Lecture 1: The Most Important Invention of the 20th Century?

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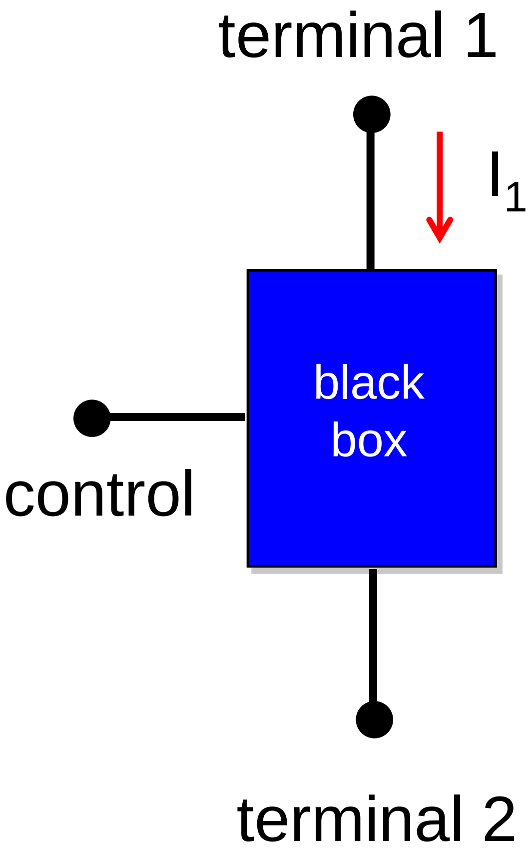
modern electronics

“The Transistor was probably the most important invention of the 20th Century, and the story behind the invention is one of clashing egos and top secret research."

- Ira Flatow, Transistorized!

http://www.pbs.org/transistor/

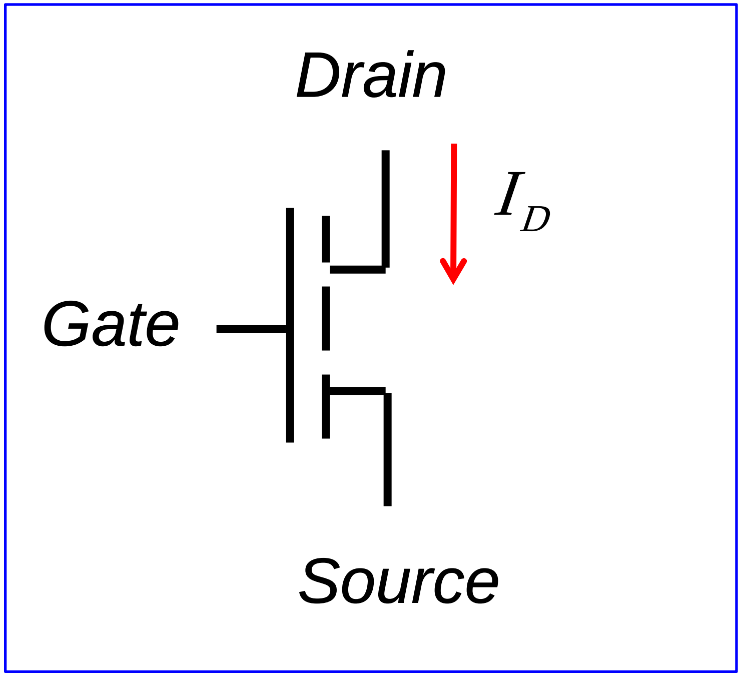
transistors



point contact transistor
bipolar transistor
MOSFET
JFET
SOI MOSFET
SB FET
FinFET
MODFET (HEMT)
heterojunction bipolar transistor
velocity modulation transistor
BTBT FET
SpinFET
…

the MOSFET as a 2-port device

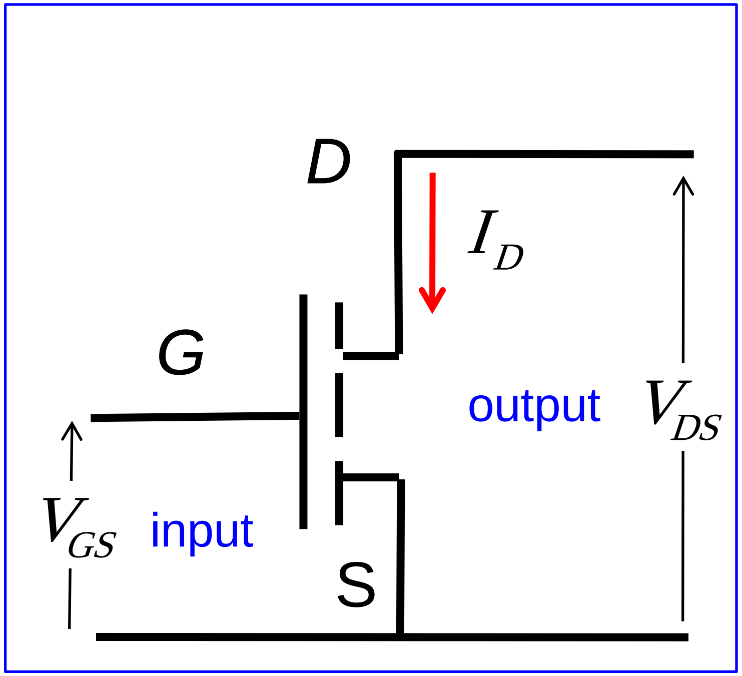
MOSFET circuit symbol



current vs. voltage (IV) characteristics

$$I_D\left(V_G, V_S, V_D\right)$$

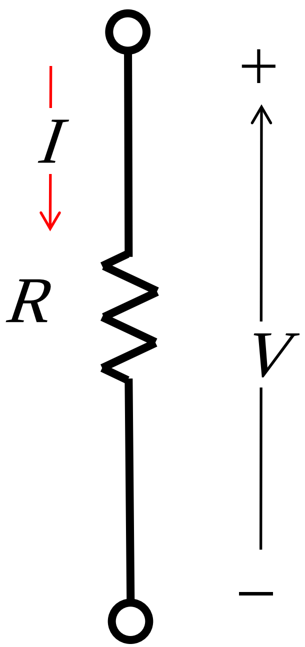
common source

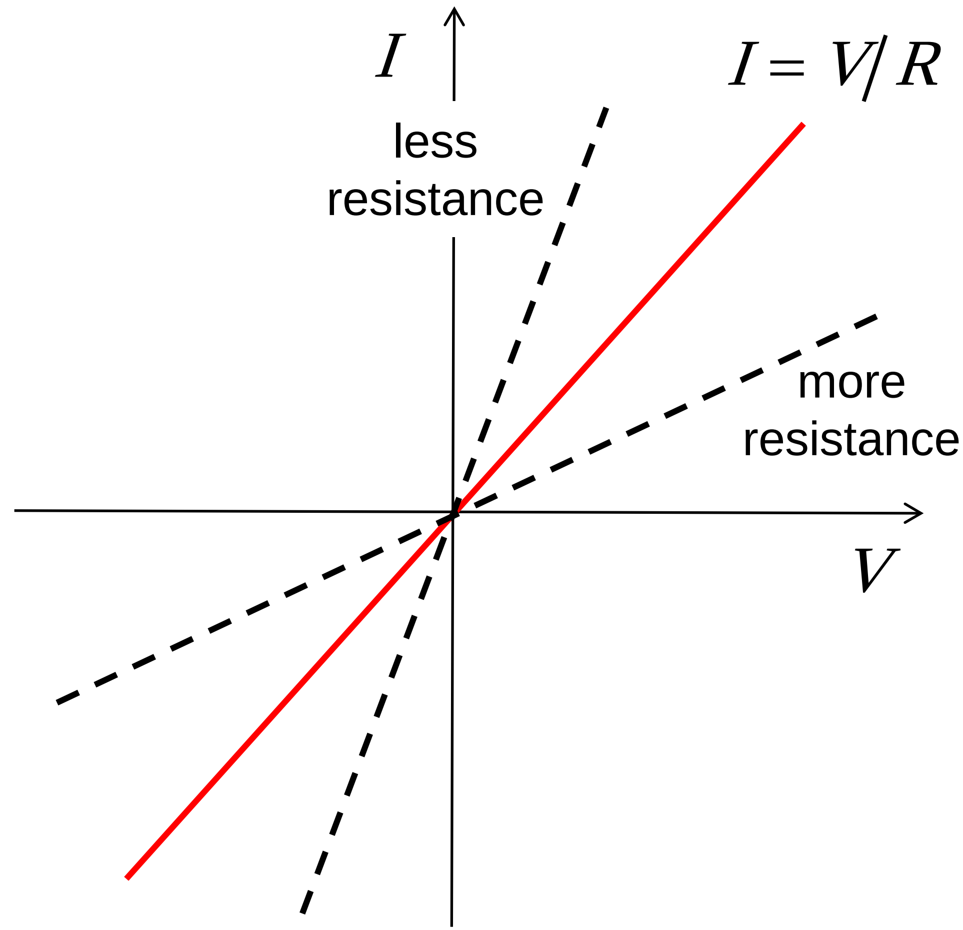


$I_D\left(V_{GS}\right)$ at a fixed V_{DS} transfer

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

IV characteristics: resistor

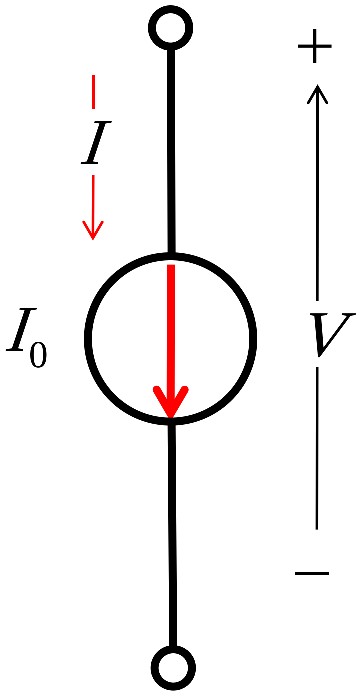




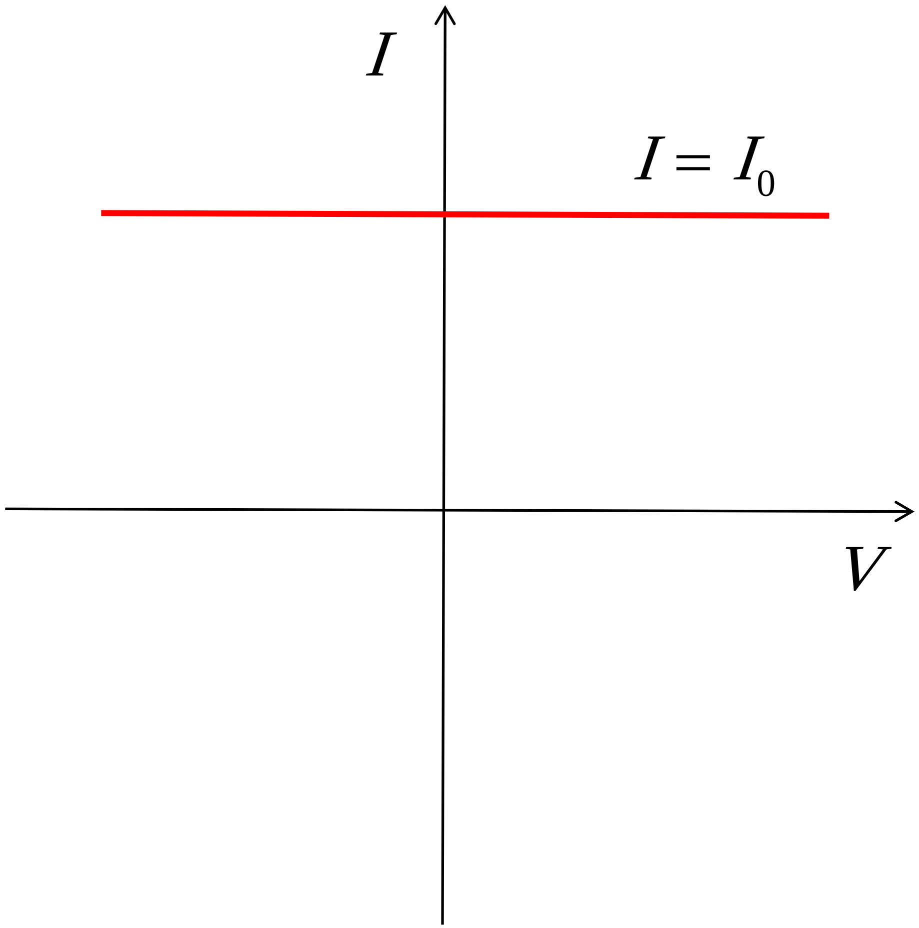
$I = V/R$ Ohm's Law

Georg Ohm, 1827

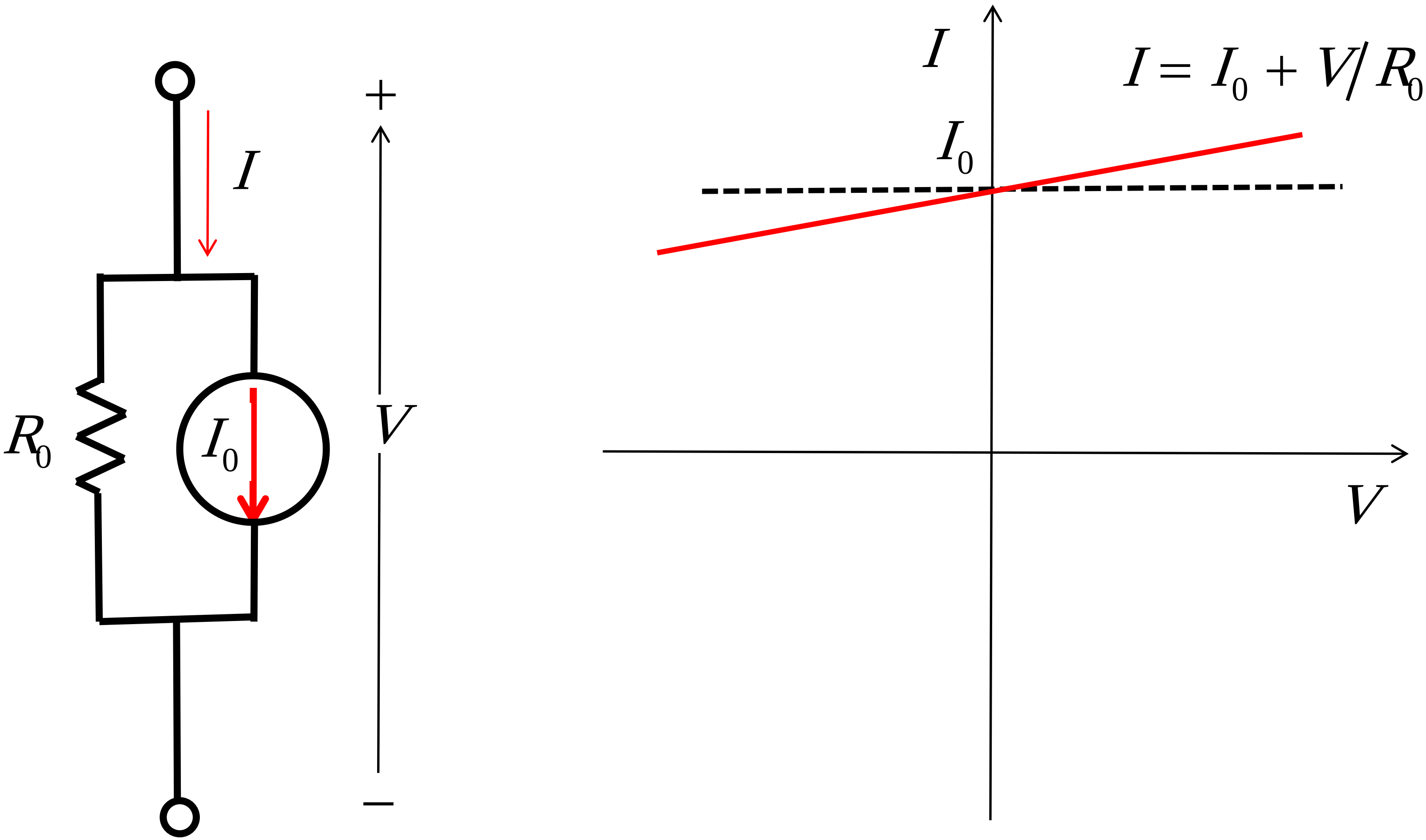
IV characteristics: ideal current source



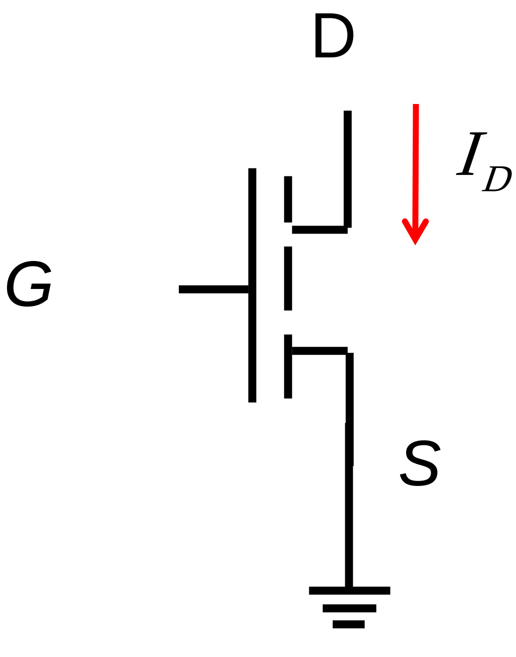
$$I = I_0$$



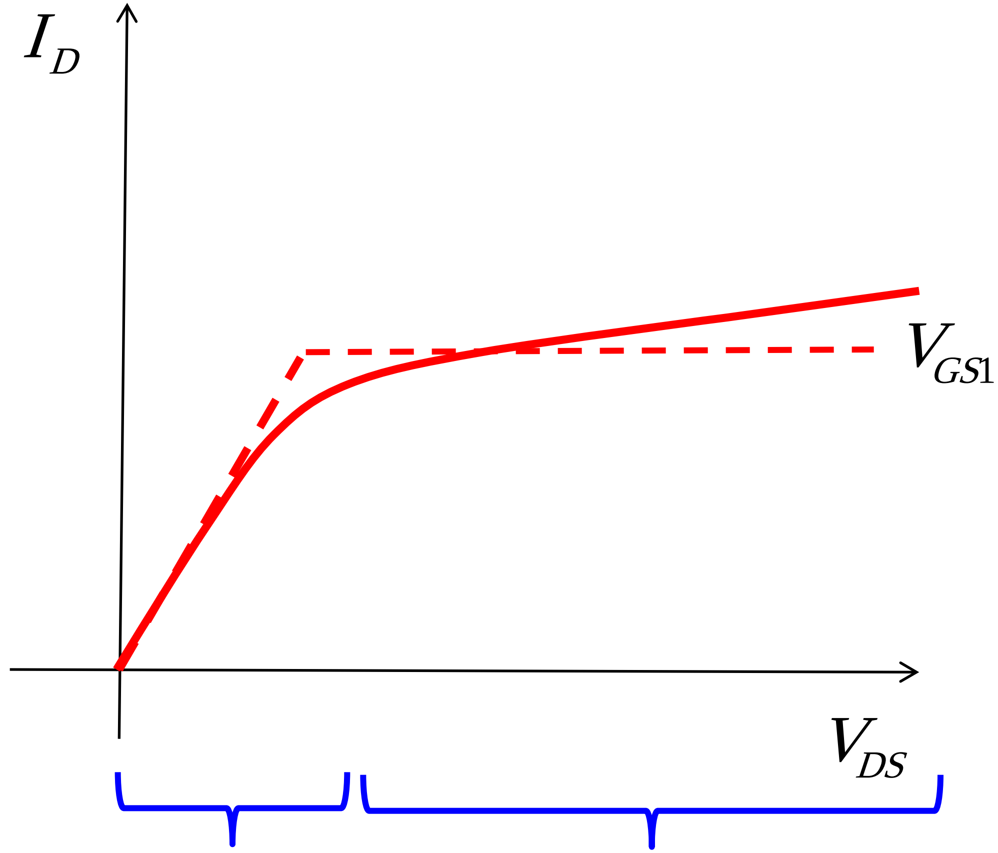
IV characteristics: real current sources



IV characteristics: transistors



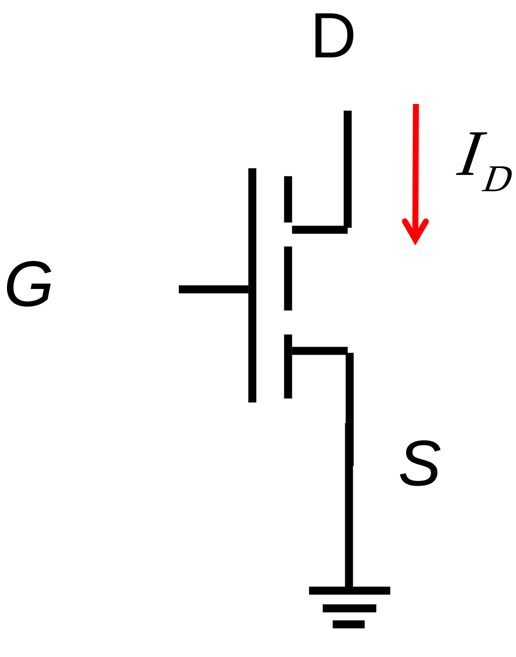
n-channel
enhancement
mode MOSFET

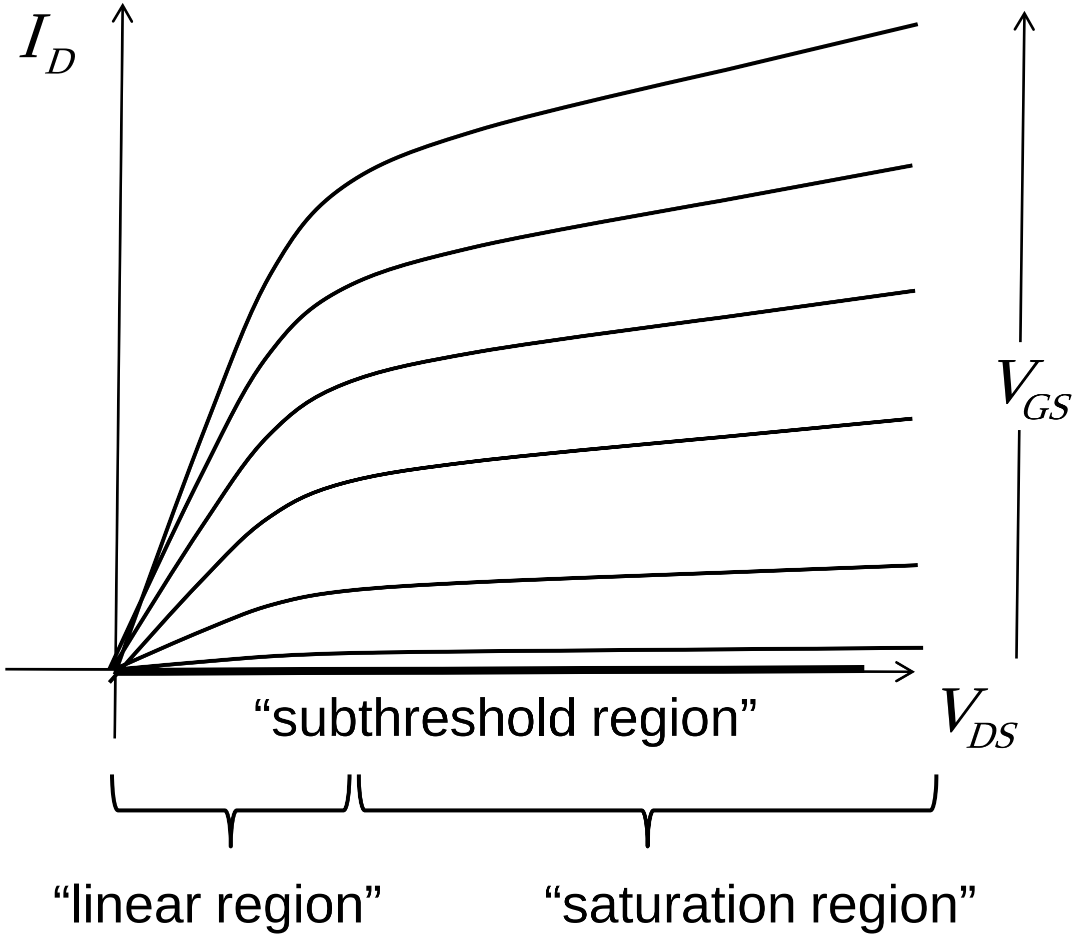


gate voltage
controlled resistor
“linear region”

gate voltage controlled
current source
“saturation region”

IV characteristics: transistors

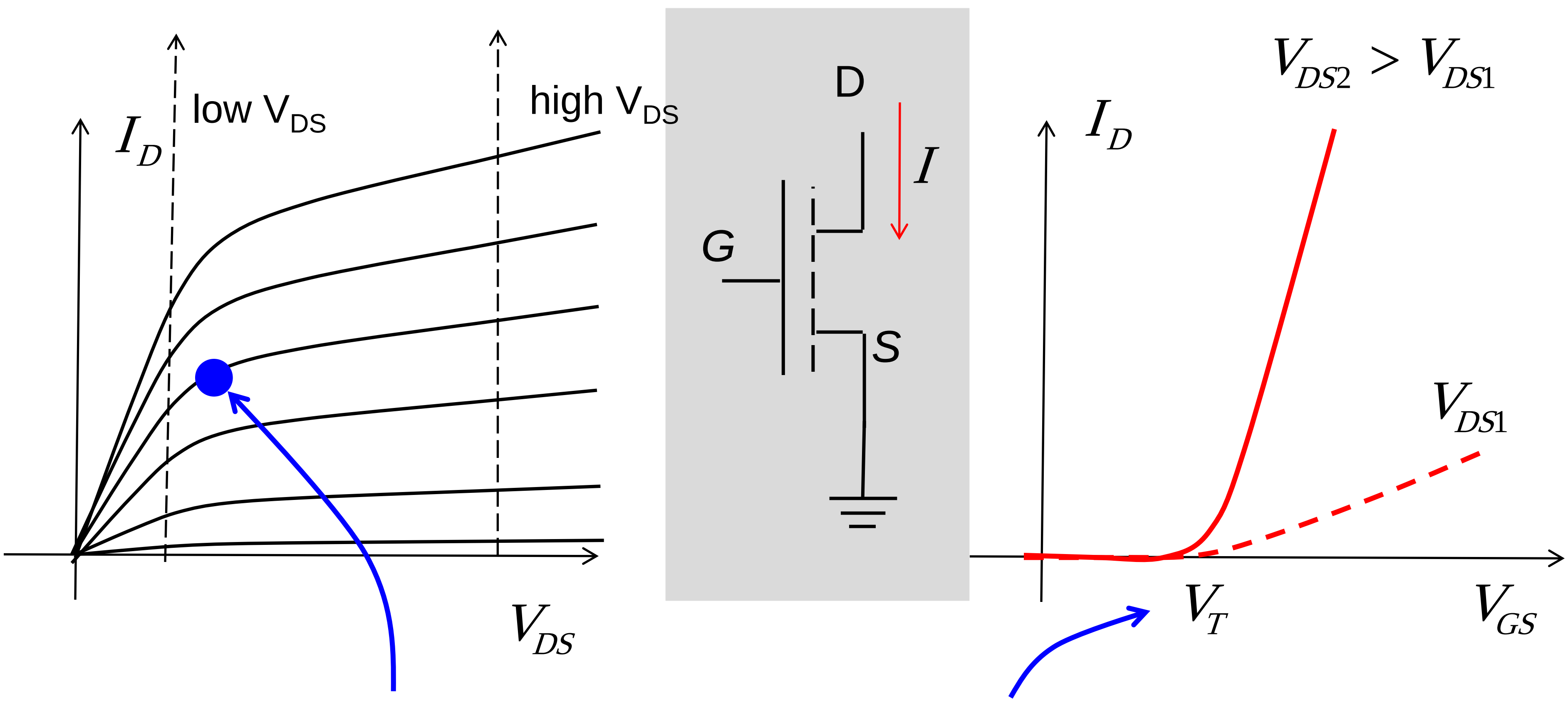




n-channel enhancement mode MOSFET

output and transfer characteristics

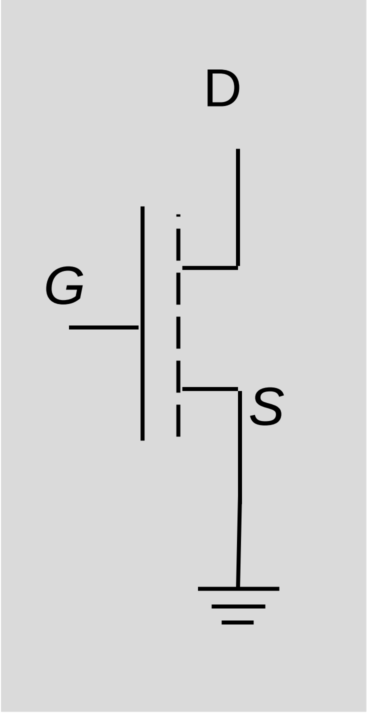
output characteristics



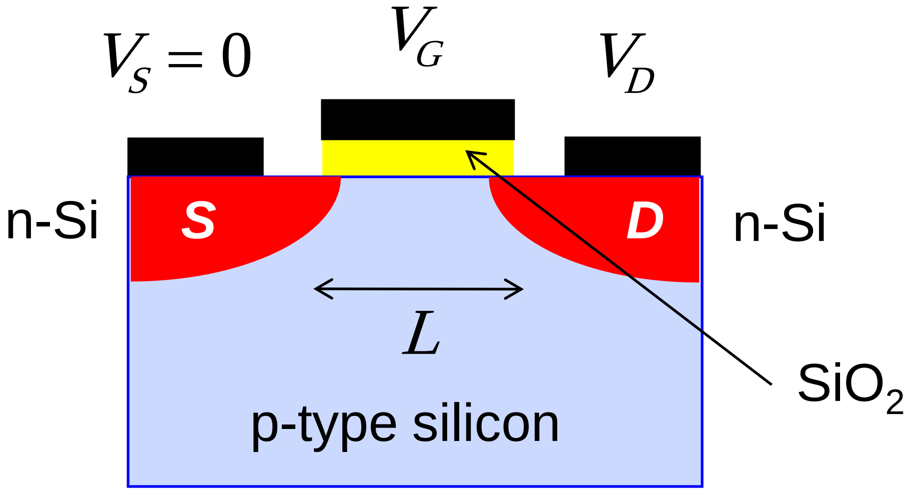
“saturation voltage” V_{DSAT}

“threshold voltage”

the physical structure of a MOSFET

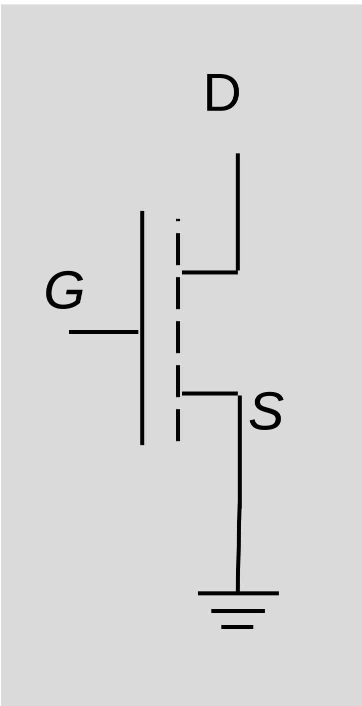


“cartoon” figure

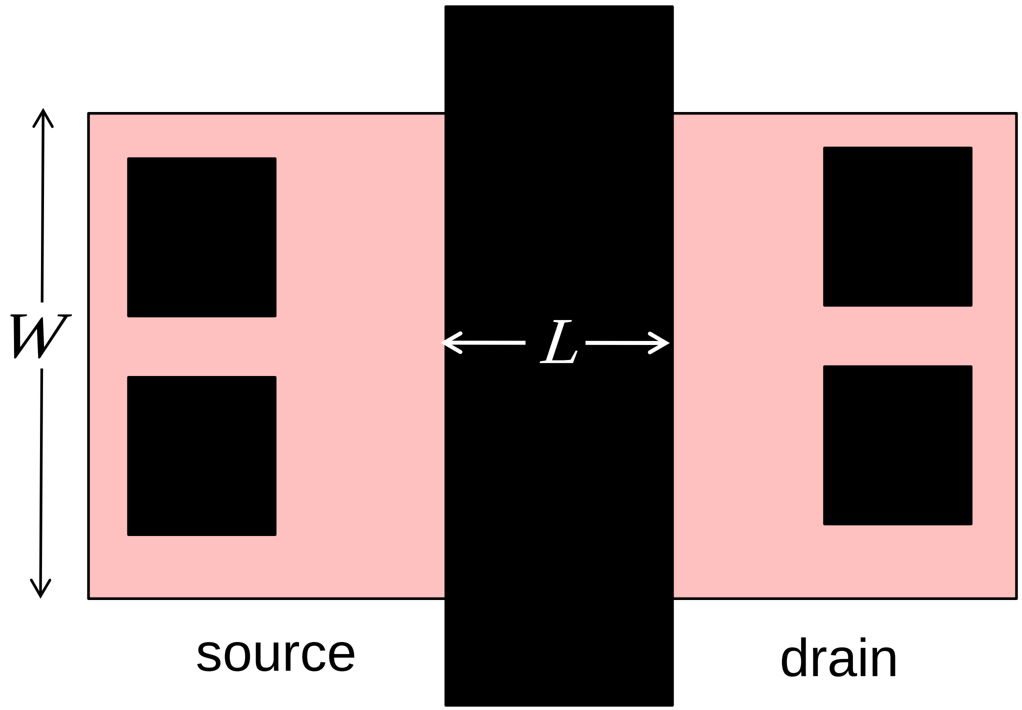


side view

the physical structure of a MOSFET

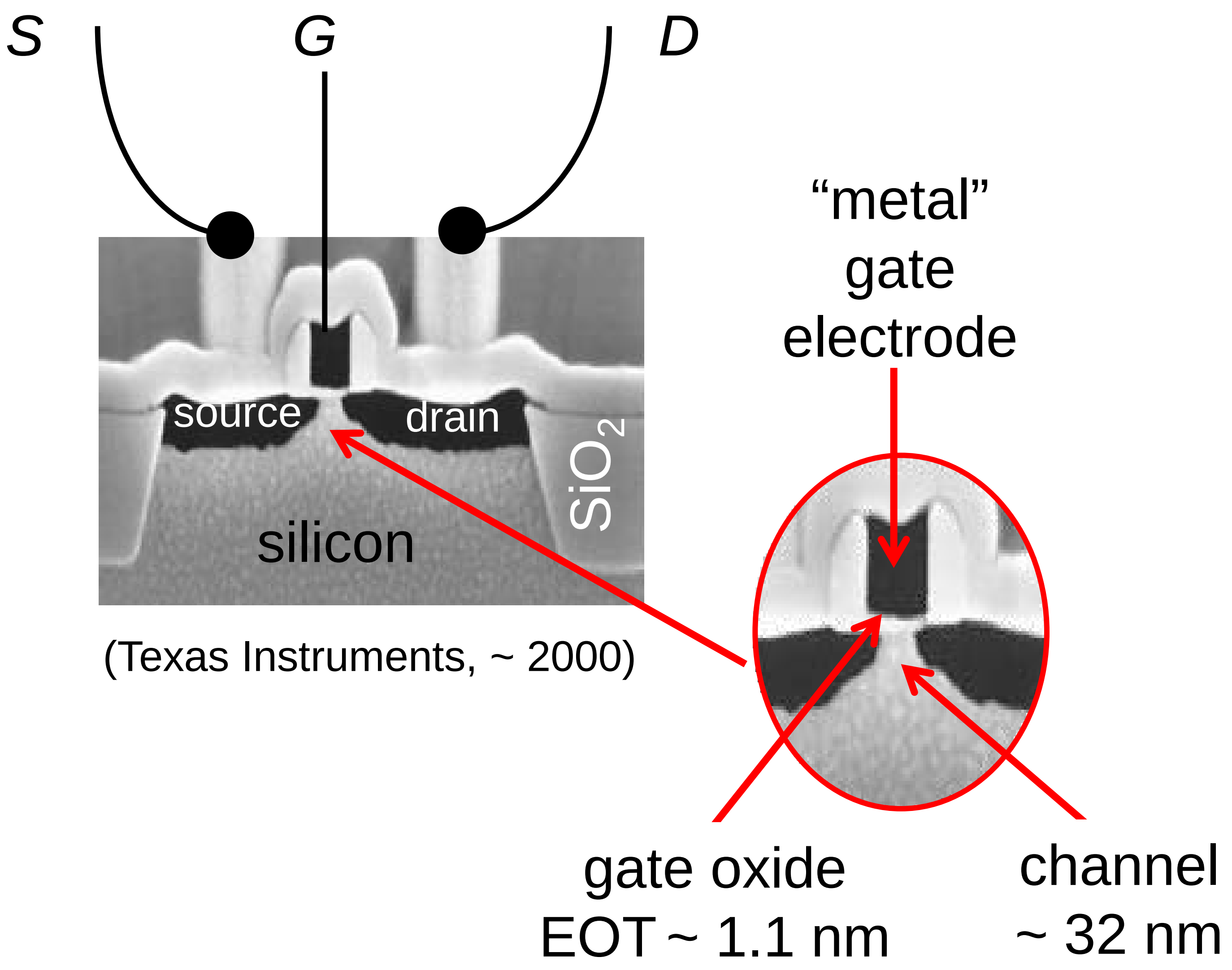


“cartoon” figure



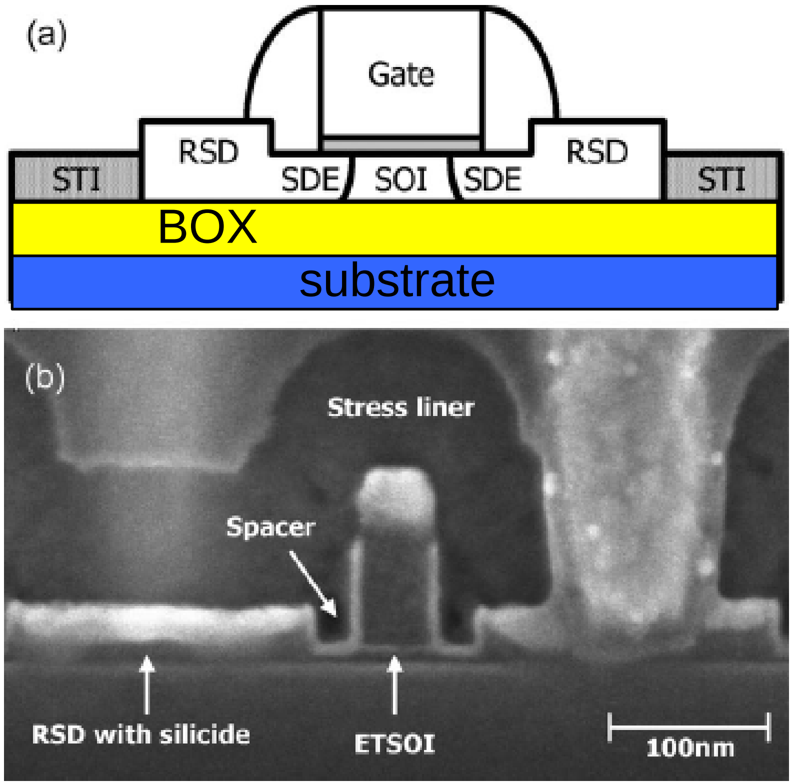
top view

nanoscale bulk MOSFETs



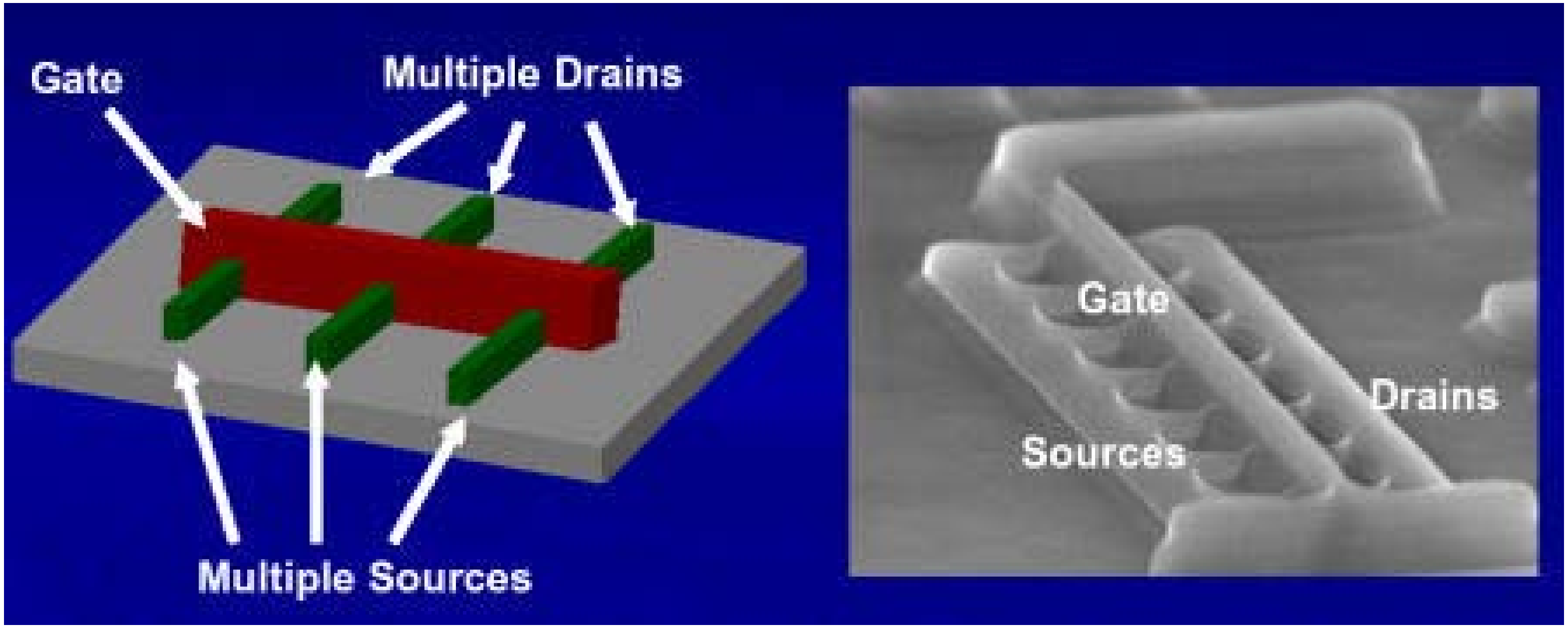
(Texas Instruments, ~ 2000)

Silicon on Insulator (SOI) MOSFETs



A. Majumdar, Z. Ren, S. J. Koester, and W. Haensch, Undoped-Body Extremely Thin SOI MOSFETs With Back Gates, *IEEE Trans. Electron Dev*., **56**, 2270-2276, 2009.

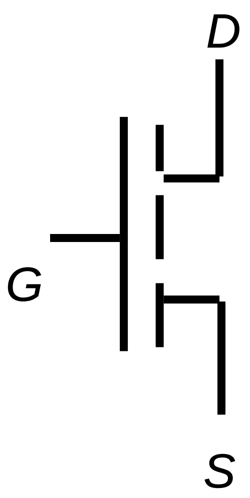
FinFETs and tri-gate FETs

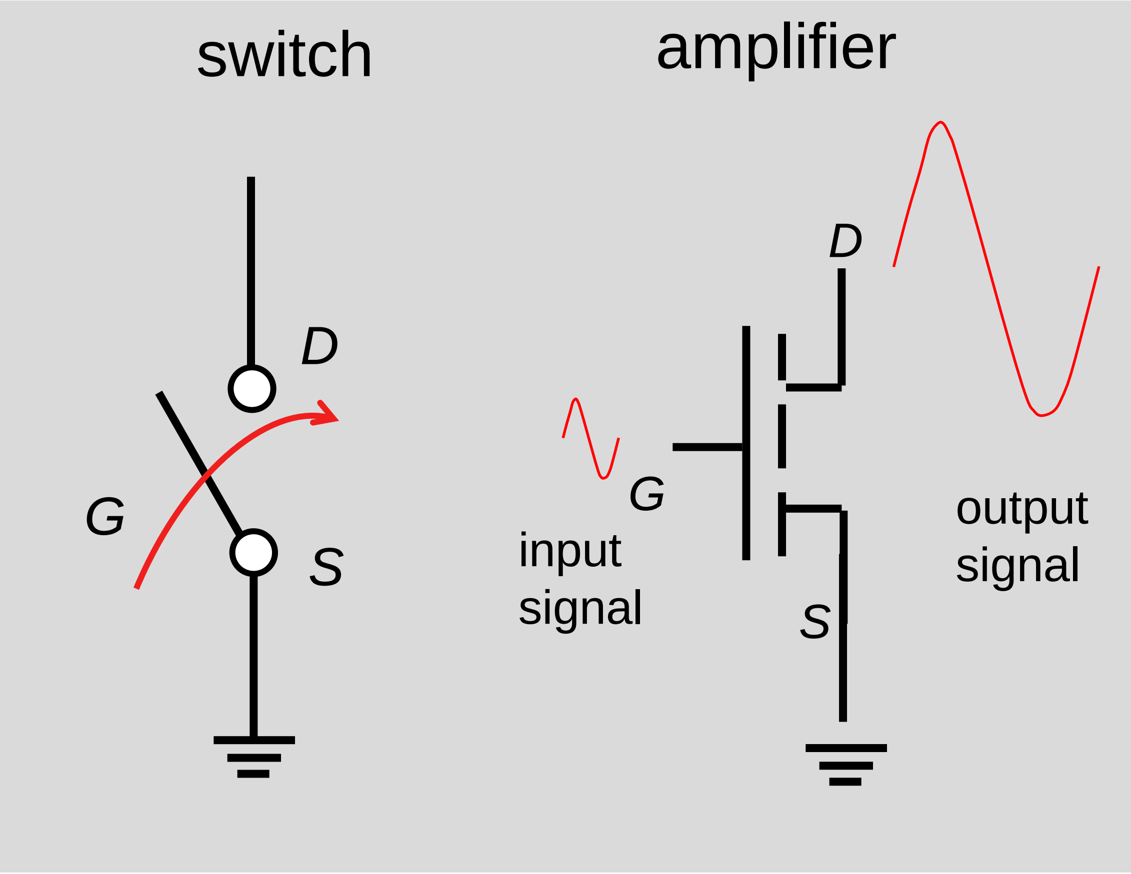


http://en.wikipedia.org/wiki/Multigate_device

applications of MOSFETs

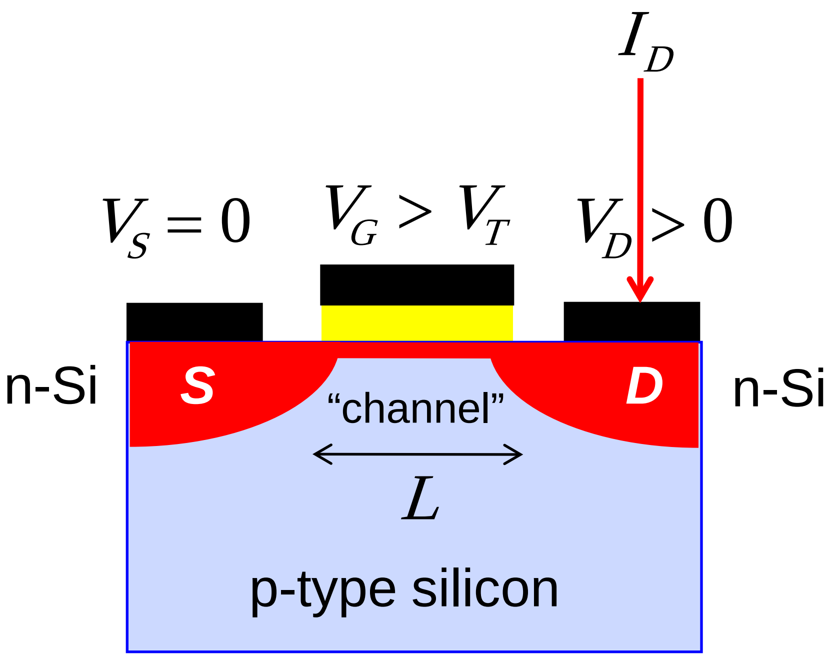
symbol





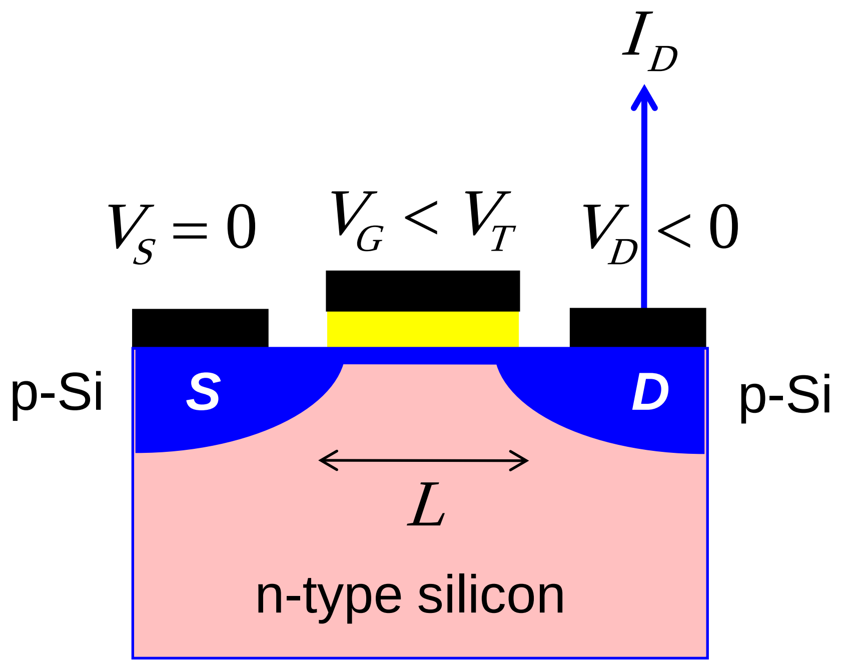
n-channel vs. p-channel MOSFET

n-MOSFET



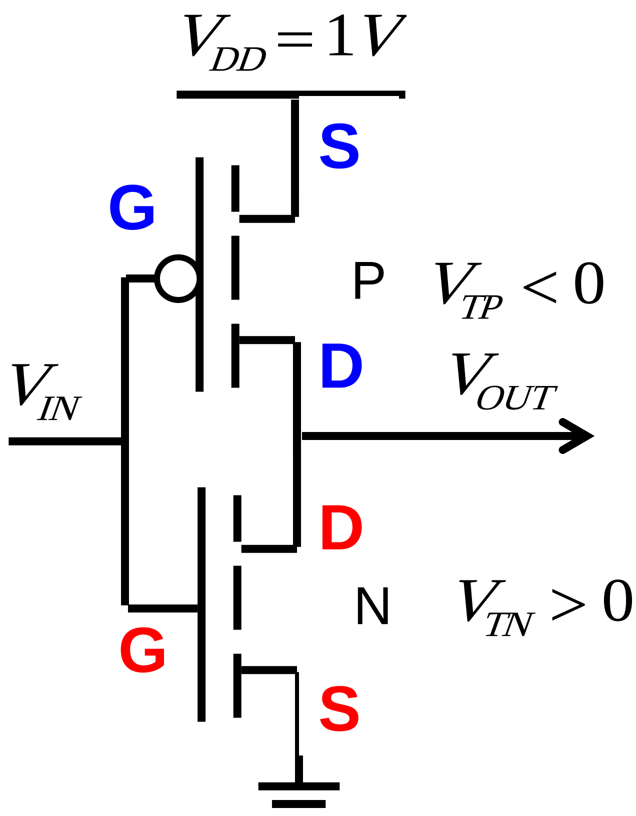
side view

p-MOSFET



side view

CMOS digital gates



"0" in:

$V_{IN} = 0$

$V_{GS})_P = -V_{DD} < V_{TP}$

$V_{OUT} = 1$

"1" out

"1" in:

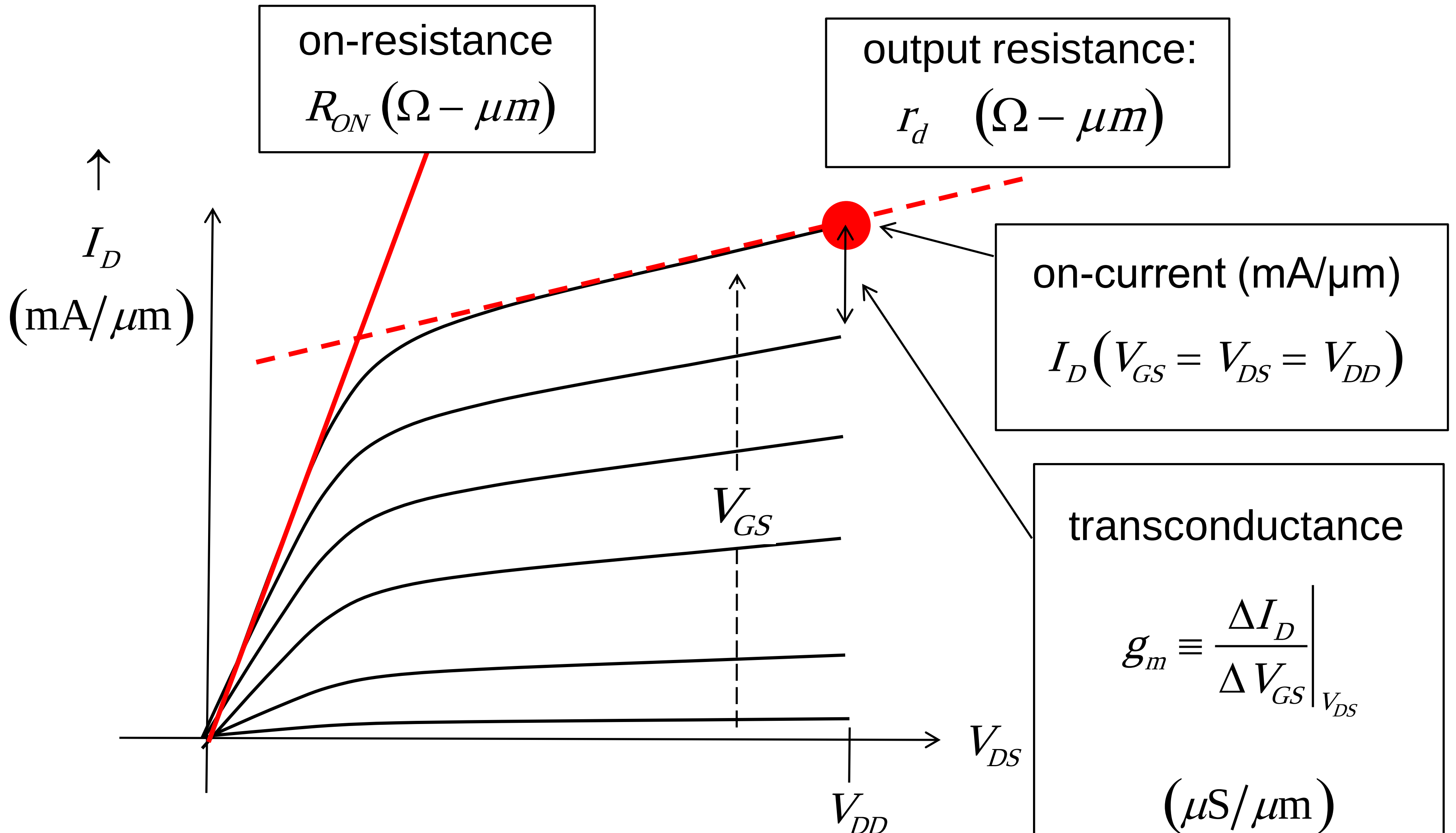
$V_{IN} = V_{DD}$

$V_{GS})_N = V_{DD} > V_{TN}$

$V_{OUT} = 0$

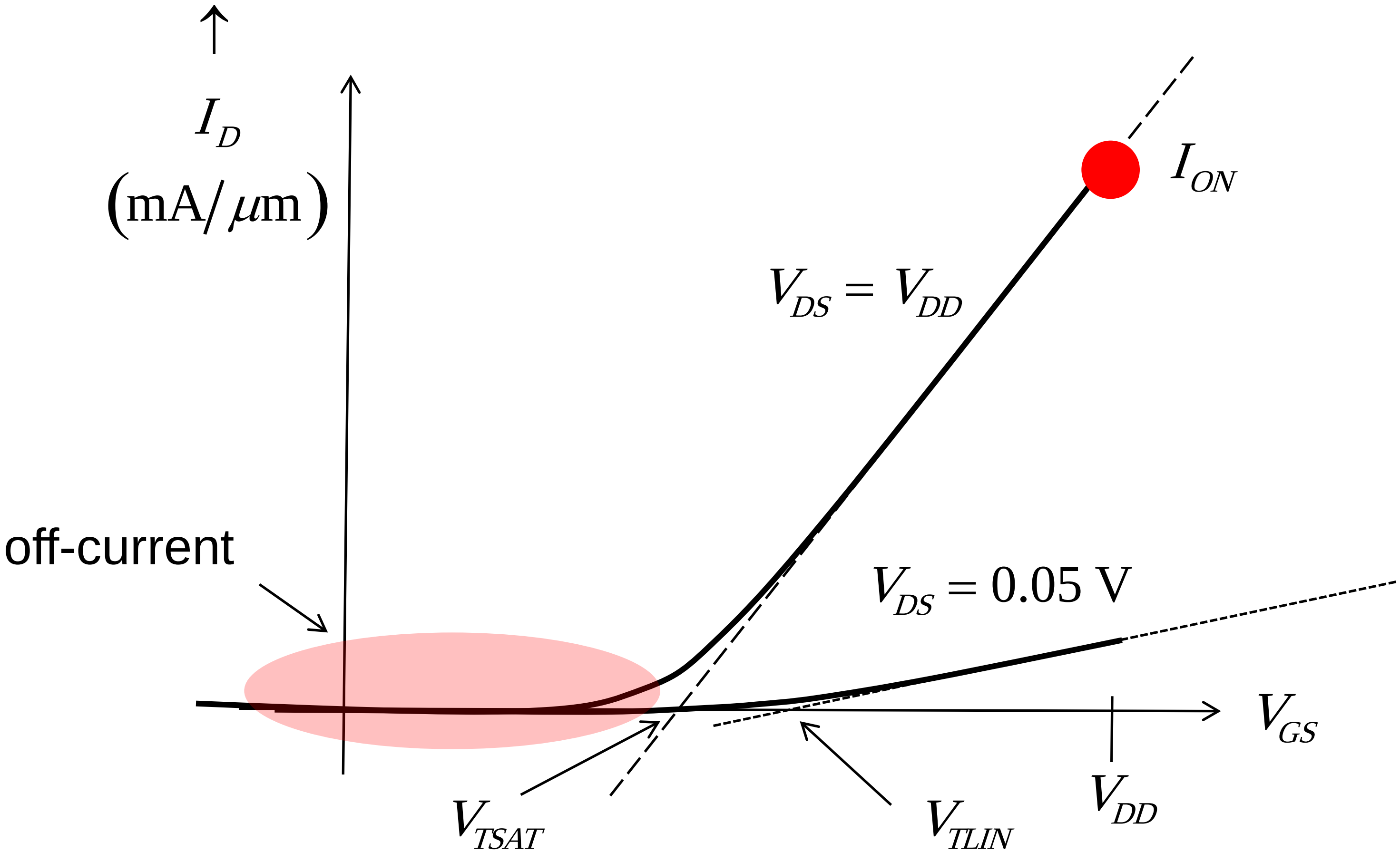
"0" out

MOSFET device metrics



MOSFET device metrics (ii)

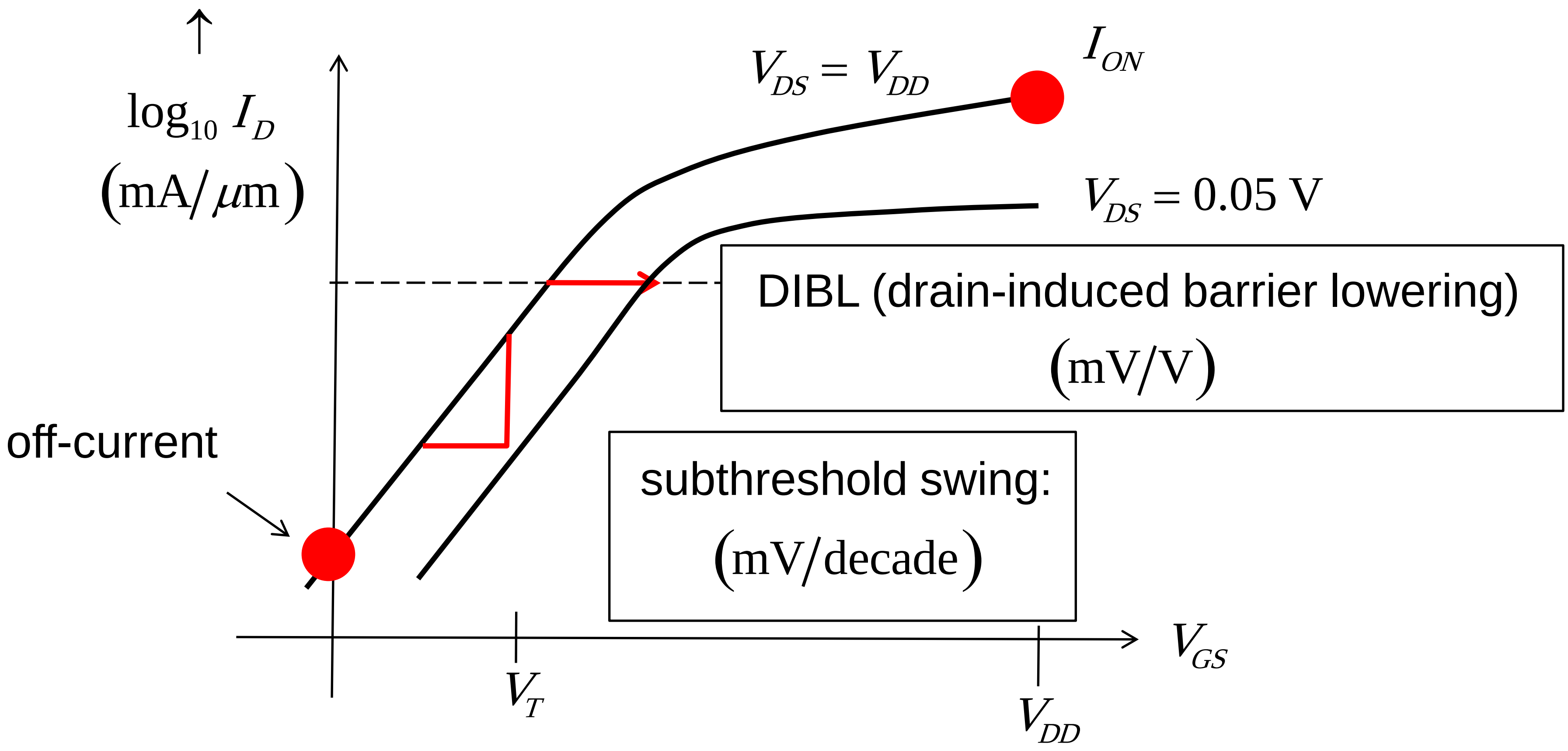
transfer characteristics:



threshold voltage

MOSFET device metrics (iii)

transfer characteristics:



Lundstrom 7.2012

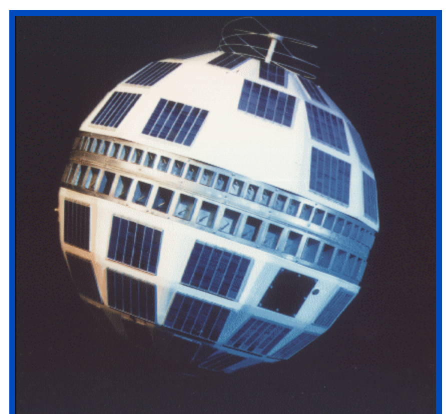
transistors (and IC's) created the modern world

supercomputers

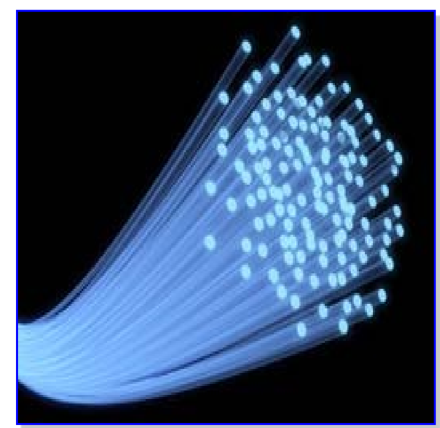
PCs

tablets

cell phones

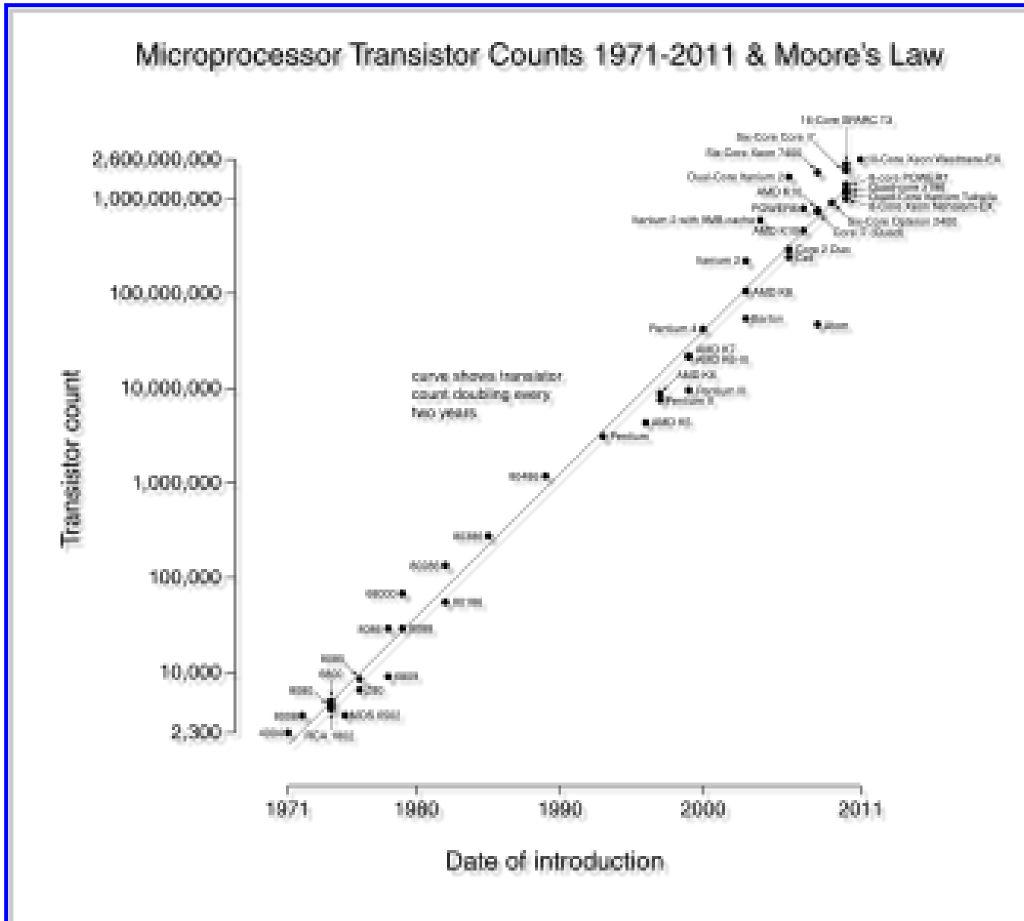


communication satellites



fiber optics / Internet

Moore’s Law: 2011



http://en.wikipedia.org/wiki/Moore's_law

some facts about transistors (and IC’s)

The number of transistors manufactured in 1997 exceeded the number of ants on the planet.

The cost of an IC “fab” is more than $3B, but the cost of a transistor has dropped by more than a factor of one million over the past 30 years.

If the definition of a nanodevice is one that has two dimensions less than 100 nm, then the silicon transistor is the most successful nanodevice currently in production.

(channel length 22 nm and gate oxide thickness, < 2 nm)

Nanoscale Transistors: the course

In this course we aim to develop a simple, physical understanding of:

- how nanoscale MOSFETs work
- what limits their performance
- how small they can be made

We'll aim for a "big picture" understanding of important concepts, but will provide pointers for those who wish to delve more deeply.

references

For a list of different types of transistors, see:

Kwok K. Ng, “A Survey of Semiconductor Devices,” *IEEE Transactions on Electron Devices*, Vol. 43, pp. 1760-1766, 1996.

Kwok K. Ng, *Complete Guide to Semiconductor Devices, 2nd Ed.,* John Wiley and Sons, New York, 2002.