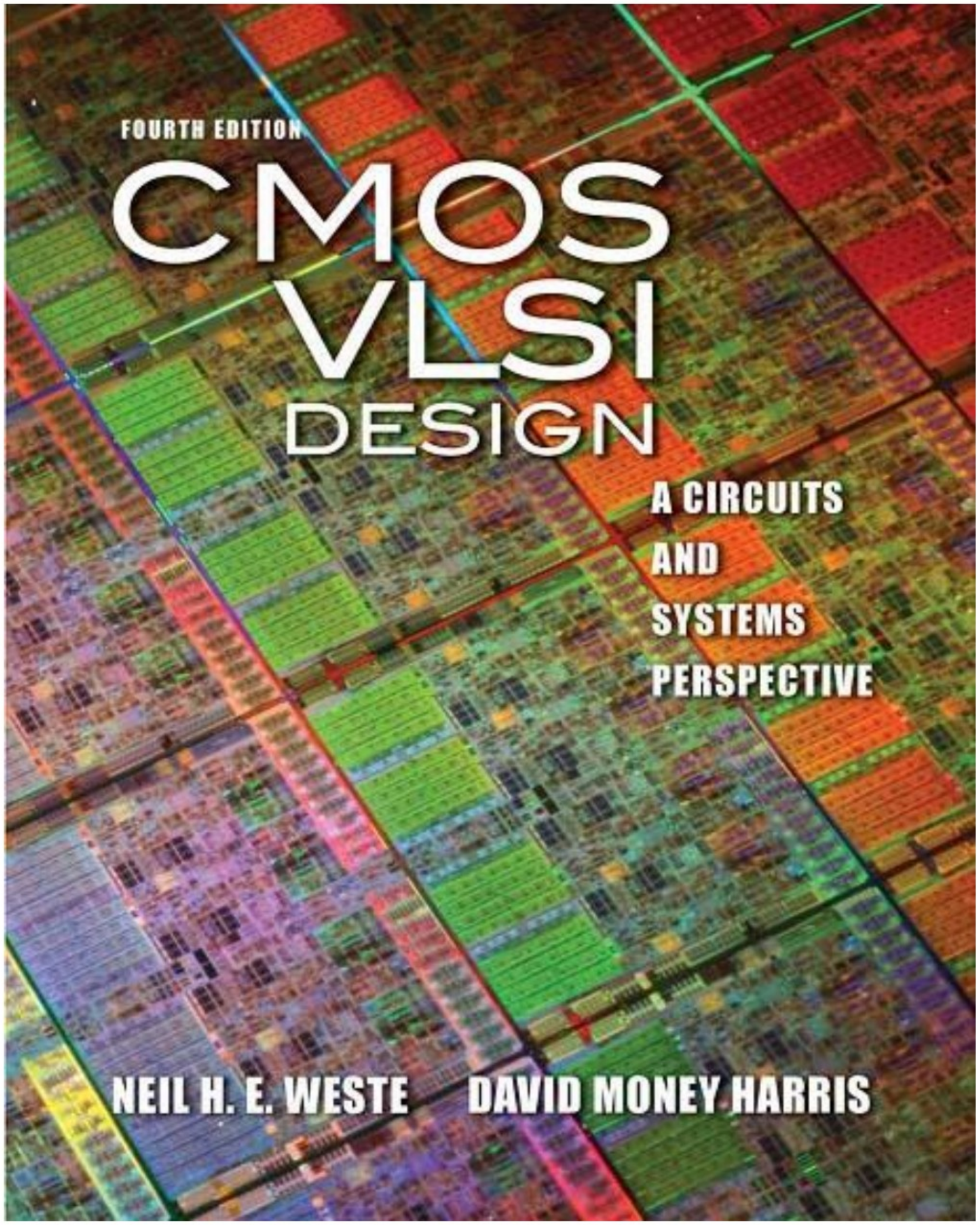


Lecture 1: Introduction

Course Description

Introduction to the concepts and techniques of VLSI (Very Large Scale Integration) design.

The VLSI design process, details of the MOS transistor, CMOS processing technology and device fabrication,

MOS transistor theory, MOS transistor I-V characteristics, design rules, digital CMOS circuits, and performance estimation.

Course main objective

1. Introduce the concepts and techniques of modern integrated circuit design (CMOS VLSI).
2. Develop an understanding of digital design using CMOS.
3. Learn how to evaluate the performance of CMOS designs.

Assessment tasks

#	Assessment task*	Week Due	Percentage of Total Assessment Score
1	Lab Exam	15	20%
2	Midterm Exam	8	20%
3	Assignments and Quizzes	Continues	10%
	Final Exam	16	50%

Materials

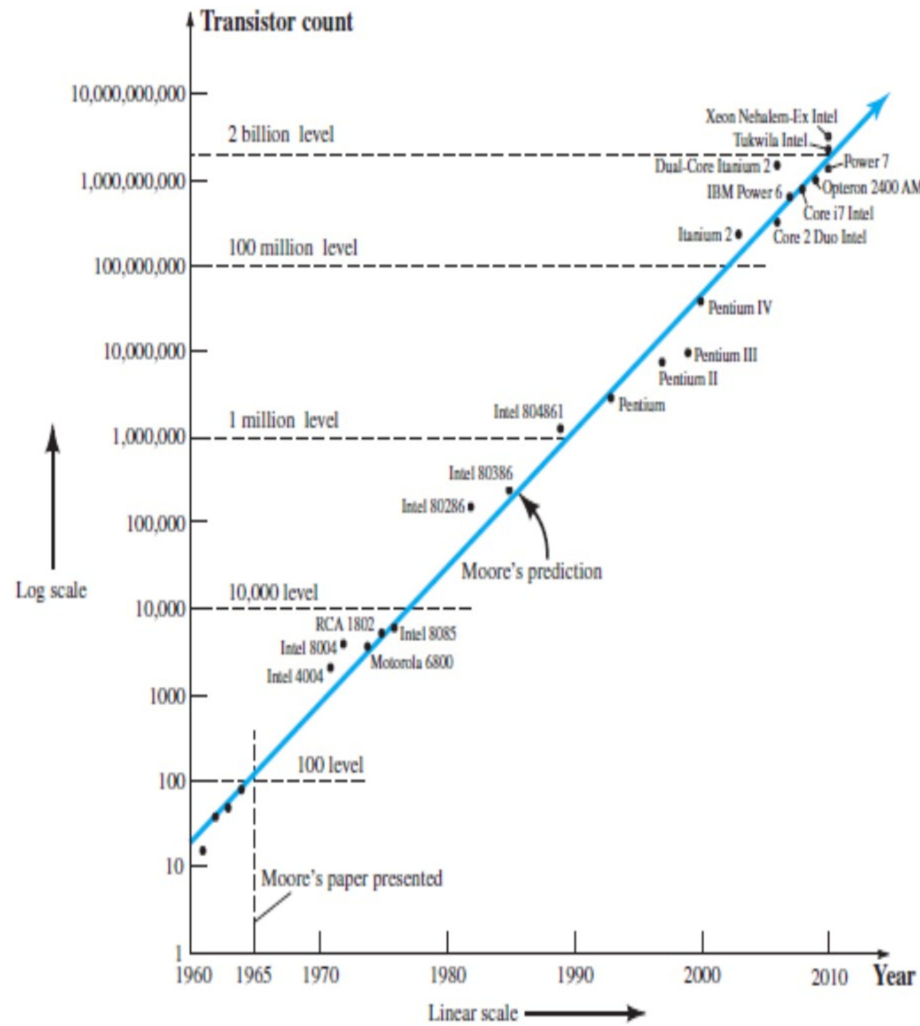
- Textbook:
  - Neil H.E. Weste and David Harris, CMOS VLSI Design: A Circuits and Systems Perspective, Addison Wesley, 4th Ed, 2011.
  - Ken Martin, Digital Integrated Circuit Design, Oxford University Press, 2000.
- Reference:
  - Jan M. Rabaey, A. Chandrakasan, B. Nikolic, Digital Integrated Circuits: A Design Perspective, Prentice Hall, 2nd Ed, 2003.
- Lecture notes.

Integrated Circuit

- IC (aka chip): Integrated Circuit is the circuit in which all the Passive(Passive components can't introduce net energy into the circuit, e.g., resistors, capacitors and inductors) and Active (active means those amplifying components such as transistors, and diodes) components are fabricated onto a single chip. Based on the number of components, IC can be classified into:
  - **Small Scale Integration (SSI):** 1-100 Transistors were fabricated on a single chip,e.g., Gates, Flipflops.
  - **Medium Scale Integration (MSI):** 100-1000 Transistors could be integrated on a single chip, e.g., 4-bit Microprocessors.
  - **Large Scale Integration** 1000-10000 Transistors could be integrated on a single chip, e.g., 8-bit Microprocessors, RAM, ROM
  - **Very Large Scale Integration(VLSI):** 10000-1 Million Transistors could be accommodated e.g., 16-32 bit Microprocessors.
  - **Ultra Large Scale Integration(ULSI):** In this Technology, 1 Million-10 Million Transistors could be accommodated. Eg Special Purpose Registers.
  - **Giant Scale Integration (GSI):** In this Technology more than 10 Million Transistors could be accommodated. Eg Embedded Systems.

VLSI

- For example, the Intel ® Core TM i7 Processor has 731 million transistors in a package that is only slightly larger than a 10 cm^2.



- Moore's law predicts that the transistor count of an integrated circuit will double every 2 years

Brief History

- 1958- first integrated circuit flip flop with 2 transistors
- 2003, Intel Pentium 4 processor 55 M transistors
- 2012, Quad core i7 processor, 1.4 Billion transistors
- 2016, the largest transistor count in a commercially available single-chip processor is over 7.2 billion transistors
- 2016, in other types of ICs, such as field-programmable gate arrays (FPGAs), the Altera Stratix 10 has the largest transistor count, containing over 30 billion transistors.

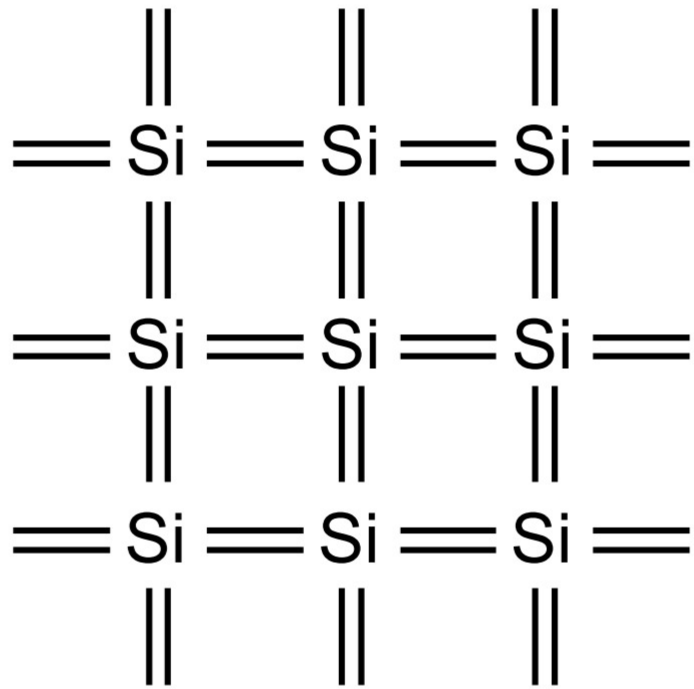
Introduction

- Integrated circuits: many transistors on one chip.
- *Very Large Scale Integration* (VLSI): bucket loads!
- *Complementary Metal Oxide Semiconductor*
  - Fast, cheap, low power transistors
- Today: How to build your own simple CMOS chip
  - CMOS transistors
  - Building logic gates from transistors
  - Transistor layout and fabrication

Silicon Lattice

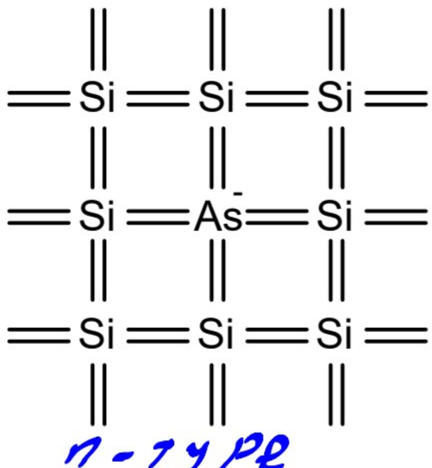
- Transistors are built on a silicon substrate
- Silicon is a Group IV material
- Forms crystal lattice with bonds to four neighbors

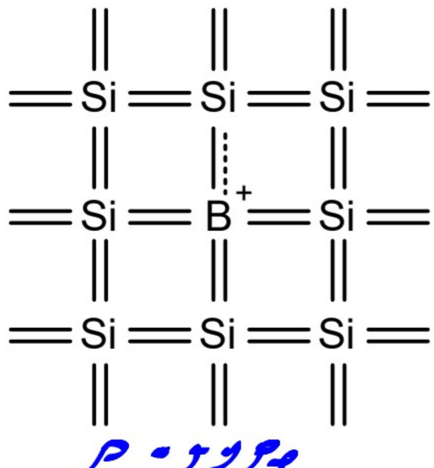
14
4
8
2



Dopants

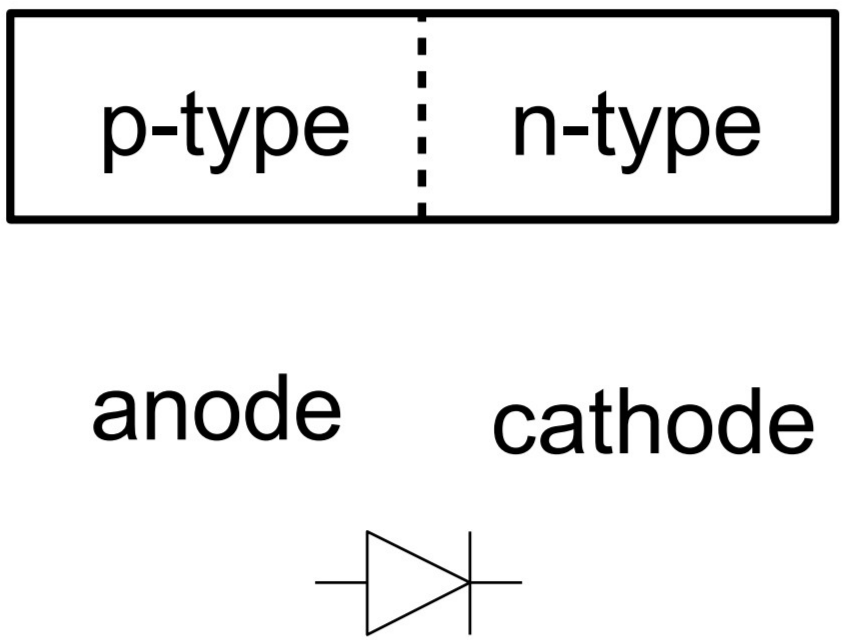
- Silicon is a semiconductor
- Pure silicon has no free carriers and conducts poorly
- Adding dopants increases the conductivity
- Group V: extra electron (n-type)
- Group III: missing electron, called hole (p-type)





p-n Junctions

- A junction between p-type and n-type semiconductor forms a diode.
- Current flows only in one direction

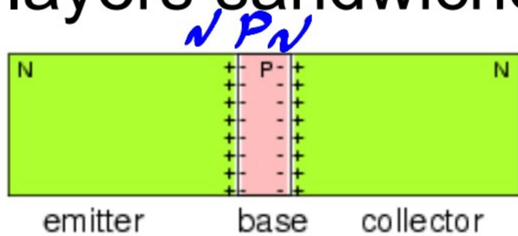


BJT Transistor

- Bipolar Junction Transistor
- 3 semiconductor layers sandwiched together

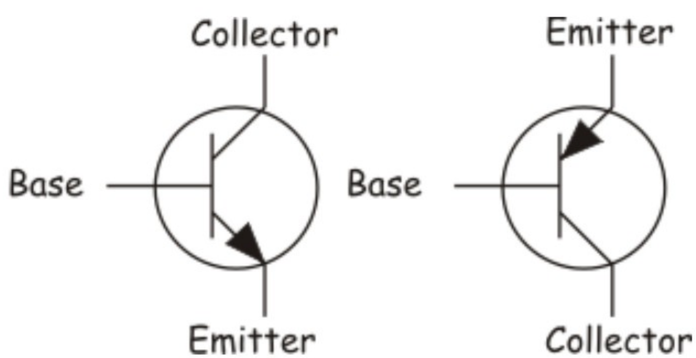
$I_C = \beta I_B$ (100)

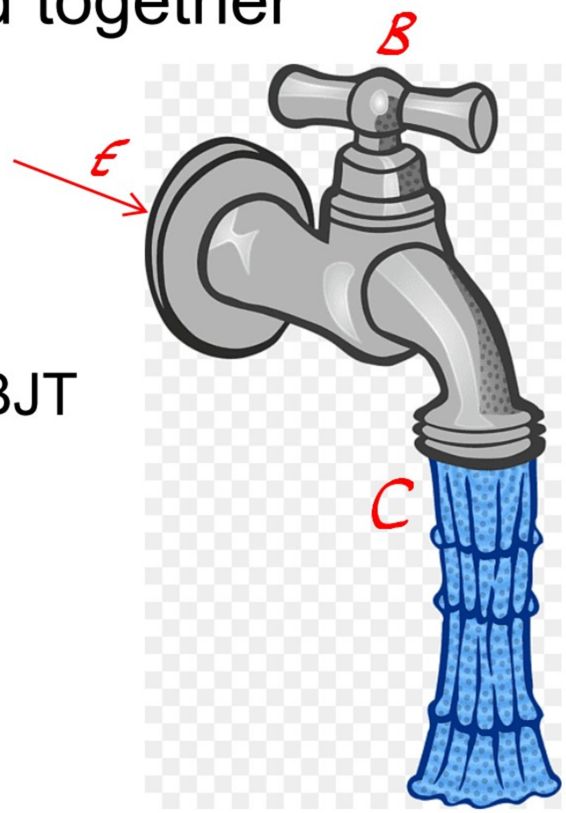
$I_E \approx (\beta + 1) I_B$



  - Comes in two flavors

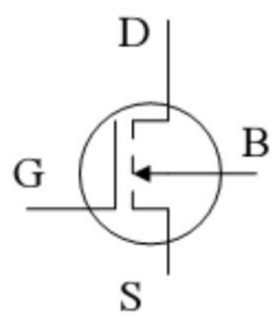
NPN BJT PNP BJT





FET Transistors

- Analogous to BJT Transistors
- Output is controlled by input **voltage** rather than by current
- 4 Pins vs. 3



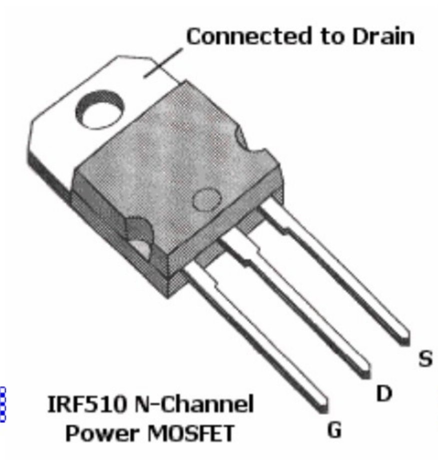
BJT	FET
Collector	Drain
Base	Gate
Emitter	Source
N/A	Body

BJT vs FET

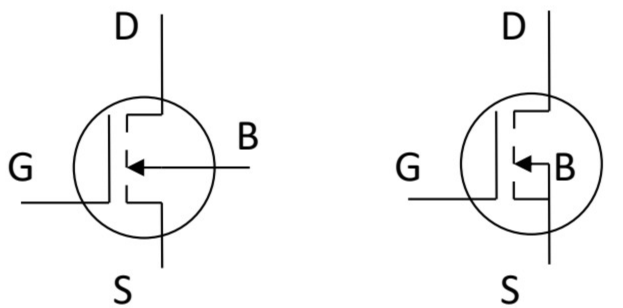
BJT	FET
Voltage control: FET the current I_D will be a function of the voltage V_{GS} applied to the input circuit.	Current control: In BJT the current I_C is a direct function of the level of I_B $I_C = \beta I_B$
Bipolar	Unipolar
Bigger size	Smaller
BJTs have high voltage and current ratings.	They have less voltage and current ratings.
The BJT has a negative temperature co-efficient.	FET has a positive temperature coefficient for stopping over heating.
BJTs offer smaller input impedances, meaning they draw more current from the power circuit feeding it, which can cause loading of the circuit. $I_E = I_B + I_C$	FETs offer greater input impedance than BJTs. This means that they practically draw no current and therefore do not load down the power circuit that's feeding it.

FET Transistors – Circuit Symbols

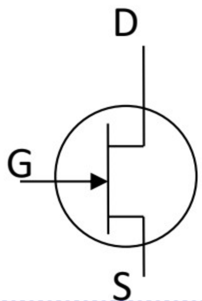
- In practice the body and source leads are almost always connected
- Most packages have these leads already connected



MOSFET



JFET



MOSFETs

- MOS - metal oxide semicondutor structure (original devices had metal gates, now they are silicon)

- NMOS - n-channel MOSFET

- PMOS - p-channel MOSFET

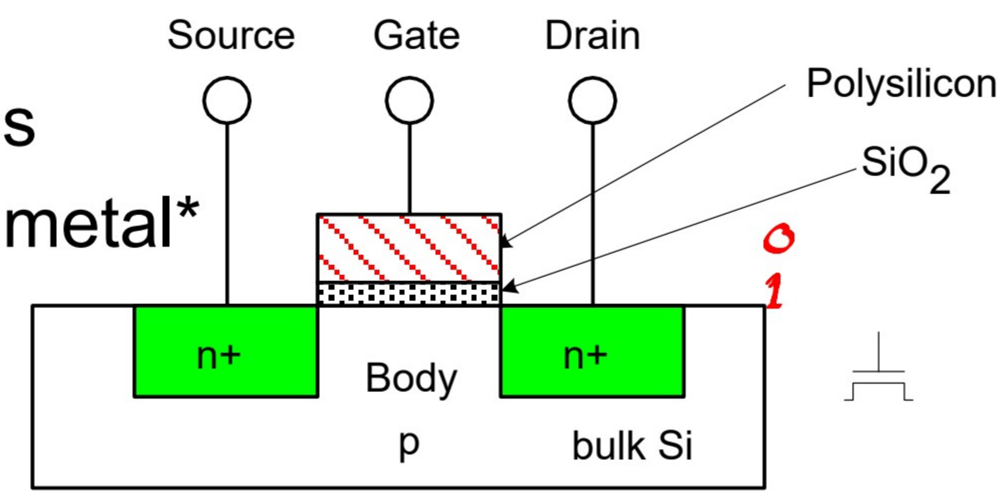
- CMOS - complementary MOS, both n-channel and p-channel devices used in conjuction with each other (most popular in IC’s)

- MESFET - metal semiconductor structure, used in high-speed GaAs devices

- JFET - junction FET, early type of FET

nMOS Transistor

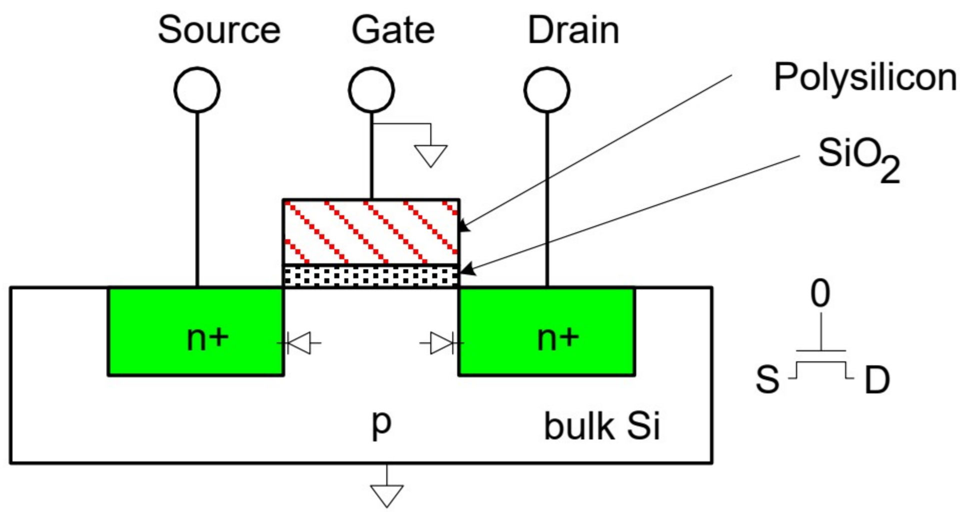
- Four terminals: gate, source, drain, body
- Gate – oxide – body stack looks like a capacitor
  - Gate and body are conductors
  - SiO_2 (oxide) is a very good insulator
  - Called metal – oxide – semiconductor (MOS) capacitor
  - Even though gate is no longer made of metal*



* Metal gates are returning today!

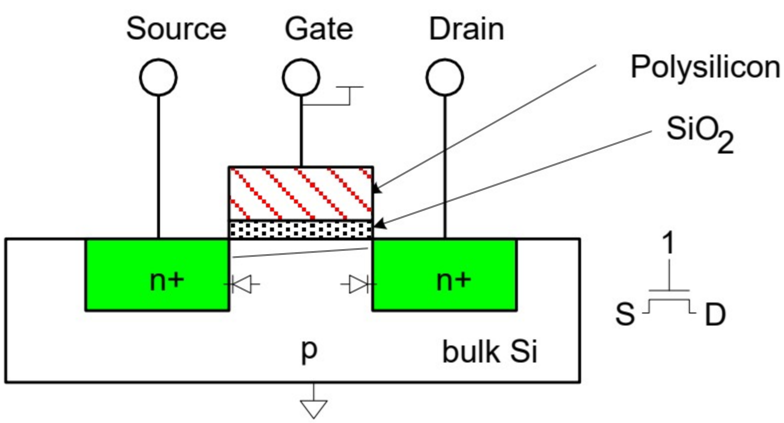
nMOS Operation

- Body is usually tied to ground (0 V)
- When the gate is at a low voltage:
  - P-type body is at low voltage
  - Source-body and drain-body diodes are OFF
  - No current flows, transistor is OFF



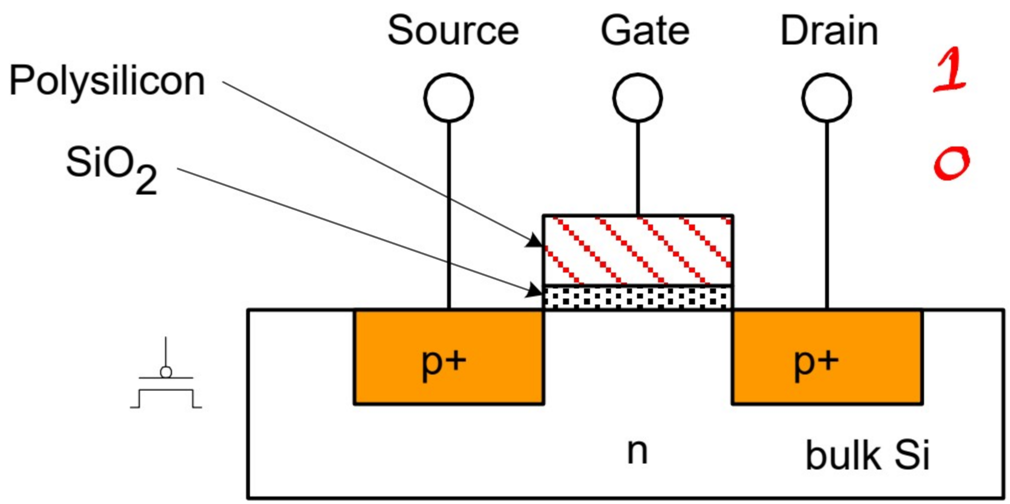
nMOS Operation Cont.

- When the gate is at a high voltage:
  - Positive charge on gate of MOS capacitor
  - Negative charge attracted to body
  - Inverts a channel under gate to n-type
  - Now current can flow through n-type silicon from source through channel to drain, transistor is ON



pMOS Transistor

- Similar, but doping and voltages reversed
  - Body tied to high voltage (V_{DD})
  - Gate low: transistor ON
  - Gate high: transistor OFF
  - Bubble indicates inverted behavior

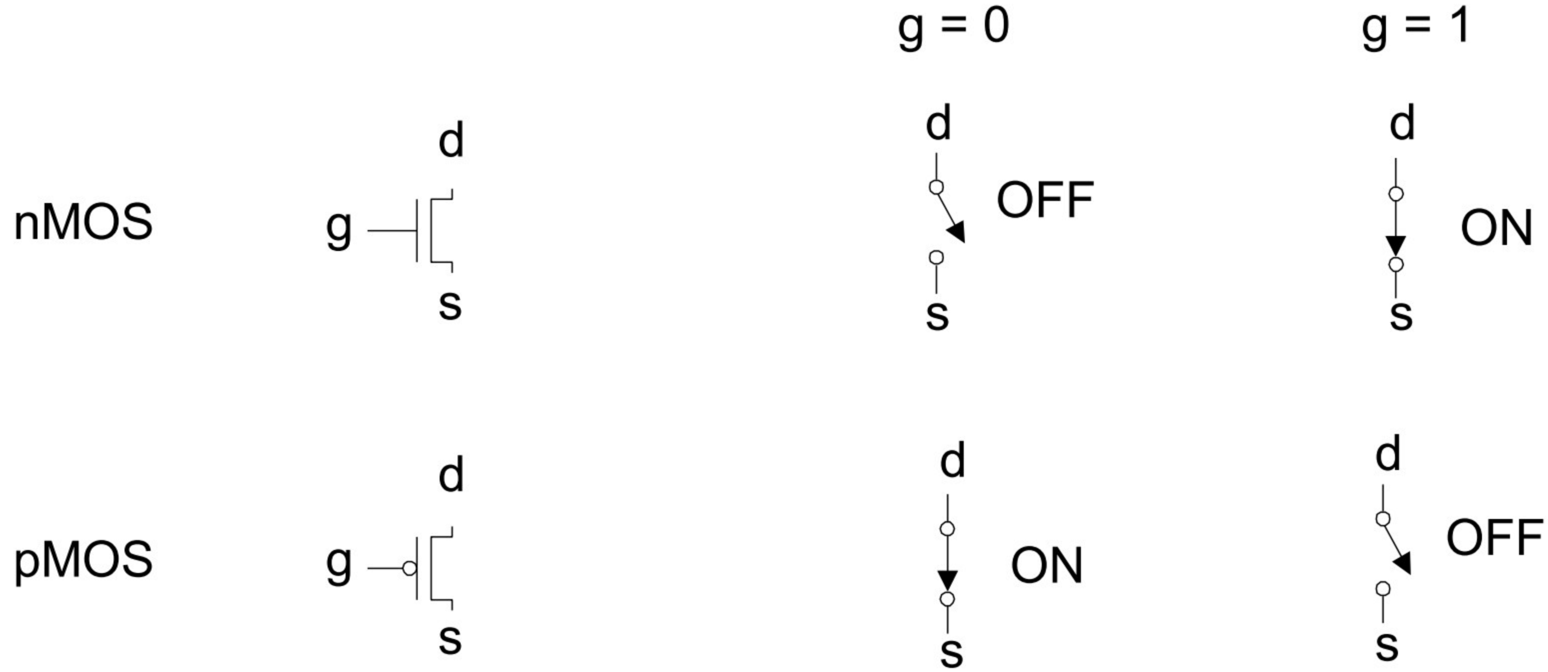


Power Supply Voltage

- GND = 0 V
- In 1980's, V_{DD} = 5V
- V_{DD} has decreased in modern processes
  - High V_{DD} would damage modern tiny transistors
  - Lower V_{DD} saves power
- V_{DD} = 3.3, 2.5, 1.8, 1.5, 1.2, 1.0, …

Transistors as Switches

- We can view MOS transistors as electrically controlled switches
- Voltage at gate controls path from source to drain



CMOS Inverter

A	Y
0	1
1	0