DEPARTMENT OF COMPUTER SYSTEM ENGINEERING

Digital Integrated Circuits - ENCS333

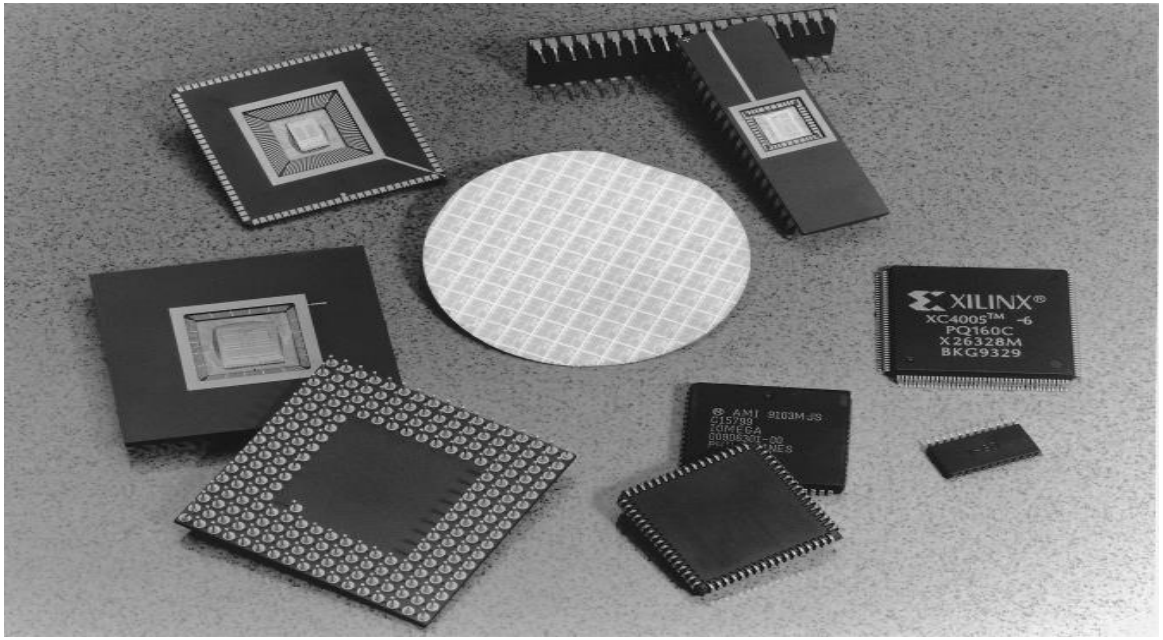
Dr. Khader Mohammad

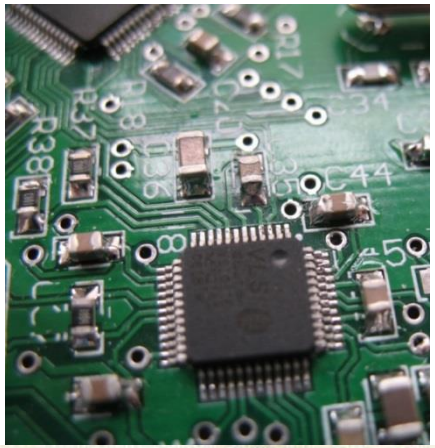
Lecture #1_part2

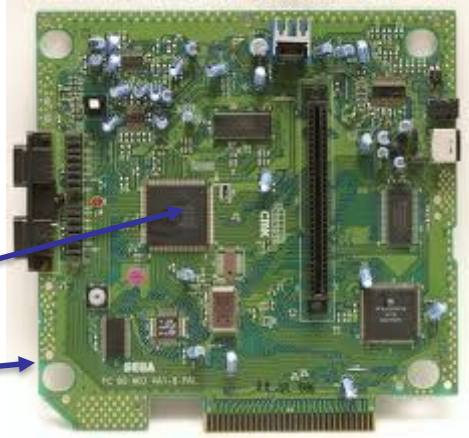
Introduction

Integrated-Circuit Devices and Modeling

PCB, SOC , Chip , Packages, Wafer







Chip

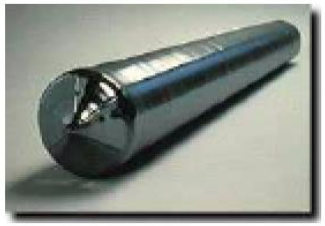
Printed circuit board (PCB)

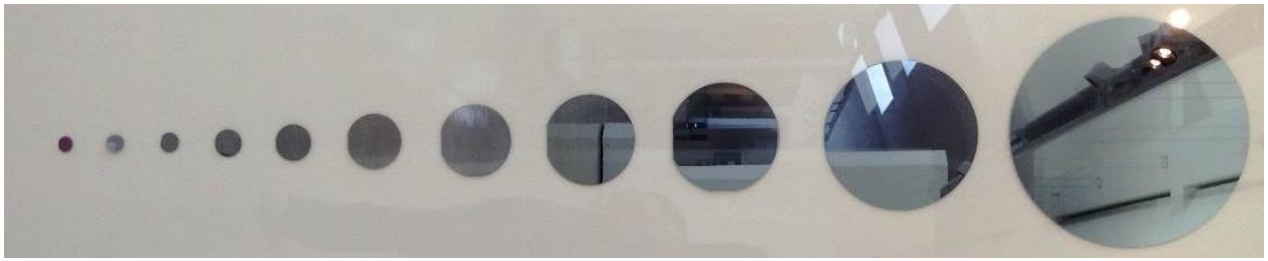
Scaling

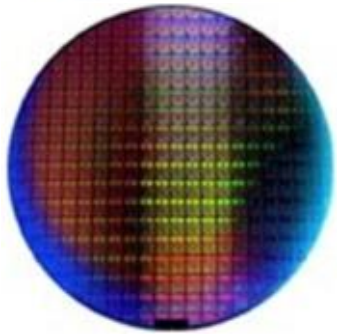
- Technology shrinks by 0.7/generation
- With every generation can integrate 2x more
- functions per chip; chip cost does not increase significantly
- Cost of a function decreases by 2x
- How to design chips with more and more functions?
- Design engineering population does not double every two years…
- Need to understand different levels of abstraction

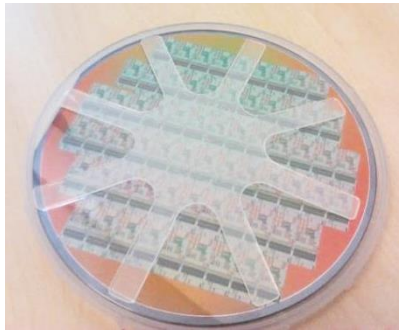
Wafer and Die (2)

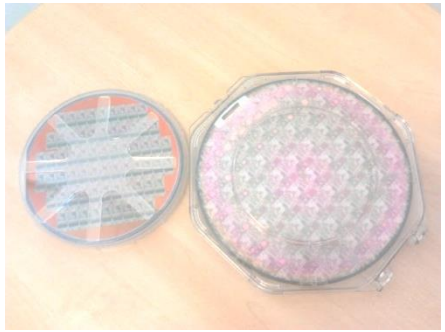
- Thickness 275um – 925um
- Diameter up to 450mm
- Wafer is cut from metal-cast of single crystal silicon.











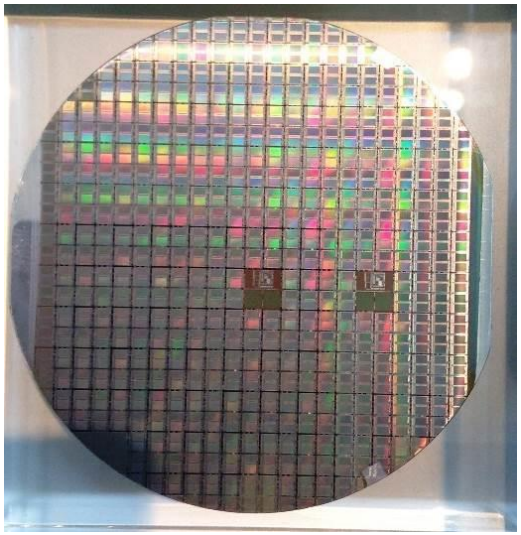
https://www.youtube.com/watch?v=qm67wbB5GmI
https://www.youtube.com/watch?v=aWVywhzuHnQ
https://www.youtube.com/watch?v=Q5paWn7bFg4&t=4s

Producing a Wafer

Watch : Sand to silicon

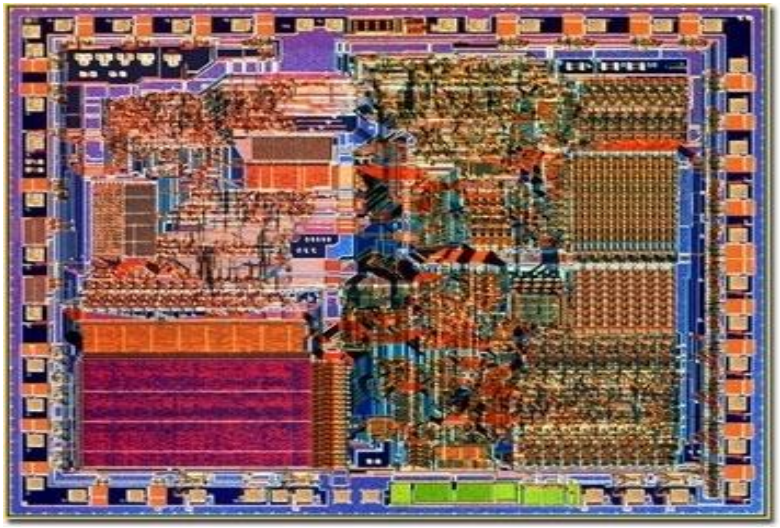



Producing a Wafer (2)

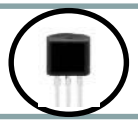
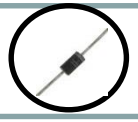
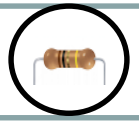


IC Definition

- Integrated circuits (IC) is a complex set of electronic components and their interconnections etched on a chip.



Basic Elements of Electronic Circuits

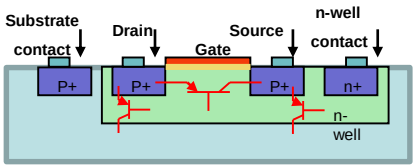
Transistor – is the switch		
Diode – is the rectifier		
Resistor - slows down electricity		
Capacitor - stores electricity		
Inductor - determines the magnitude of the electromagnetic force		
Connecting them with interconnects, an IC is obtained.		

*The elements, being prepared by discrete technology, are shown.

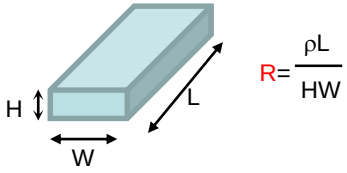
Types of IC Elements

Useful

Parasitic

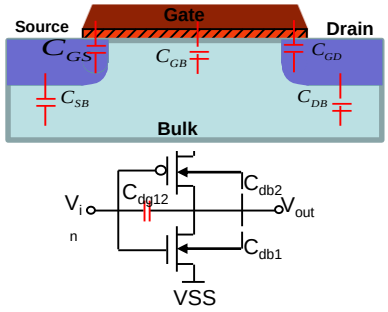


Bipolar Transistors

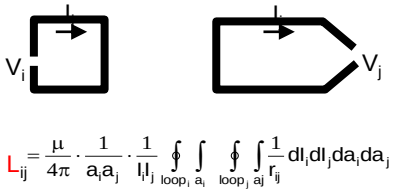


$$R = \frac{\rho L}{HW}$$

Resistances



Capacitances

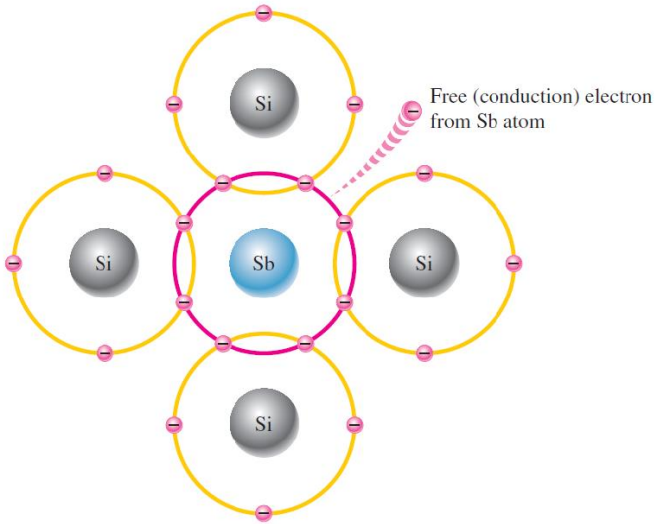


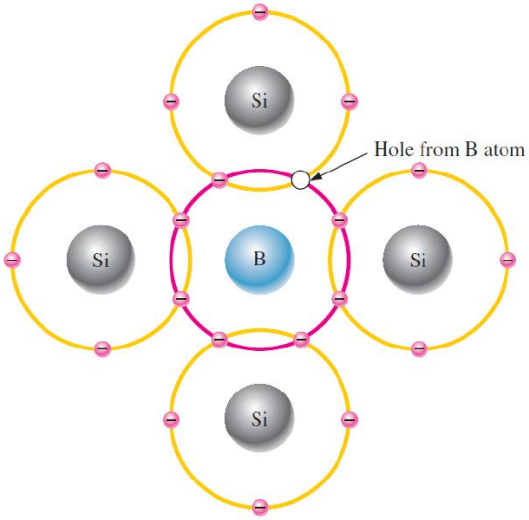
Inductances

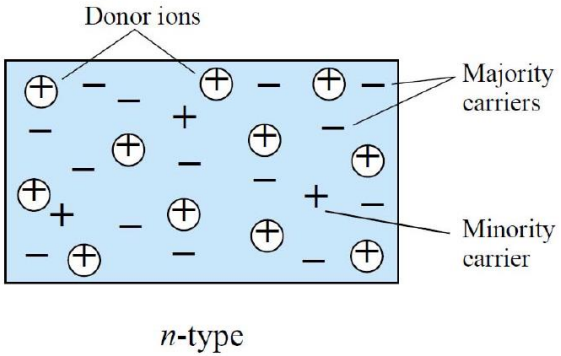
Semiconductor

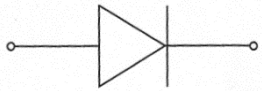
N - type semiconductor

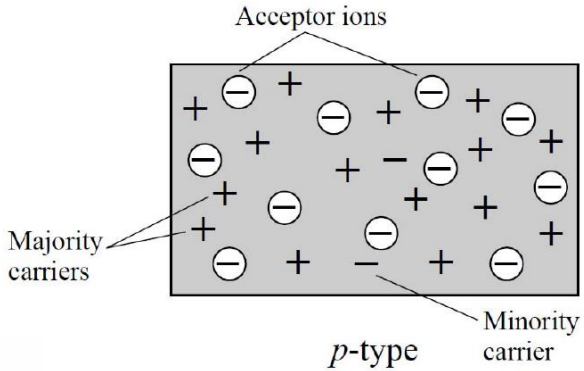
P - type semiconductor

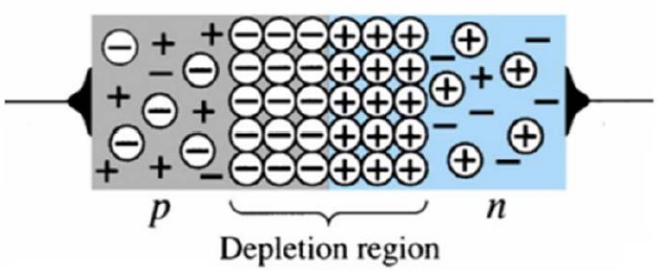








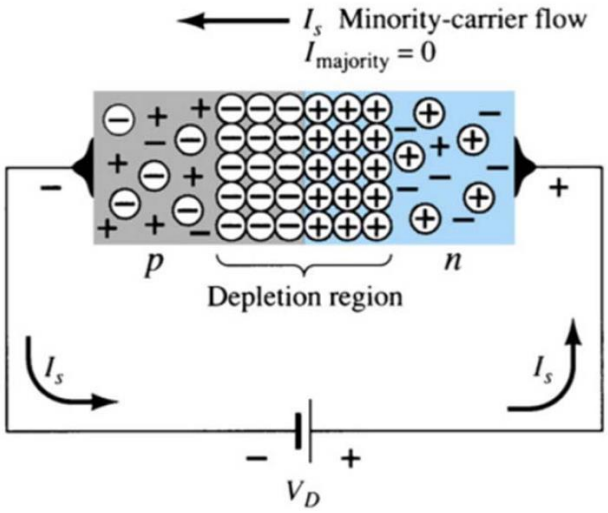




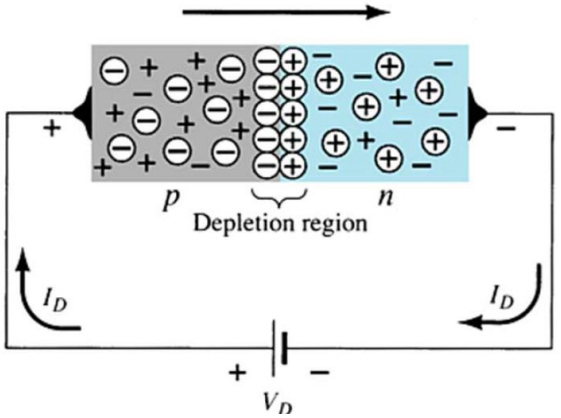
- The p-n junction is the basis for diodes, certain transistors ,and other devices.

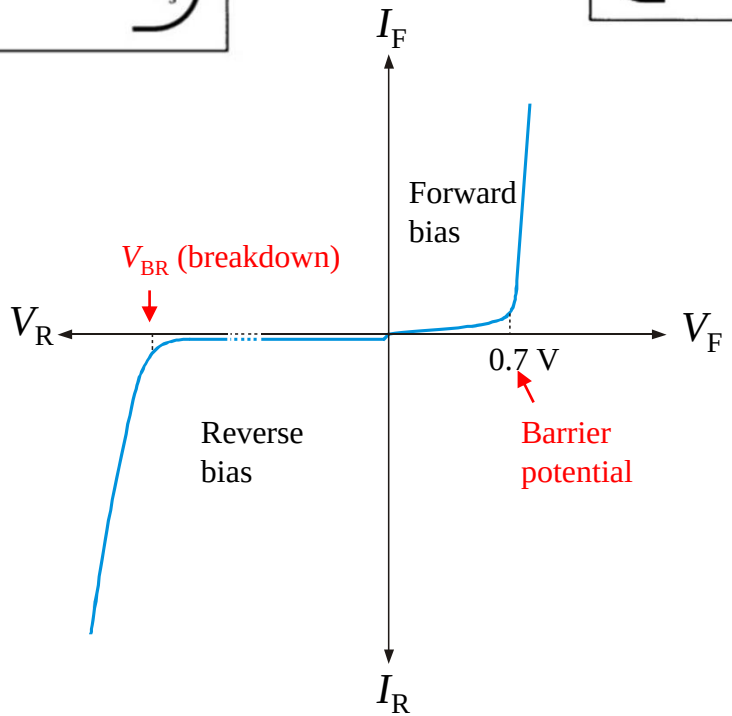
Semiconductor- Diods

Reverse bias of a pn junction



Forward bias of a pn junction



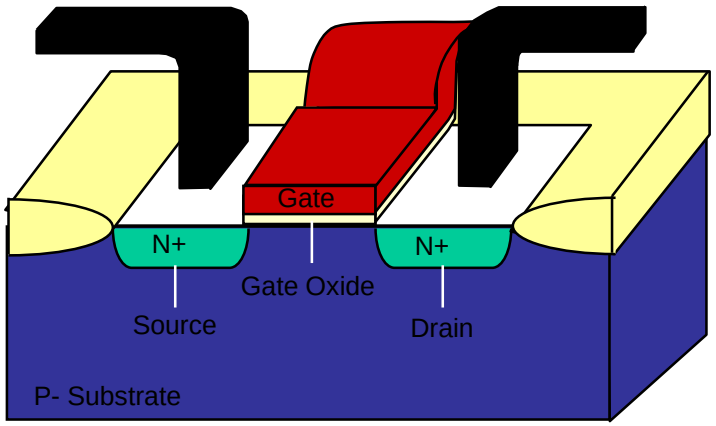


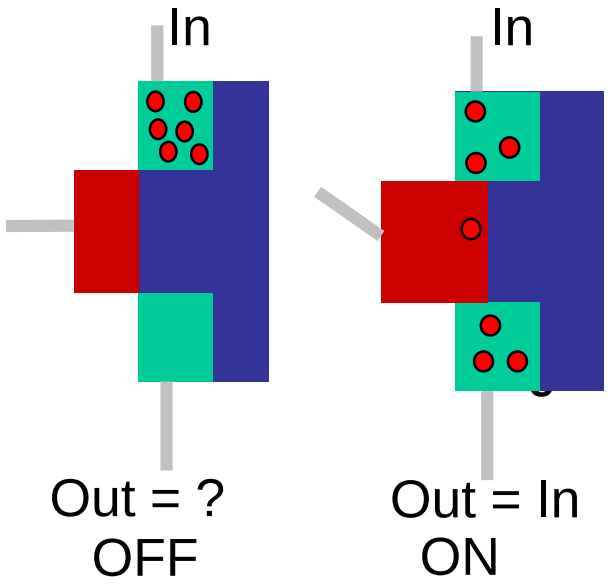
What are P-type and N-type ?

- Semiconductors are classified in to P-type and N-type semiconductor
- P-type: A P-type material is one in which holes are majority carriers i.e. they are positively charged materials (++++)
- N-type: A N-type material is one in which electrons are majority charge carriers i.e. they are negatively charged materials (-----)

Basic Element of IC

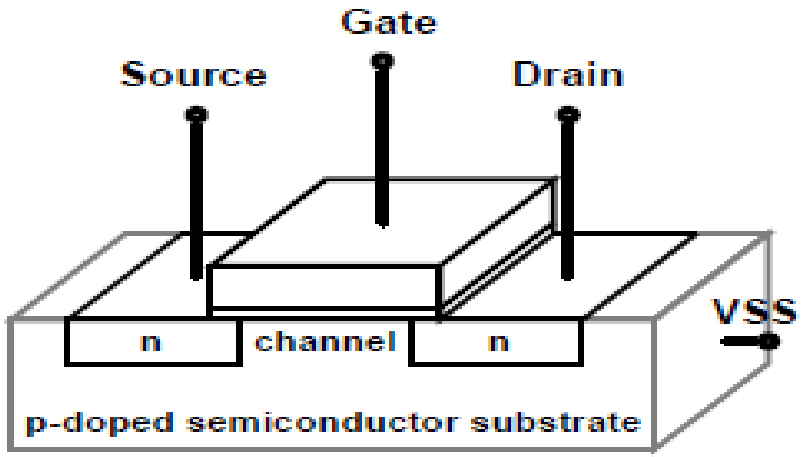
- CMOS Transistor is a switch



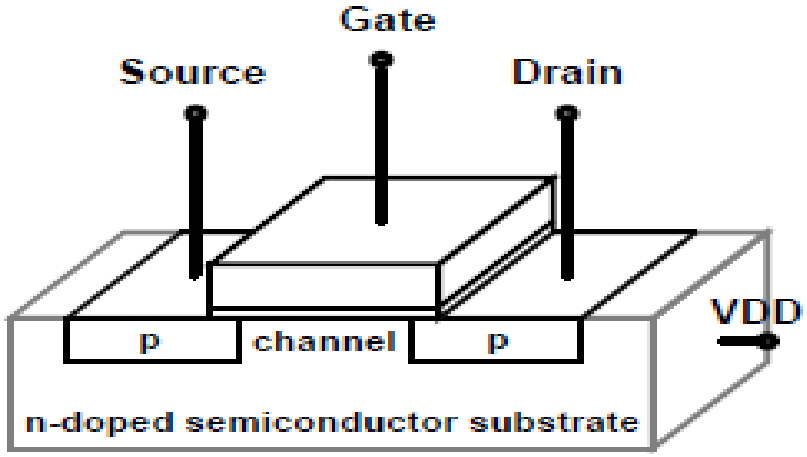


How Is It Done? (devices)

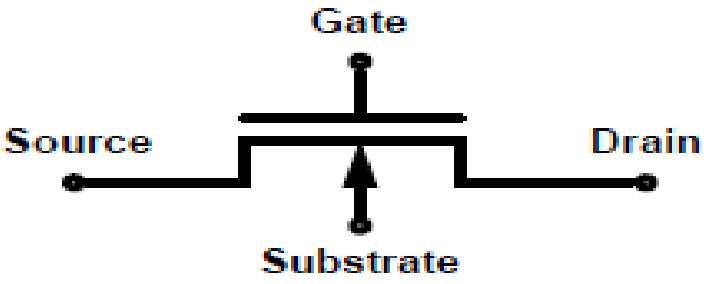
MOS Transistors:

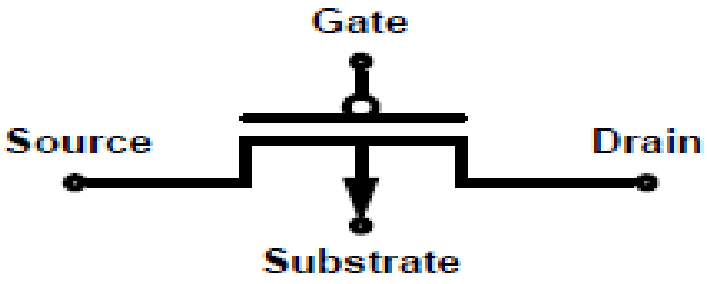


NMOS



PMOS

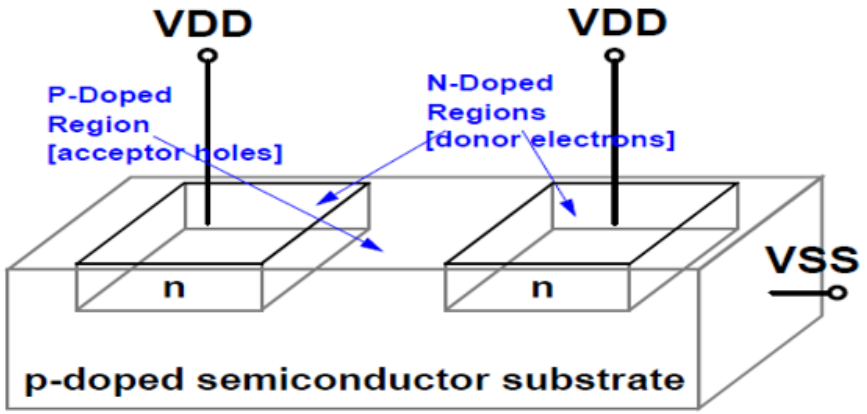


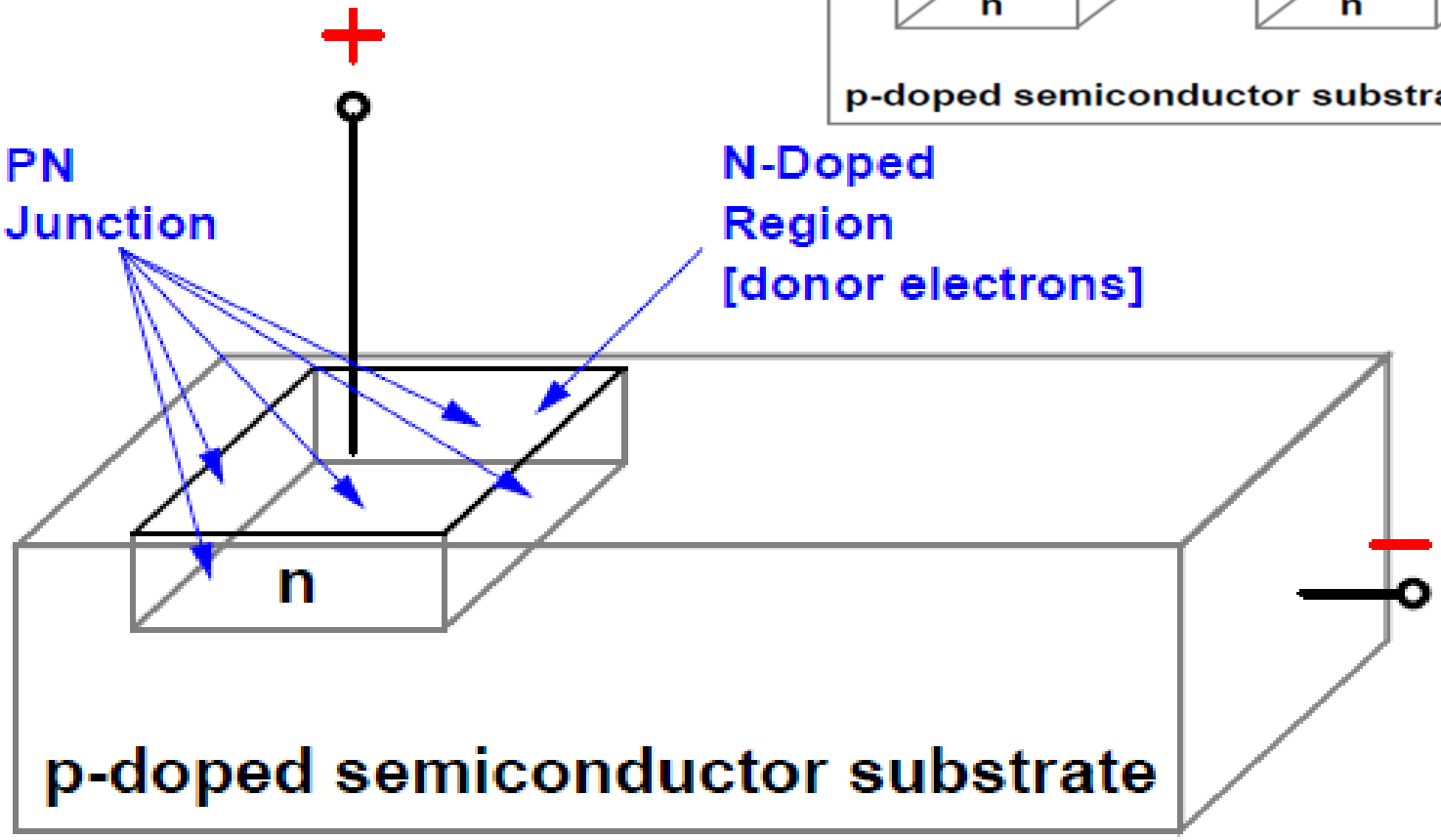


What's a "C" MOS?

How Is It Done? (devices)

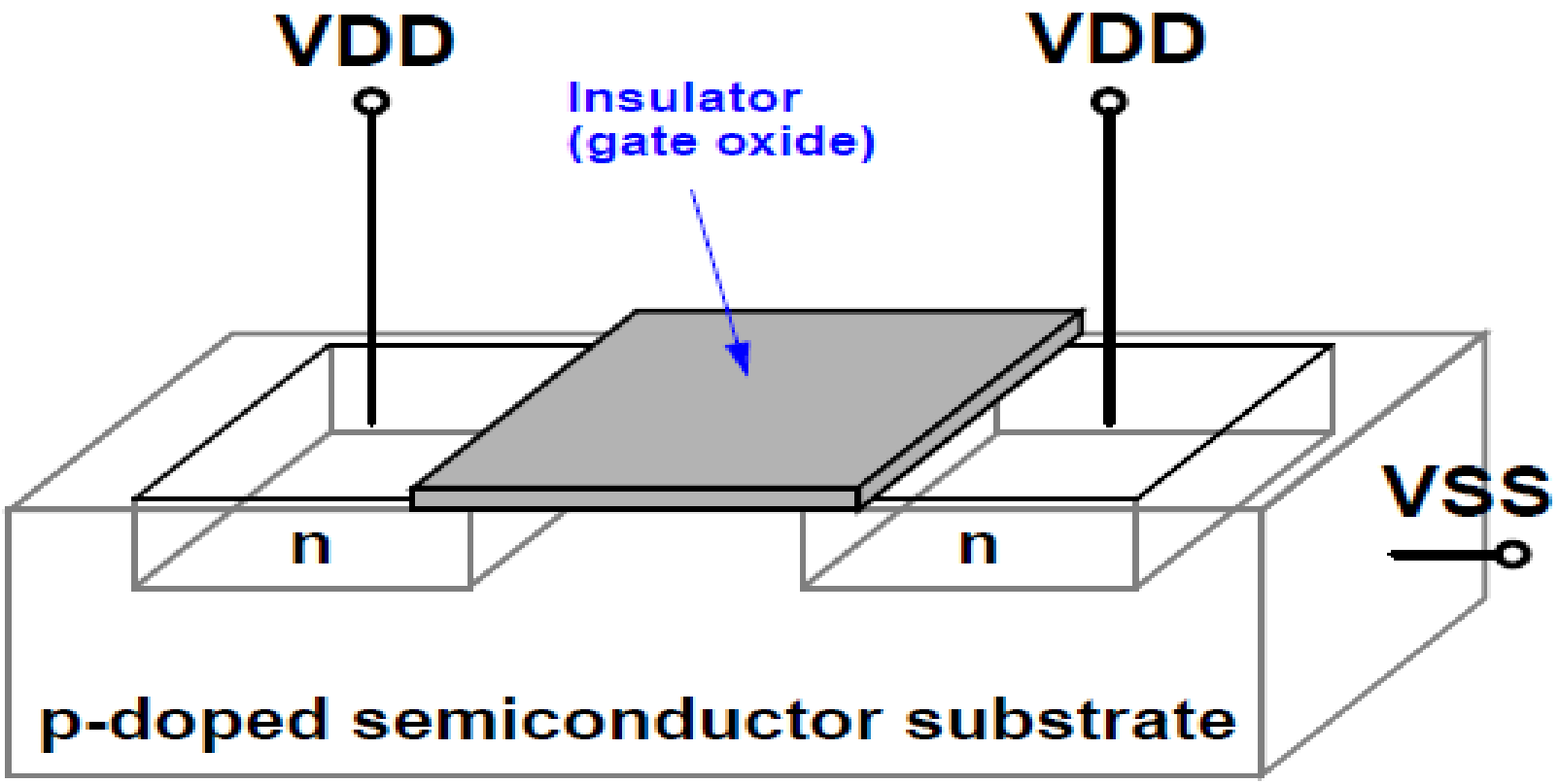
MOS Transistor:





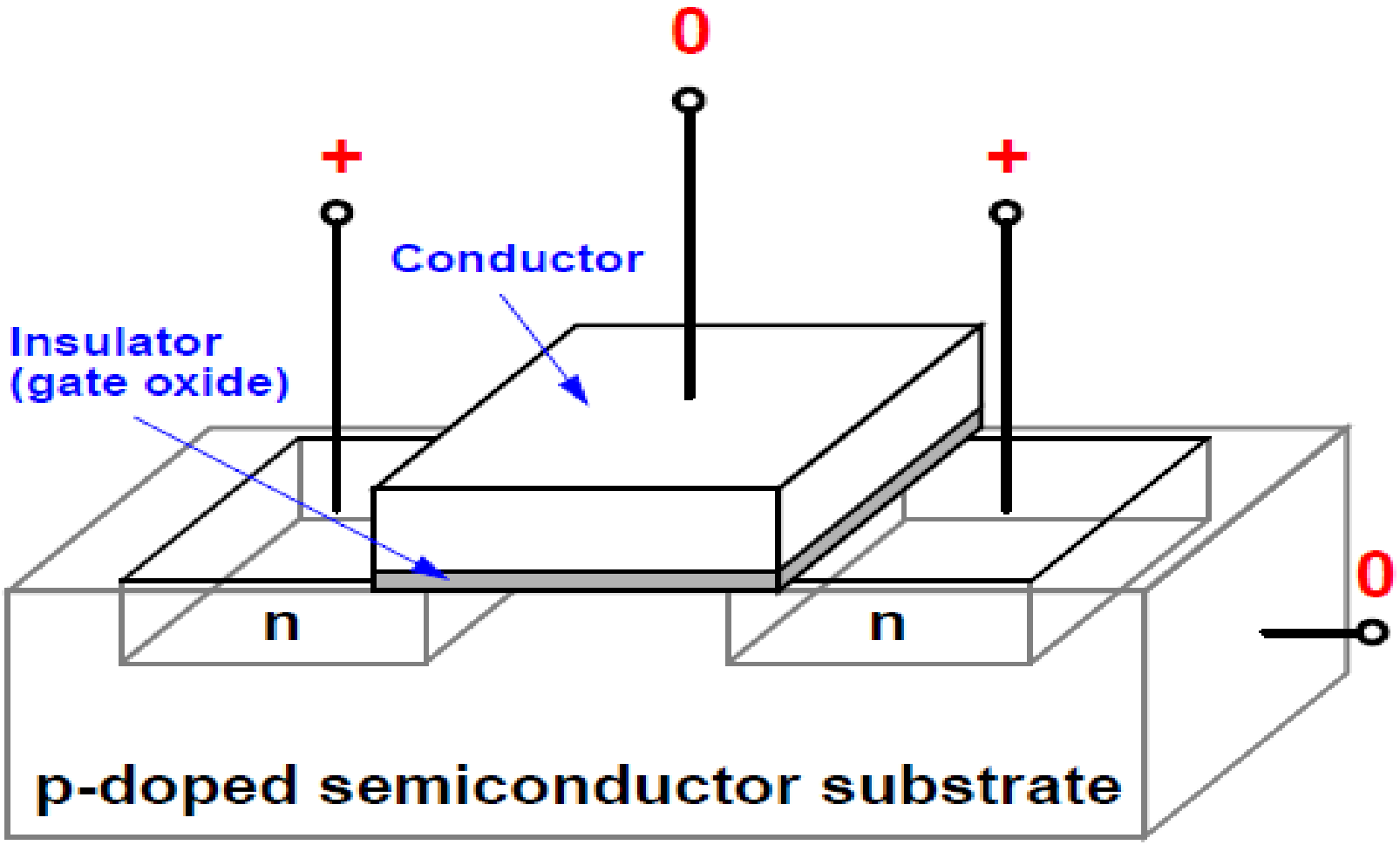
How Is It Done? (devices)

MOS Transistor:



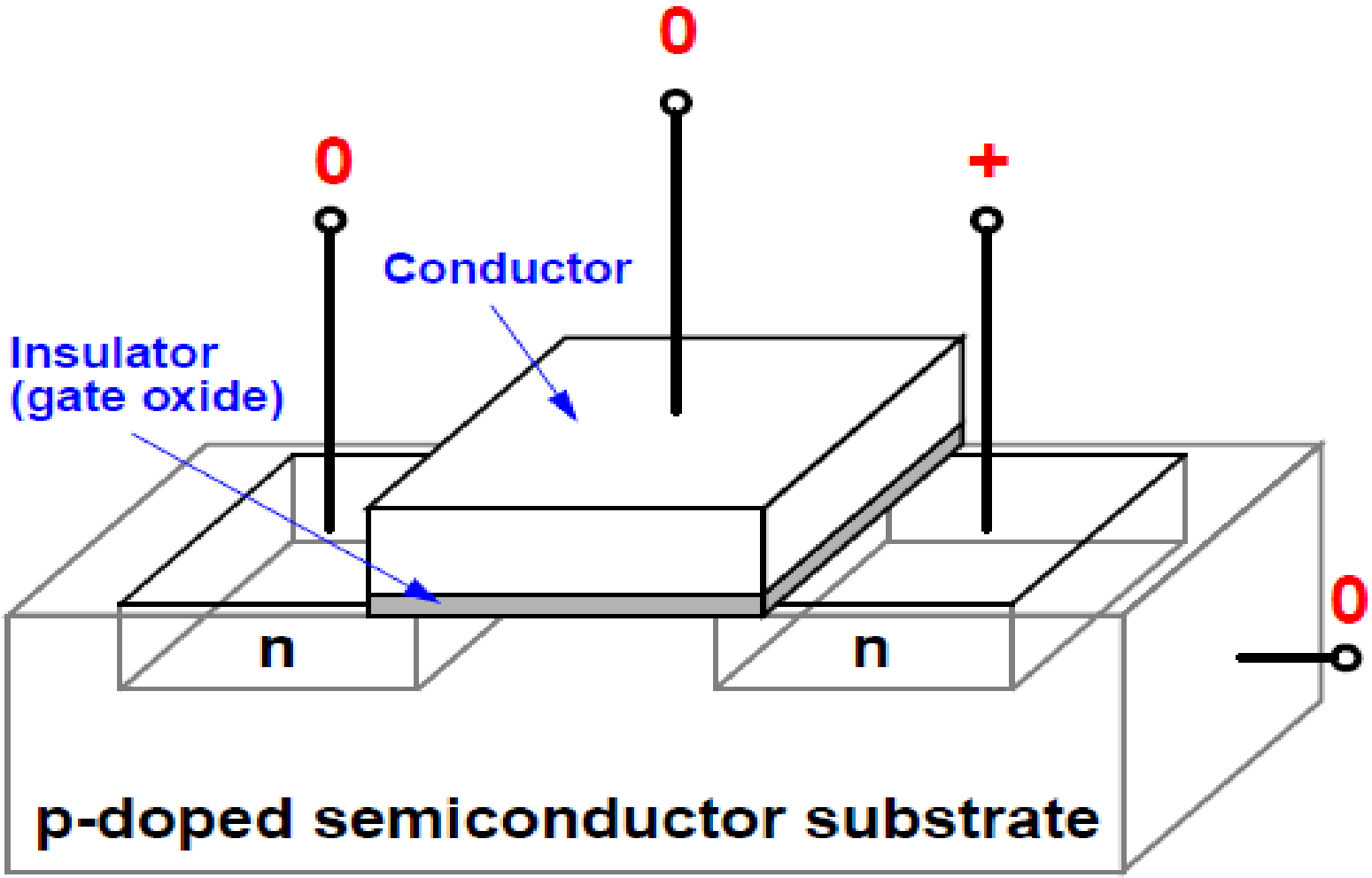
How Is It Done? (devices)

NMOS Transistor with gate:



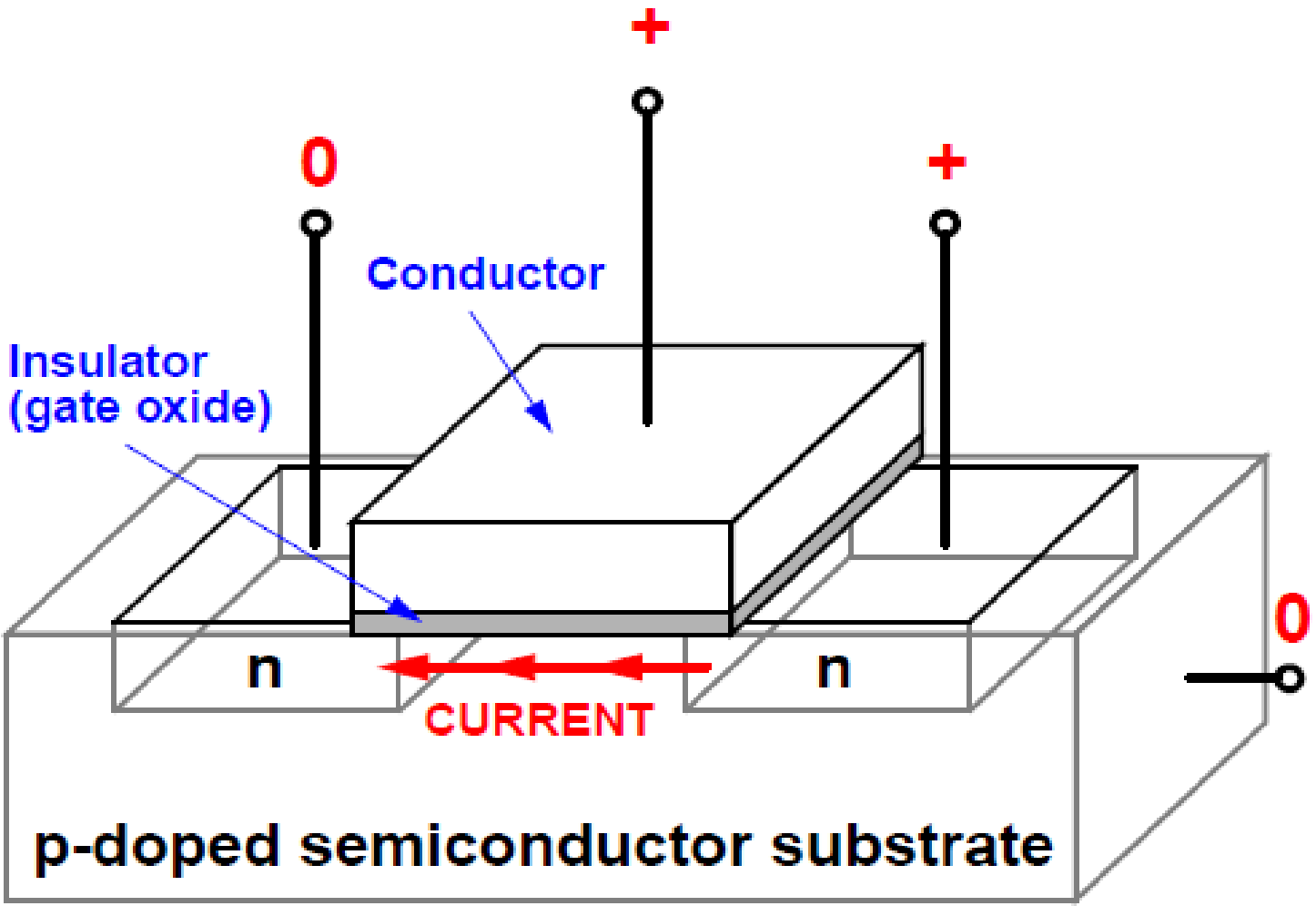
How Is It Done? (devices)

NMOS Transistor with bias voltages:



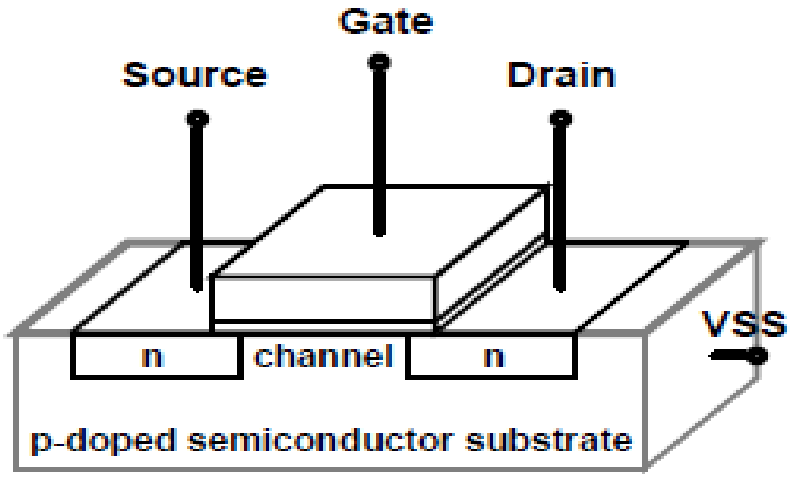
How Is It Done? (devices)

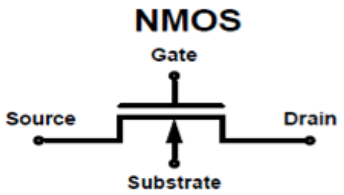
NMOS Transistor with bias voltages:

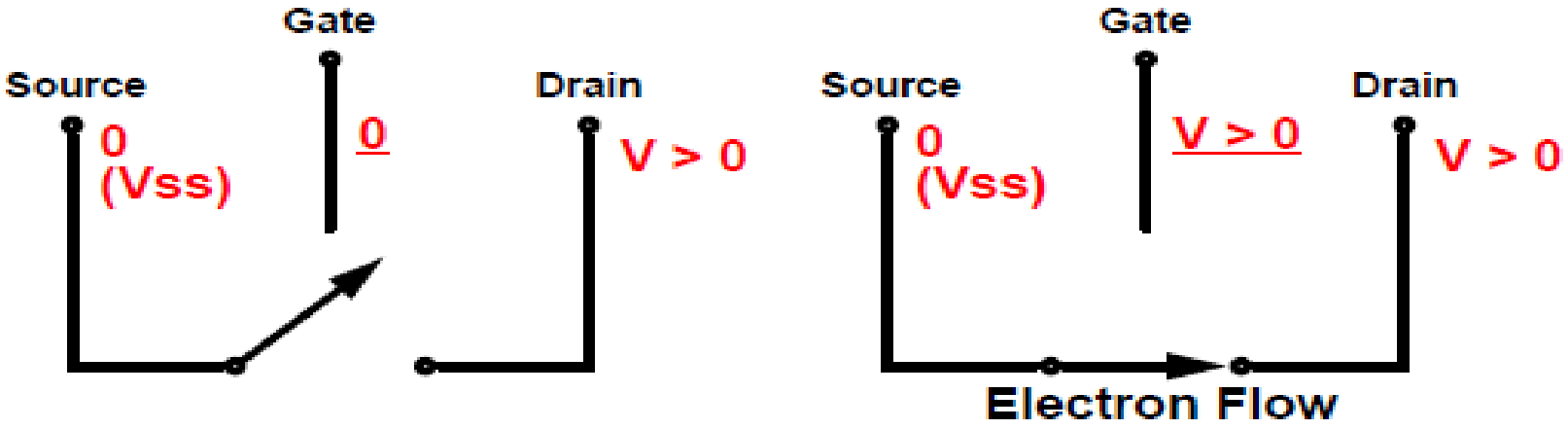


How Is It Done? (devices)

NMOS Transistor with bias voltages:

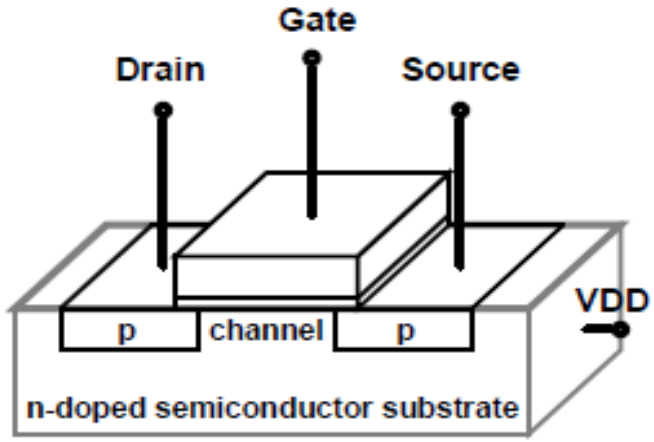


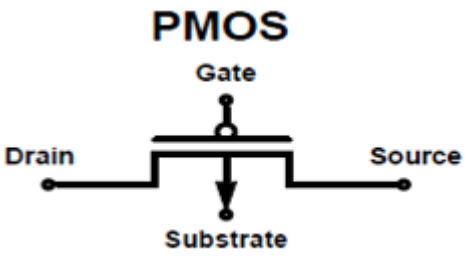


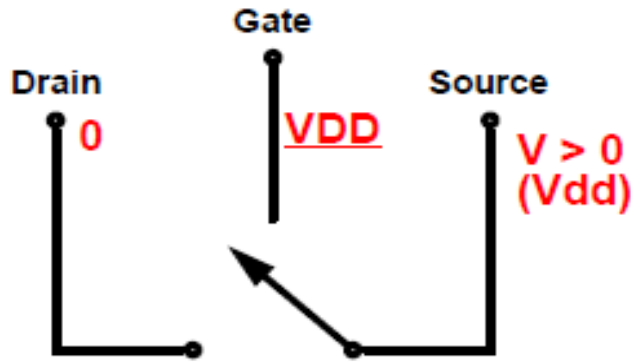


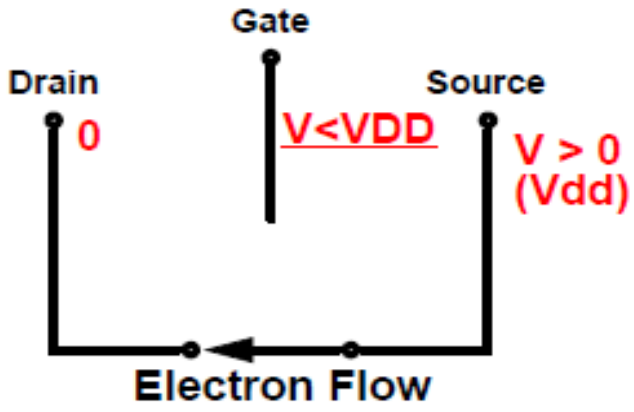
How Is It Done? (devices)

PMOS Transistor with bias voltages:



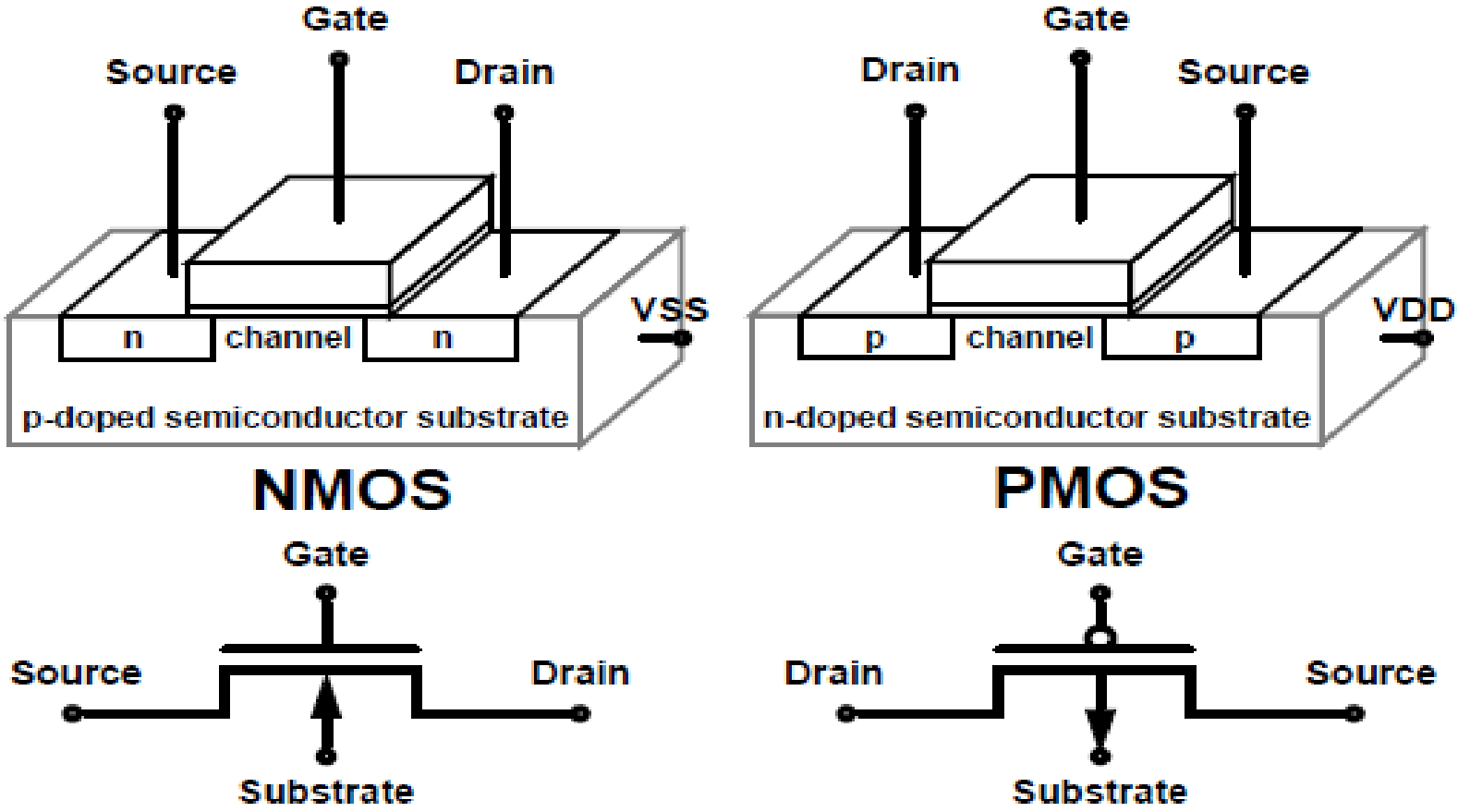






How Is It Done? (devices)

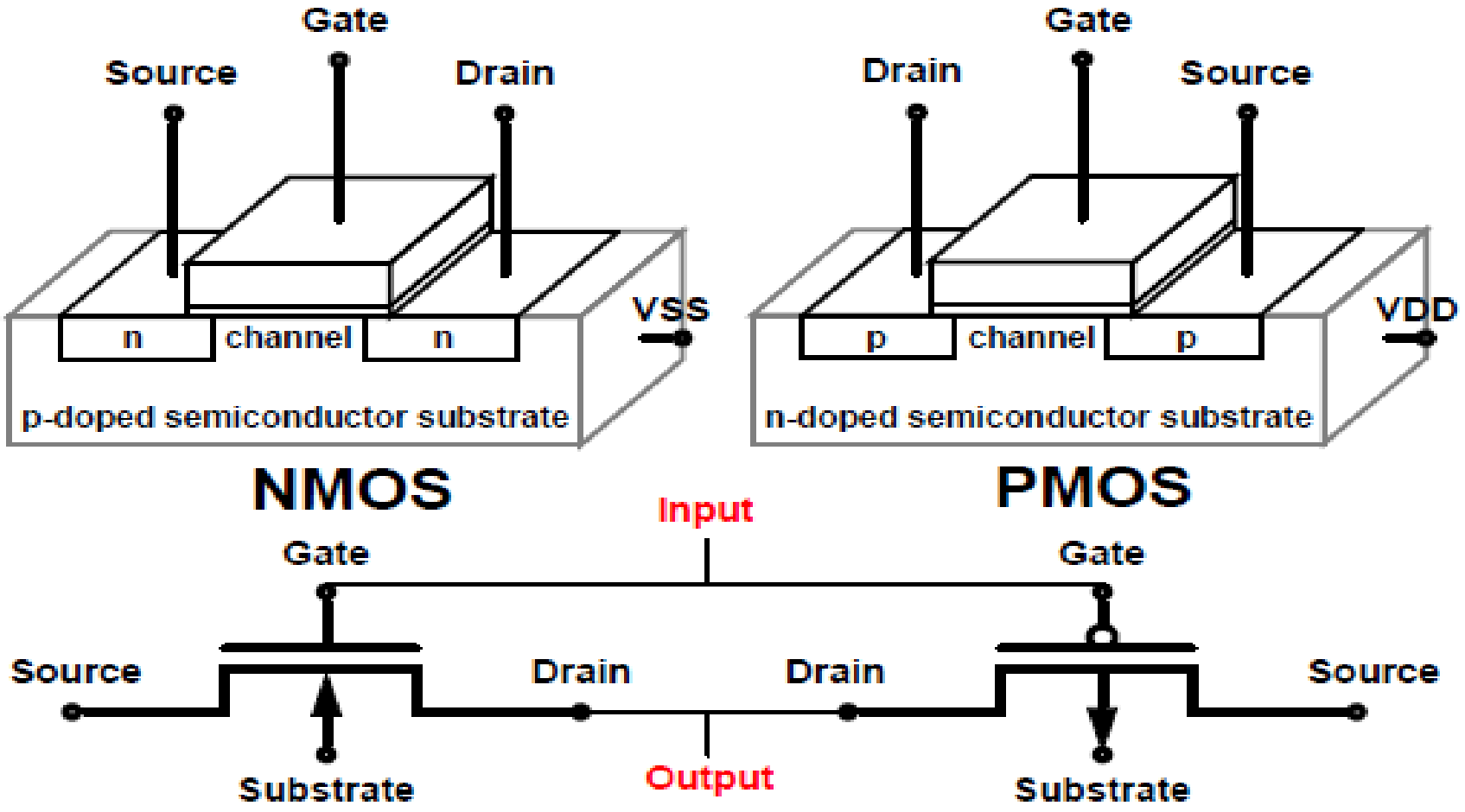
MOS Transistors:



CMOS Inverter = one of each

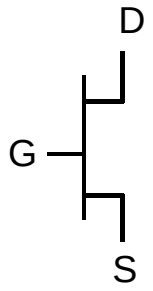
How Is It Done? (devices)

MOS Transistors:

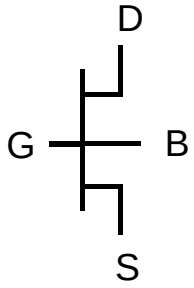


CMOS Inverter = one of each

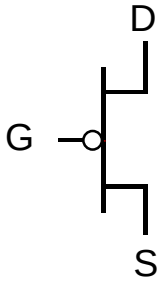
CMOS Transistor - Types and Symbols



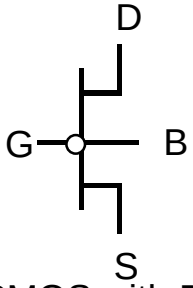
NMOS Enhancement



NMOS with Bulk Contact

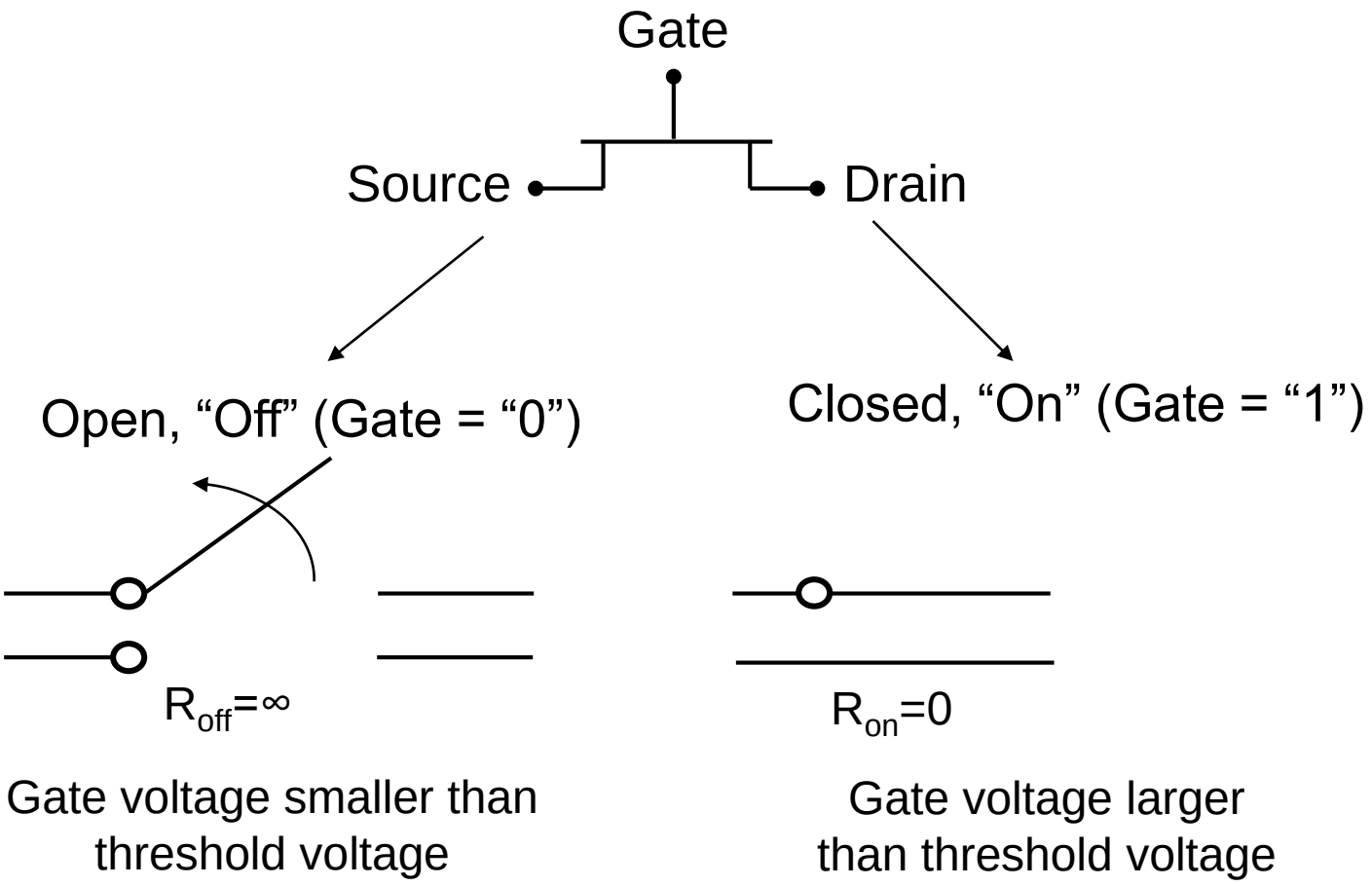


PMOS Enhancement



PMOS with Bulk Contact

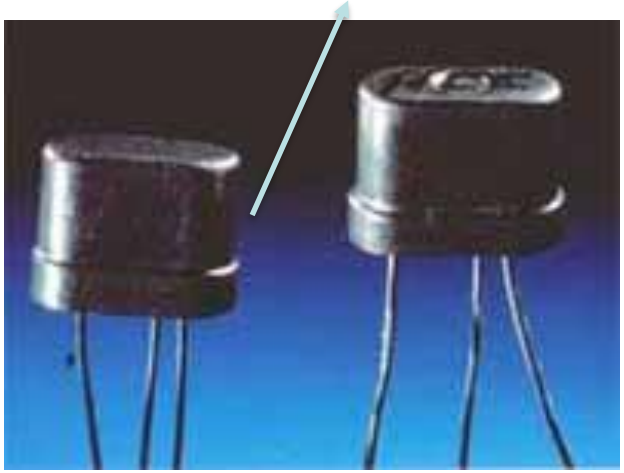
Switch Model of NMOS Transistor



Sizes of IC Components

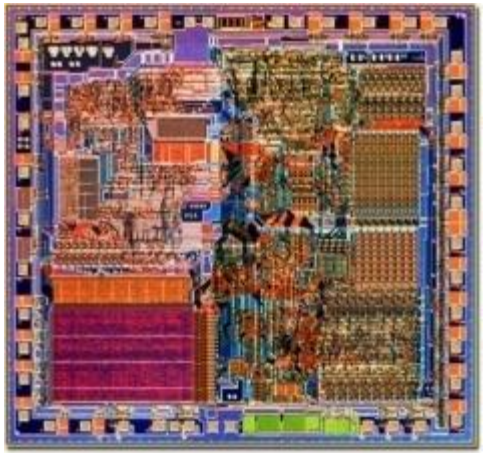
- IC components and interconnects have very small sizes
  - For micron technology, a million or more switches on a single chip are obtained.
  - For contemporary technologies, up to a dozen of billions switches on a single chip are obtained.

Transistor

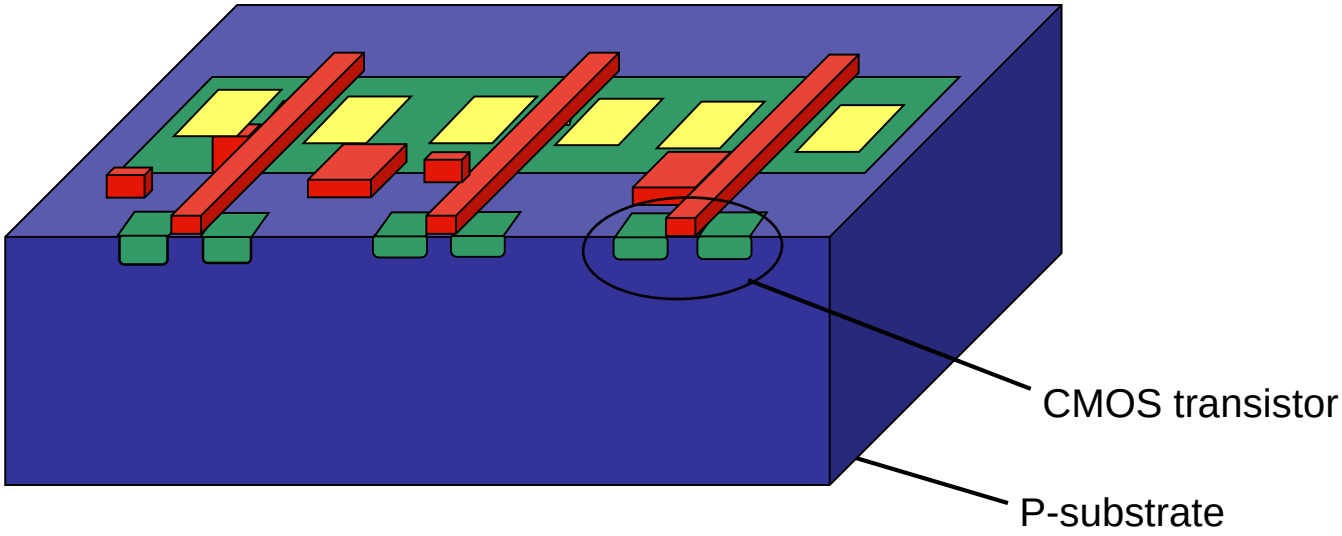


150000 transistors

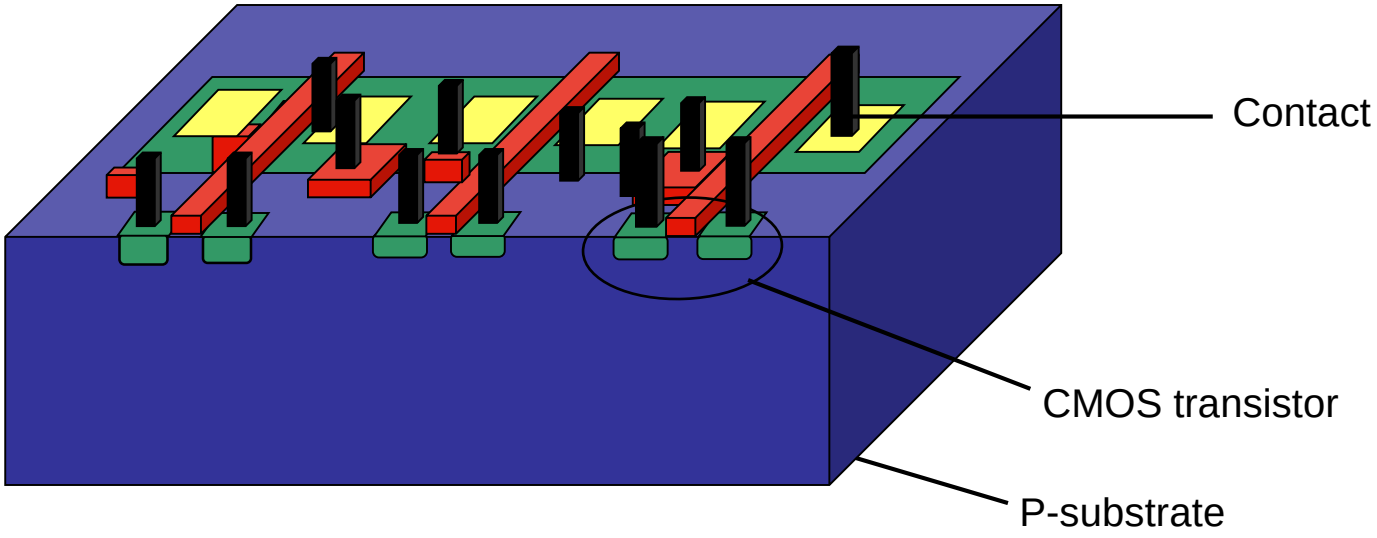
Dozen of billions transistors



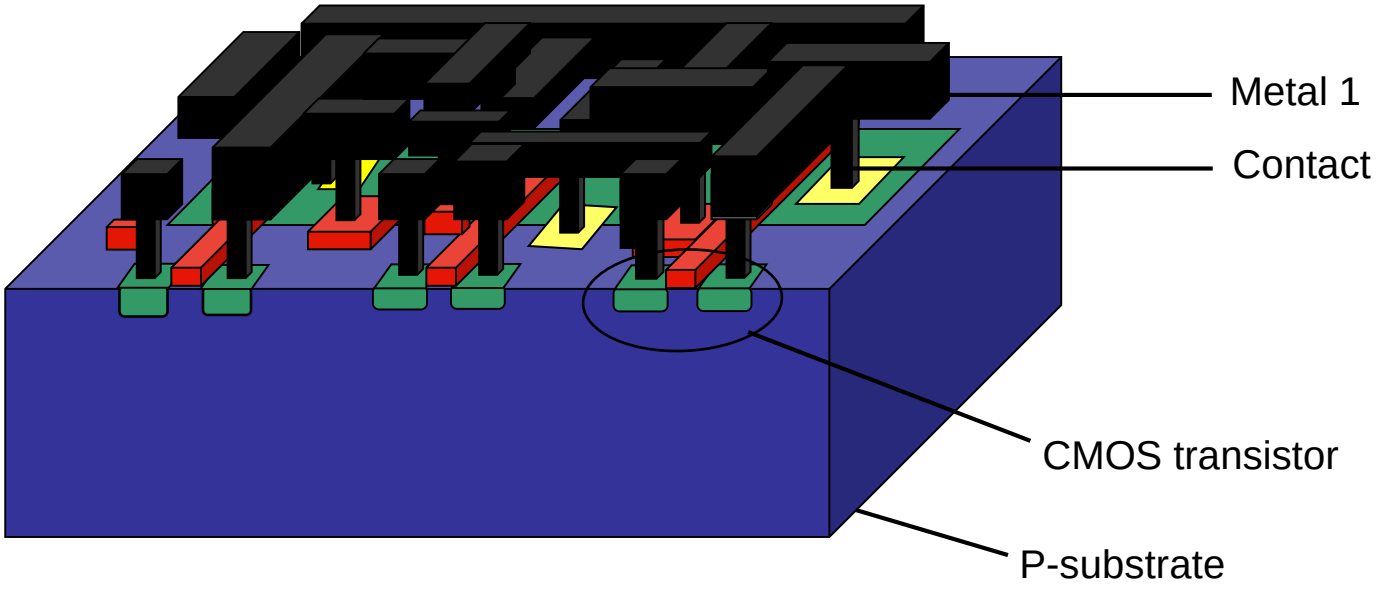
IC as a Multi Layer Structure



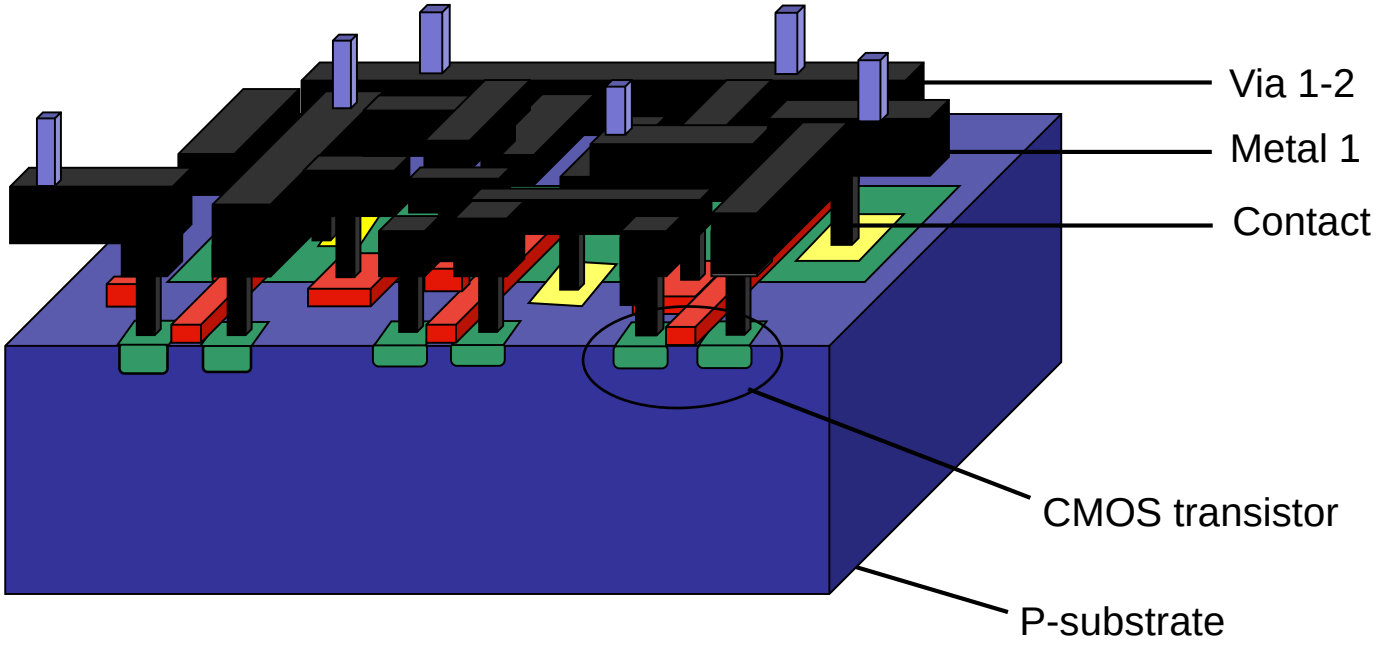
IC as a Multi Layer Structure (2)



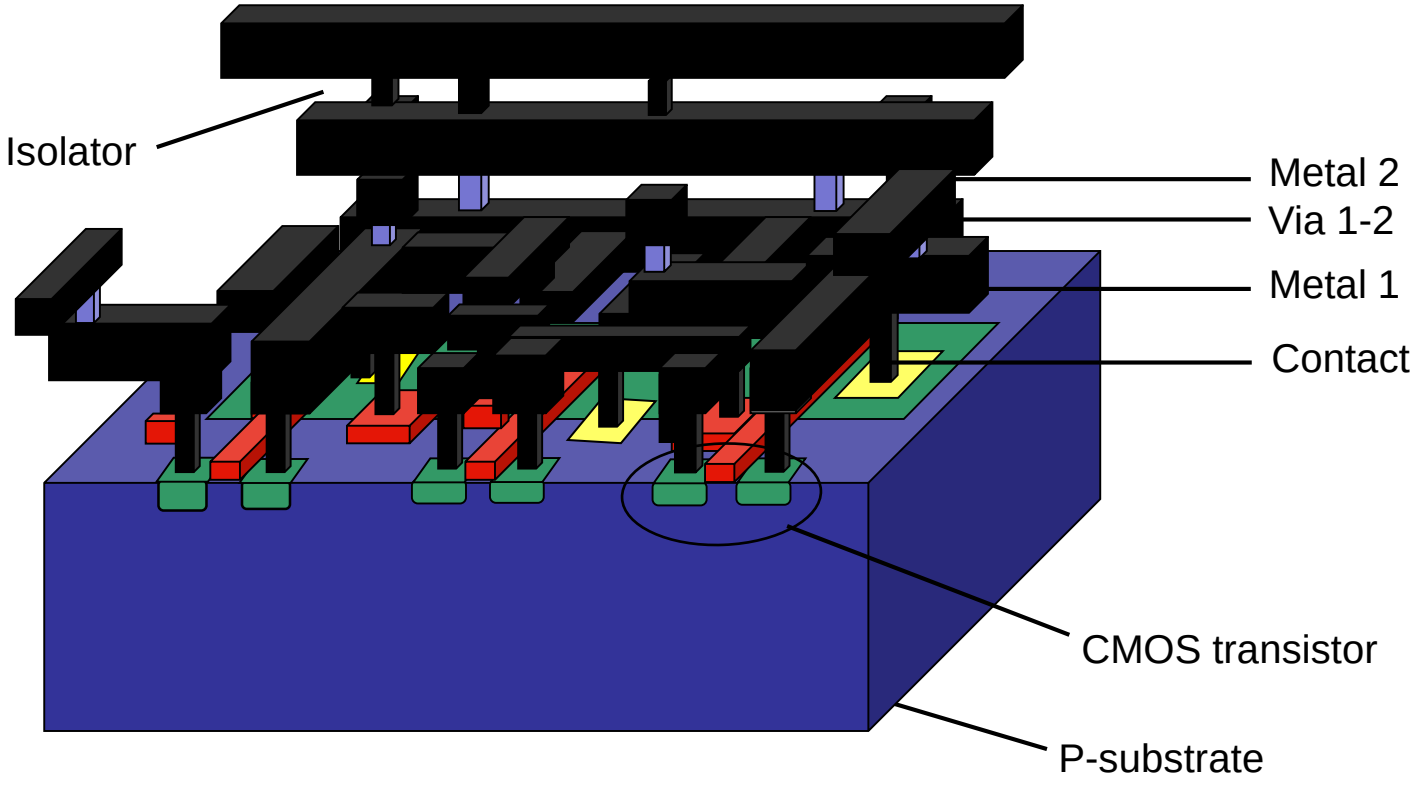
IC as a Multi Layer Structure (3)



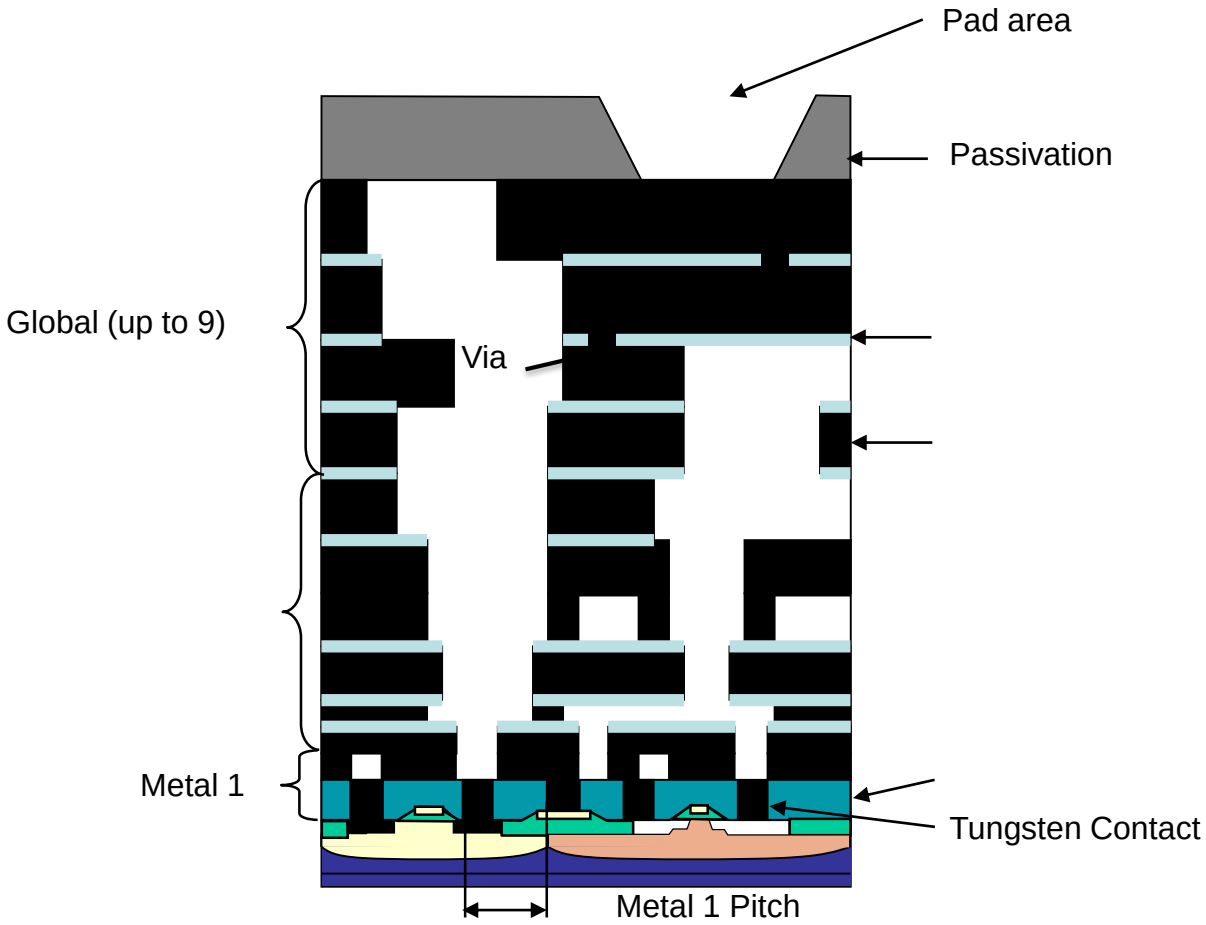
IC as a Multi Layer Structure (4)



IC as a Multi Layer Structure (5)

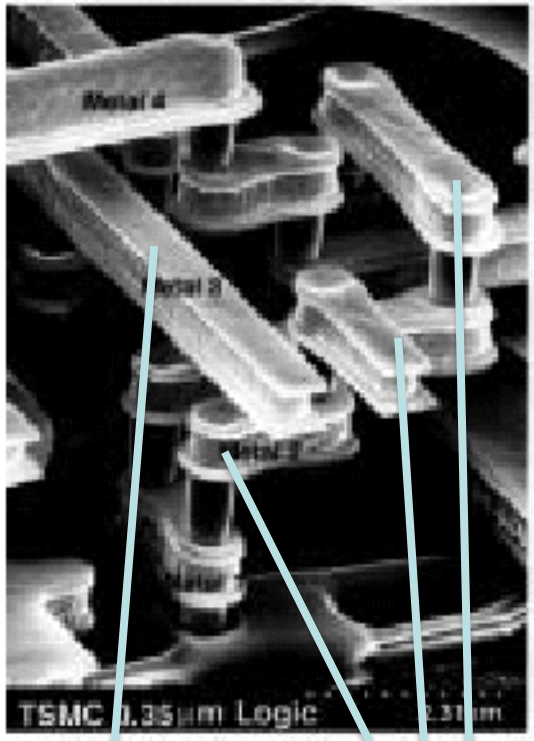


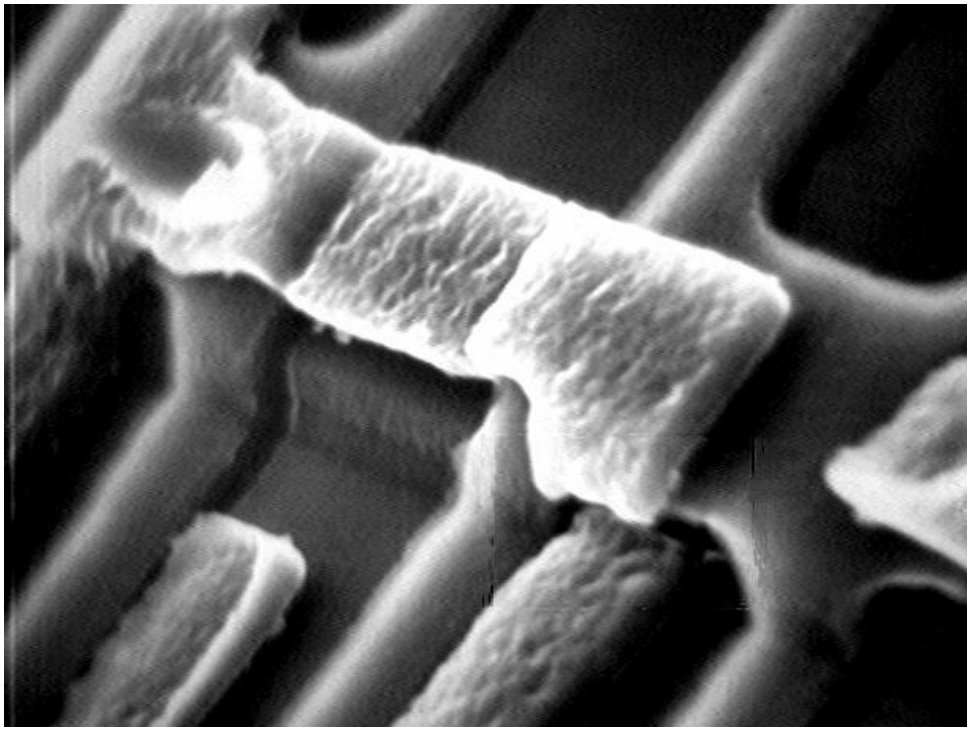
IC as a Multi Layer Structure (6)



IC as a Multi Layer Structure (7)

Under the microscope

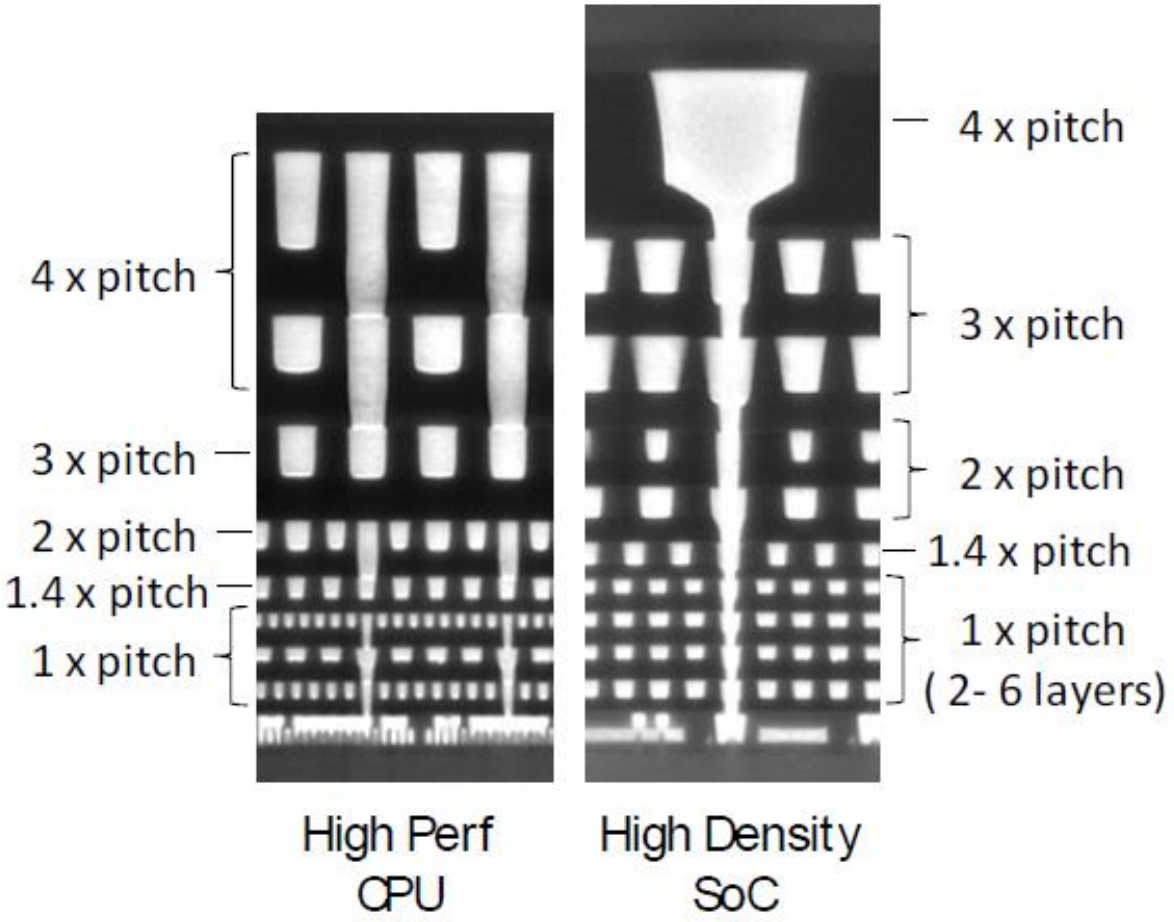




Interconnect Via Interconnects have roughness and are not smooth

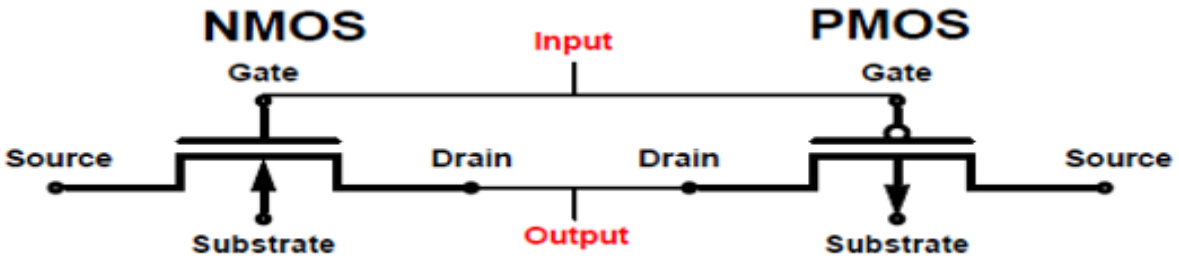
IC as a Multi Layer Structure (8)

- Intel 22nm trigate SoC process
- up to 12 metal layers,
  - up to six 1×layers
  - extra 3× level
  - only one 4× level
- 6µm thick top metal

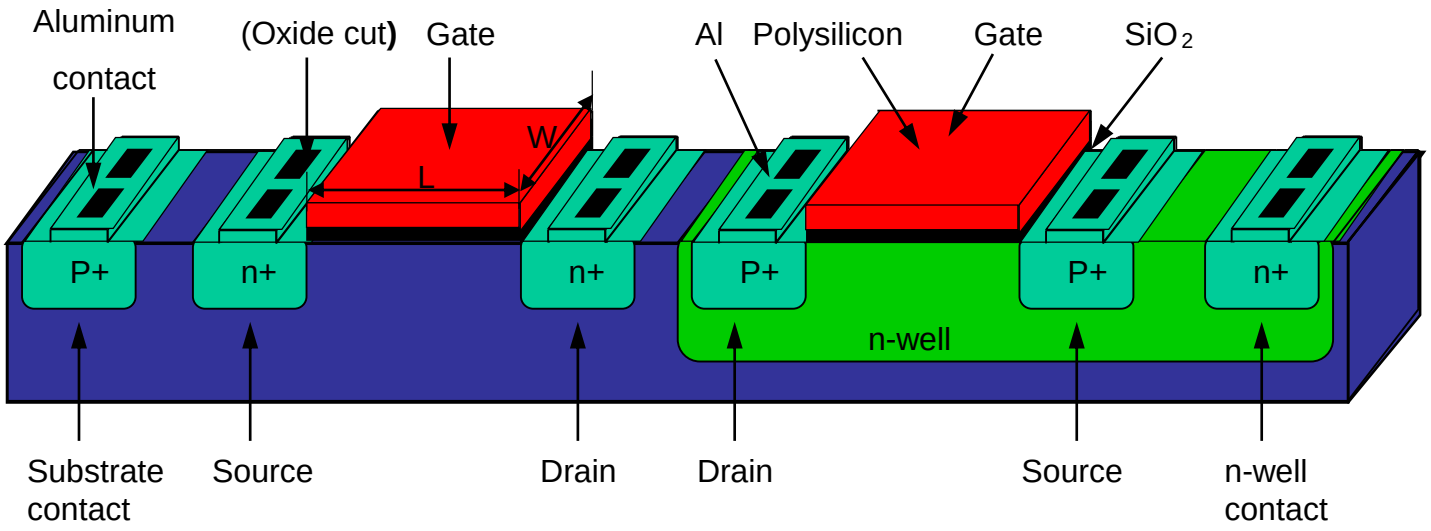


Source: chipworks.com, “Intel details 22nm trigate SoC process at IEDM”

NMOS and PMOS Transistor Structures

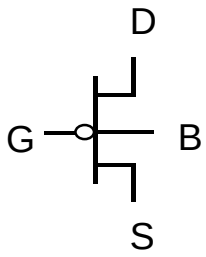


S S

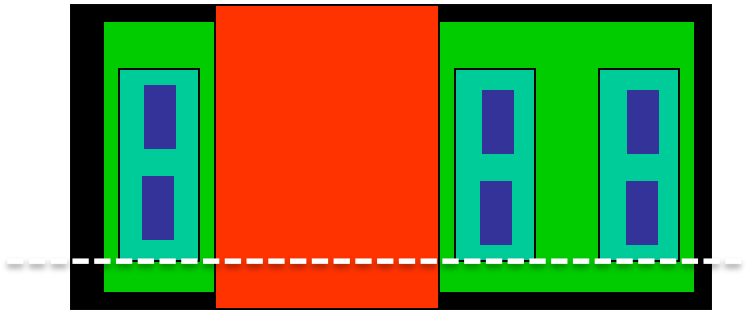


Concepts of the Circuit and Layout

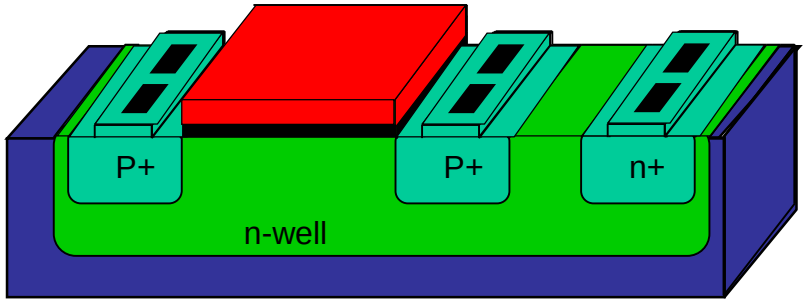
Circuit



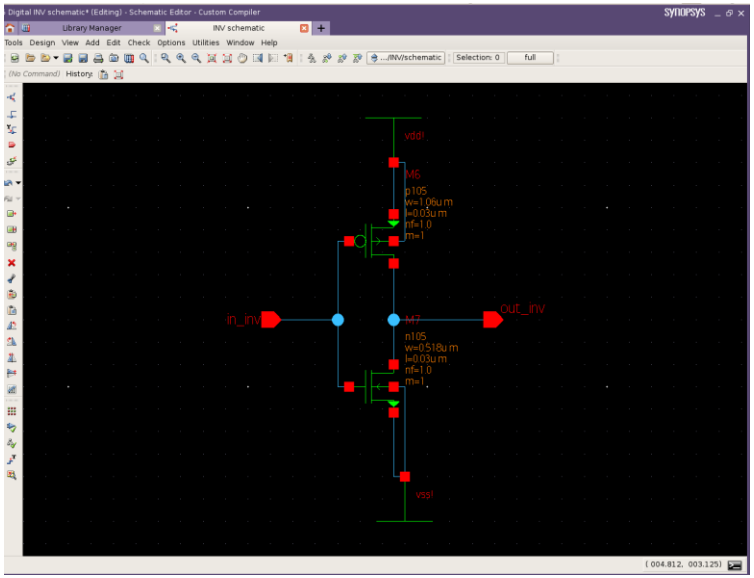
Layout



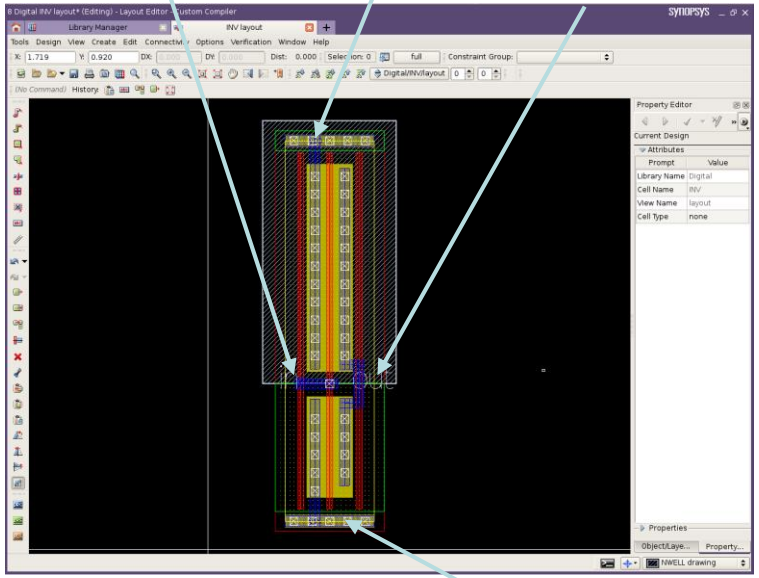
Resulting structure in manufactured IC



Circuit and Layout Editors

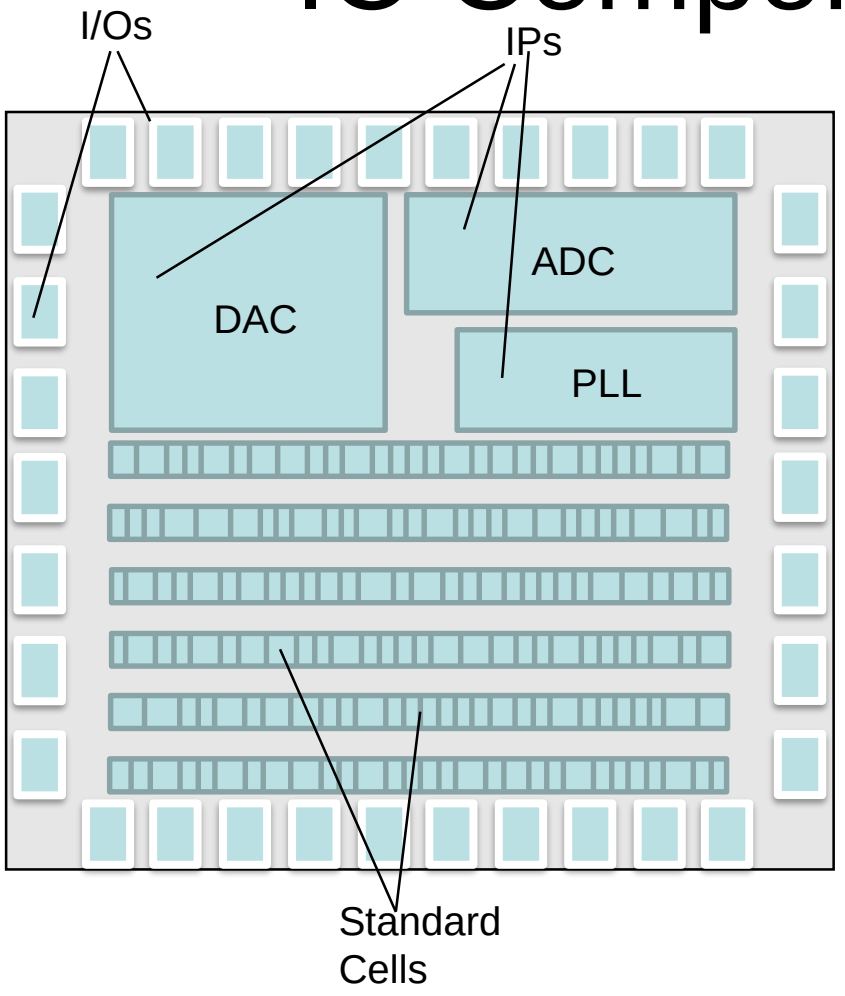


Circuit



Layout

IC Component Types



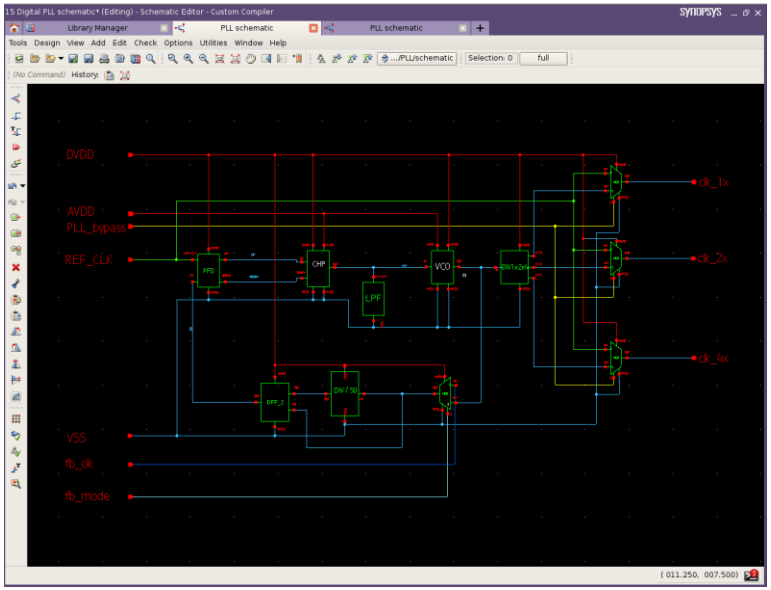
- Input/Output (I/O) Cells
  - Implement the connection between IC inner circuitry and external environment (PCB)
- Digital Standard Cells
  - Basic cells performing simplest functions (e.g. AND, OR, etc.) or more complex functions (Multiplexers, Latches, Flip-Flops, etc.) used as building blocks for large digital circuits
- Intellectual Property (IP) Blocks
  - Large blocks performing completed functions (DAC, ADC, PLL, etc), used in large designs

IC Component Types (2)

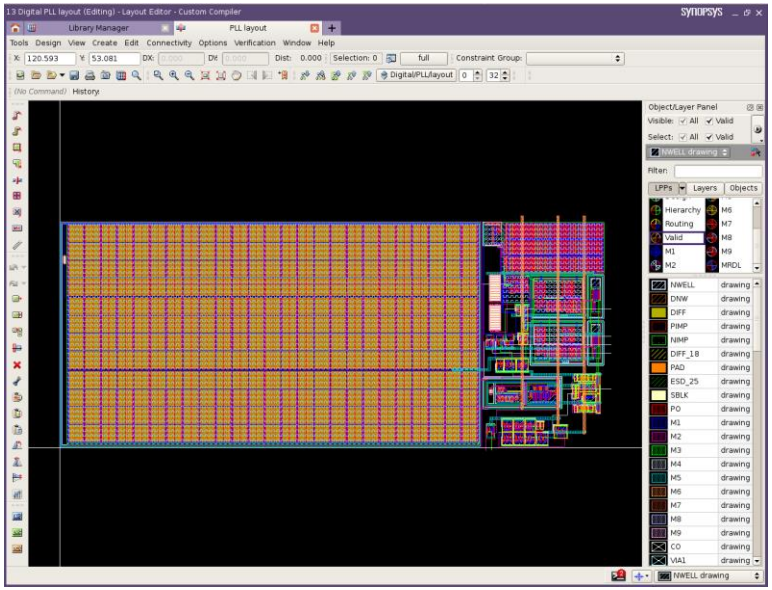
- Digital Standard Cells
  - Basic cells performing simplest functions (e.g. AND, OR, etc.) or more complex functions (Multiplexers, Latches, Flip-Flops, etc.) used as building blocks for large digital circuits
- Intellectual Property (IP) Blocks
  - Large blocks performing completed functions (DAC, ADC, PLL, etc), used in large designs
- Input/Output (I/O) Cells
  - Implement the connection between IC inner circuitry and external environment (PCB)
- Digital ICs
  - Large ICs (e.g. processor, GPU, etc.), distributed to end-users

IP Example

PLL

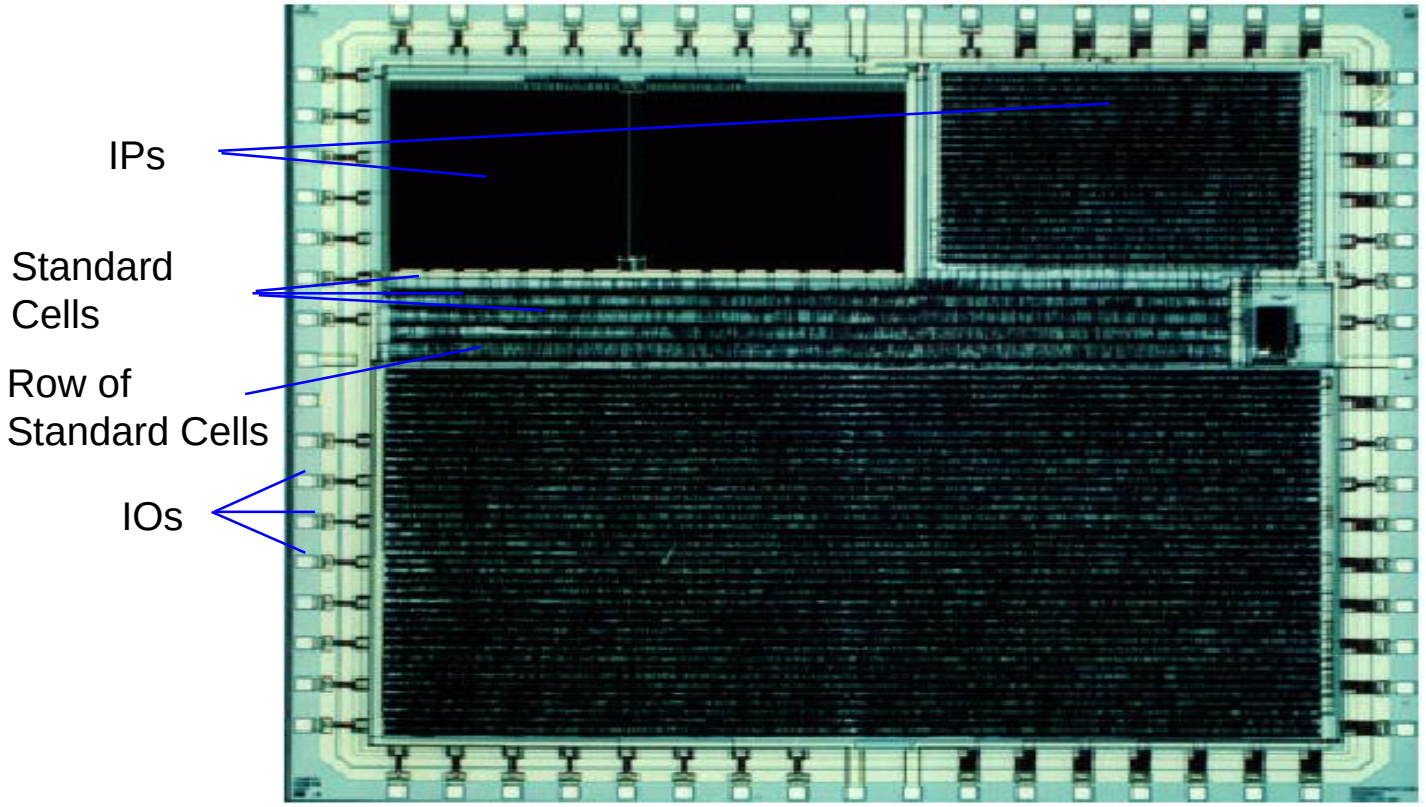


Circuit



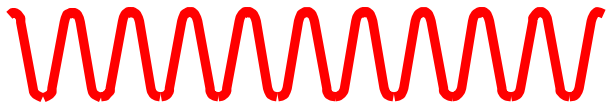
Layout

Real IC Example



IC Classification : Signal Type

Analog

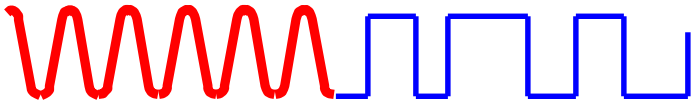


Electrical levels move up and down continuously

Digital

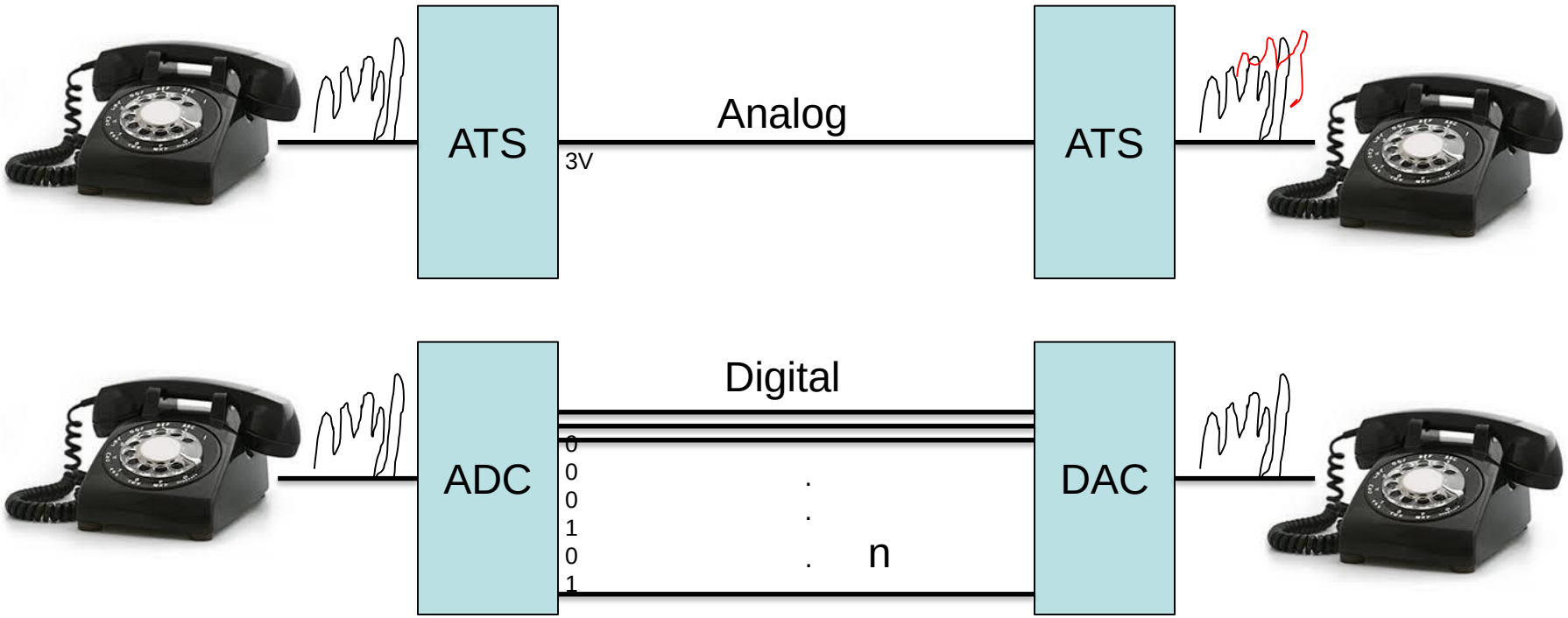
Electrical levels are either ON (“1”) or OFF (“0”)

Mixed Signal



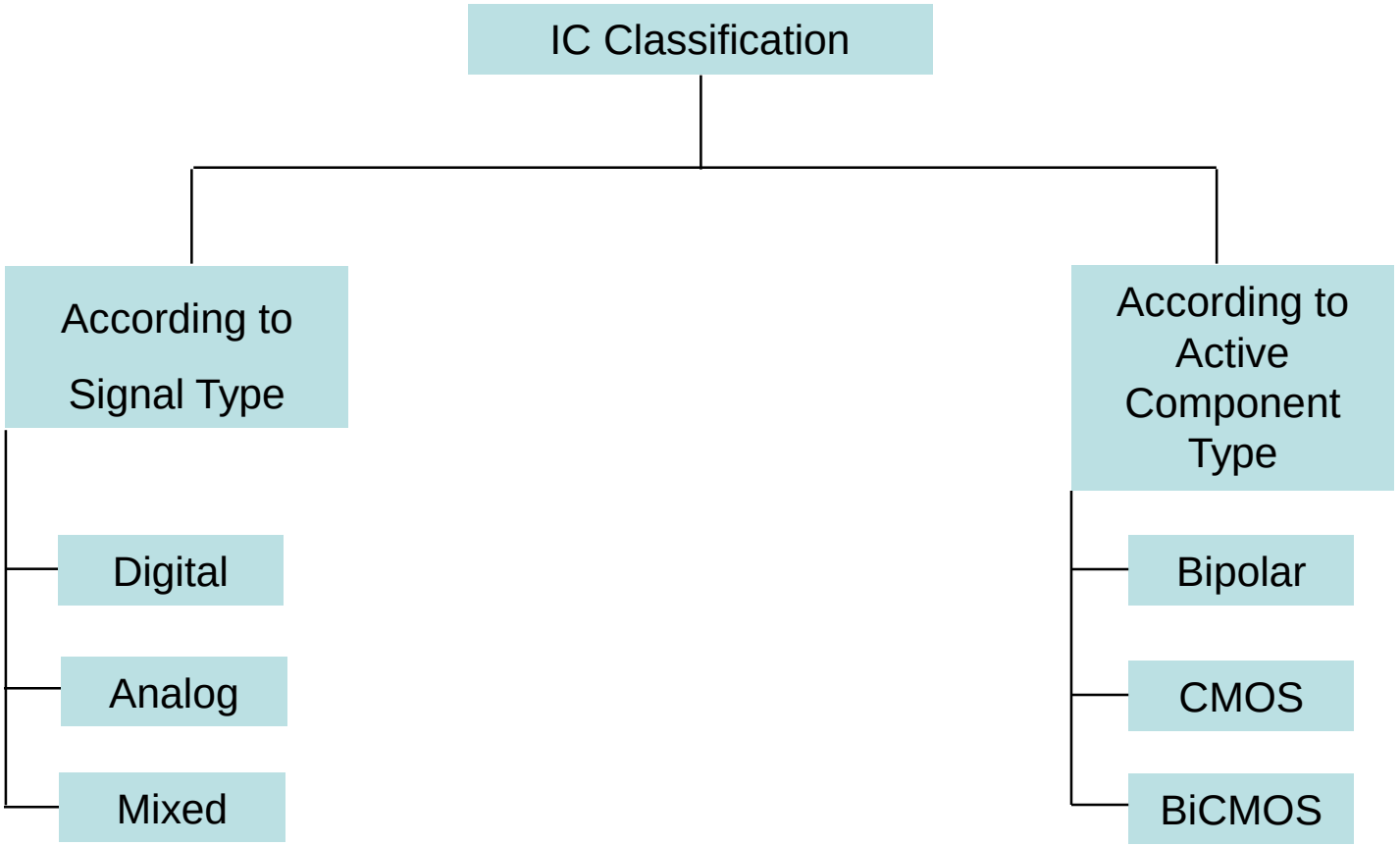
Combination of the first two

Reason of Digital Signals



Digital - noise immune

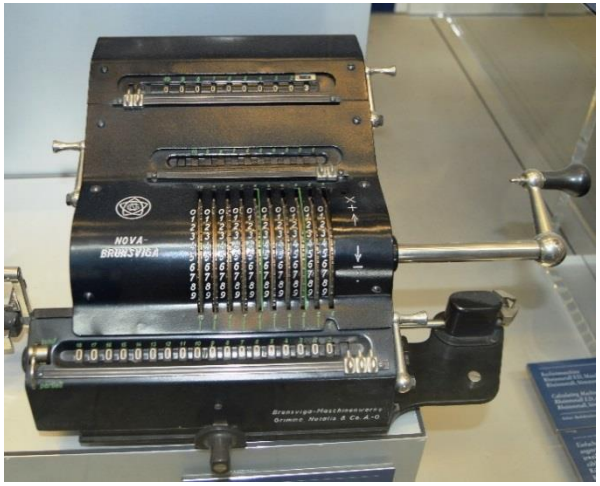
IC Classification



History and Evolution of The IC Industry (Mechanical Calculators)

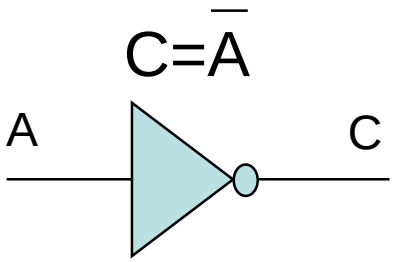
Calculator

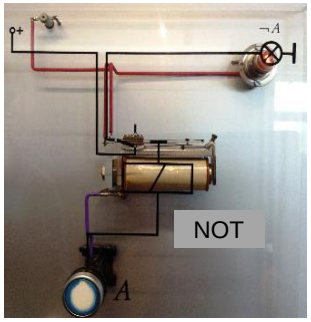
Logarithmic ruler

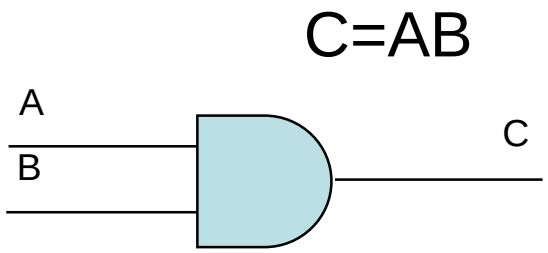


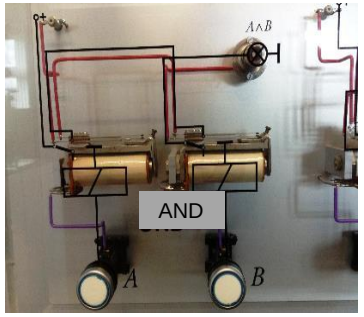
Mechanical calculator

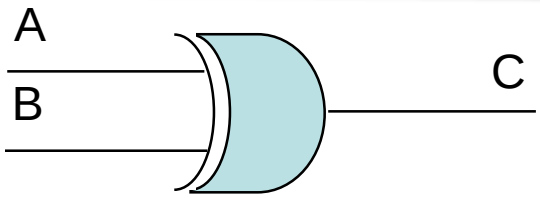
History and Evolution of The IC Industry (Mechanical Logic Gates)

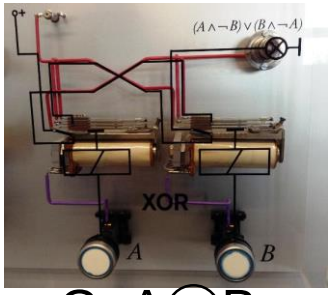




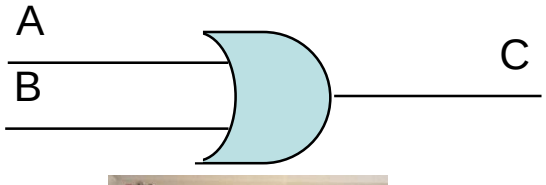


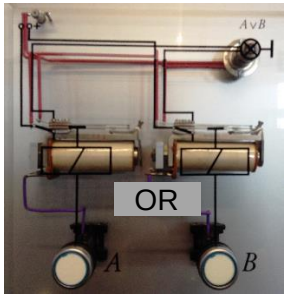




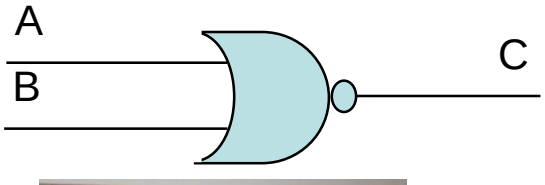


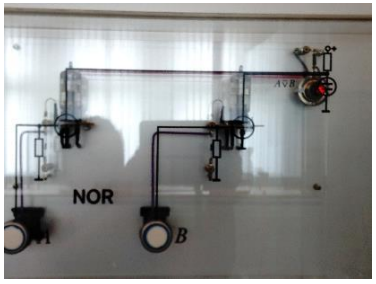
C=A⊕B





C=A+B

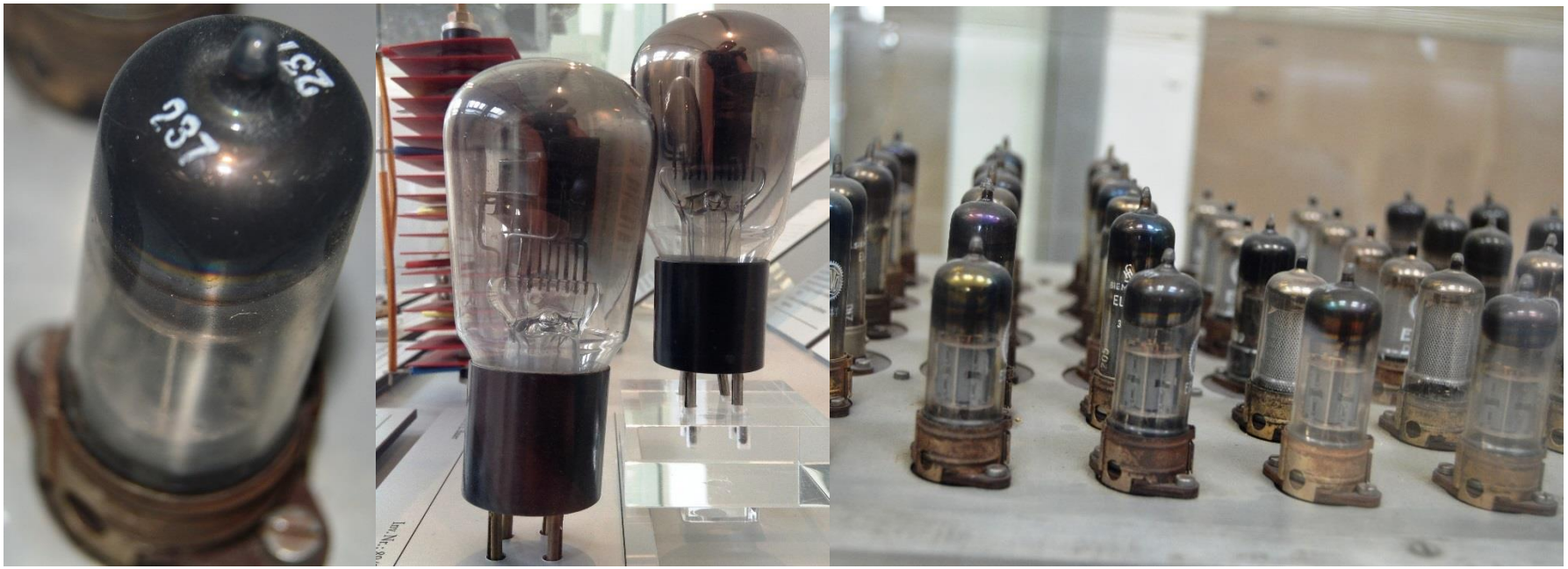




C=$\overline{A+B}$

History and Evolution of The IC Industry (Lamp Computers)

Vacuum lamp



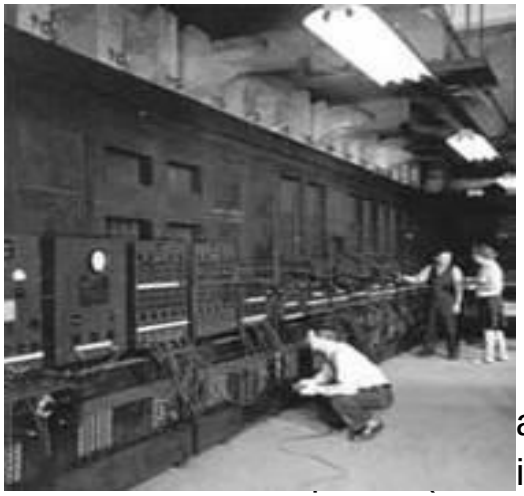
- Large size
- High heat removal
- Low reliability

History and Evolution of The IC Industry (Lamp Computers) (2)

History and Evolution of The IC Industry (Lamp Computers) (3)

History and Evolution of The IC Industry (Lamp Computers) (4)

- 1946. The first electronic computers were created which operated by vacuum lamps.

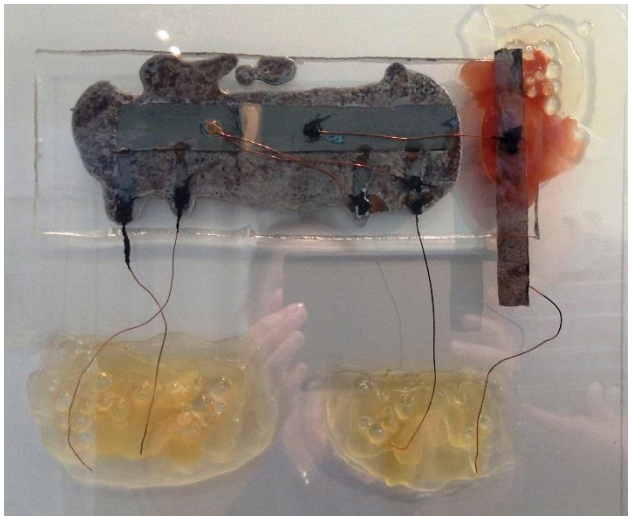


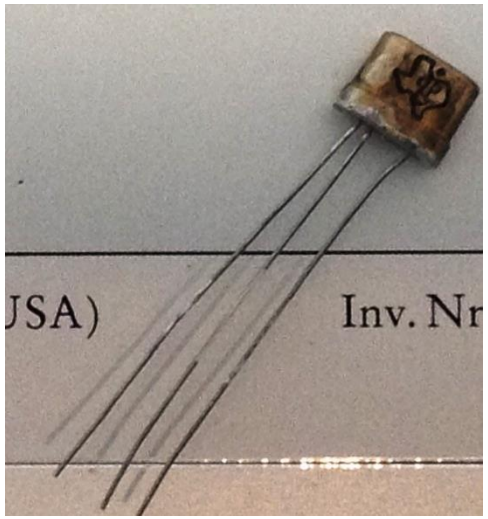
The first electronic “ENIAC” computer

- arge halls)
- ize of several powerful heaters)
- Had low performance (even smaller than contemporary calculators)
- Low reliability (the time of non-failure operation did not exceed 30 minutes)

History and Evolution of The IC Industry (Transistor Computers)

- 1948. The first transistor was created in Bell Labs

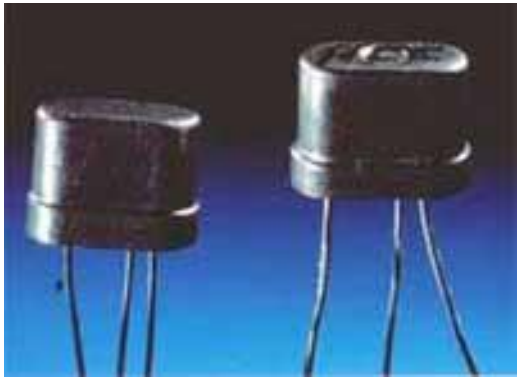




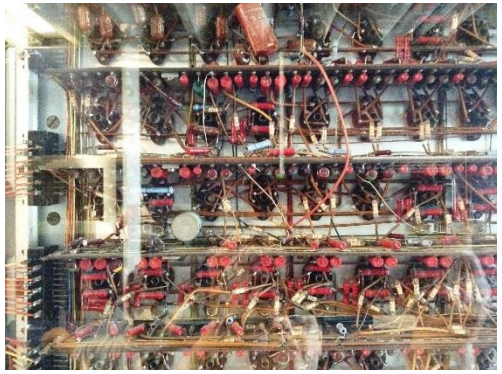
The first transistor created in Bell Labs

History and Evolution of The IC Industry (Transistor Computers) (2)

- 1954. The first fully transistor computer was developed



Examples of separate semiconductor transistors of 1950s

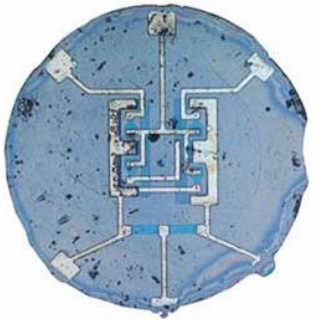


A block of fully transistor computer

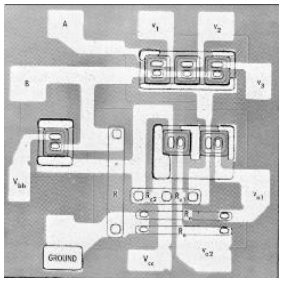
An example of fully transistor computer

History and Evolution of The IC Industry (IC Based Computers)

- 1959. The first integrated circuit was created



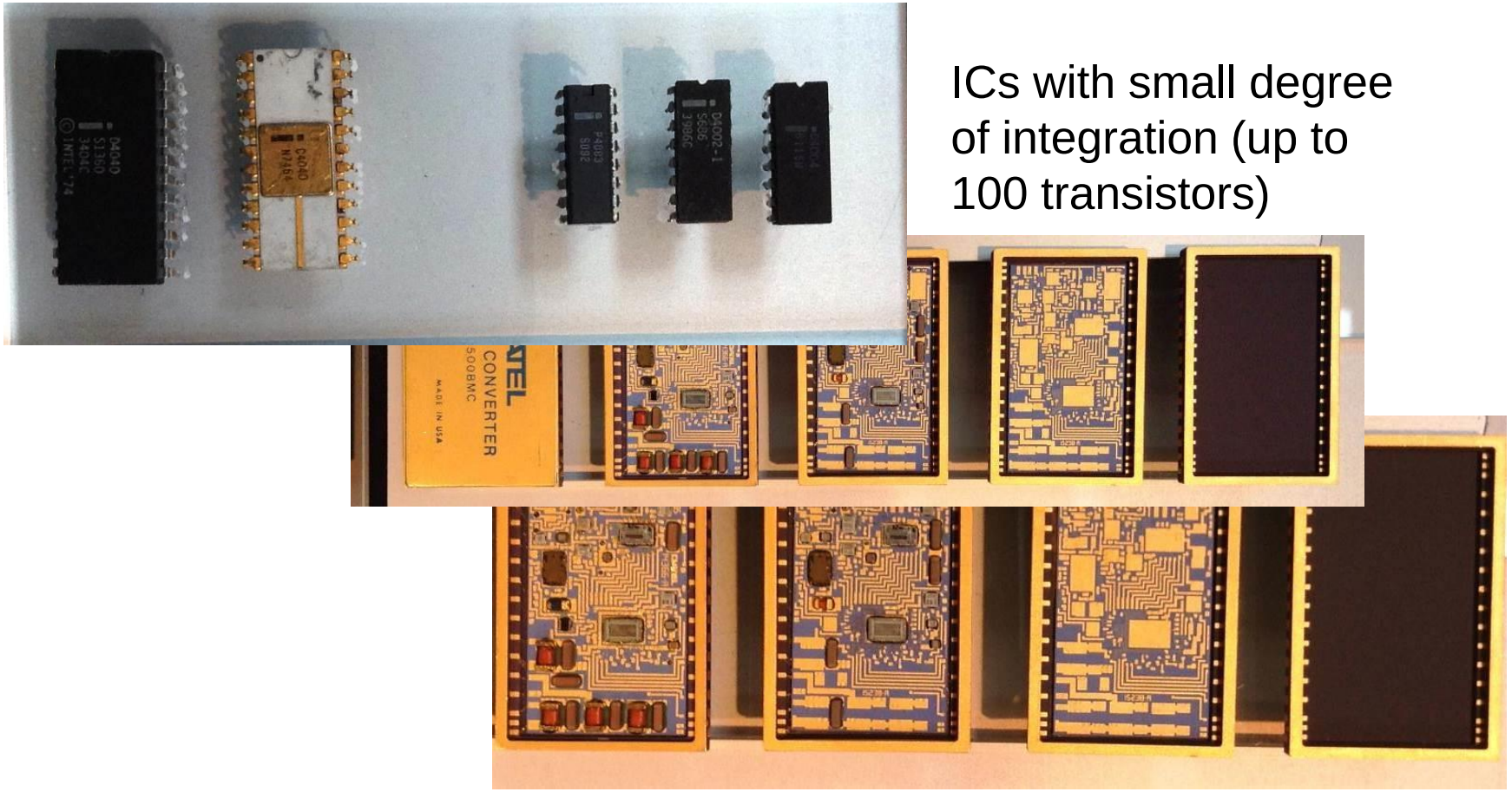
The first commercial IC which in 1959 was developed by the British architecture Robert Noyce and manufactured by “Texas Instruments”



3-input Gate, which in 1966 was manufactured by Motorola

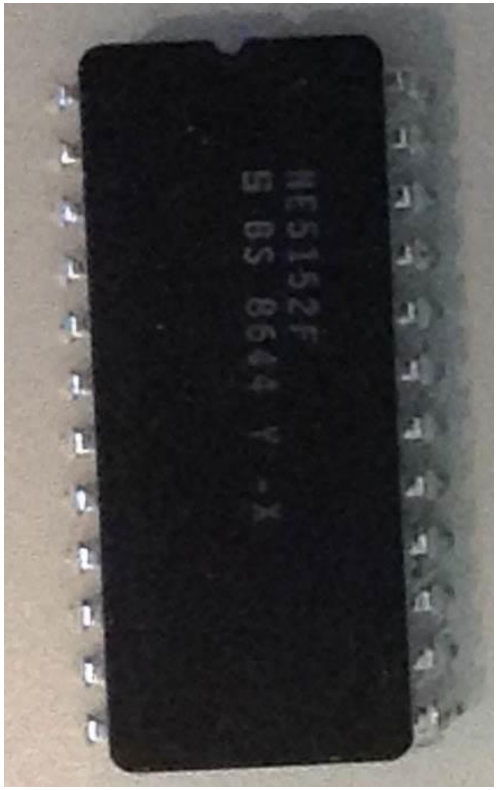
- The first ICs contained only several transistors
- The first ICs were manufactured in small quantities as they were rather expensive

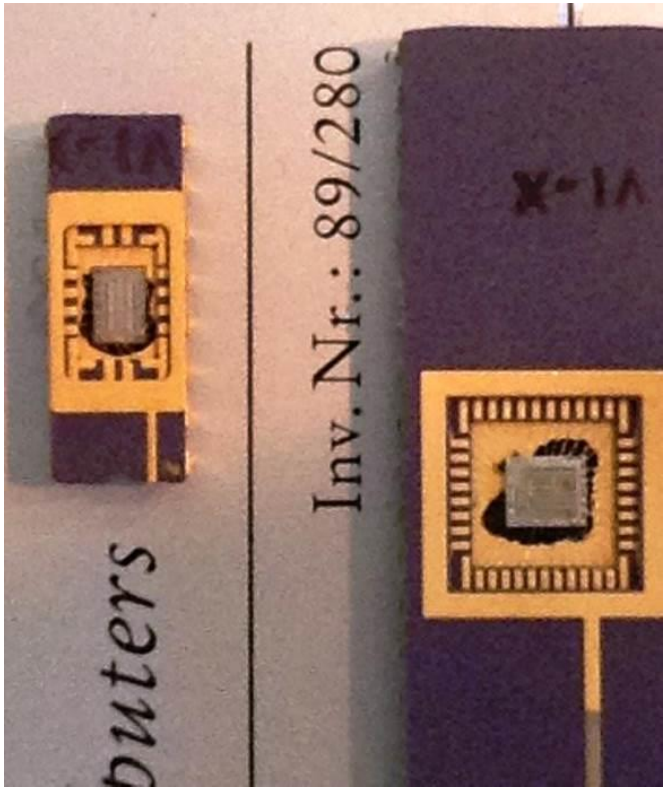
History and Evolution of The IC Industry (IC Based Computers) (2)

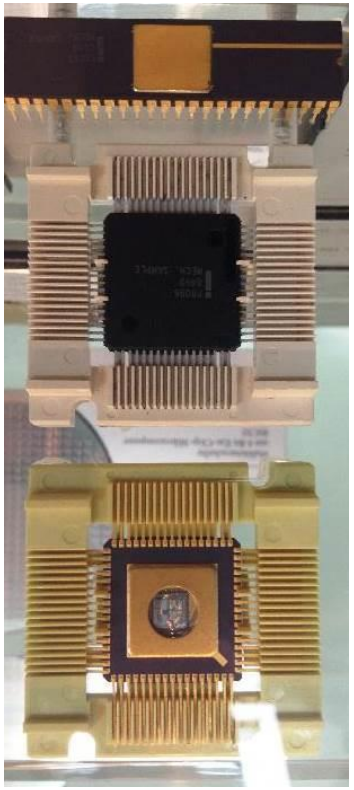


ICs with small degree of integration (up to 100 transistors)

History and Evolution of The IC Industry (IC Based Computers) (3)

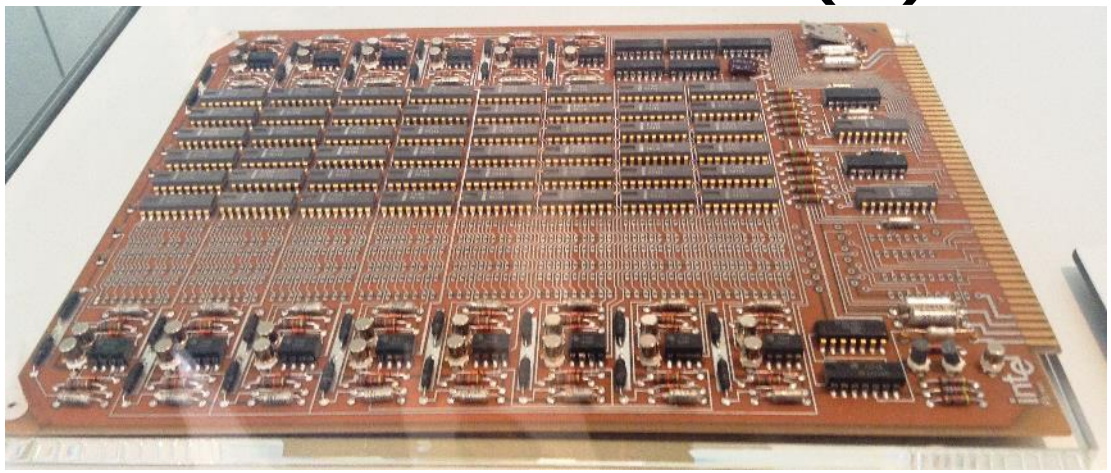


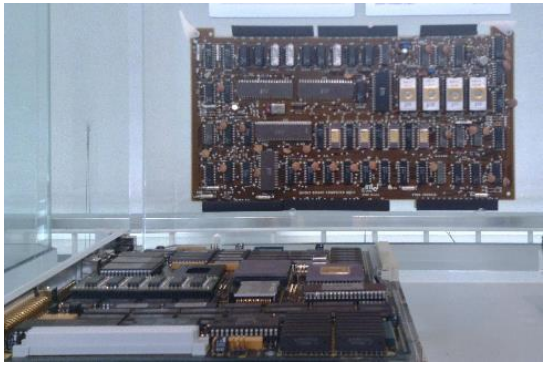


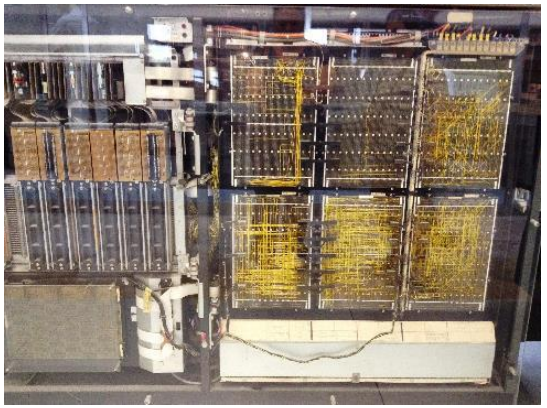


ICs with small degree of integration (up to 1000 transistors)

History and Evolution of The IC Industry (IC Based Computers) (4)

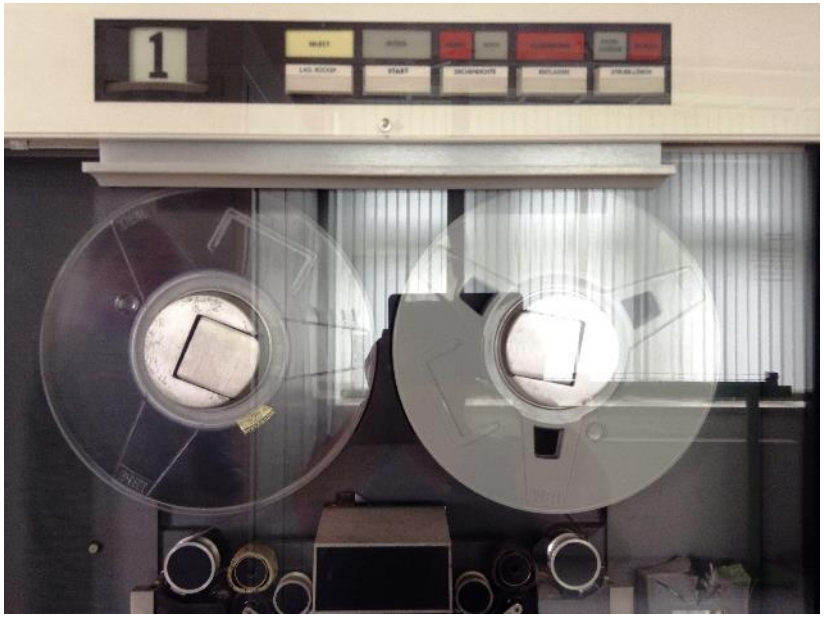






Blocks of IC based computers

History and Evolution of The IC Industry (IC Based Computers) (5)



History and Evolution of The IC Industry (IC Based Computers) (6)

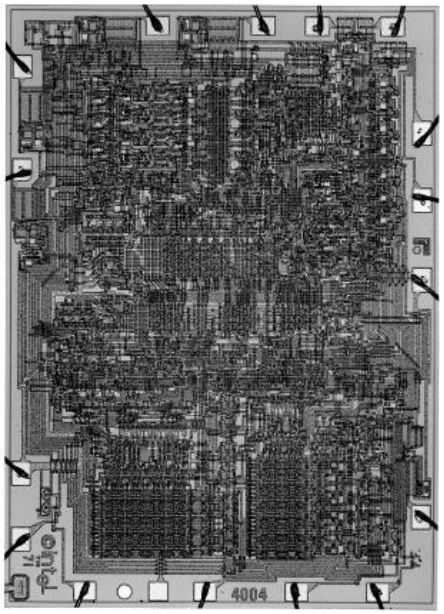
History and Evolution of The IC Industry (IC Based Computers) (7)

History and Evolution of The IC Industry (IC Based Computers) (8)

History and Evolution of The IC Industry (IC Based Computers) (9)

History and Evolution of The IC Industry (IC Based Computers) (10)

- 1971. The first microprocessor was created



Intel 4004 Microprocessor

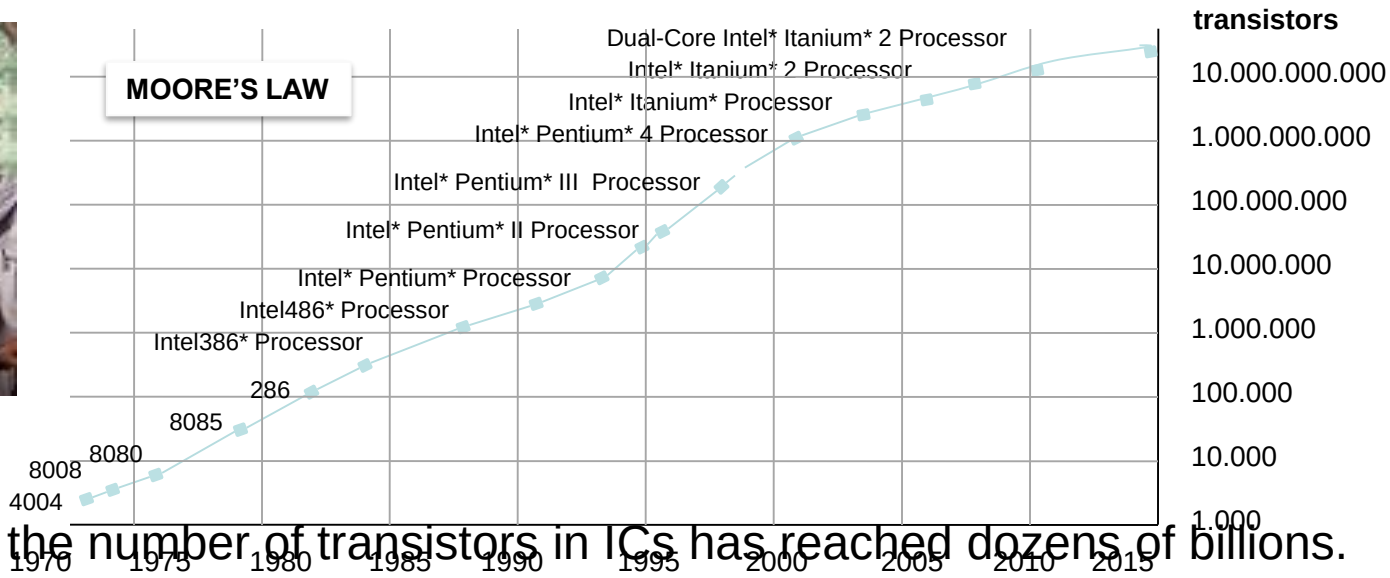
- Created in 1971
- Contained 1000 transistors
- 1 MHz operation

History and Evolution of The IC Industry (IC Based Computers) (11)

Calculators have been produced which exceeded the calculation power of the previous calculators for several times

History and Evolution of The IC Industry

- 1965. Moore's law was discovered, according to which the number of transistors in ICs doubles every 18 months



- At present, the number of transistors in ICs has reached dozens of billions.

Web-site: http://www.intel.com/technology/mooreslaw/

History and Evolution of The IC Industry (2)

- 1983. Apple created the first PC

An example of the first PC

History and Evolution of The IC Industry (3)

- 1983. Other companies also created PCs

An example of other PCs

History and Evolution of The IC Industry (4)

2010. Xeon 7500

- Technology: 45nm
- Contains 2.3 bln transistors
- 8x2.6 GHz operation

2011. Six-Core Core i7

- Technology: 32nm
- Contains 2.7 bln transistors
- 6x3.6 GHz operation

2013. Xbox One SoC

- Technology: 32nm
- Contains 5 bln transistors
- 8x2.6 GHz operation

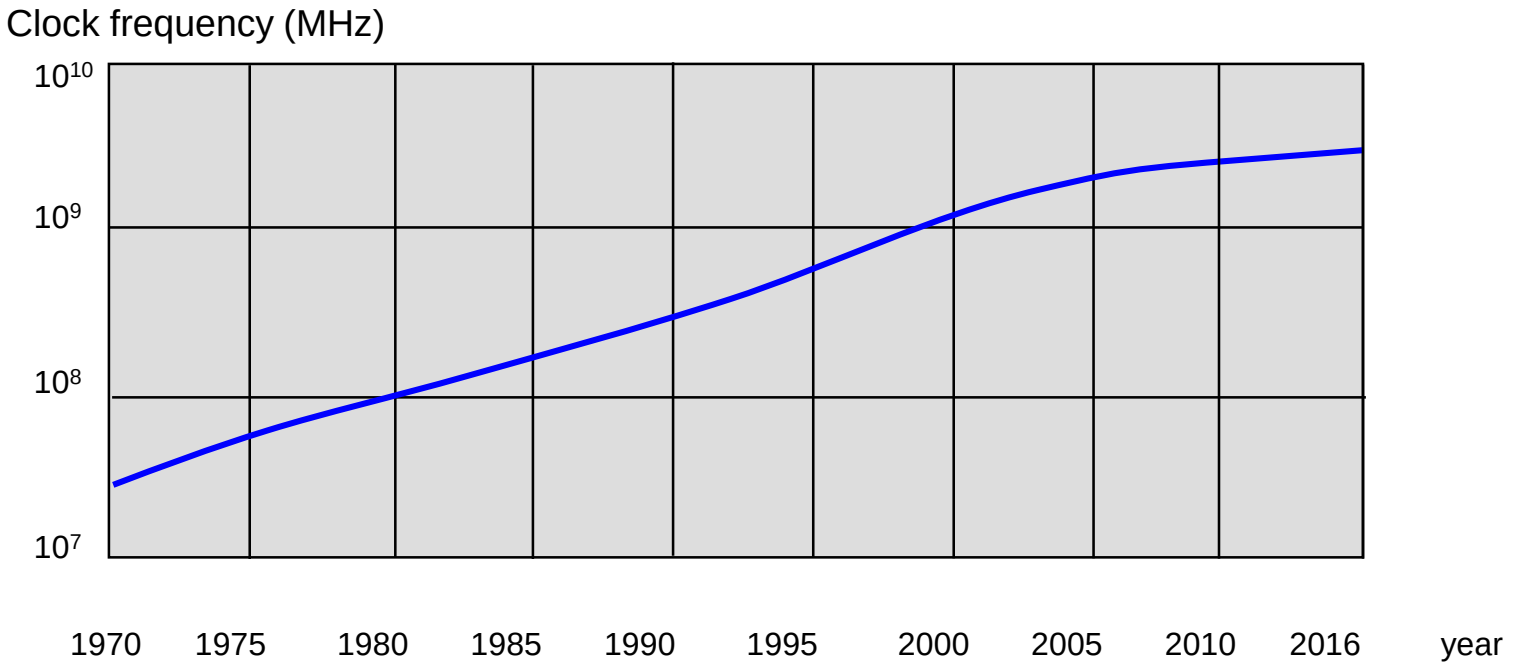
History and Evolution of The IC Industry (5)

- Contemporary integrated circuits

- Contain several dozen billions of transistors
- Operate at dozens of

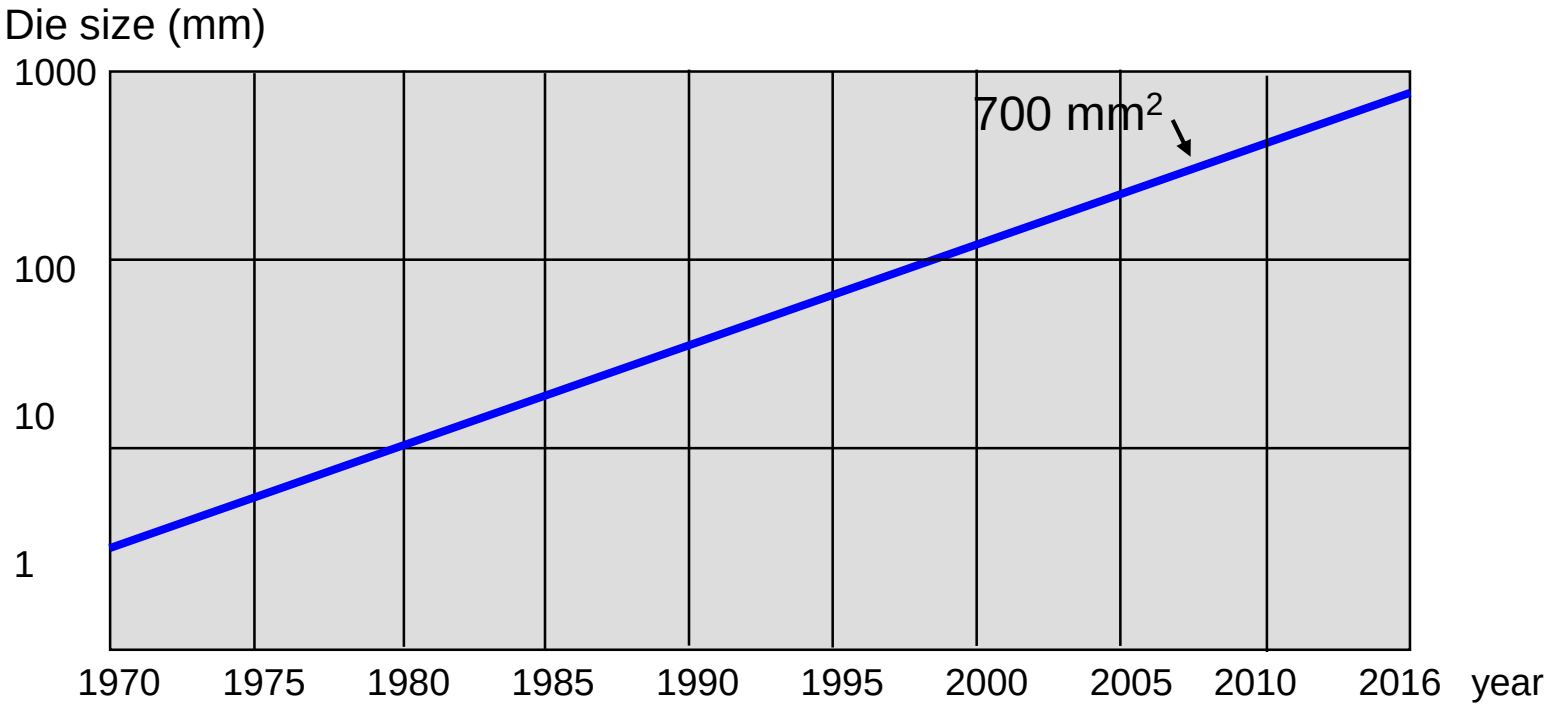
History and Evolution of The IC Industry (6)

- Clock frequency doubles every 2 years



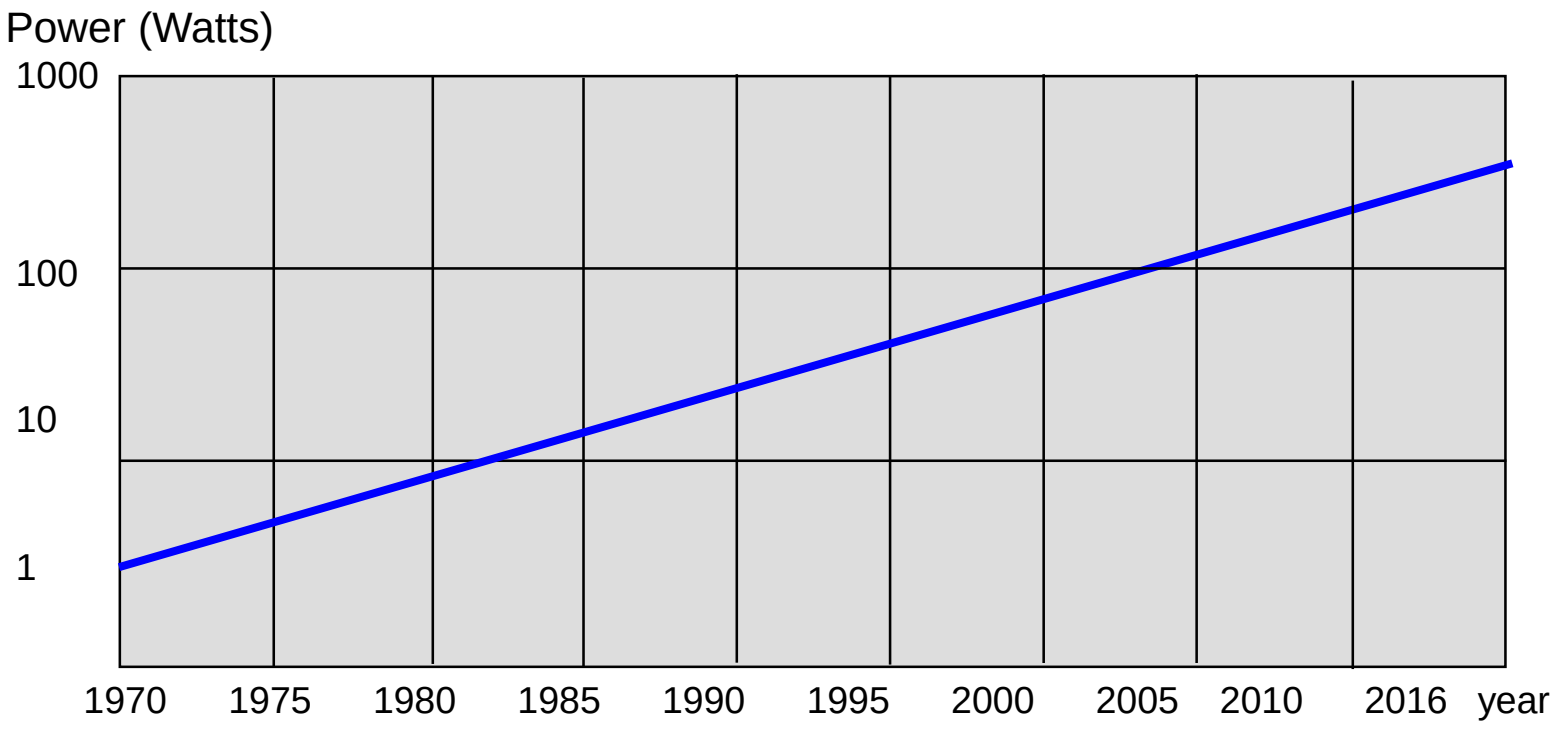
History and Evolution of The IC Industry (7)

- Die size grows by 14% every year



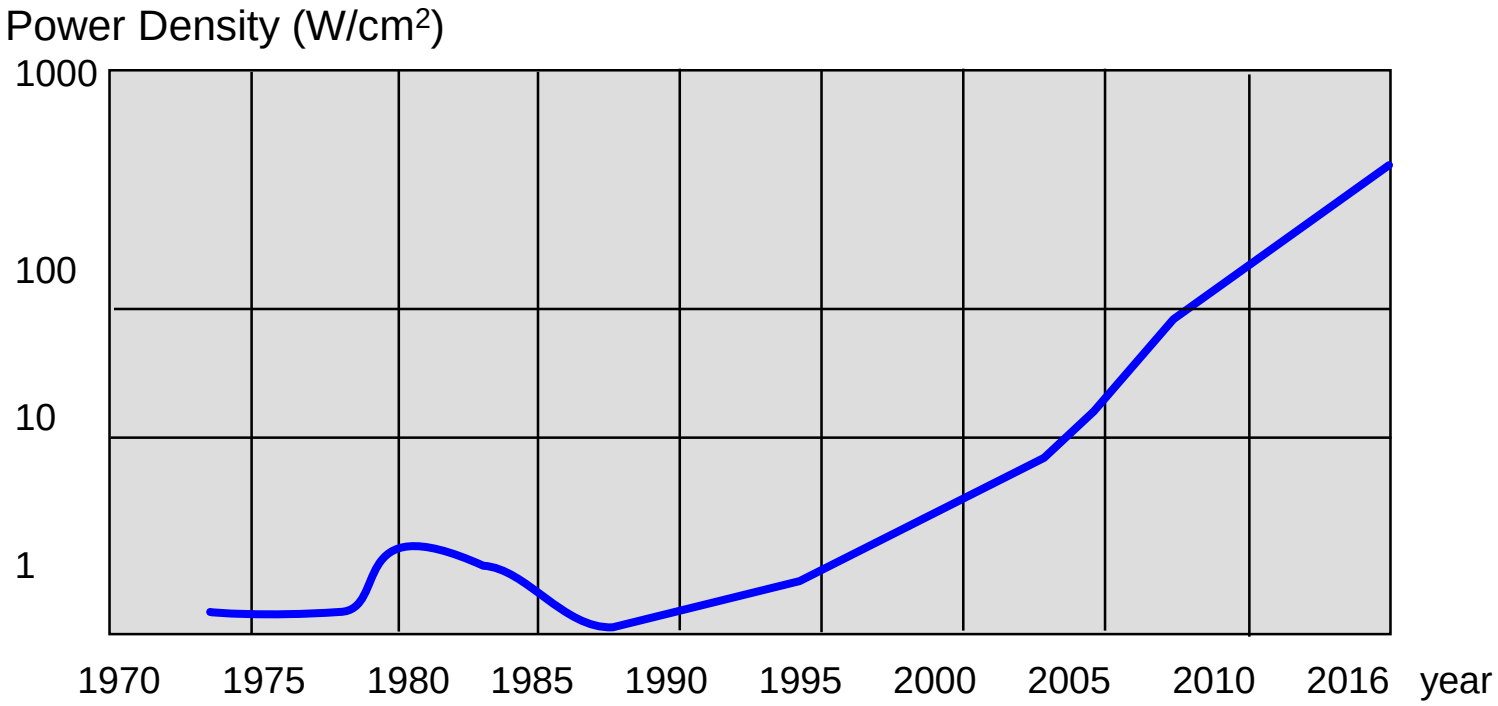
History and Evolution of The IC Industry (8)

- Powers increase about ten times every 3 years



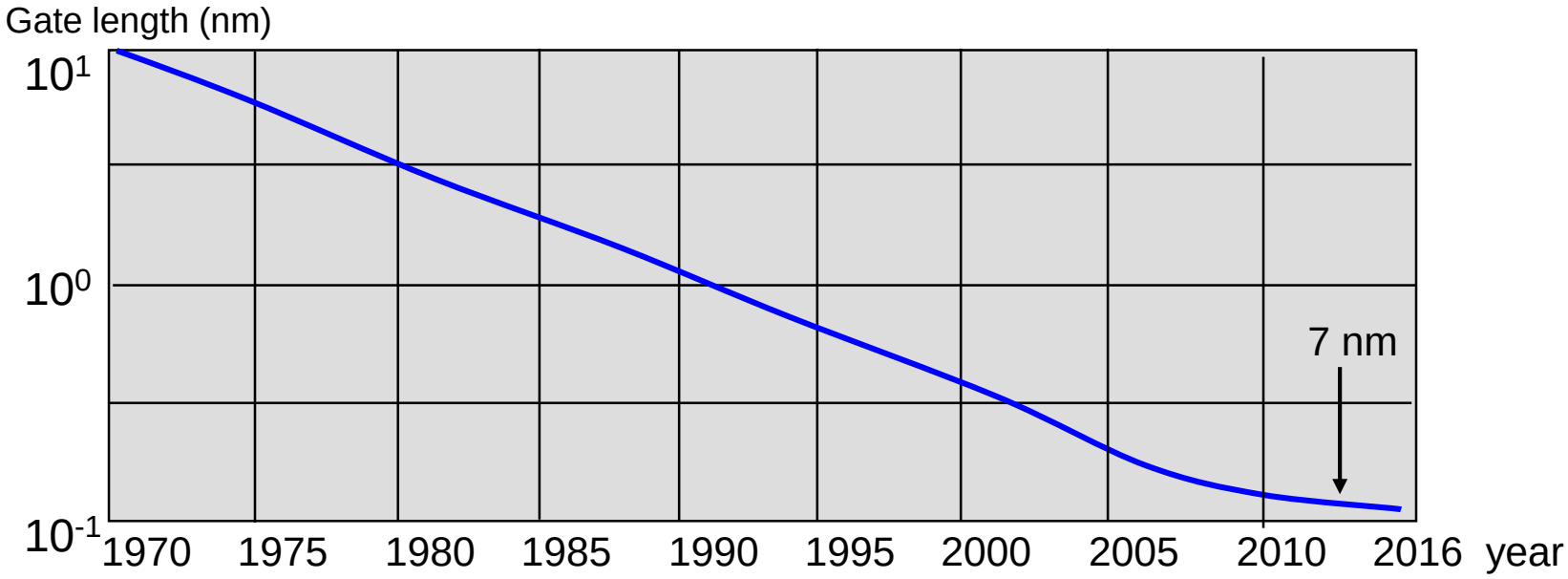
History and Evolution of The IC Industry (9)

- Power densities increase twice every year



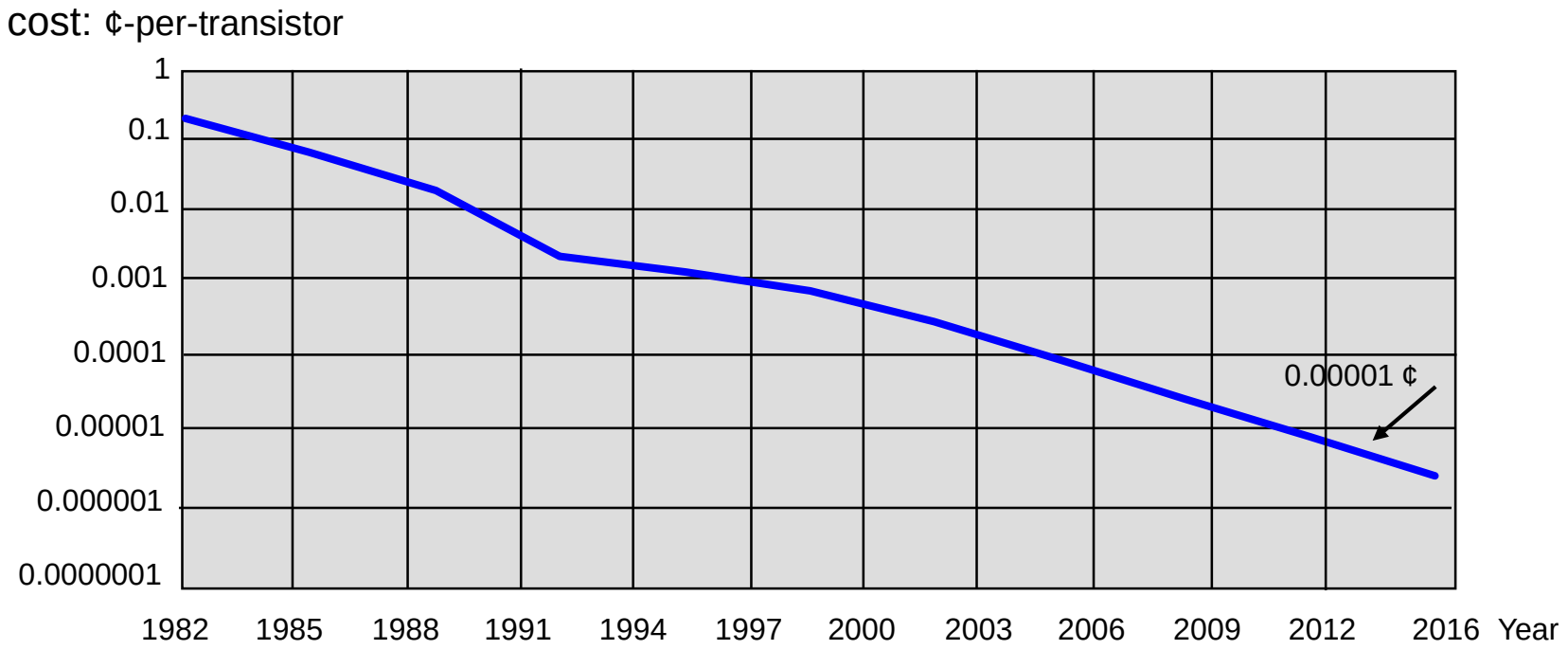
History and Evolution of The IC Industry (10)

- The minimum length of gate is divided by two every 5.4 years



Cost of Transistor

- The cost of transistors reduce twice every 1.5 years



History and Evolution of The IC Industry (11)

- Semiconductor Industry Association (SIA) Roadmap

Date	1999	2005	2010	2016
Technology (nm)	180	65	28	7
Minimum mask count	22/24	25	27	29/30
Wafer diameter (mm)	200	400	400	450
Memory samples (bits)	1G	8G	32G	10T
Transistors/cm^2	6.2M	180M	330M	1.5G
Maximum number of metal layers	6-7	9	9	12
Clock frequency (MHz)	1250	3200	5200	20000
IC sizes (mm^2)	400	596	699	750
Power supply (V)	1.5-1.6	0.8-1.2	1.2-1	0.37-0.42
Maximum power (W)	90	150	171	183
Number of pins	700	1957	2734	3350

Technology Roadmap