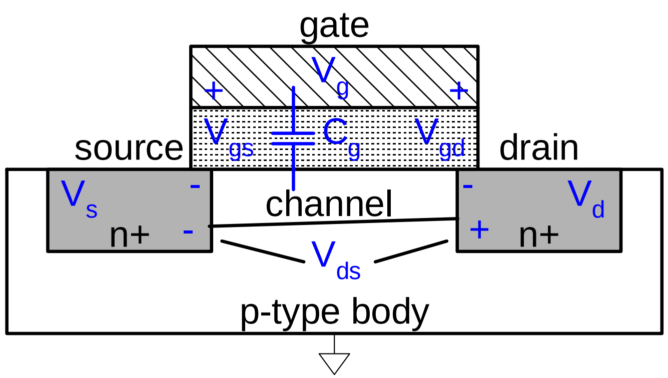
- $V = V_{gc} – V_t = (V_{gs} – V_{ds}/2) – V_t$





Carrier velocity

- Charge is carried by e-
- Carrier velocity v proportional to lateral E-field between source and drain
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nMOS Linear I-V

- Now we know
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$$I_{ds} = \frac{Q_{\text{channel}}}{t}$$

$$= \mu C_{\text{ox}} \frac{W}{L} \left(V_{gs} - V_t - {V_{ds}}/{2} \right) V_{ds}$$

$$= \beta \left(V_{gs} - V_t - {V_{ds}}/{2} \right) V_{ds}$$

$$\beta = \mu C_{\text{ox}} \frac{W}{L}$$

nMOS Saturation I-V

- If $V_{gd} < V_t$, channel pinches off near drain
  - When $V_{ds} > V_{dsat} = V_{gs} - V_t$
- Now drain voltage no longer increases current

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$$= \frac{\beta}{2}\left(V_{gs} - V_t\right)^2$$

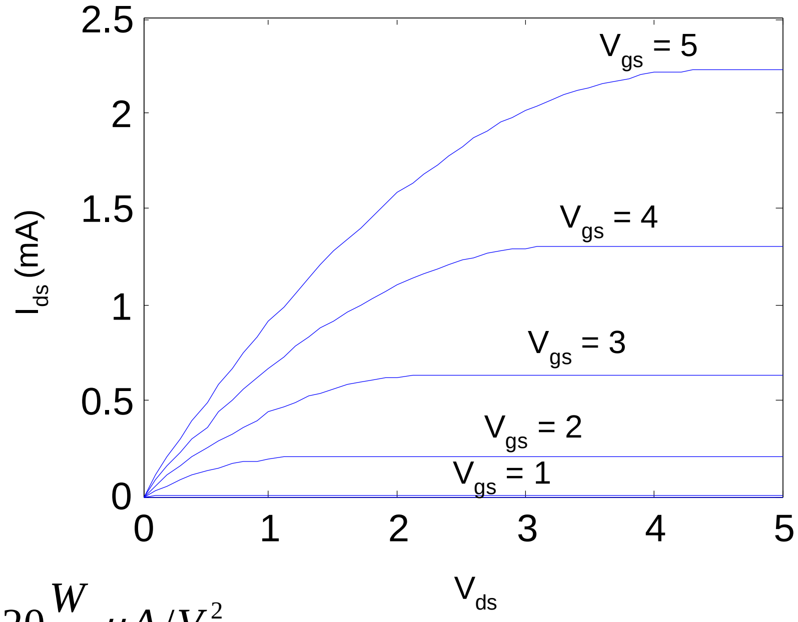
nMOS I-V Summary

- *Shockley* 1st order transistor models

$$I_{ds} = \begin{cases} 0 & V_{gs} < V_t & \text{cutoff} \\ \beta\left(V_{gs} - V_t - \dfrac{V_{ds}}{2}\right)V_{ds} & V_{ds} < V_{dsat} & \text{linear} \\ \dfrac{\beta}{2}\left(V_{gs} - V_t\right)^2 & V_{ds} > V_{dsat} & \text{saturation} \end{cases}$$

Example

- Example: a 0.6 μm process from AMI semiconductor
  - t_{ox} = 100 Å
  - μ = 350 cm²/V*s
  - V_t = 0.7 V
- Plot I_{ds} vs. V_{ds}
  - V_{gs} = 0, 1, 2, 3, 4, 5
  - Use W/L = 4/2 λ



$$\beta = \mu C_{ox}\frac{W}{L} = (350)\left(\frac{3.9 \bullet 8.85\cdot 10^{-14}}{100\cdot 10^{-8}}\right)\left(\frac{W}{L}\right) = 120\frac{W}{L}\,\mu A/V^2$$