EE-612:
Lecture 1: MOSFET Review

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NCN

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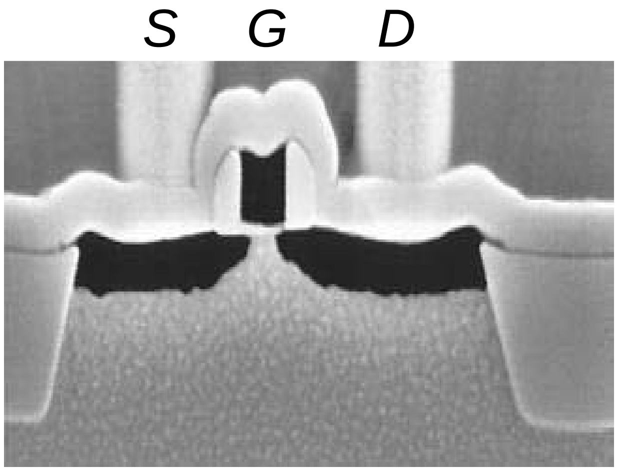
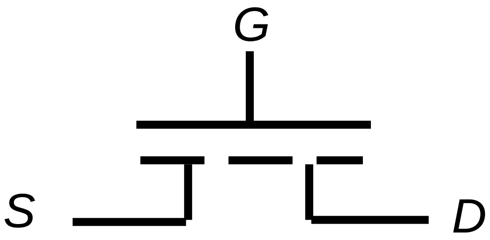
MOSFETs

physical structure



circuit schematic



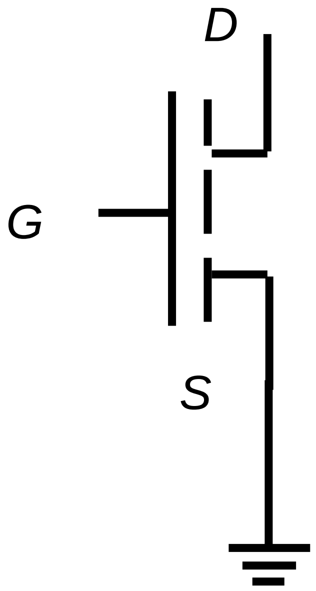
65 nm technology node:

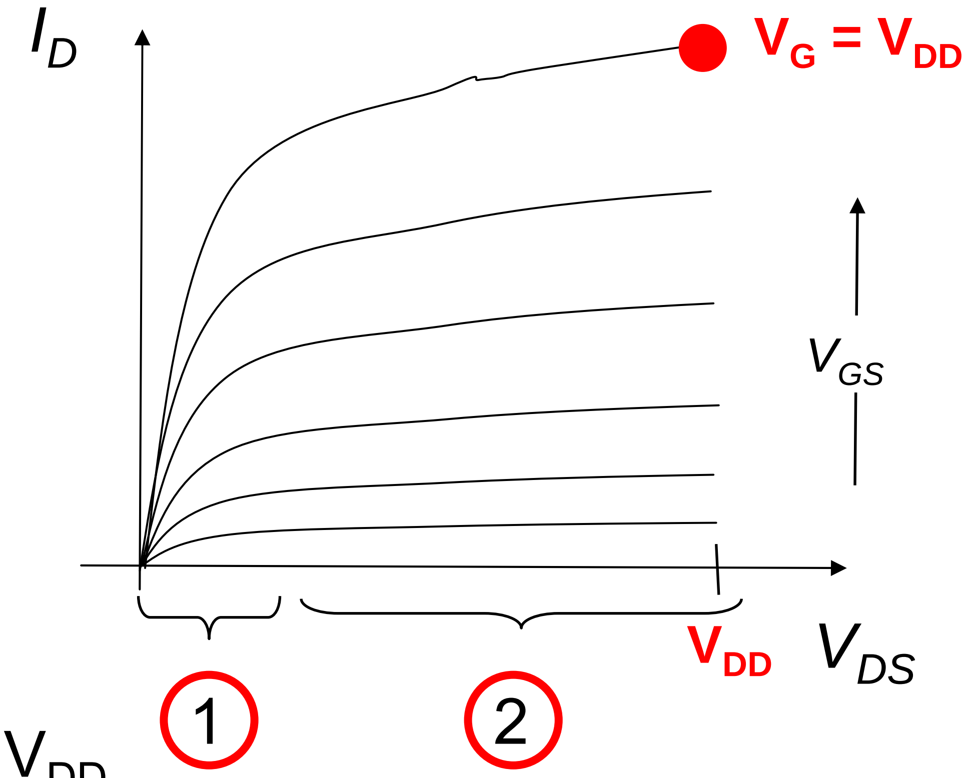
L = 35 nm

T_{ox} = 1.2nm

V_{DD} = 1.2V

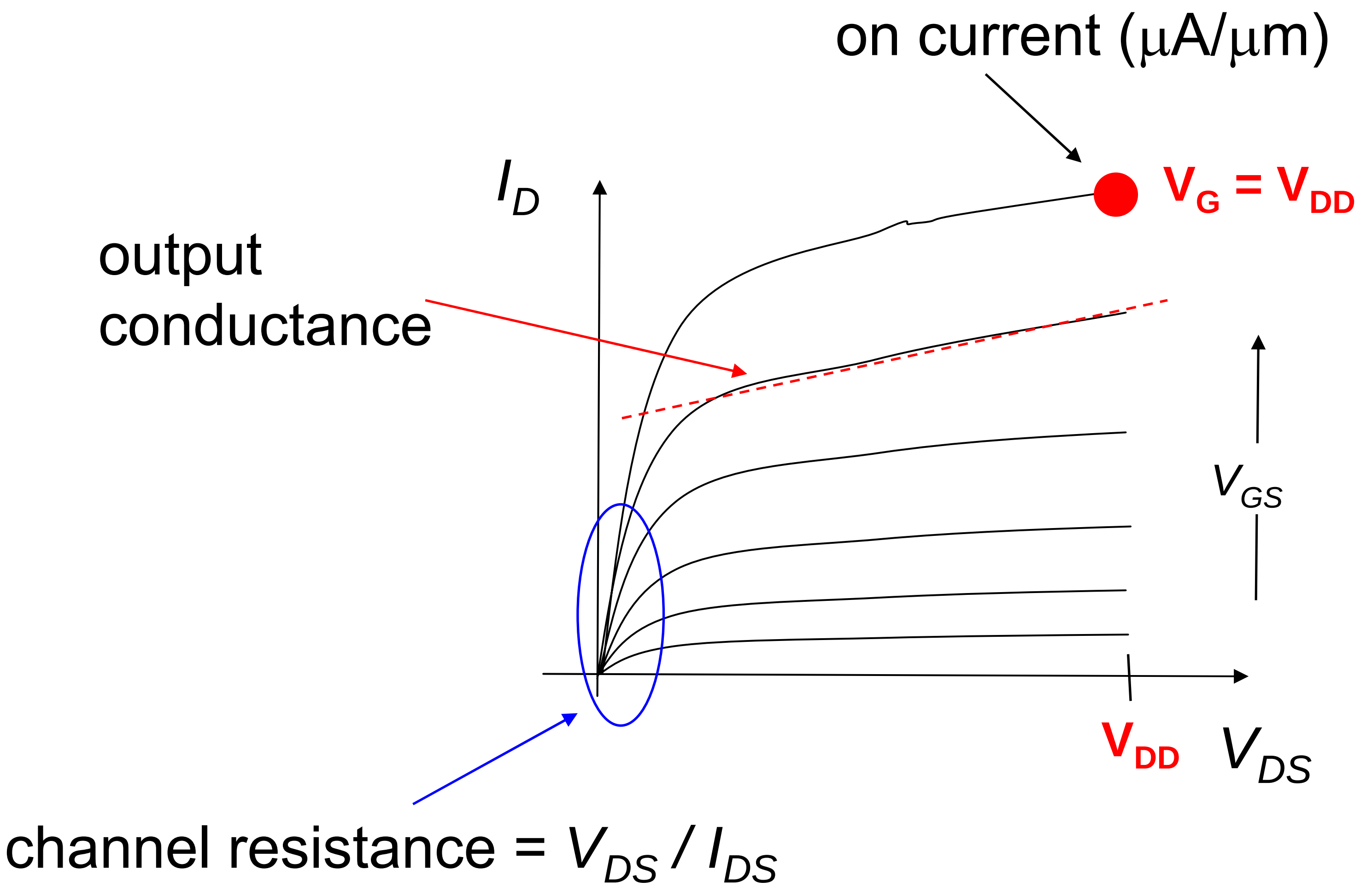
common source characteristics





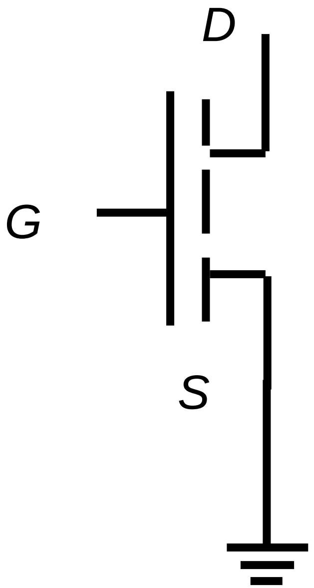
1) ground source
2) set V_G
3) sweep V_D from 0 to V_{DD}
4) Step V_G from 0 to V_{DD}

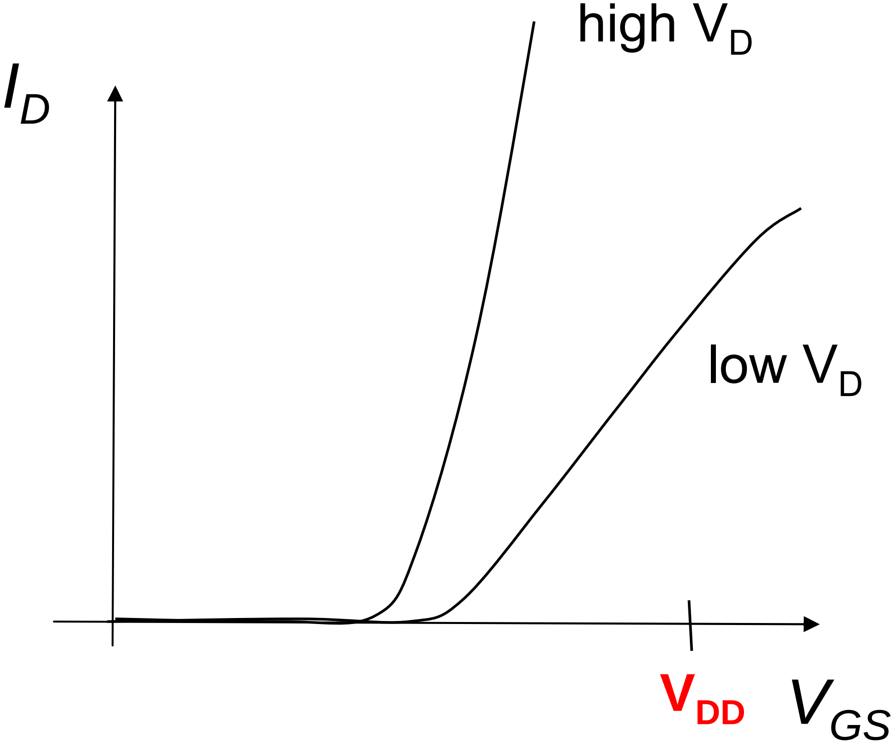
common source characteristics



channel resistance = V_{DS} / I_{DS}

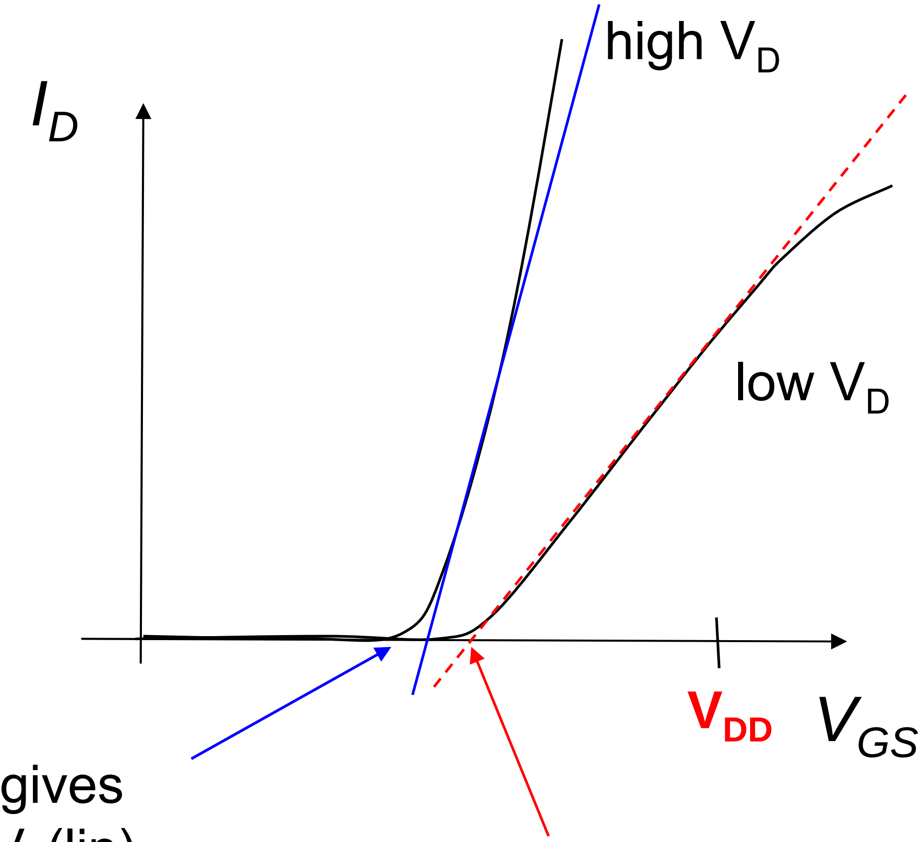
transfer characteristics





1) ground source
2) set V_D
3) sweep V_G from 0 to V_{DD}

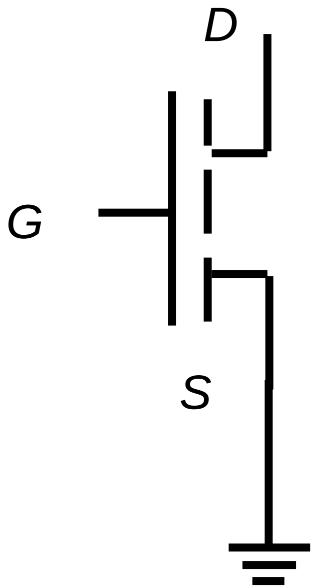
transfer characteristics



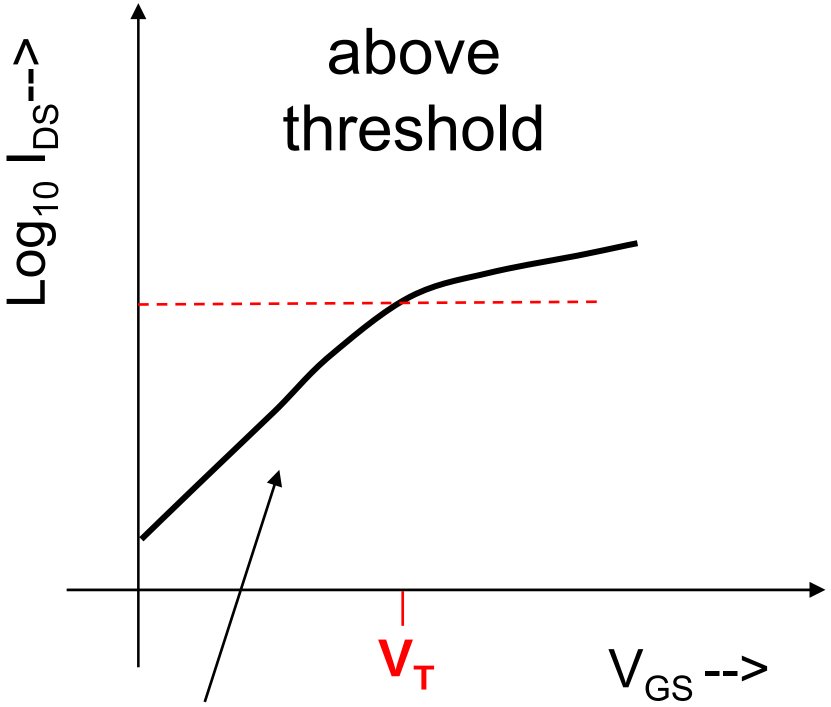
intercept gives
V_T(sat) < V_T(lin)

intercept gives V_T(lin)
slope is related to the effective mobility

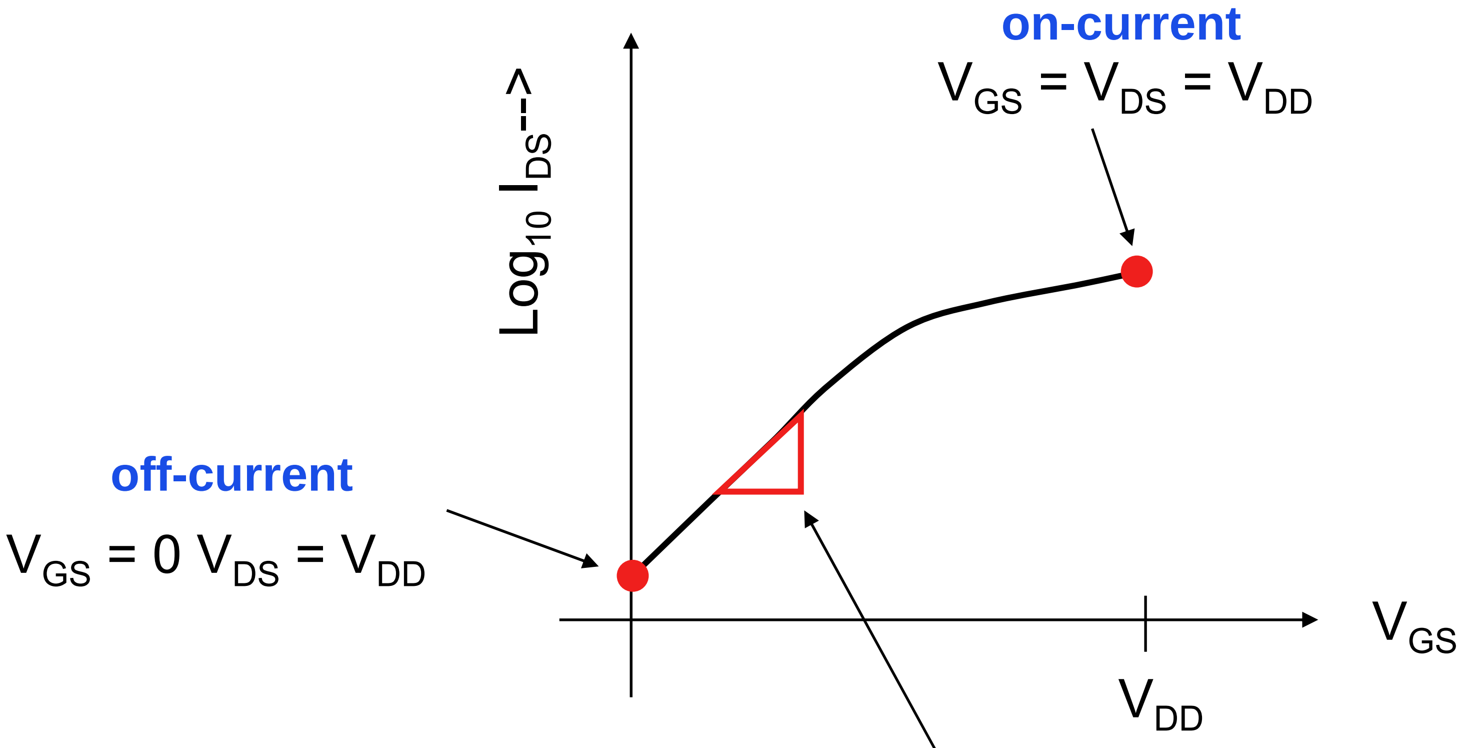
$\log_{10} I_D$ vs. V_{GS}



1) ground source
2) set $V_D = V_{DD}$
3) sweep V_G from 0 to V_{DD}



$\log_{10} I_D$ vs. V_{GS}



on-current

$V_{GS} = V_{DS} = V_{DD}$

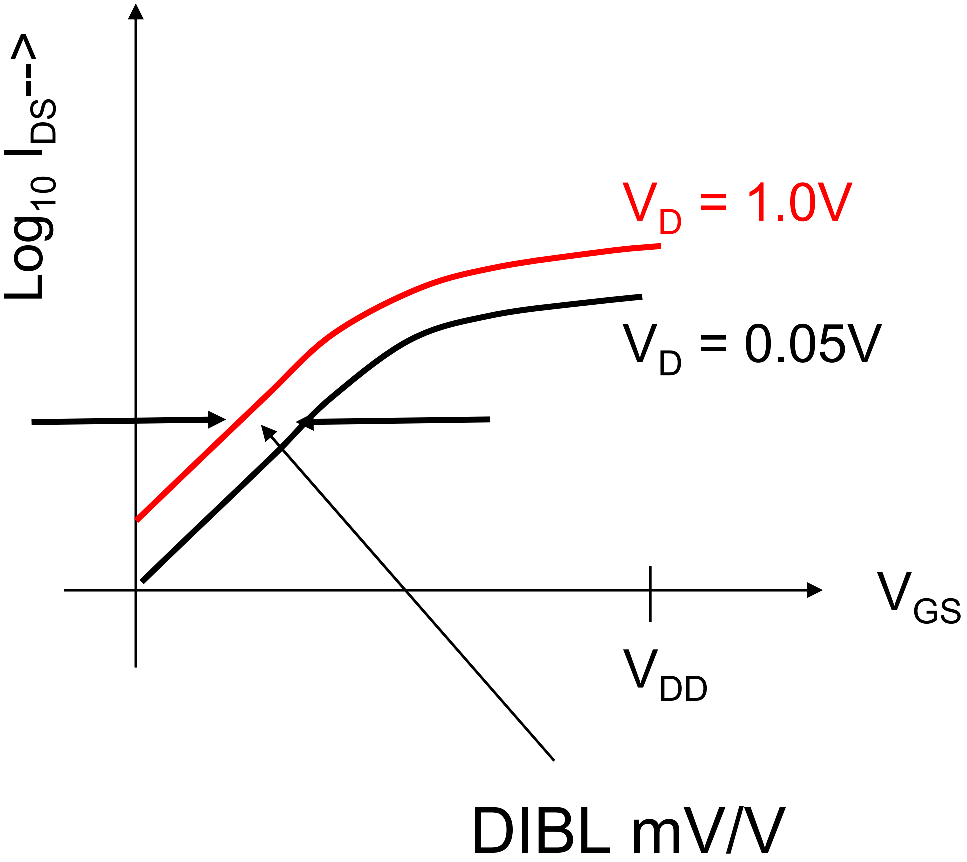
off-current

$V_{GS} = 0\ V_{DS} = V_{DD}$

subthreshold swing

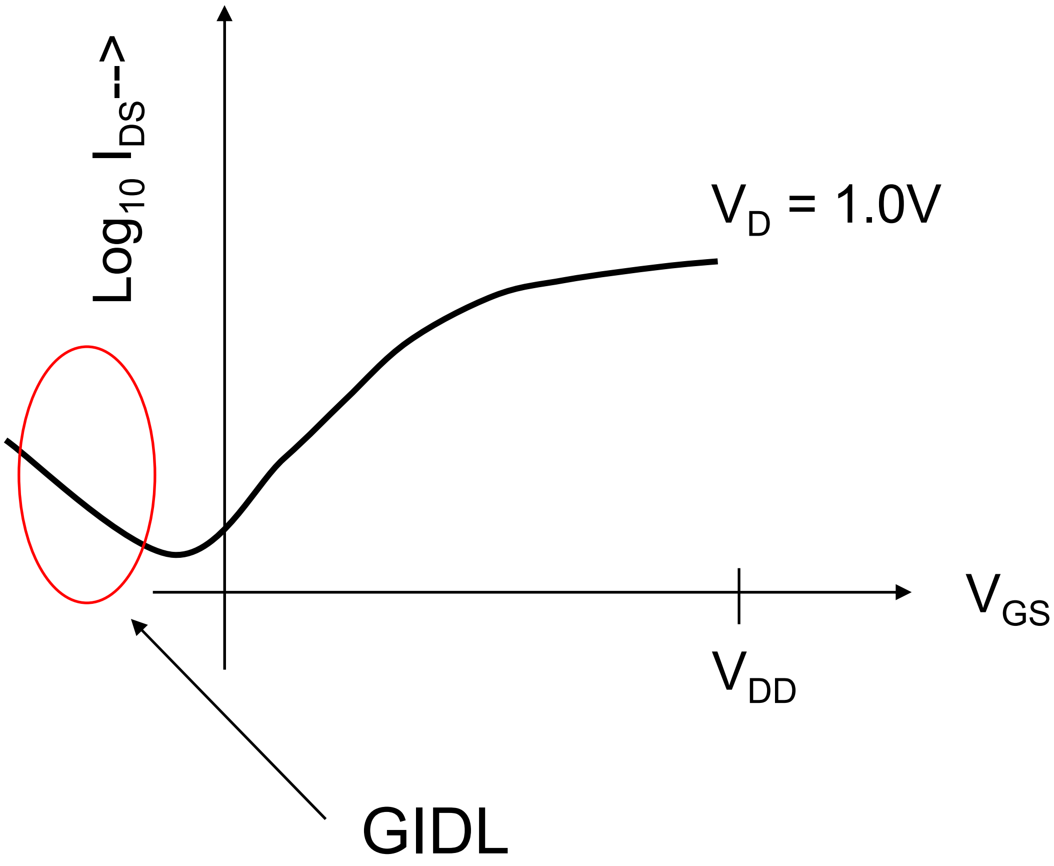
S > 60 mV/decade

DIBL (drain-induced barrier lowering)

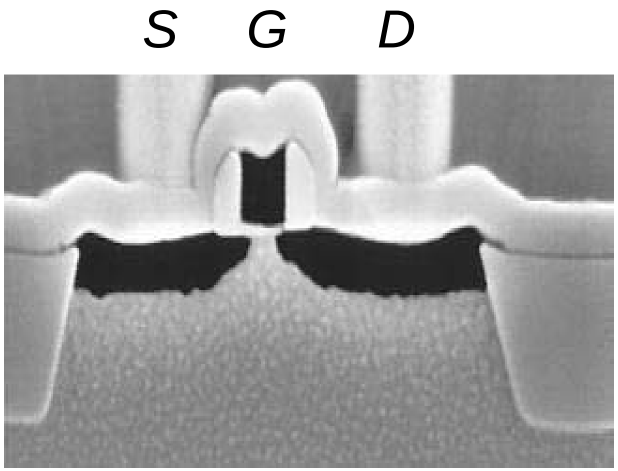


$V_T(V_D = 1.0V) < V_T(V_D = 0.05V)$

GIDL (gate-induced drain leakage)

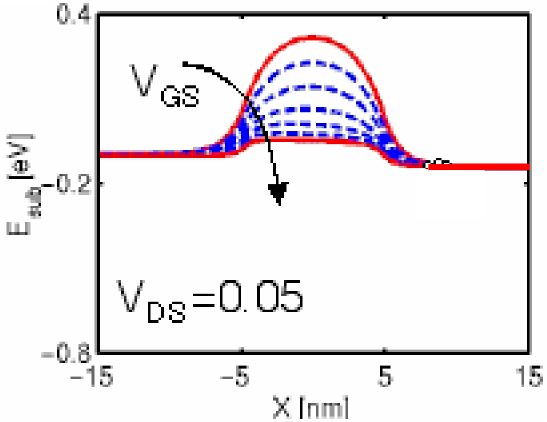


physics of MOSFETs

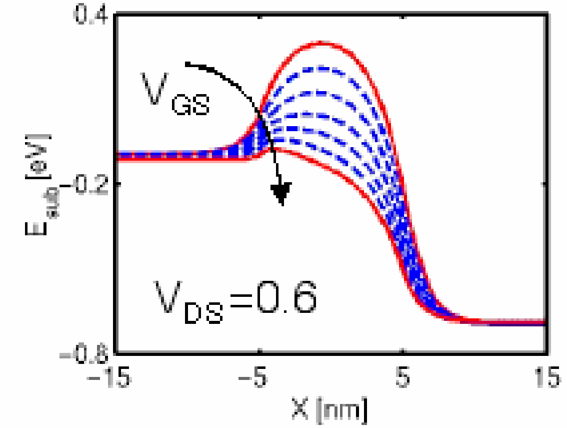


electron energy vs. position

$$E = -qV$$



$V_D \approx 0V$

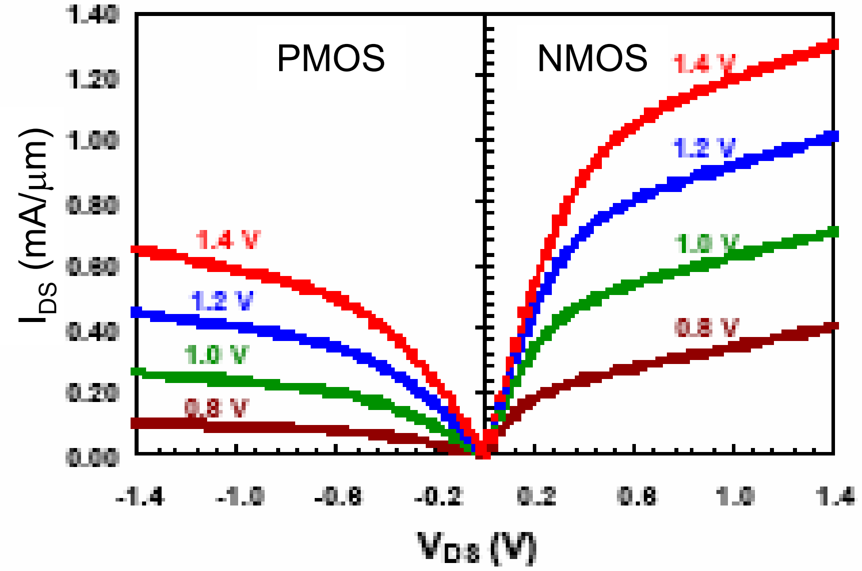


$V_D = V_{DD}$

E.O. Johnson, *RCA Review*, **34**, 80, 1973

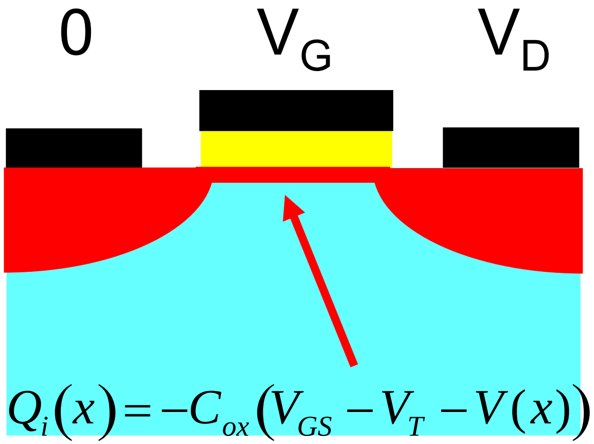
modern MOSFETs

130 nm technology (L_G = 60 nm)

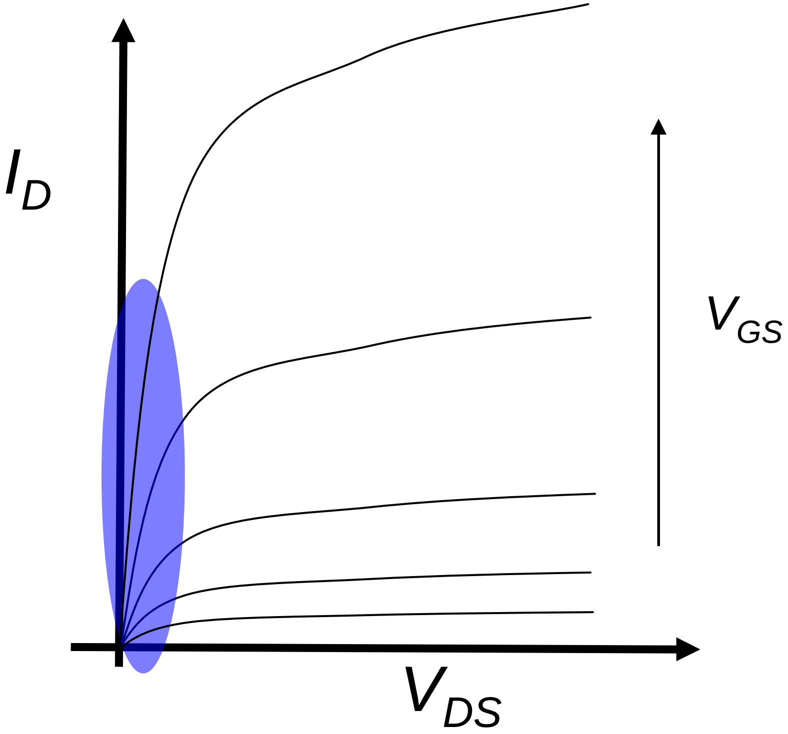


Intel Technical J., Vol. 6, May 16, 2002.
(low V_T device)

MOSFET IV: low V_{DS}



$$Q_i(x) = -C_{ox}\left(V_{GS} - V_T - V(x)\right)$$



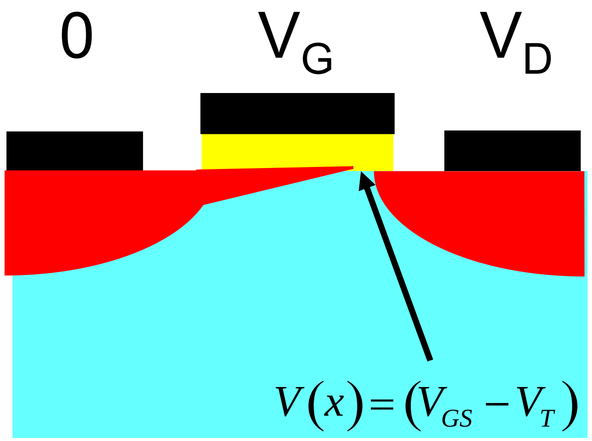
$$I_D = W\,Q_i(x)\upsilon_x(x) = W\,Q_i(0)\upsilon_x(0)$$

$$I_D = W\,C_{ox}\left(V_{GS} - V_T\right)\mu_{eff} E_x$$

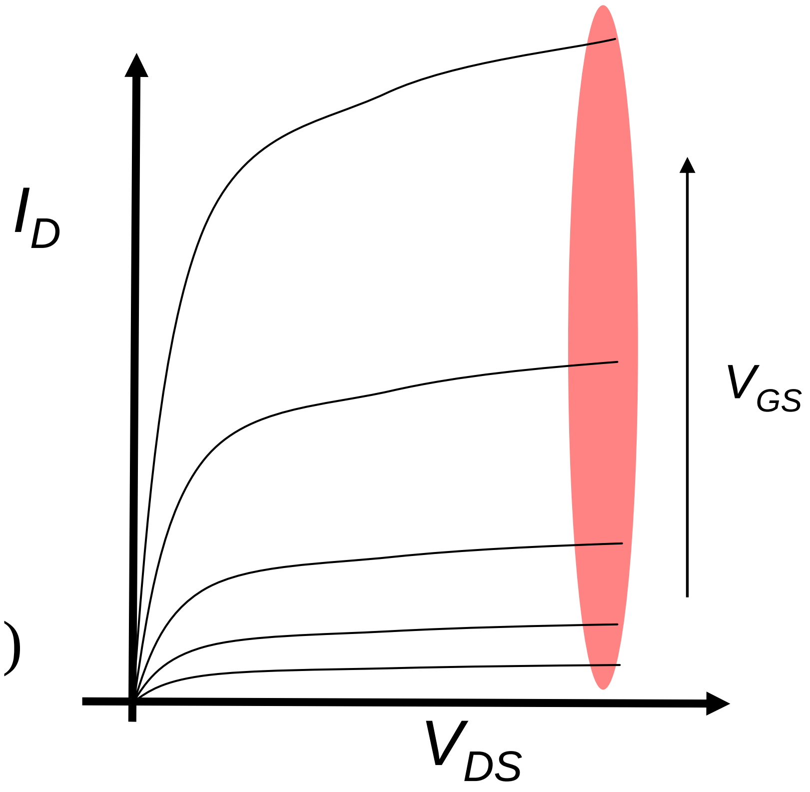
$$E_x = \frac{V_{DS}}{L}$$

$$\boxed{I_D = \frac{W}{L}\mu_{eff} C_{ox}\left(V_{GS} - V_T\right)V_{DS}}$$

MOSFET IV: high V_{DS}



$$V(x) = (V_{GS} - V_T)$$



$$I_D = W\,Q_i(x)\upsilon_x(x) = W\,Q_i(0)\upsilon_x(0)$$

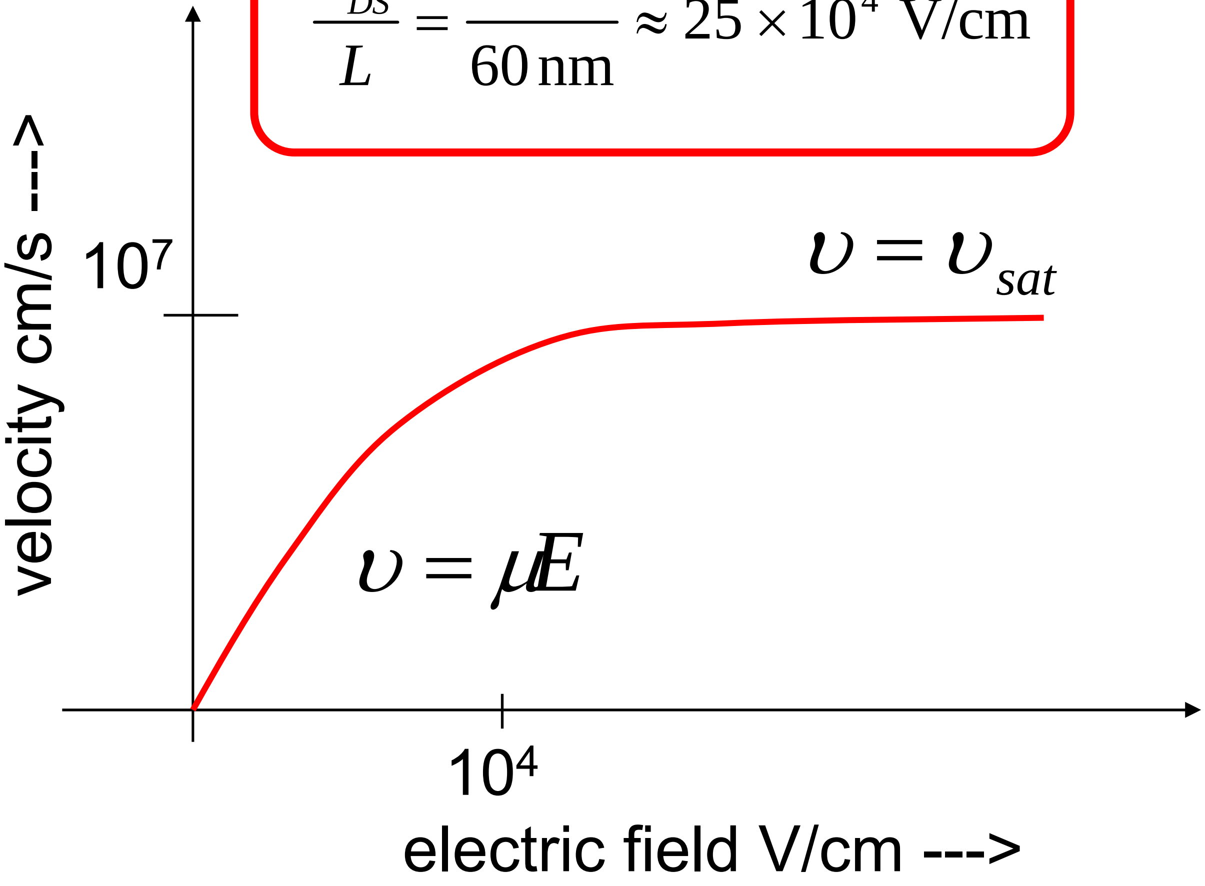
$$I_D = W\,C_{ox}(V_{GS} - V_T)\mu_{eff}E_x$$

$$E_x \approx \frac{V_{GS} - V_T}{L}$$

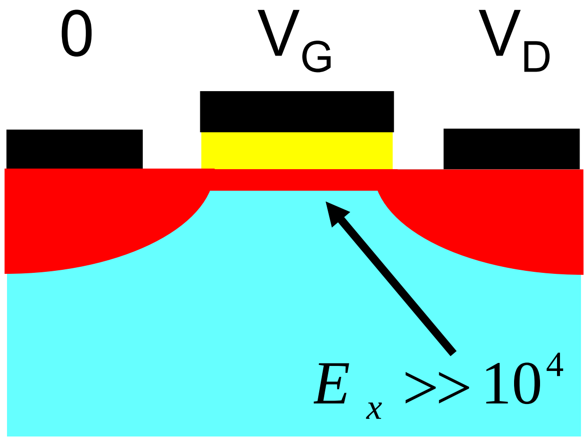
$$\boxed{I_D = \frac{W}{2L}\mu_{eff}C_{ox}(V_{GS} - V_T)^2}$$

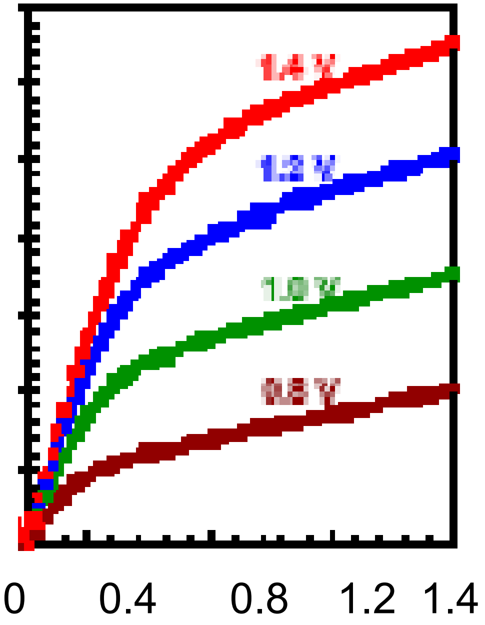
velocity saturation

$$\frac{V_{DS}}{L} = \frac{1.5\,\mathrm{V}}{60\,\mathrm{nm}} \approx 25 \times 10^{4}\ \mathrm{V/cm}$$



MOSFET IV: velocity saturation





$$I_D = W\,Q_i(x)\upsilon_x(x) = W\,Q_i(0)\upsilon_x(0)$$

$$I_D = W\,C_{ox}(V_{GS} - V_T)\upsilon_{sat}$$

$$\boxed{I_D = W\,C_{ox}\,\upsilon_{sat}(V_{GS} - V_T)}$$

MOSFET IV: discussion

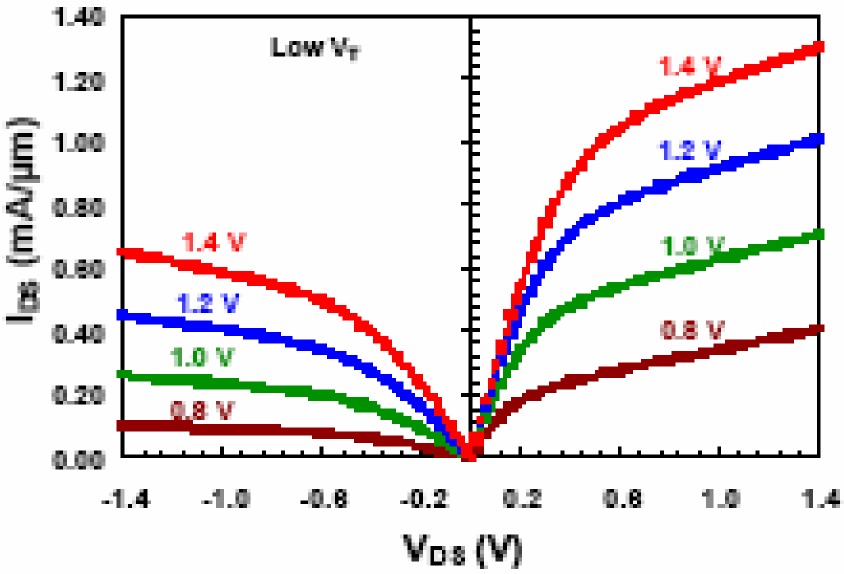
$$Q_i = -C_{ox}\left(V_{GS} - V_T\right) \approx ?$$

$$\left.\begin{array}{l} V_{GS}\ \ 1.2\text{V} \\[1em] V_T = 0.3\text{V} \\[1em] T_{ox} = 1.5\ \text{nm} \end{array}\right\} \quad \left|Q_i\right| \approx 2\times10^{-6}\ \text{C/cm}^2$$

$$\boxed{\frac{\left|Q_i\right|}{q} \approx 1\times10^{13}\ /\text{cm}^2}$$

MOSFET IV: discussion

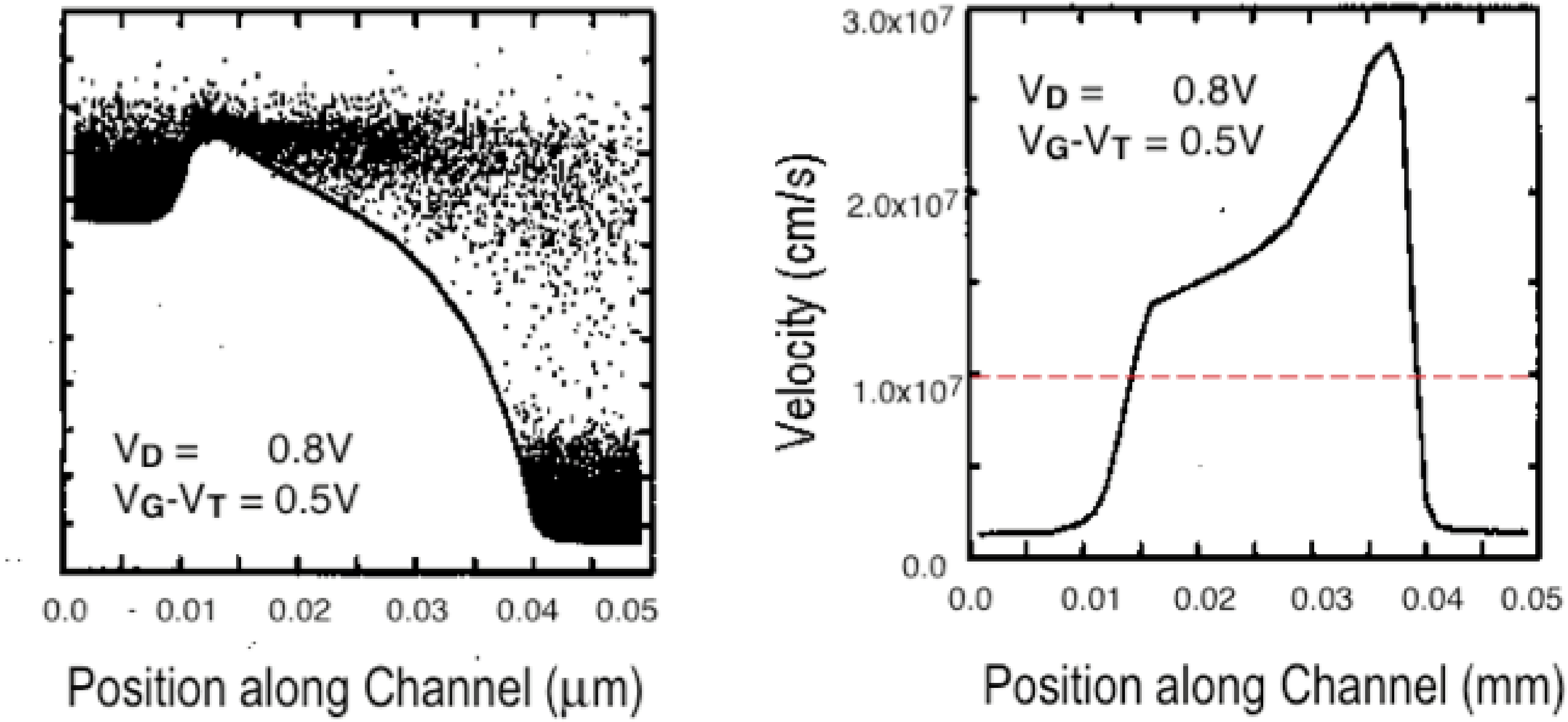
130 nm technology (L_G = 60 nm)



Intel Technical J., Vol. 6, May 16, 2002.

$$I_D \approx W\, Q_i(0) \upsilon_{sat} \approx 1.6 \text{ mA/}\mu\text{m}$$

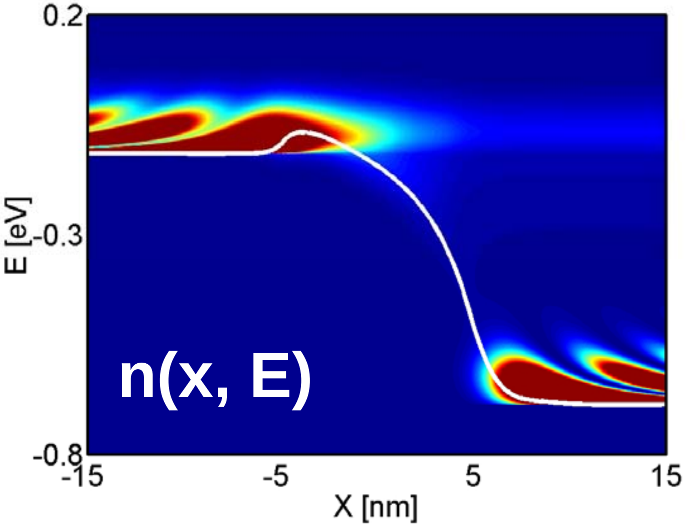
MOSFET IV: velocity overshoot



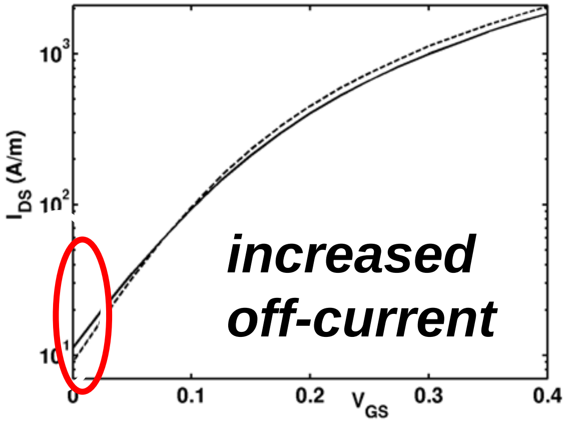
Frank, Laux, and Fischetti, IEDM Tech. Dig., p. 553, 1992

MOSFET IV: Quantum effects

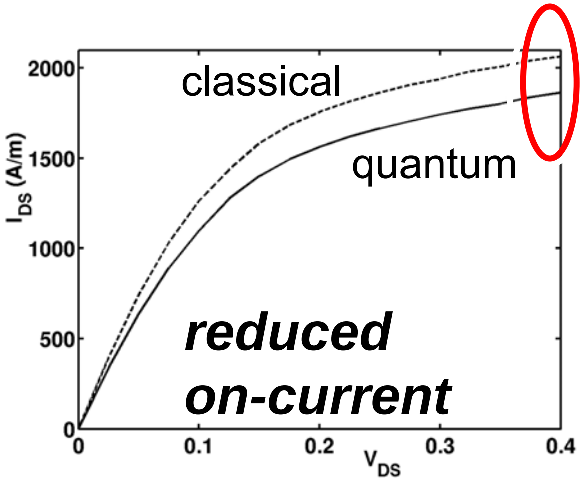
L = 10 nm



(quantum confinement treated in both cases)



Log I_D vs. V_{GS}



I_D vs. V_{DS}

nanoMOS at www.nanohub.org

Summary

1) A MOSFET's I_D = inversion layer charge times velocity

2) 2D electrostatics determine Q_i

3) *Carrier transport determines the velocity*

4) *Second order effects are becoming first order (e.g. leakage)*