Fundamentals of Nanotransistors

Unit 1: Transistor Fundamentals

Lecture 1.3: MOSFET Device Metrics

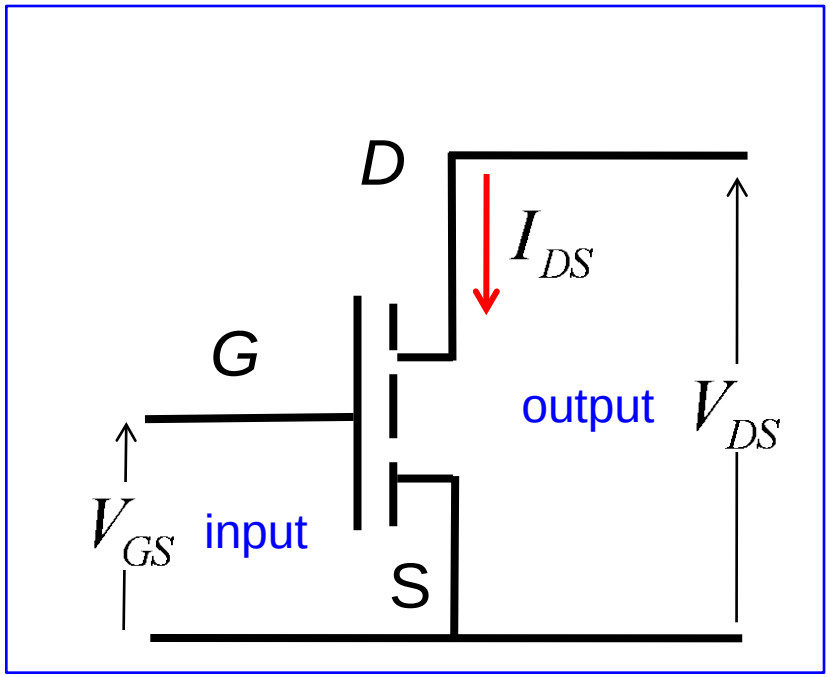
Mark Lundstrom

lundstro@purdue.edu
Electrical and Computer Engineering
Birck Nanotechnology Center
Purdue University, West Lafayette, Indiana USA

PURDUE UNIVERSITY

MOSFET IV characteristics

common source

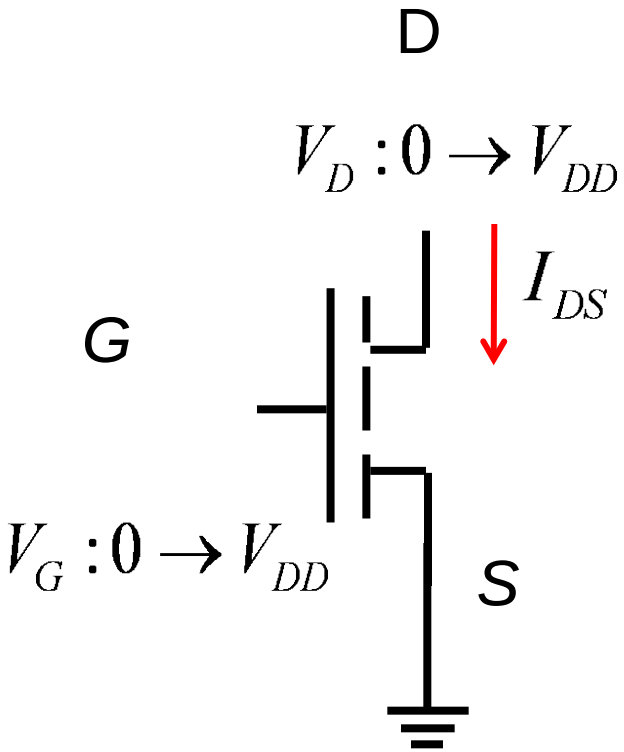


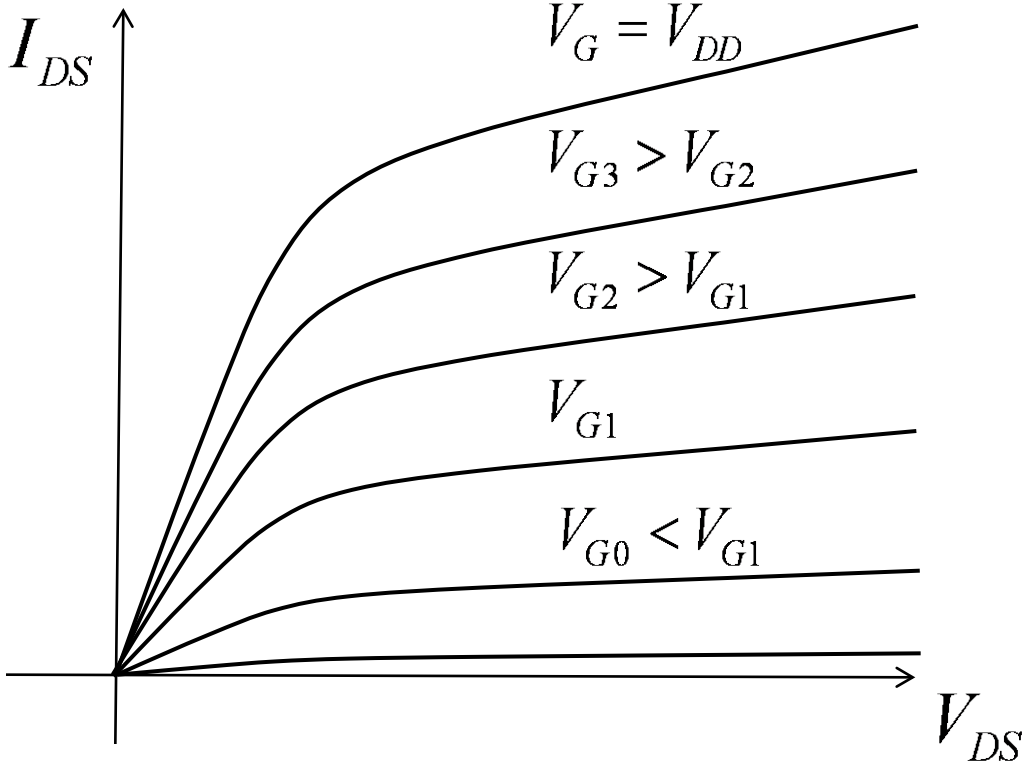
$$I_{DS}\left(V_G, V_S, V_D\right)$$

$I_{DS}\left(V_{GS}\right)$ at a fixed V_{DS} transfer

$I_{DS}\left(V_{DS}\right)$ at a fixed V_{GS} output

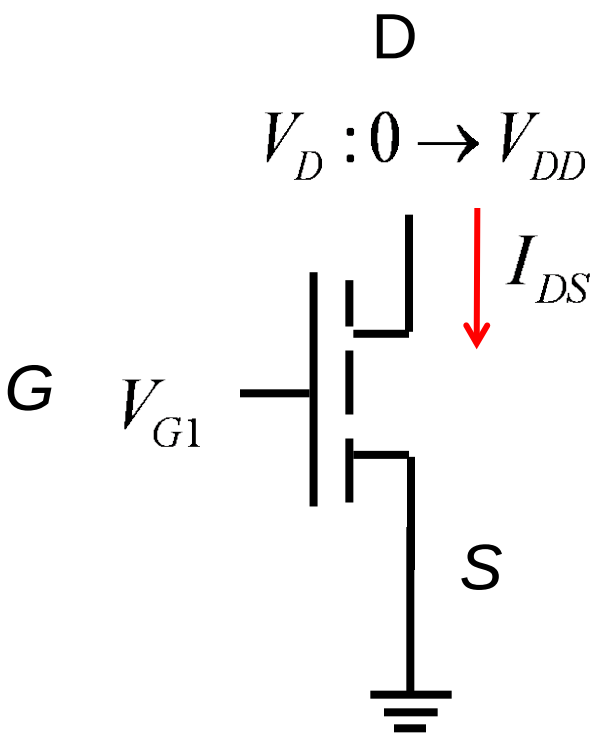
Output characteristics

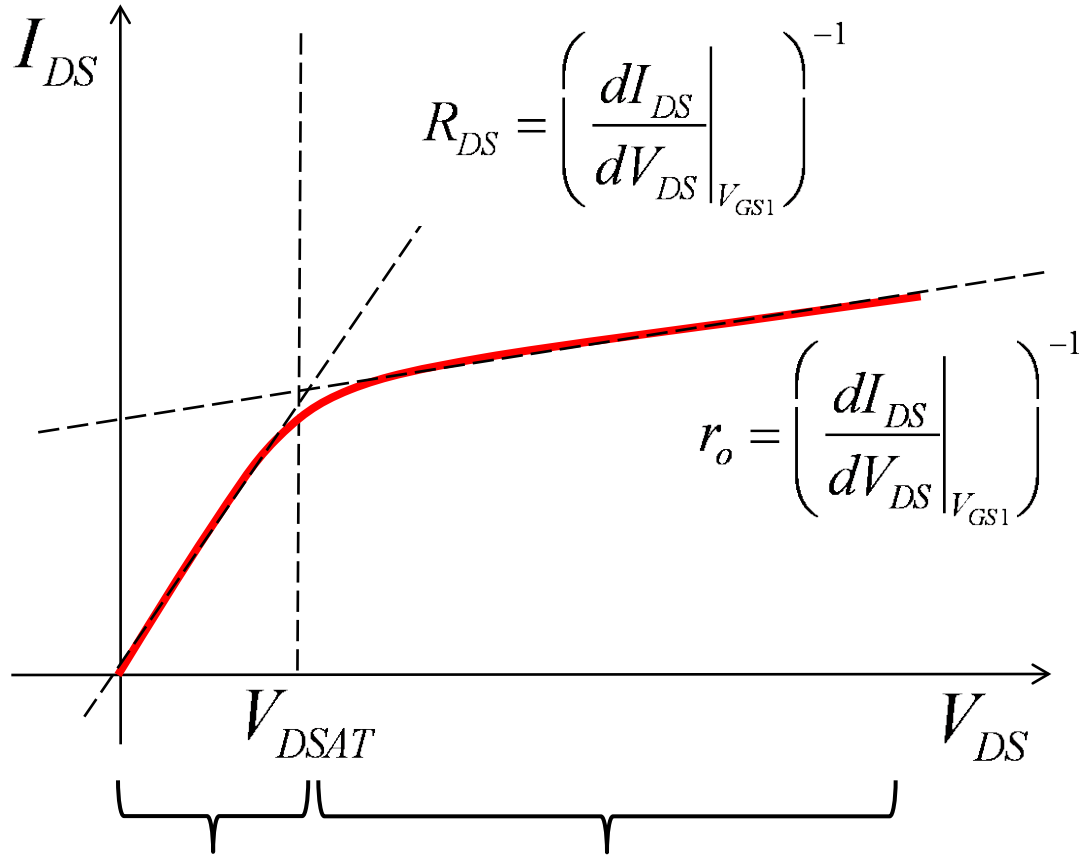




n-channel enhancement mode MOSFET

Output characteristic at a specific V_{GS}





n-channel enhancement mode MOSFET

Output characteristics

Above threshold: $V_{GS} > V_T$

Below threshold: $V_{GS} < V_T$

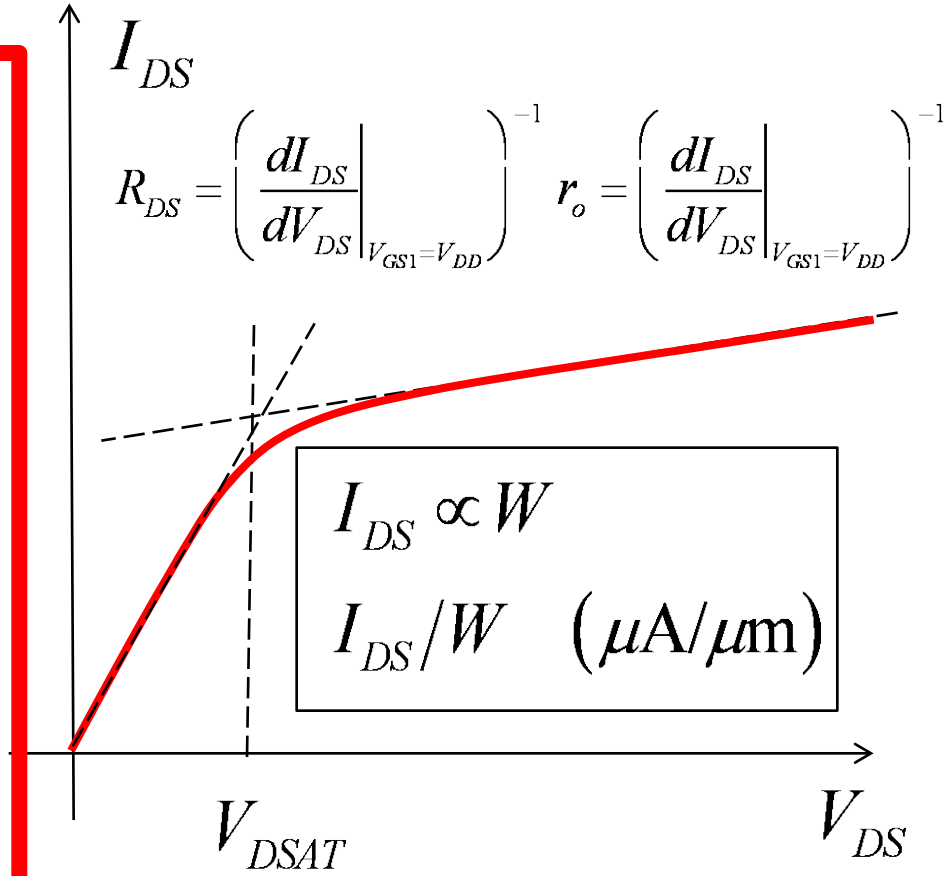
Linear region: $V_D < V_{DSAT}$

Saturation region: $V_D > V_{DSAT}$

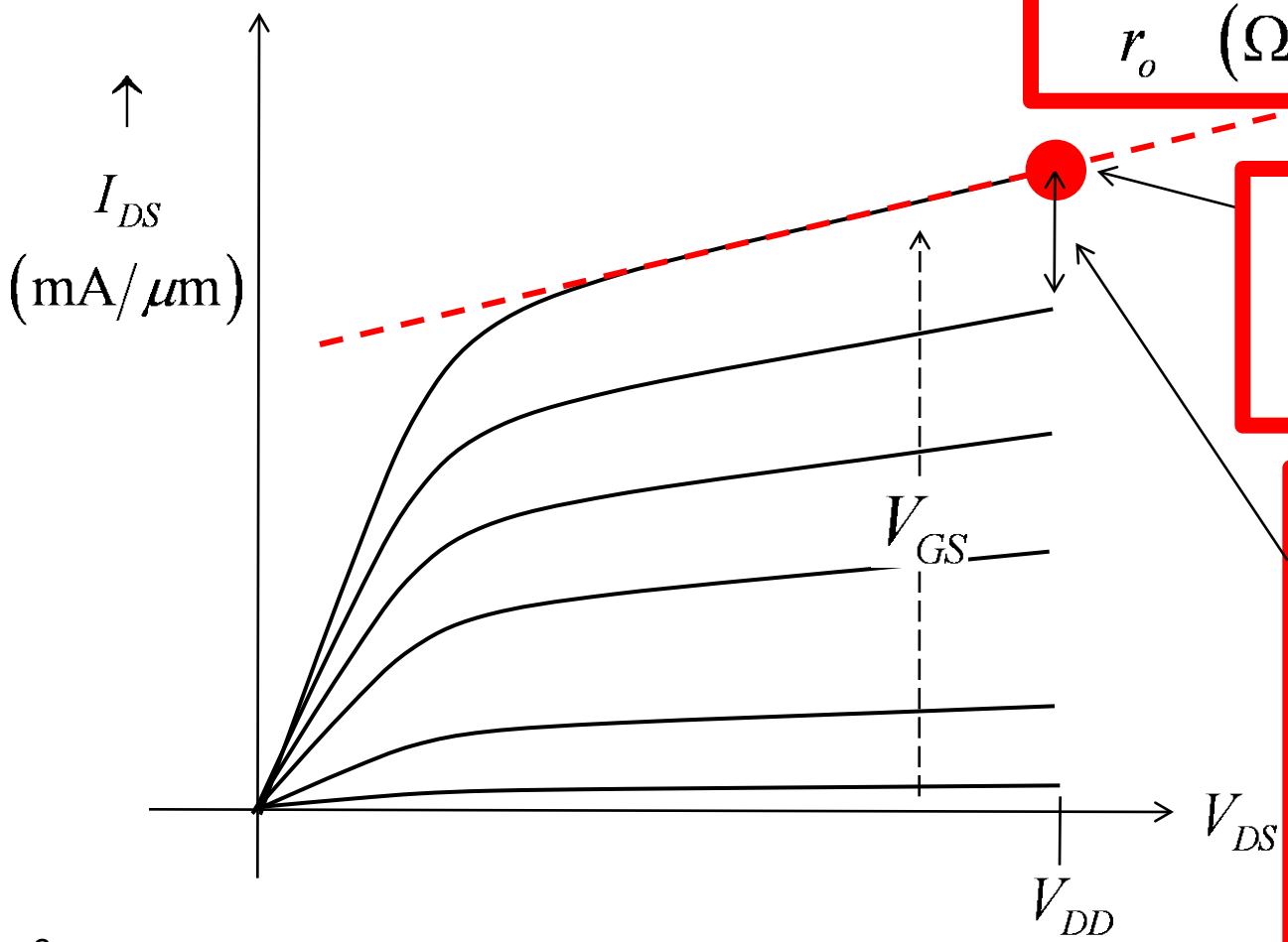
Drain saturation voltage: V_{DSAT}

Output resistance: r_o

Drain-Source resistance: R_{SD}



MOSFET device metrics (i)



output resistance:

$$r_o \quad (\Omega - \mu m)$$

on-current (μA/μm)

$$I_{DS}\left(V_{GS} = V_{DS} = V_{DD}\right)$$

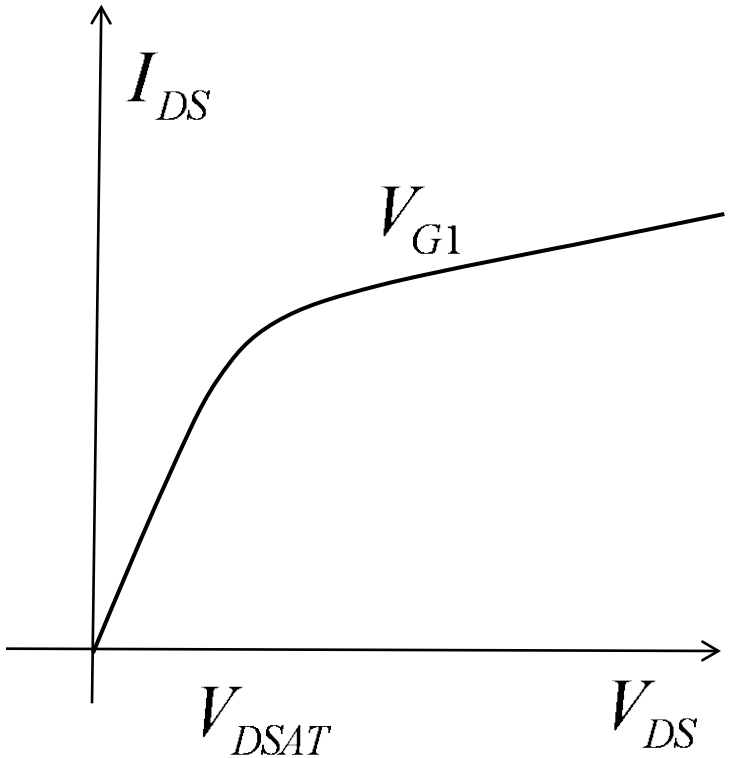
transconductance

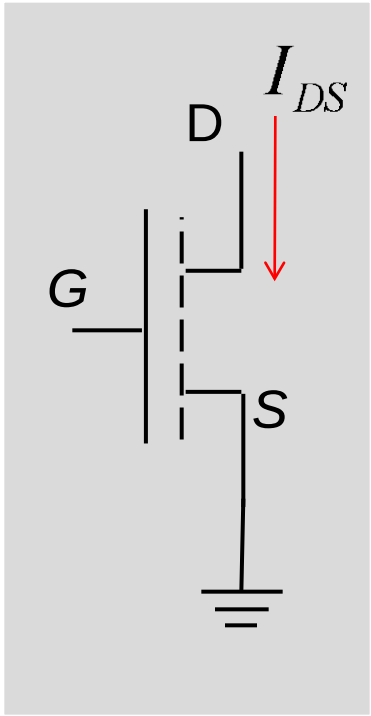
$$g_m \equiv \left.\frac{\Delta I_{DS}}{\Delta V_{GS}}\right|_{V_{DS}}$$

$$(\mu\mathrm{S}/\mu\mathrm{m})$$

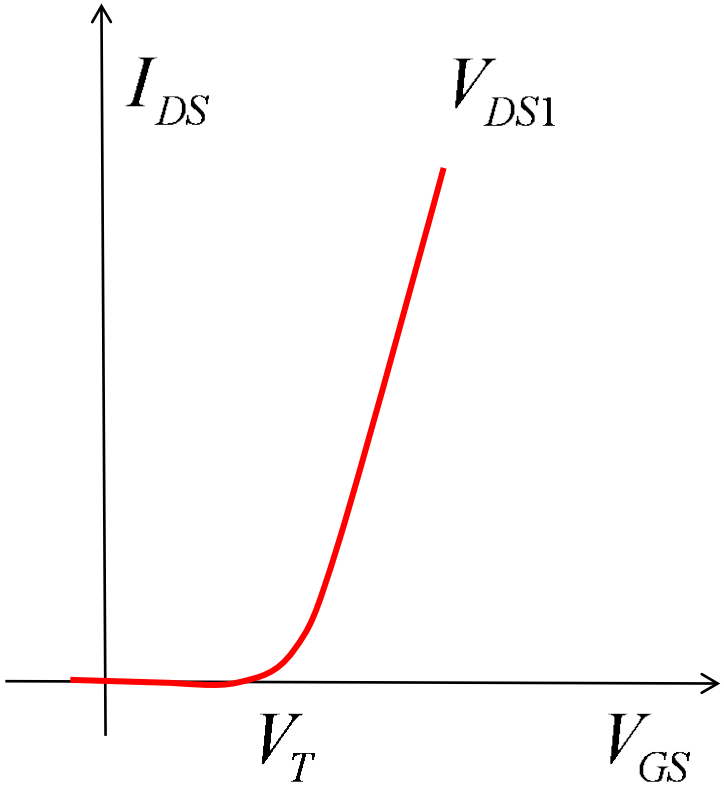
Output vs. **transfer** characteristics

output characteristics





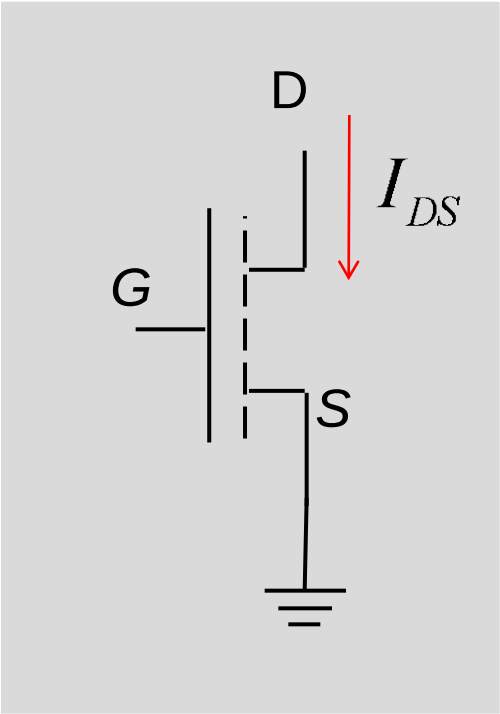
transfer characteristics

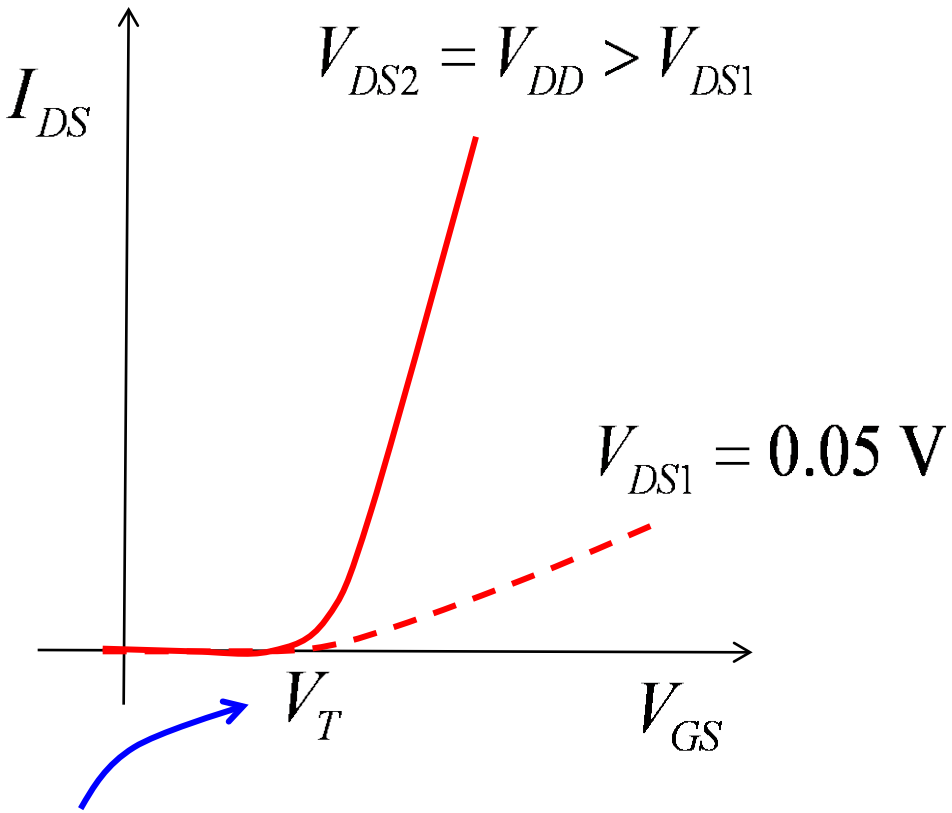


Fix **gate** voltage then sweep the **drain** voltage

Fix **drain** voltage then sweep the **gate** voltage

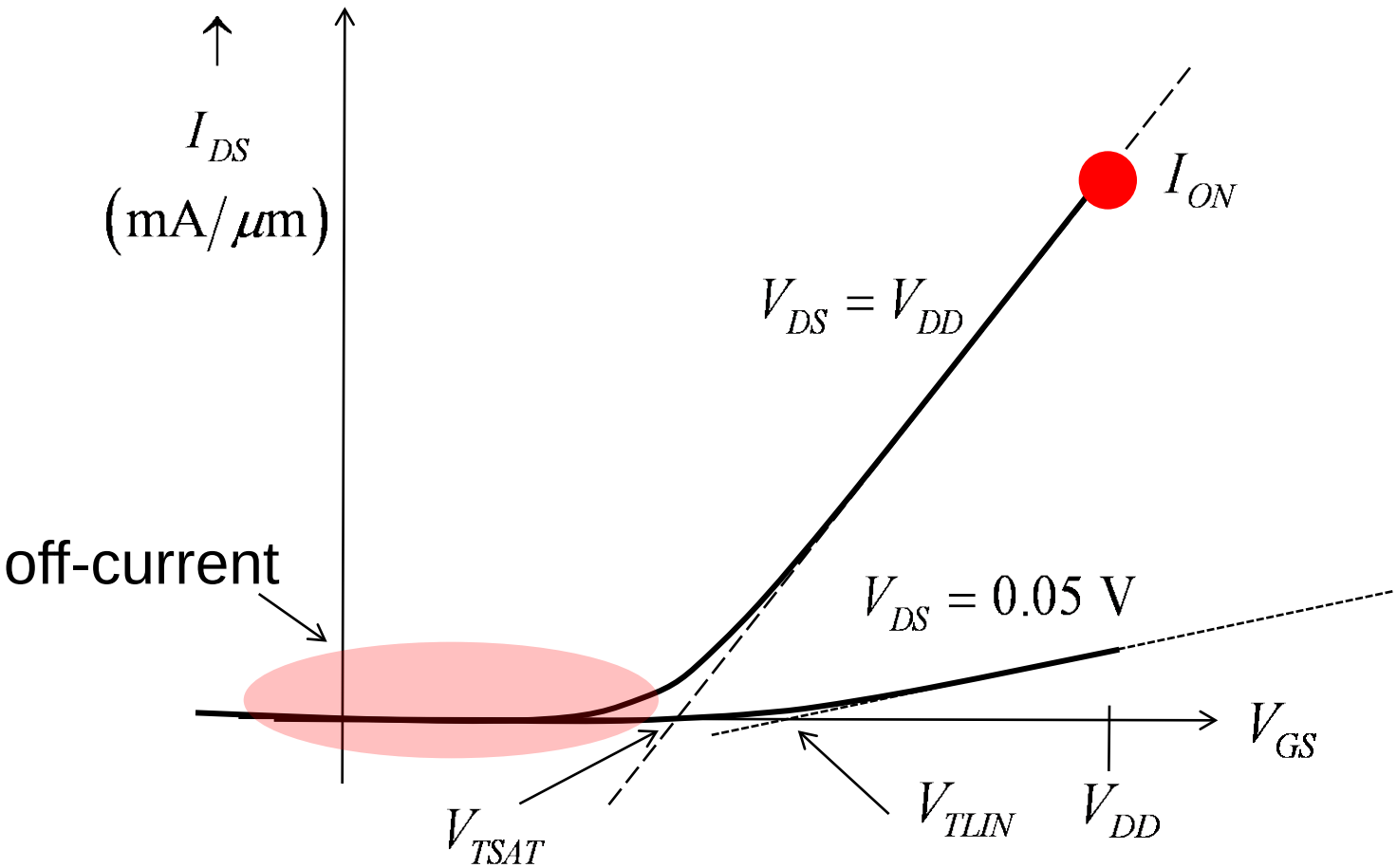
Transfer characteristics





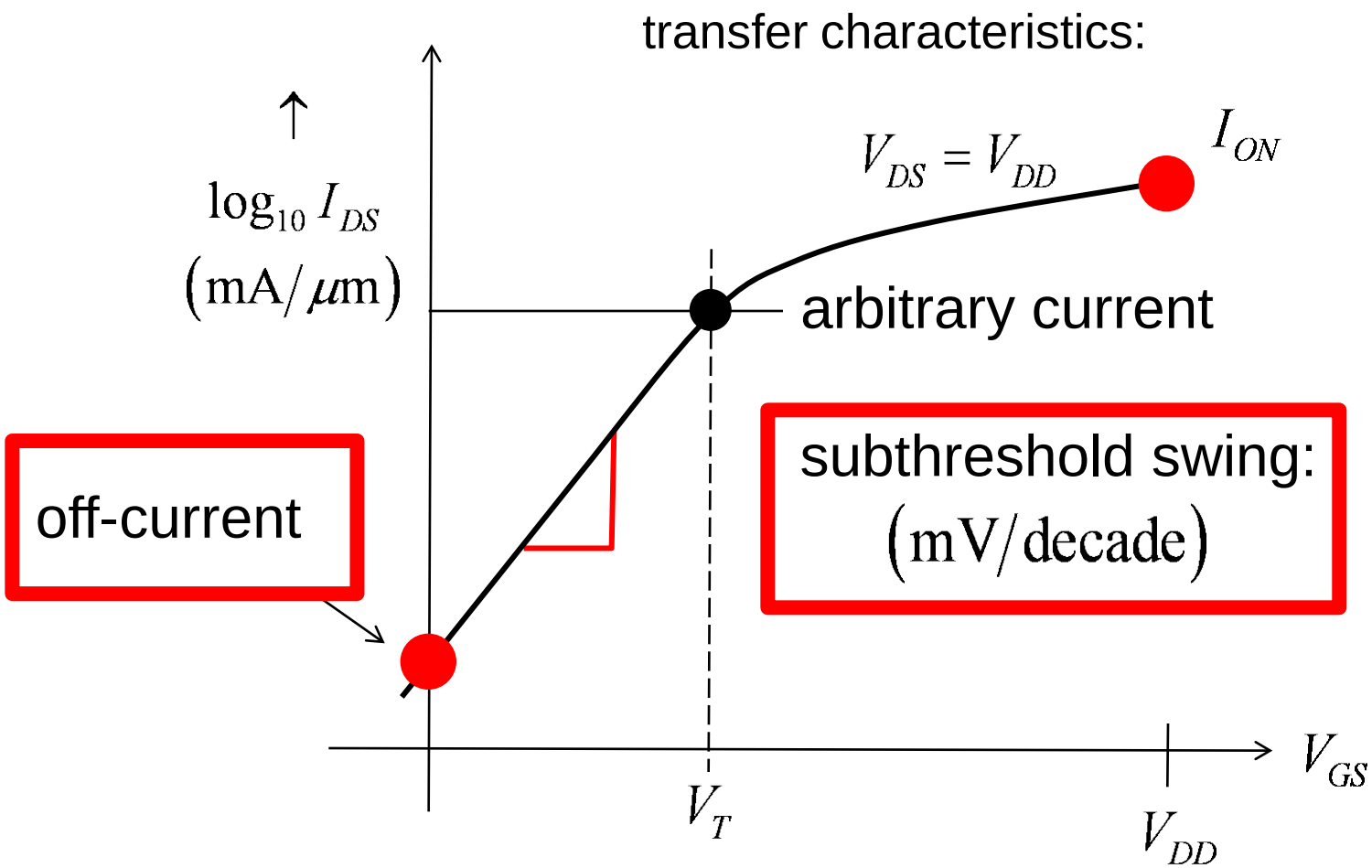
"threshold voltage"

MOSFET transfer characteristics



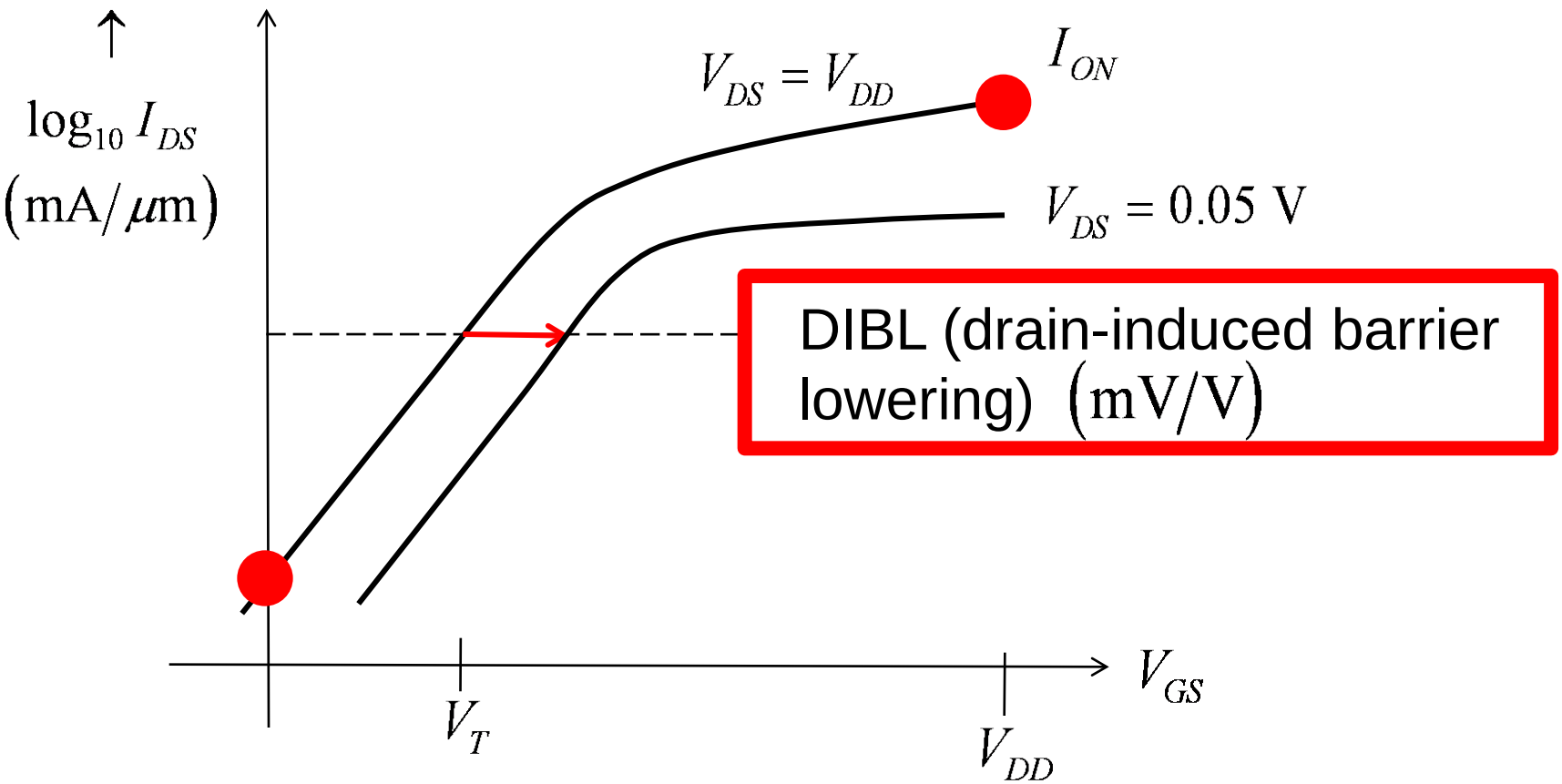
threshold voltage

MOSFET device metrics (ii)



MOSFET device metrics (iii)

transfer characteristics:



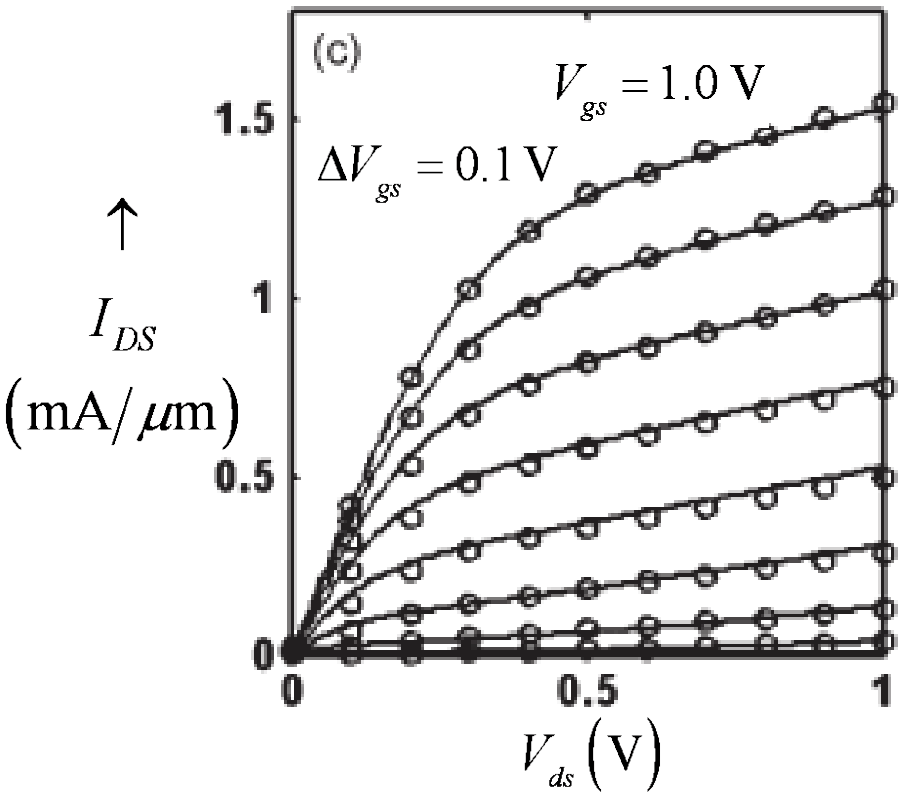
Summary

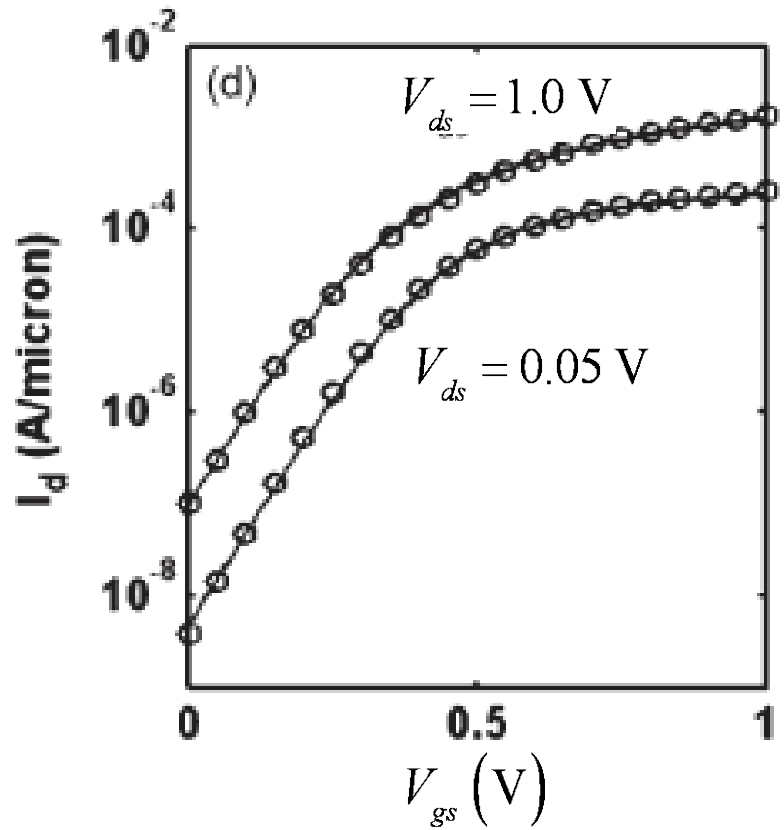
Given the measured characteristics of a MOSFET, you should be able to determine:

1. on-current: I_{ON}
2. off-current: I_{OFF}
3. subthreshold swing, *SS*
4. drain induced barrier lowering: DIBL
5. threshold voltage: V_T (lin) and V_T (sat)
6. Drain to source resistance: R_{DS}
7. drain saturation voltage: V_{DSAT}
8. output resistance: r_o
9. *transconductance:* g_m

Our goal is to understand these device metrics.

Example: 32 nm N-MOS technology





Source: Ali Khakifirooz, Osama M. Nayfeh, and Dimitri Antoniadis, "A Simple Semiempirical Short-Channel MOSFET Current–Voltage Model Continuous Across All Regions of Operation and Employing Only Physical Parameters, *IEEE Trans. Electron Dev.*, **56**, pp. 1674-1680, 2009,

Answers

$I_{ON} \approx 1.55\ \text{mA}/\mu\text{m}$

$I_{OFF} \approx 0.1\ \mu\text{A}/\mu\text{m}$

$SS \approx 95\ \text{mV/decade}$

$\text{DIBL} \approx 110\ \text{mV/V}$

$R_{DS} \approx 200\ \Omega\text{-}\mu\text{m}$

$r_o \approx 2.5\ \text{K}\Omega\text{-}\mu\text{m}$

$g_m \approx 3\ \text{mS}/\mu\text{m}$ (in the on-state)

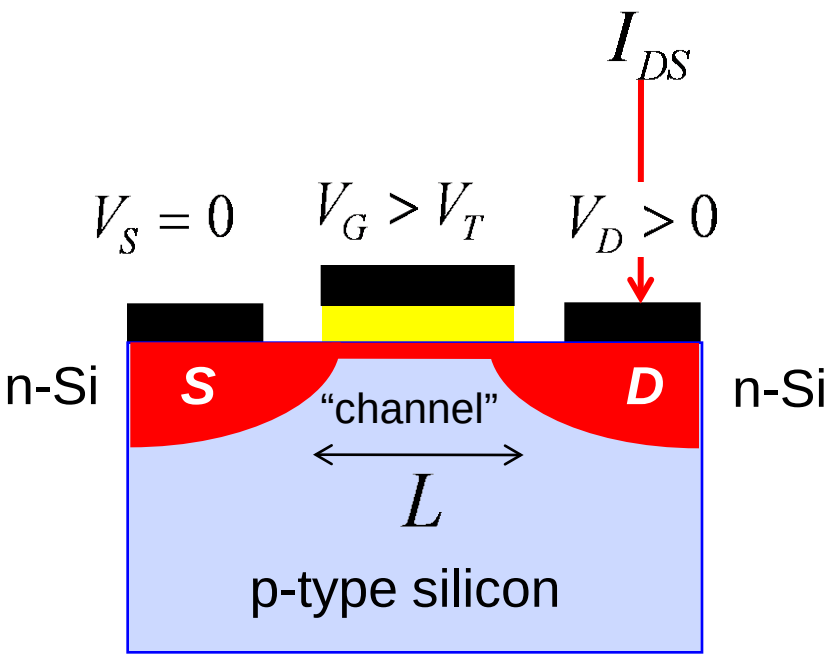
$V_T \approx 0.3 - 0.4\ \text{V}$

$V_{DSAT} \approx 0.4\ \text{V}$ (for $V_{GS} = V_{DD}$)

(These values were read off of the plots on the previous slide and are only rough estimates.)

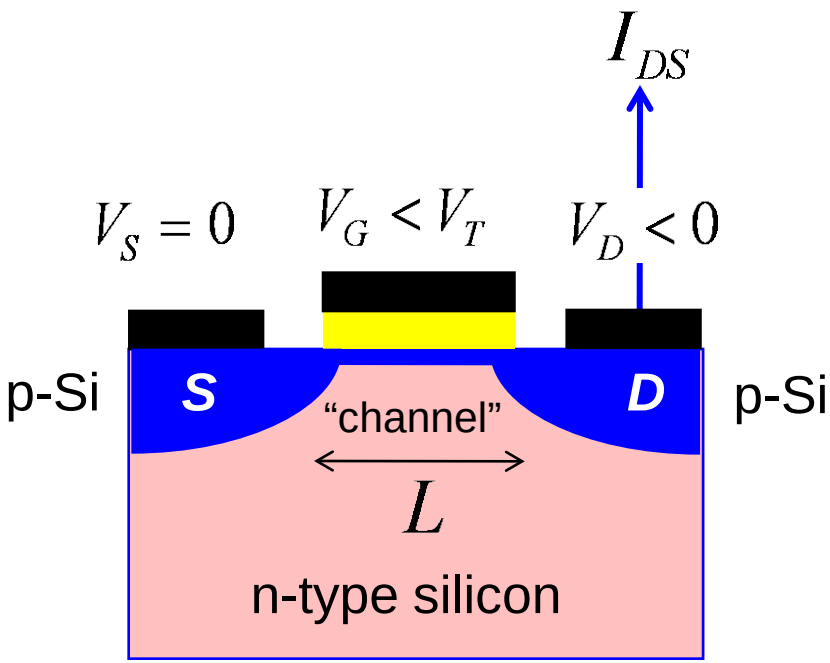
N-channel vs. P-channel MOSFET

n-MOSFET



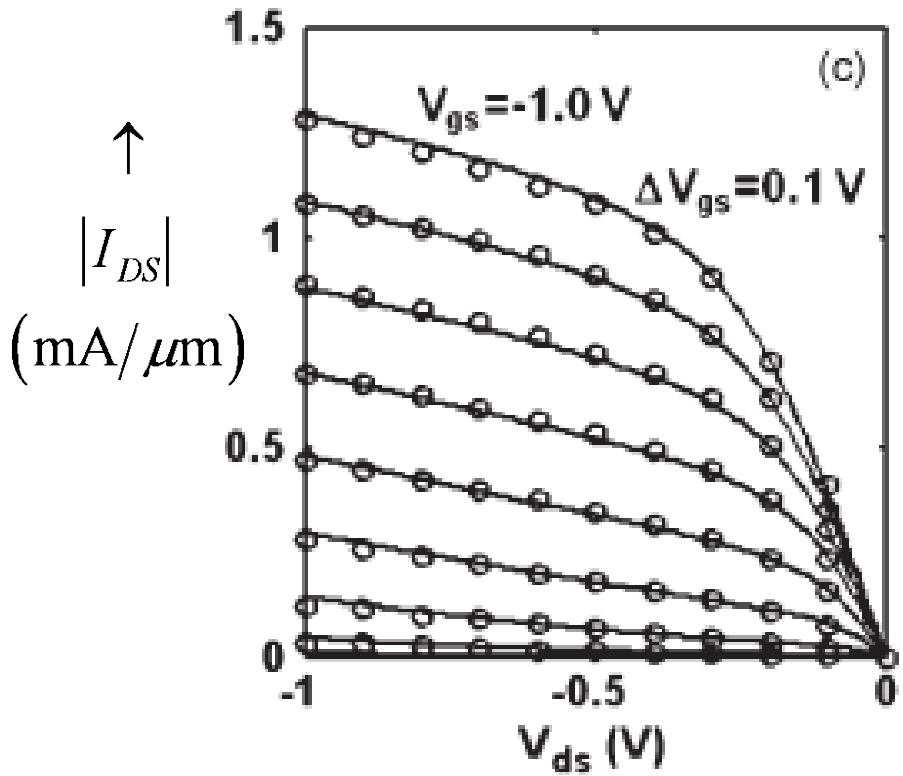
side view

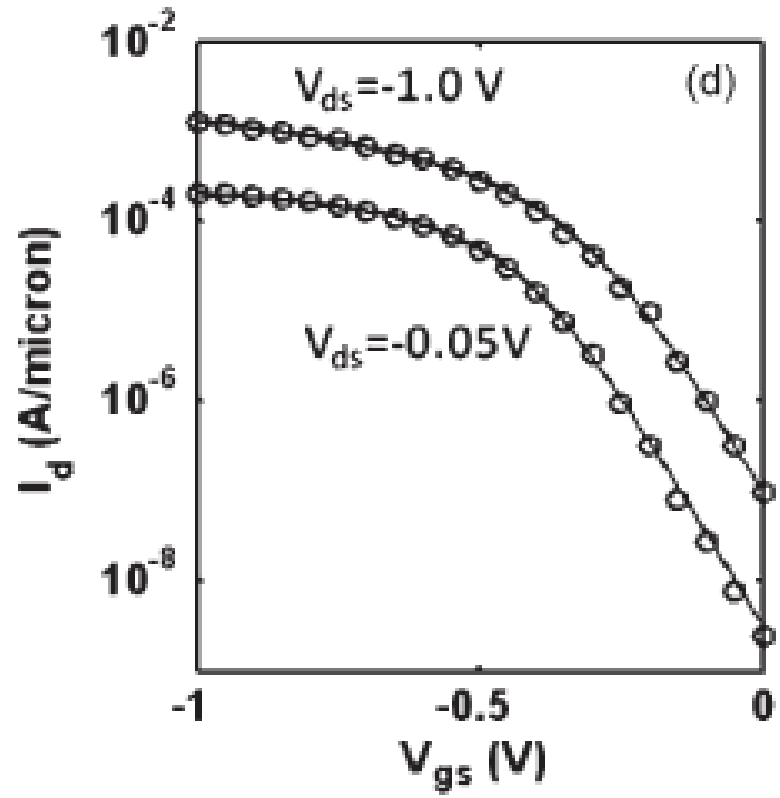
p-MOSFET



side view

Example: 32 nm P-MOS technology





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Lecture 1.3 Wrap-up

We have learned how to extract some key device parameters (e.g. threshold voltage, drain saturation voltage) and device performance metrics (e.g. on-current and off-current).

Most of the course is about understanding the *IV* characteristics of nanoscale MOSFETs – qualitatively and quantitatively.

But in the next lecture, we'll discuss some of the reasons for the device metrics (e.g. why is a high on-current important?).