u3a Computing Group

Alan Hopwood, 7 March 2024

Agenda

Welcome
Current News, Issues and Questions
Topic Planning
Topic: integrated Circuit Design
AOB and Follow up

Presentation

Integrated Circuit Design

(Squeezing 2 University years into an hour)

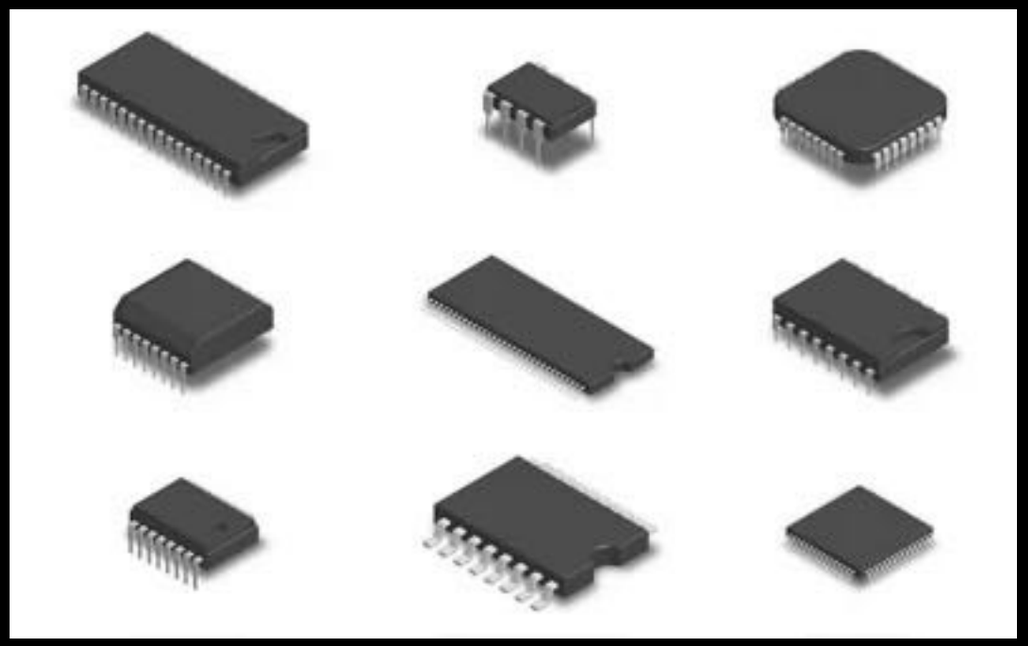
Agenda

Integrated Circuit Design

- What are Integrated Circuits?
- Building Blocks
- Fabrication process

What are Integrated Circuits?

Integrated Circuit Design



They are electronic devices made up of multiple interconnected electronic components such as transistors, resistors, and capacitors. These components are etched onto a small piece of semiconductor material, usually silicon.

<u>Analogue ICs</u>

- Power Supply chips
- Sensors
- Amplifiers
- RF applications
- Motor controllers
- …

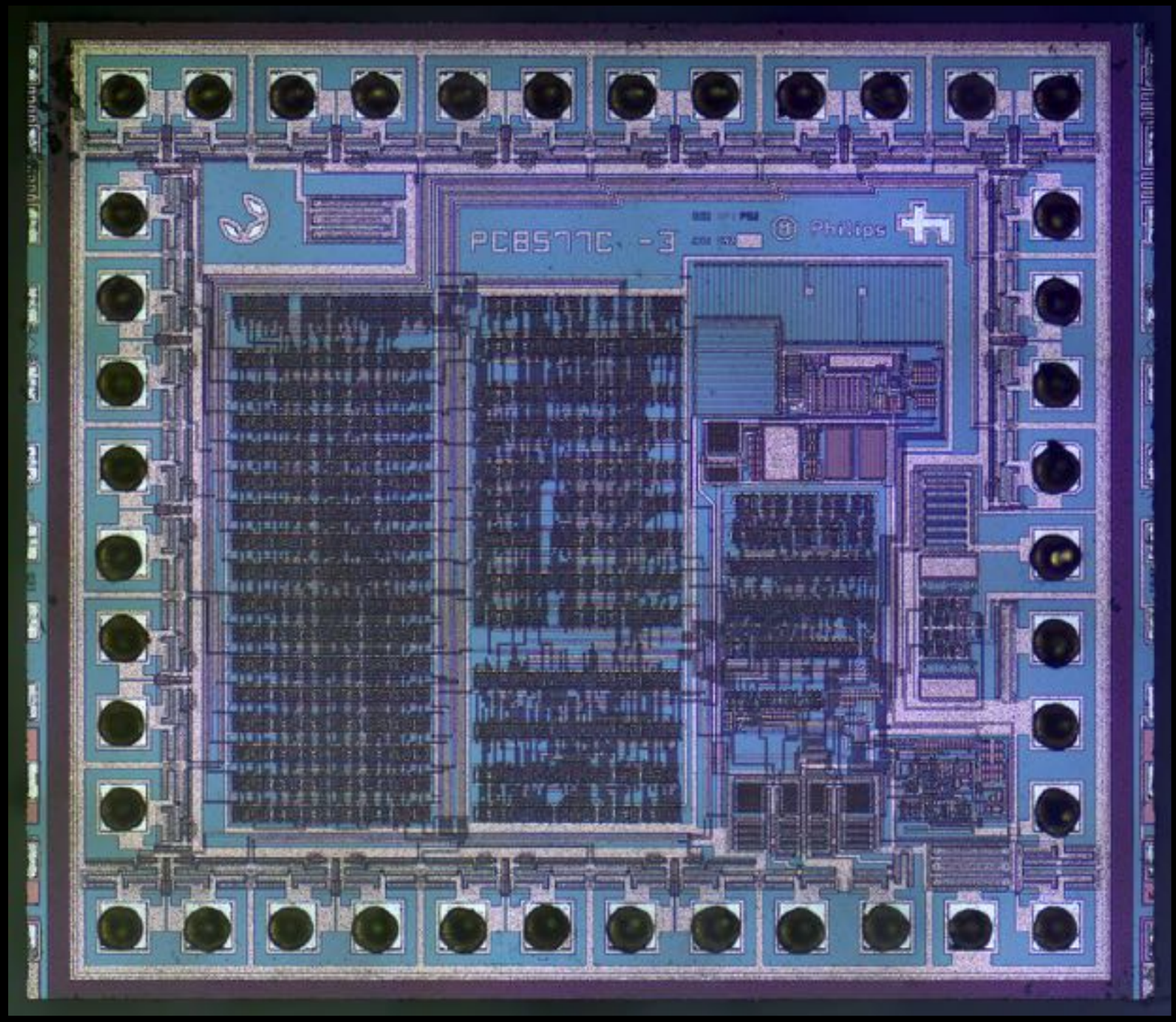
<u>Digital ICs</u>

- Memory (RAM, ROM, CMOS, Flash)
- Microprocessors
- Logic ICs
- Programable ICs
- digital signal processors
- …

What are Integrated Circuits

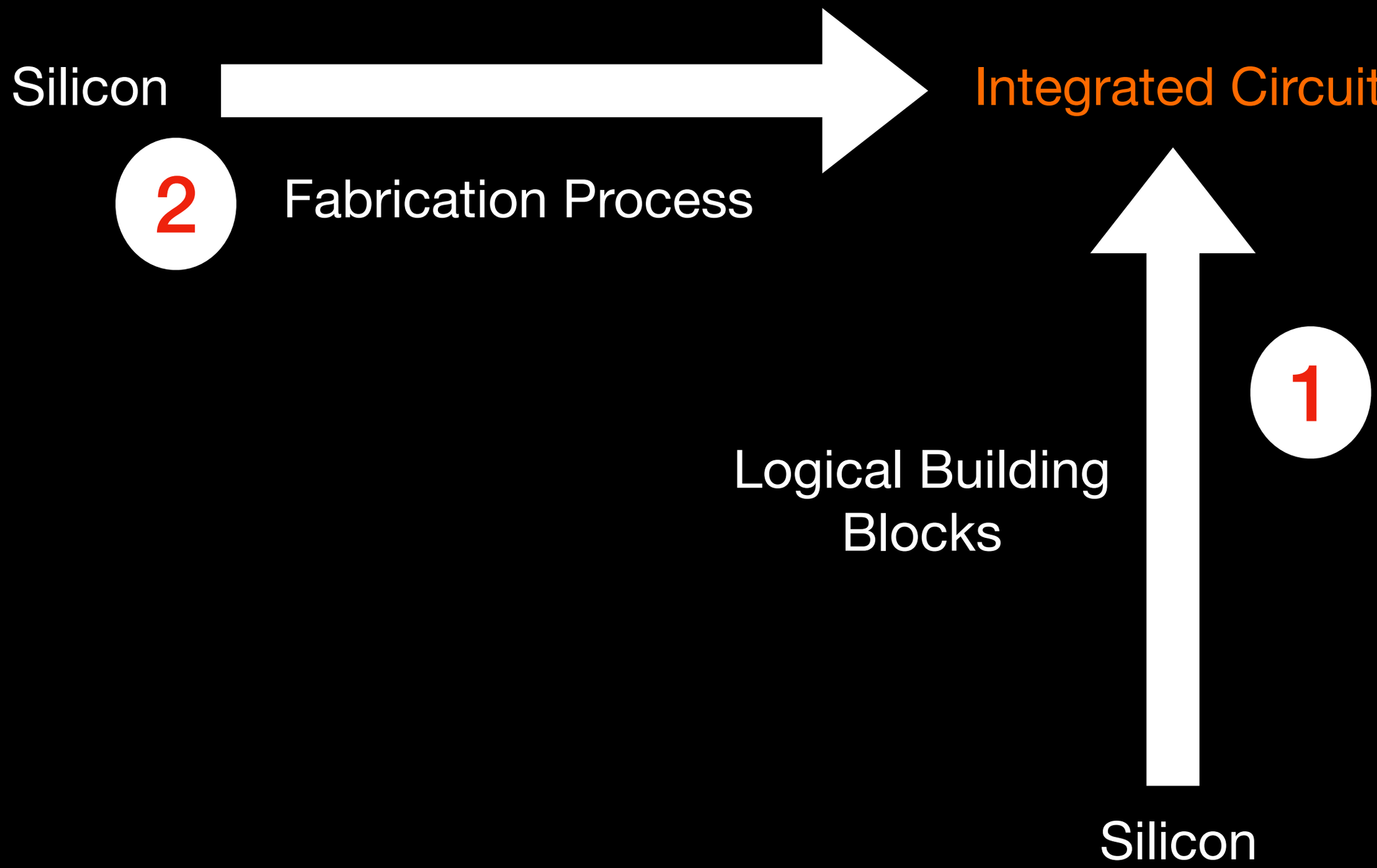
Integrated Circuit Design

- A microscope image of an integrated circuit used to control LCDs.
- Dark circles are the external connections to the IC.



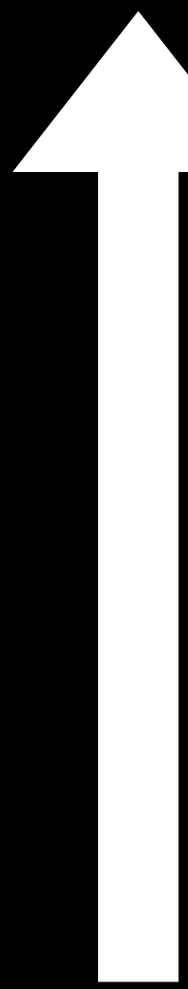
Approach to topic

Integrated Circuit Design

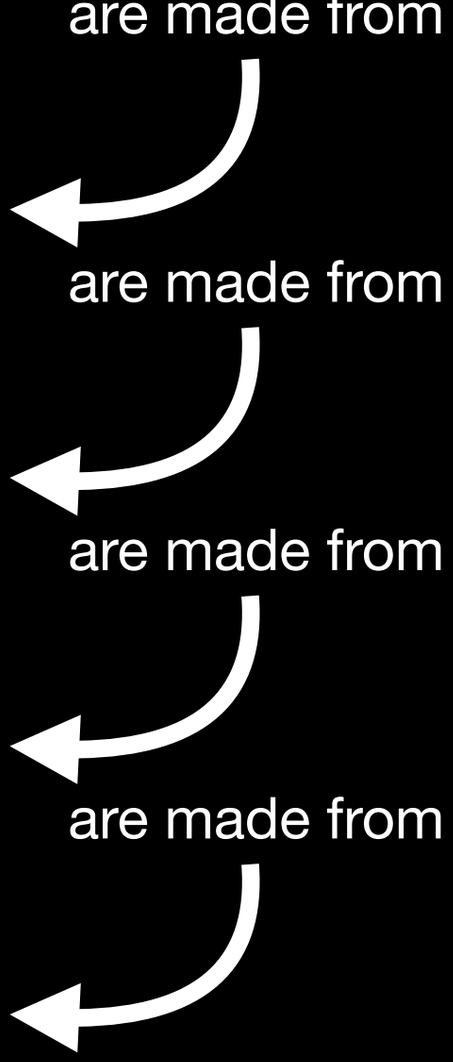


IC Building Blocks

Integrated Circuit Design



Integrated Digital systems	Microprocessor, Memory etc.
Digital system building blocks	adder, memory, flip-flop, shift register, counter…
Logic Gate Assemblies	AND, NAND, NOR, AOI (And Or Invert)…
Basic electronic components	Diode, transister, capacitor, resistor
Silicon material	Pure wafer, semiconductor substrates



Semiconductor Material

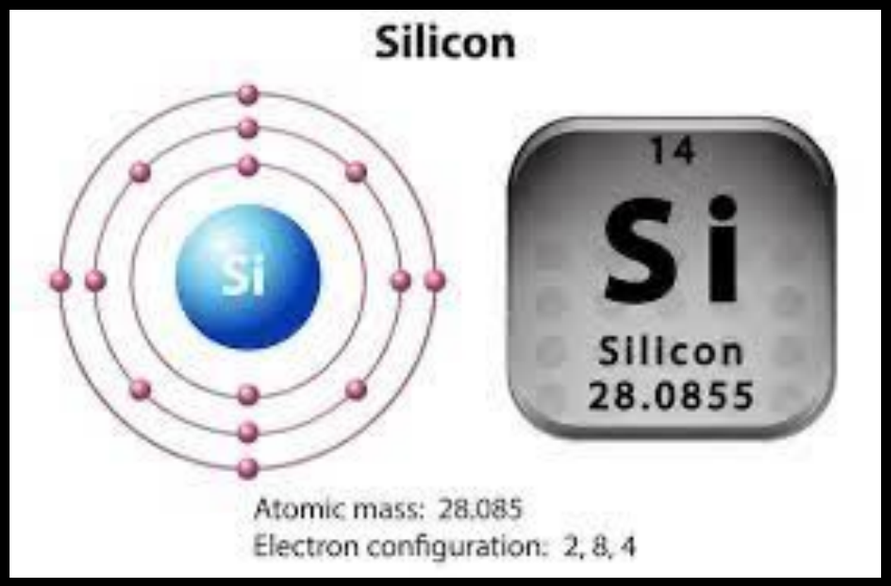
Integrated Circuit Design

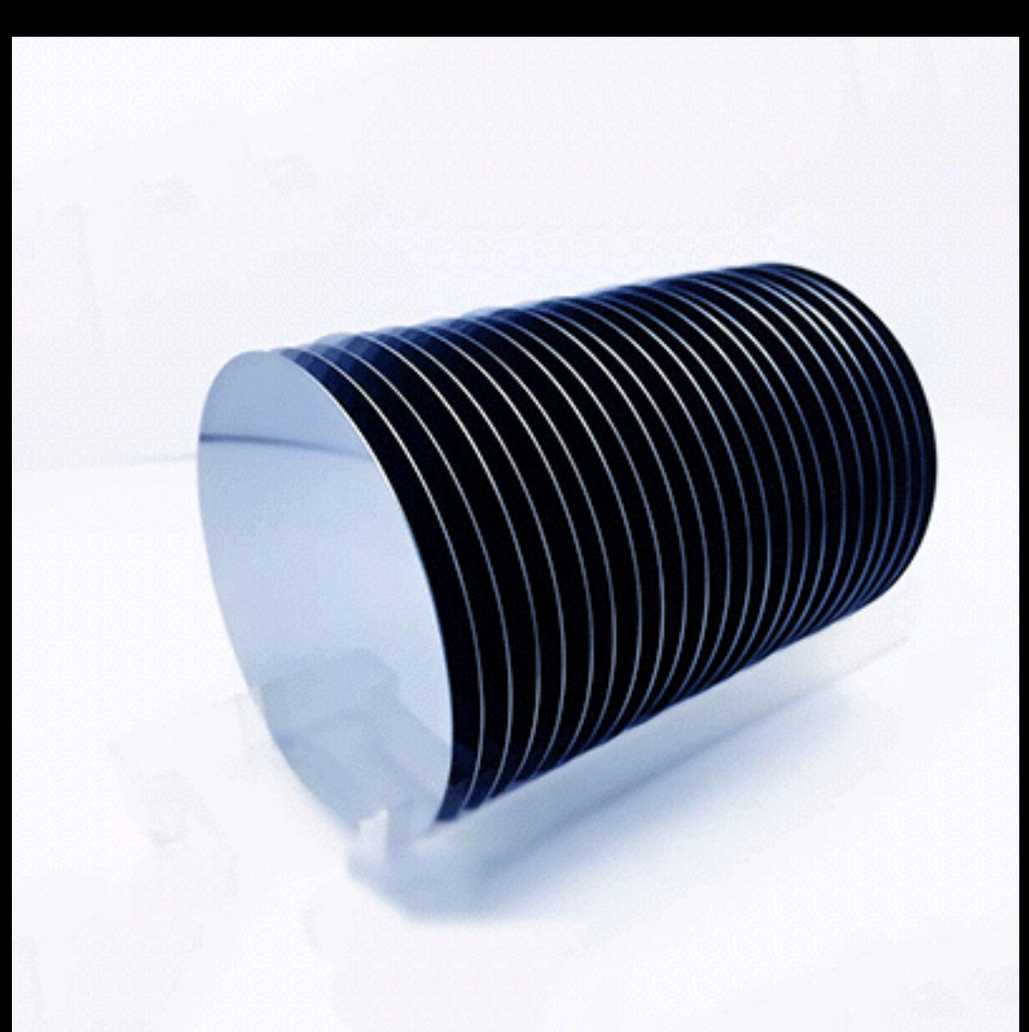
Silicon:	**the basic material - sand**
Semiconductor material:	**Provides characteristics needed for electronic devices**
The P-N Junction:	**The start point for diode & transistor technology**

Silicon - the foundation material

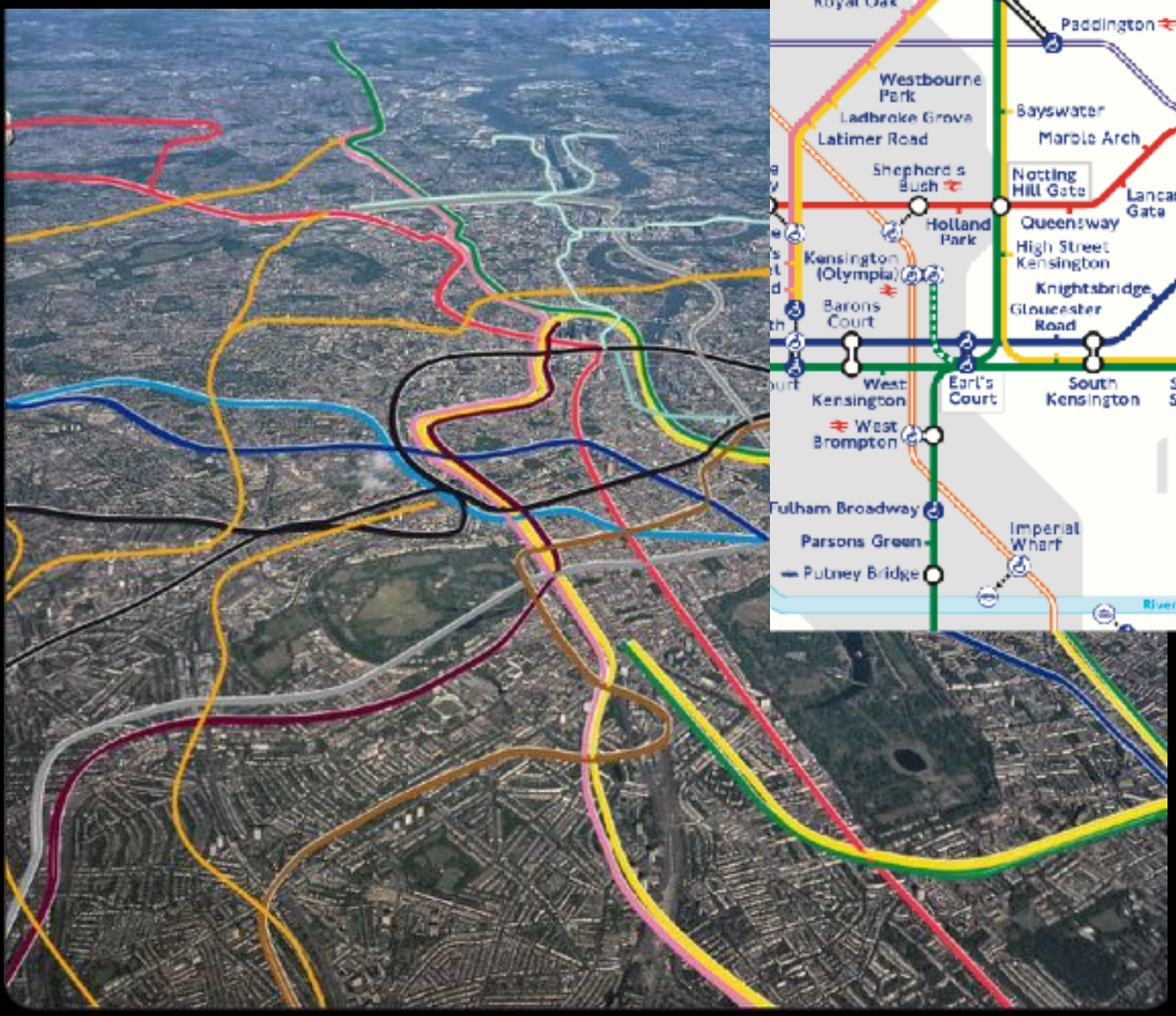
Integrated Circuit Design

IC production requires purification to better than 1 part per 10^{10}, and in special cases impurity levels below 1 part per 10^{12}





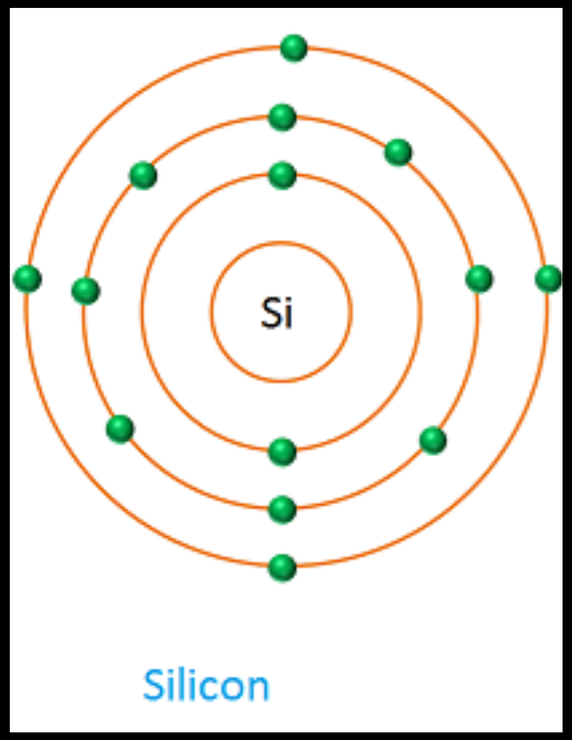
Models ease understanding

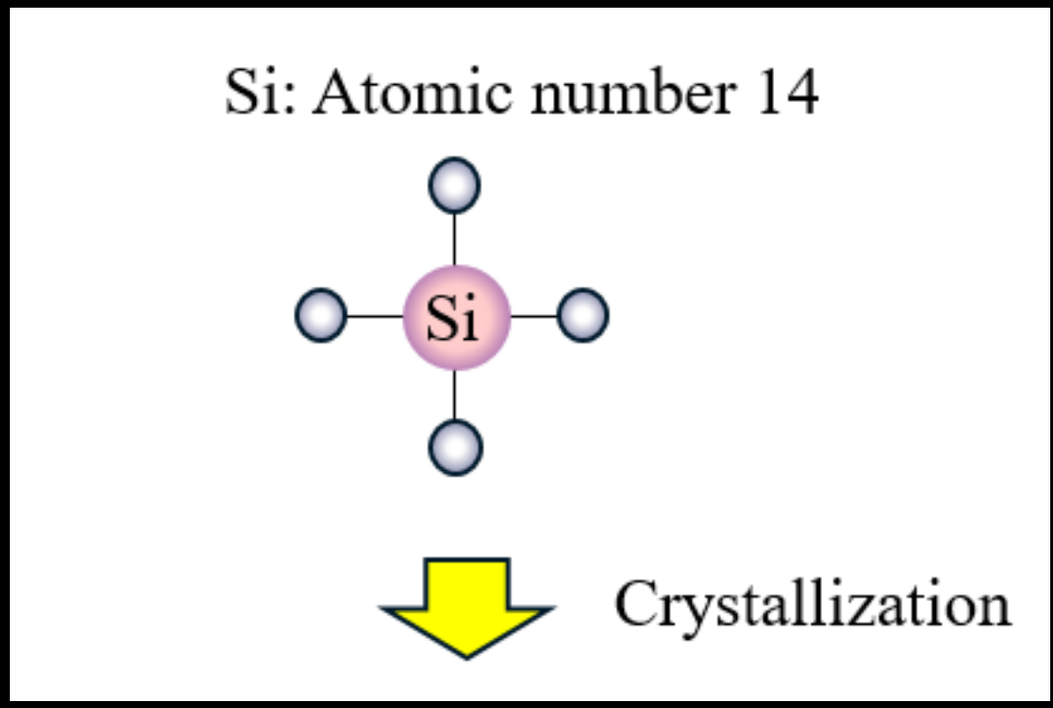


But are not truth

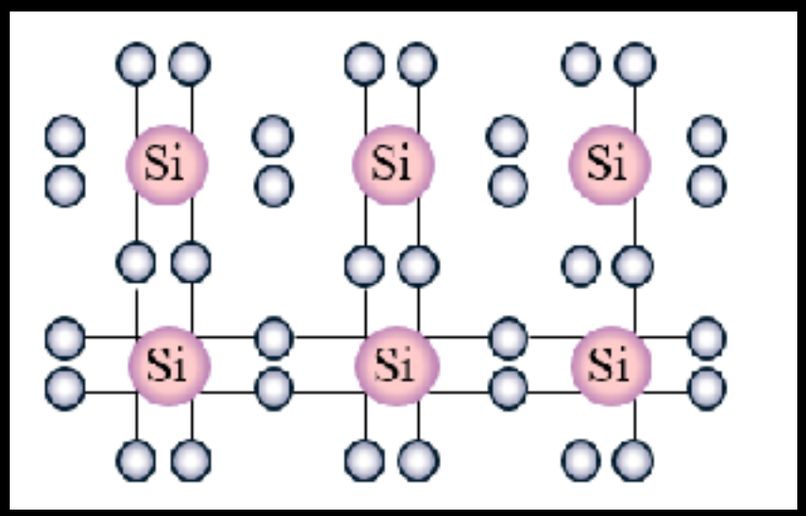
Silicon Atomic Structure

Integrated Circuit Design





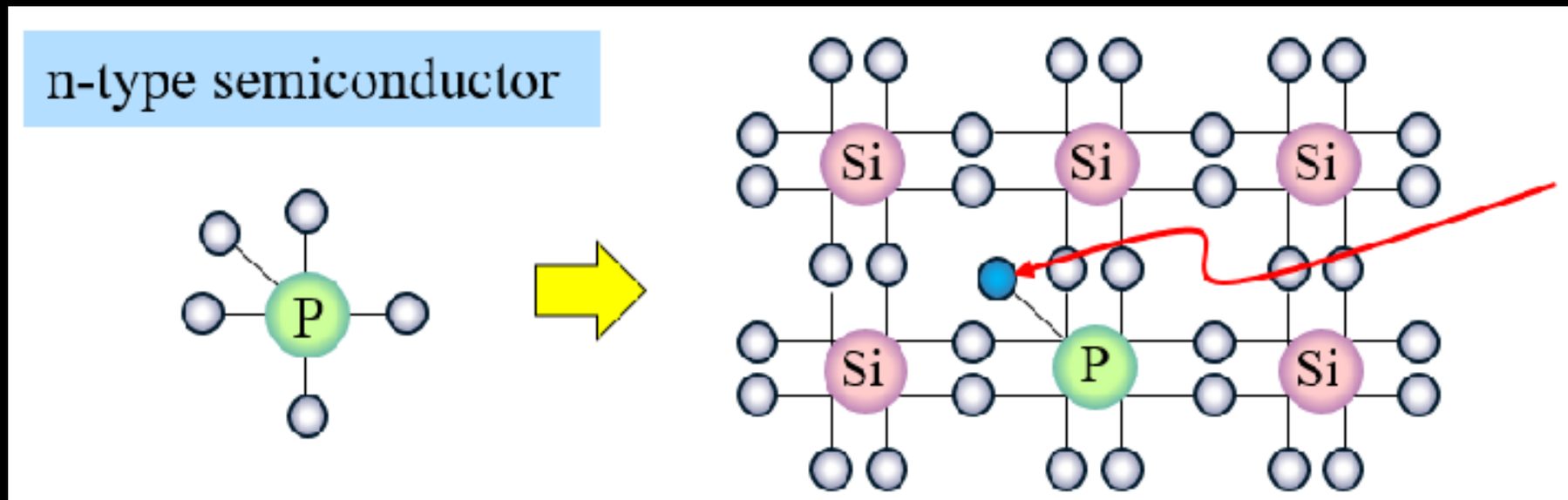
- Atoms have a “preferred” number of electrons in the outer ring
- Silicon have 4 electrons in the outer layer while 8 gives the most stable structure
- In crystal form, atoms “share” their outer electrons



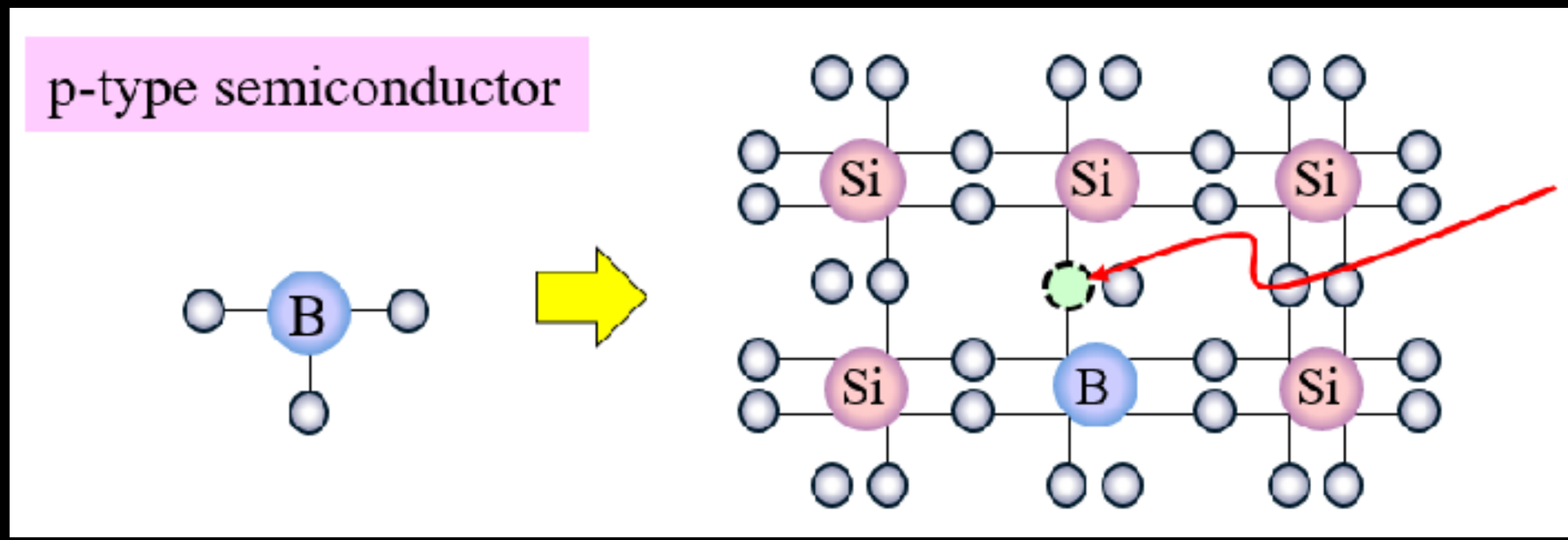
Semiconductor Doping

Integrated Circuit Design

- Phosphorus has 5 electrons in the outer layer
- Inserting Phosphorus atoms into the crystal structure gives rise to mobile electrons

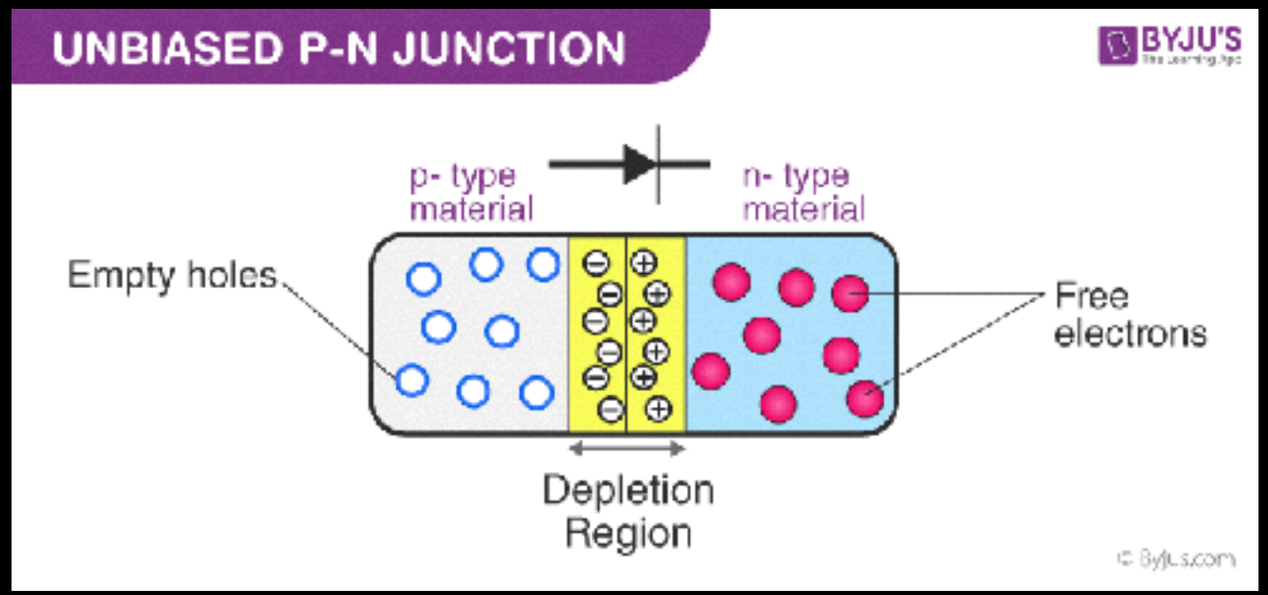


- Boron has 3 electrons in the outer layer
- Inserting Boron atoms into the crystal structure gives rise to mobile “holes”

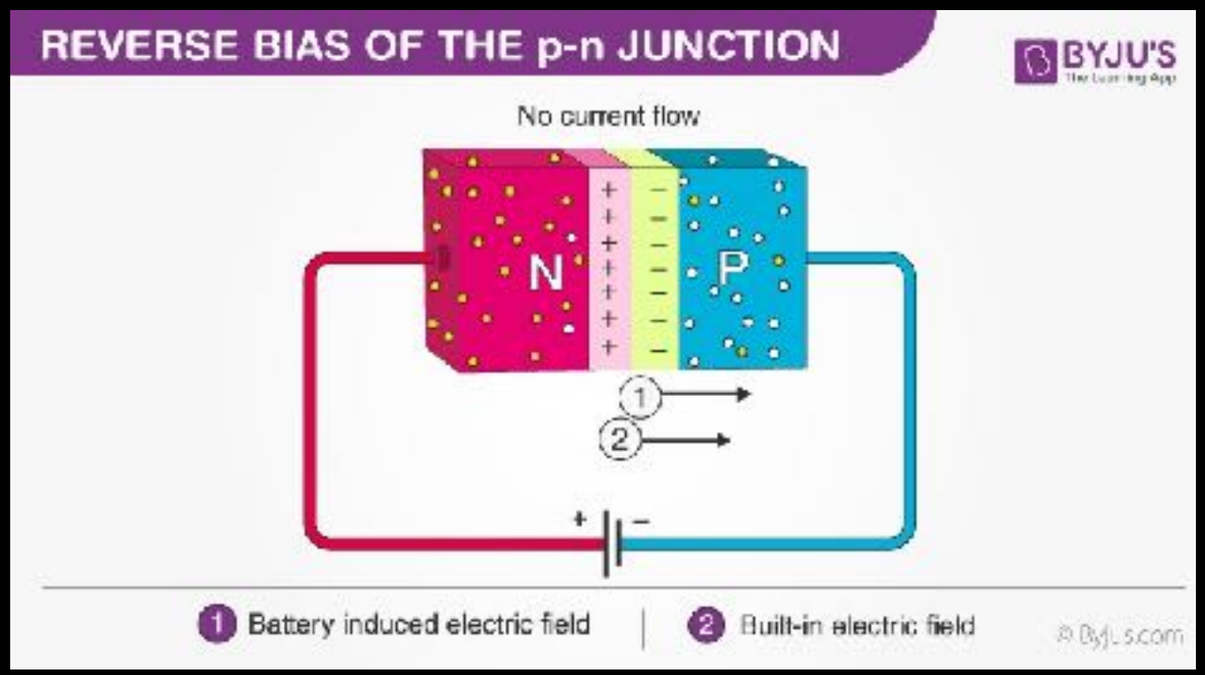


The P-N Junction

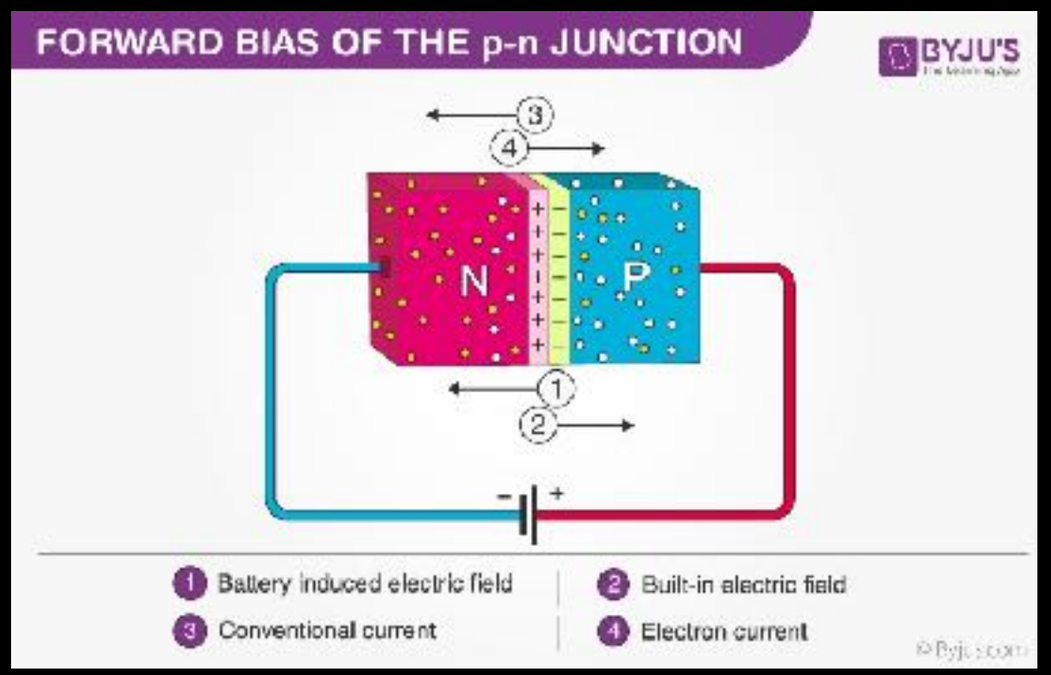
Integrated Circuit Design



electron distribution - electric field



electric field stops current flow



electric field allows current flow

Basic electronic components

Integrated Circuit Design

Resistor: A “drag” on electron flow. Causes voltage drop as electricity flows. (narrow pipe)

Capacitor: buffer, can store power (pipe with rubber membrane)

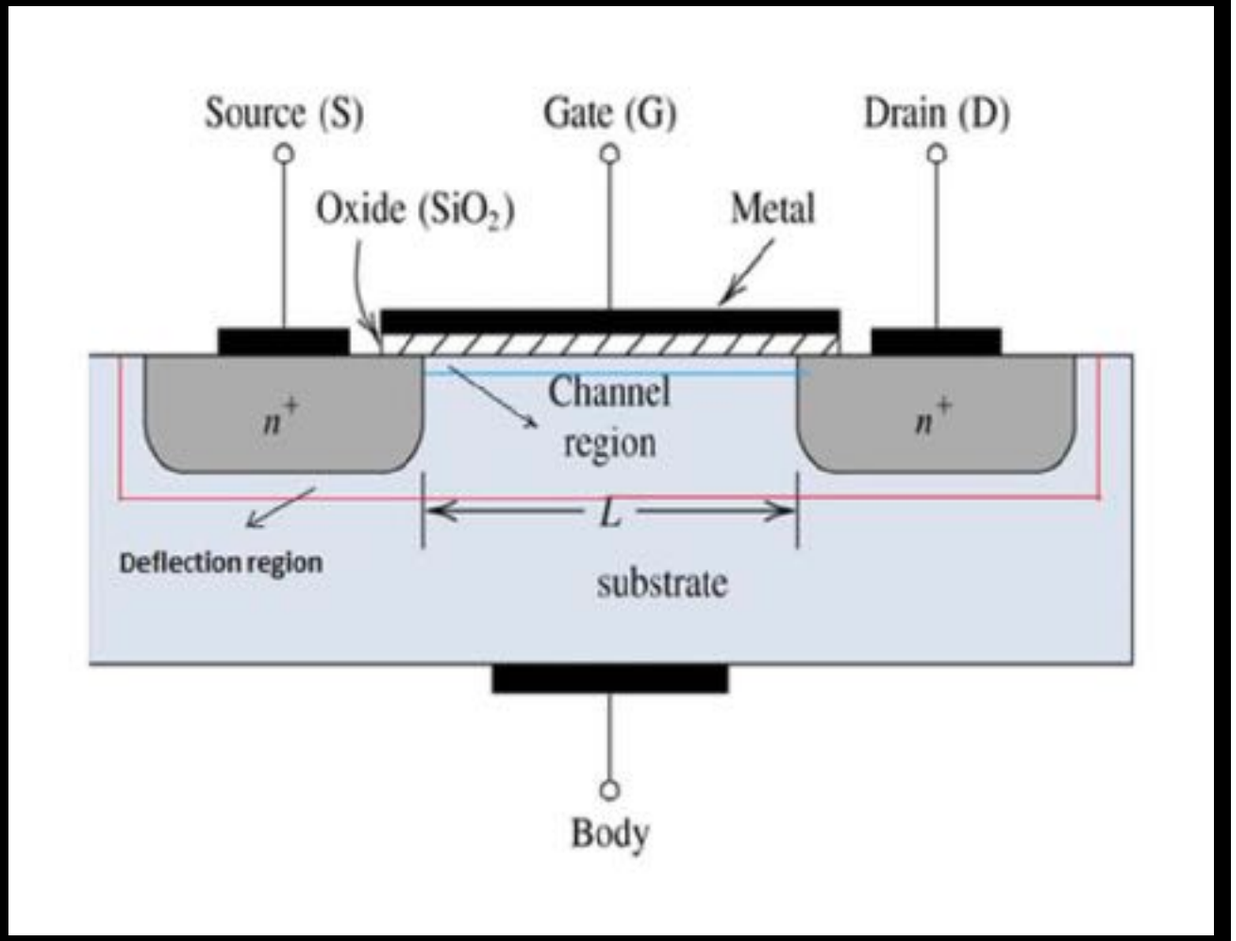
Diode: One way only transmission (one way valve

Transistor: voltage operated valve - turns on and off the flow of electricity. (tap)

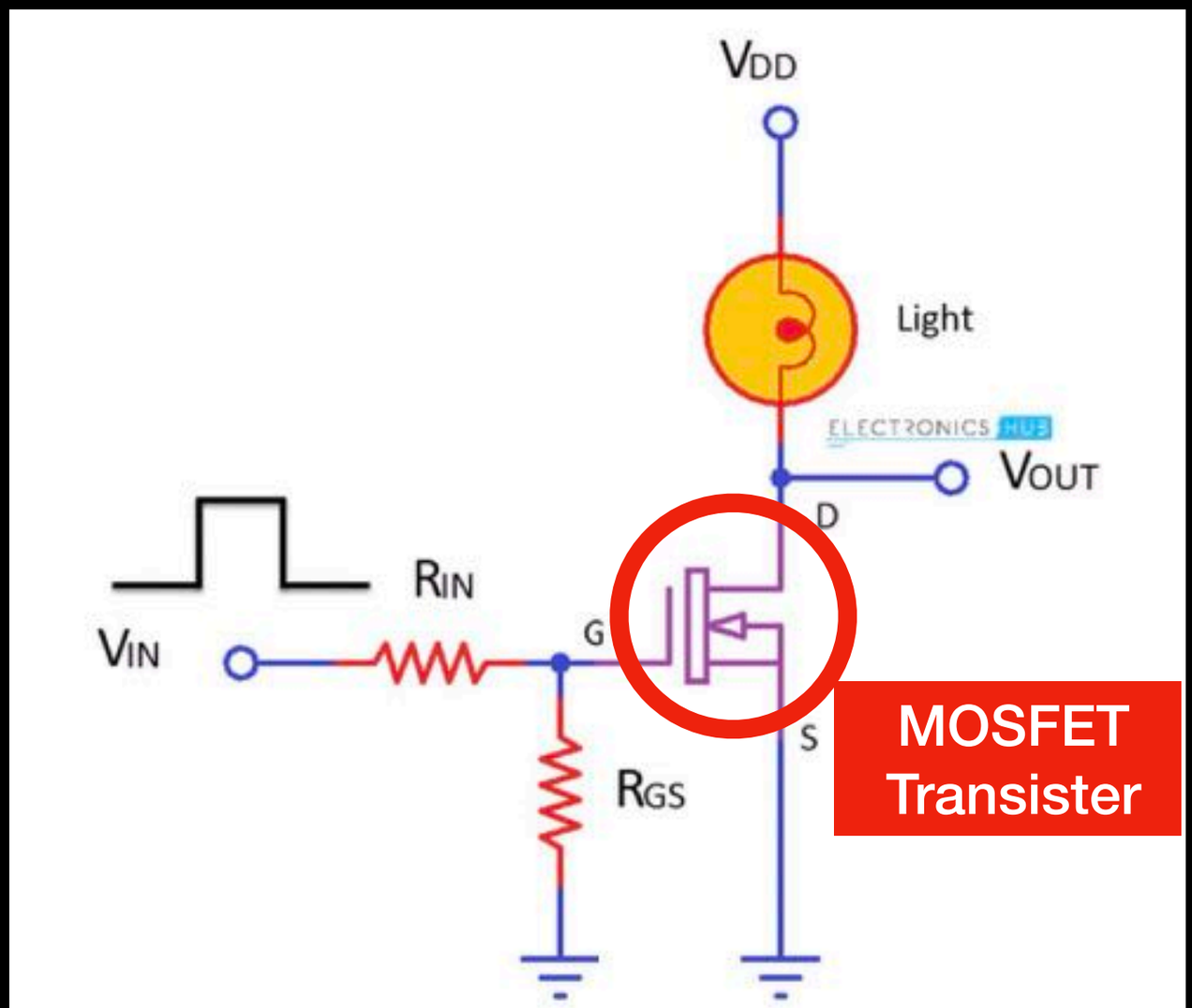
Transistor

Integrated Circuit Design

MOSFET Transistor
(Metal Oxide Semiconductor
Field Effect Transistor)



Used as a switch



Logic Gates

Integrated Circuit Design

AND
NAND = Not AND
NOR = Not OR
XOR = Exclusive OR
AOI = AND or INVERT

AND

INPUT		OUTPUT
A	B	
0	0	0
1	0	0
0	1	0
1	1	1

OR

INPUT		OUTPUT
A	B	
0	0	0
1	0	1
0	1	1
1	1	1

XOR

INPUT		OUTPUT
A	B	
0	0	0
1	0	1
0	1	1
1	1	0

NAND

INPUT		OUTPUT
A	B	
0	0	1
1	0	1
0	1	1
1	1	0

NOR

INPUT		OUTPUT
A	B	
0	0	1
1	0	0
0	1	0
1	1	0

XNOR

INPUT		OUTPUT
A	B	
0	0	1
1	0	0
0	1	0
1	1	1

706 × 8

Logic Gates (AND, NAND, NOR, AOI)

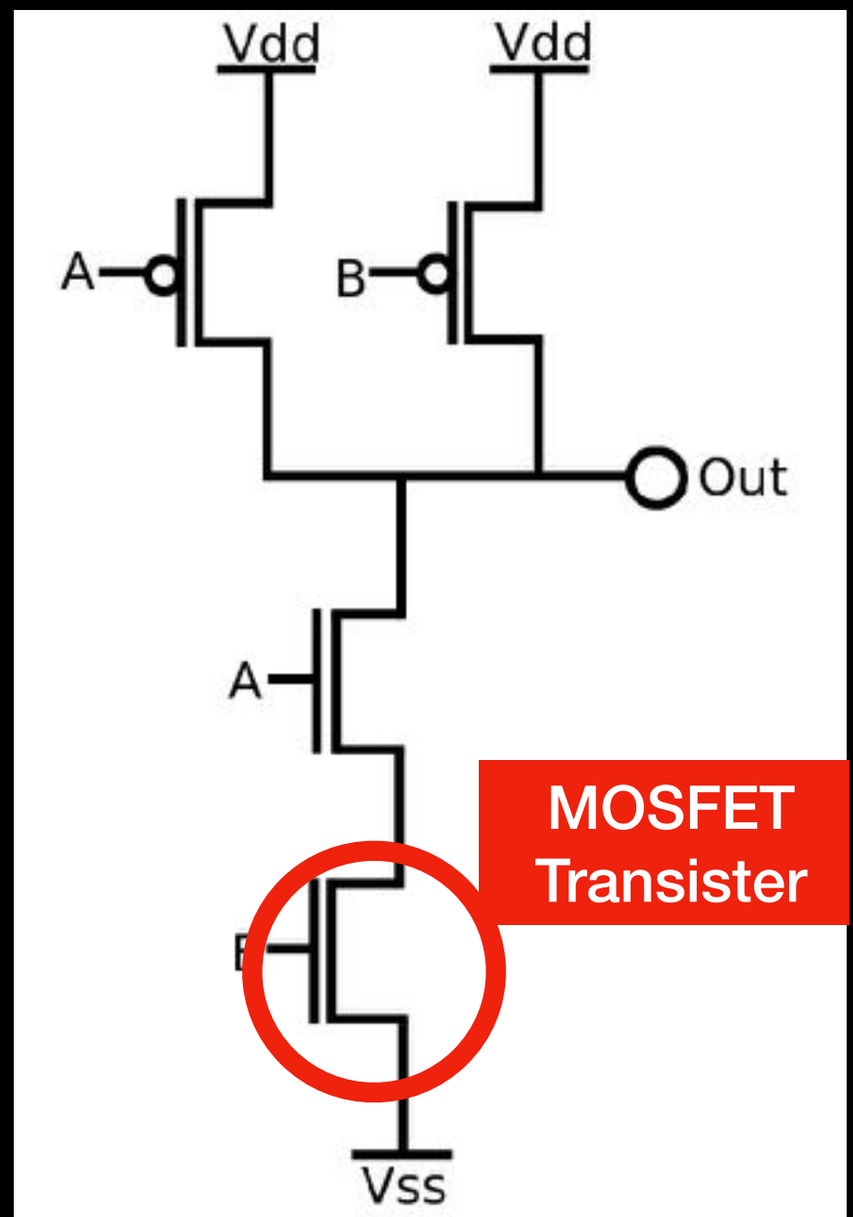
Integrated Circuit Design

NAND symbol &
logic table

NAND gate

A	B	Output
0	0	1
0	1	1
1	0	1
1	1	0

NAND circuit



Digital System building blocks

Integrated Circuit Design

adder:	**Sums binary numbers**
memory:	**Stores binary number**
flip-flop:	**typically toggle output on pulse**
shift register:	**typically used to convert serial to parallel data**
counter:	**typically input clock pulses & output count**

Full adder (carry in / carry out)

Integrated Circuit Design

Binary

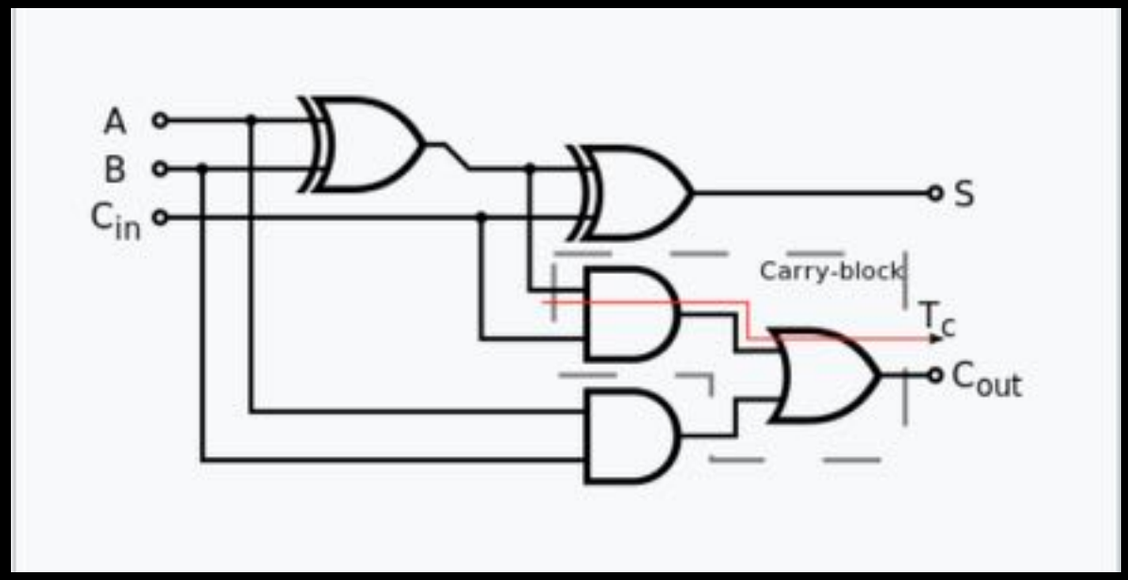
Decimal number	Binary number
0	0
1	1
2	10
3	11
4	100
5	101
6	110
7	111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

Adder truth table (C = Carry)

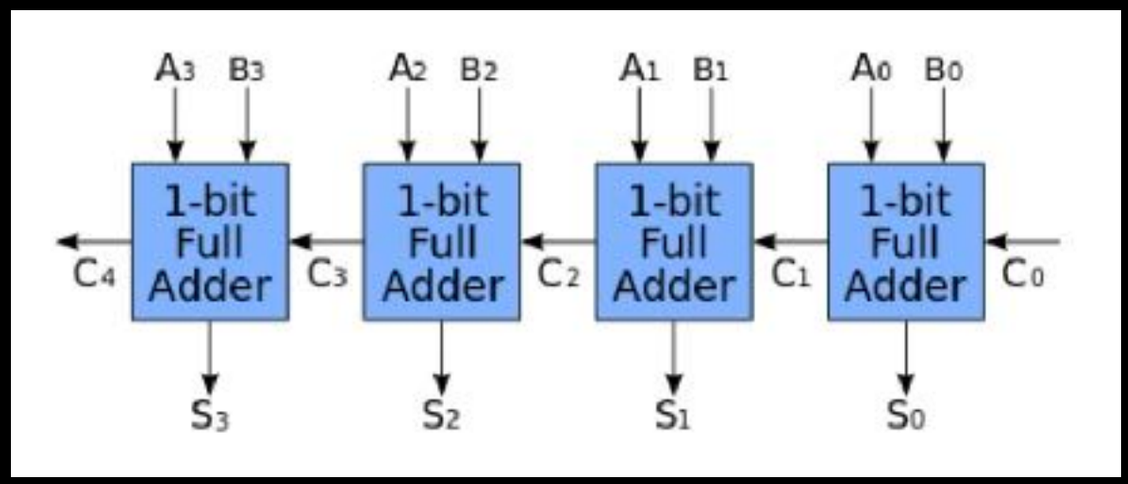
Inputs			Outputs	
A	B	C_{in}	C_{out}	S
0	0	0	0	0
0	0	1	0	1
0	1	0	0	1
0	1	1	1	0
1	0	0	0	1
1	0	1	1	0
1	1	0	1	0
1	1	1	1	1

1 bit Full Adder Logic

2 XOR gates, 2 AND gates, 1 OR gate.



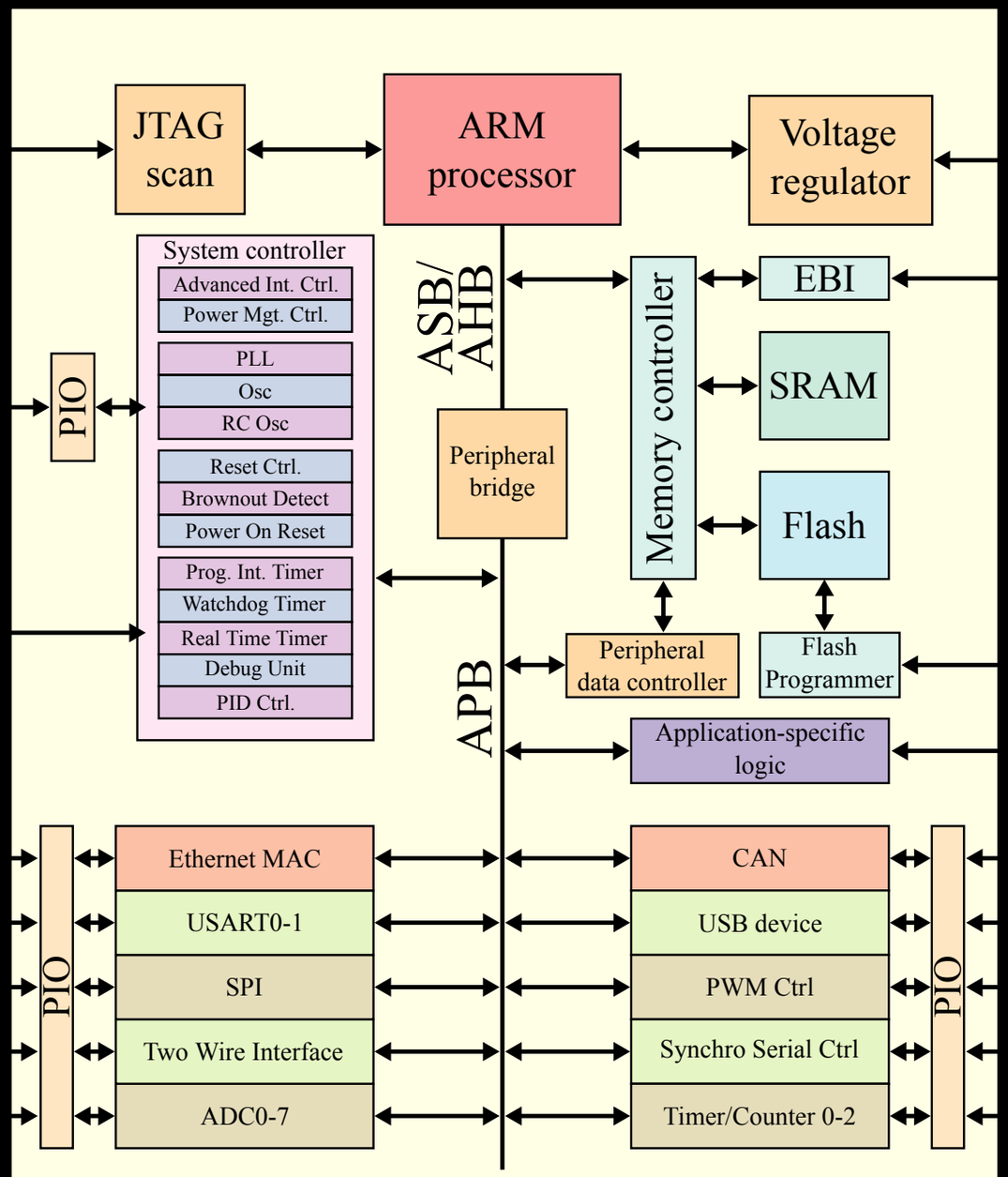
4 bit adder



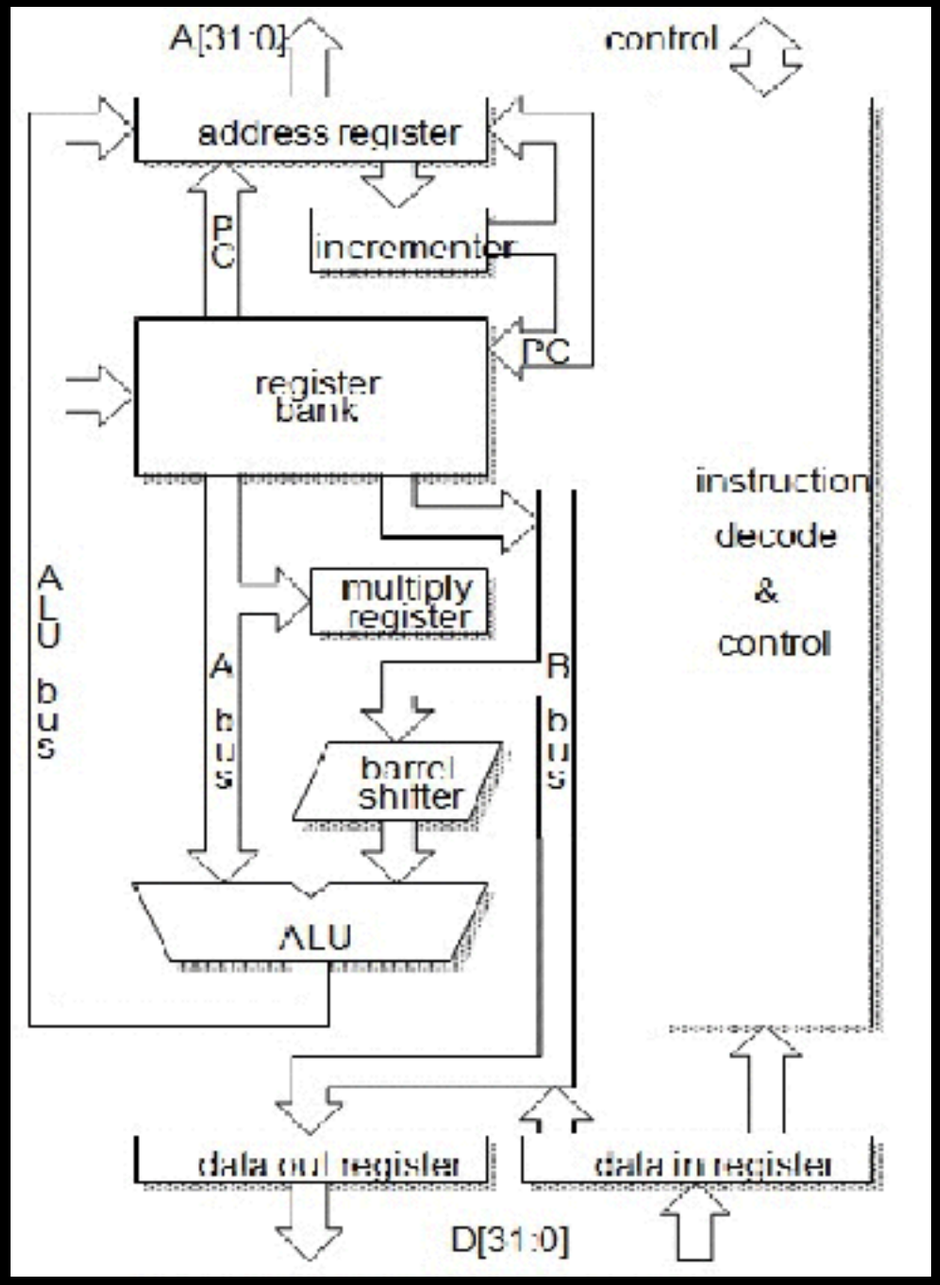
ARM Processor Architecture

Integrated Circuit Design

ARM Integrated Circuit

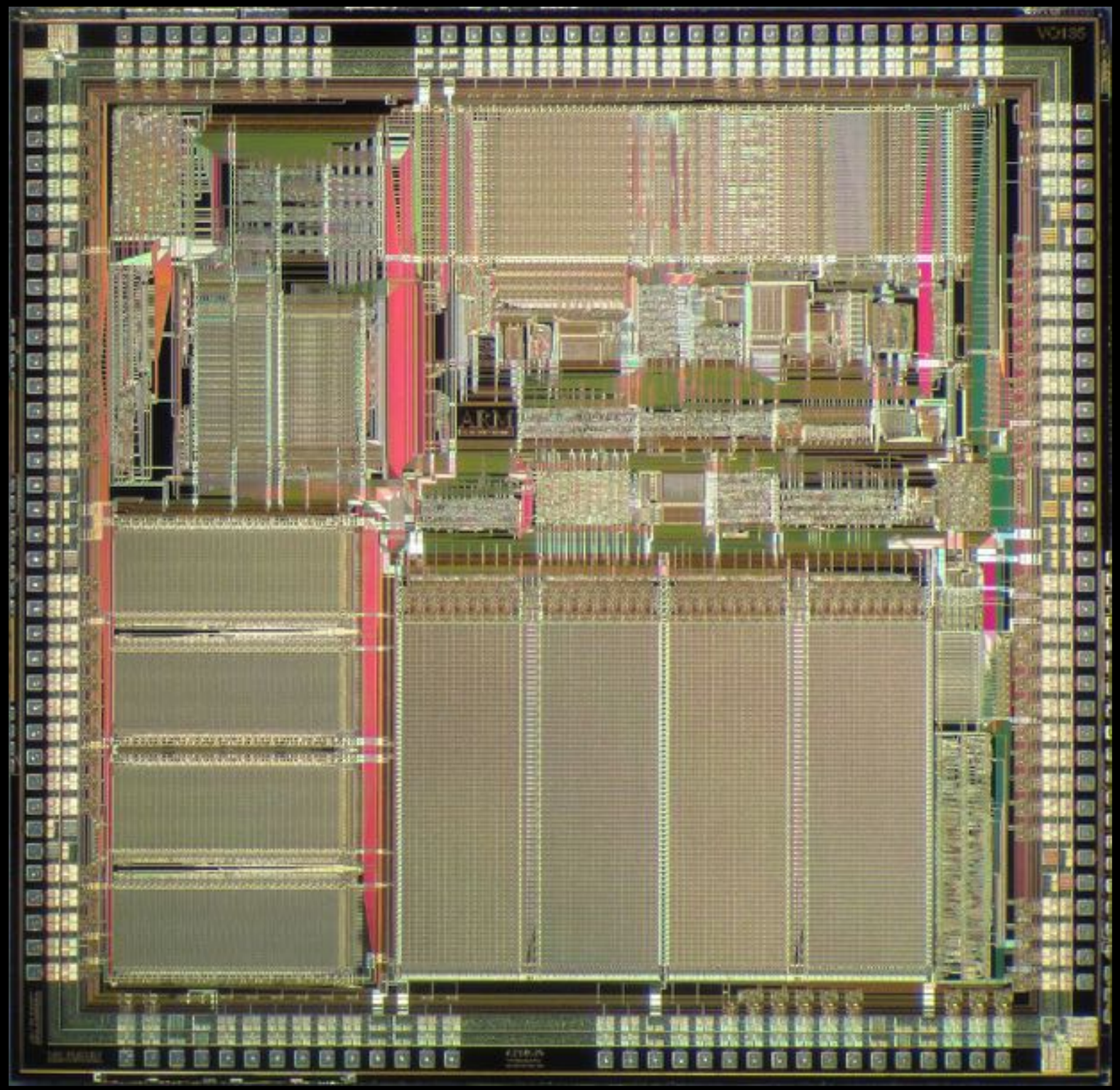


ARM processor



ARM Processor

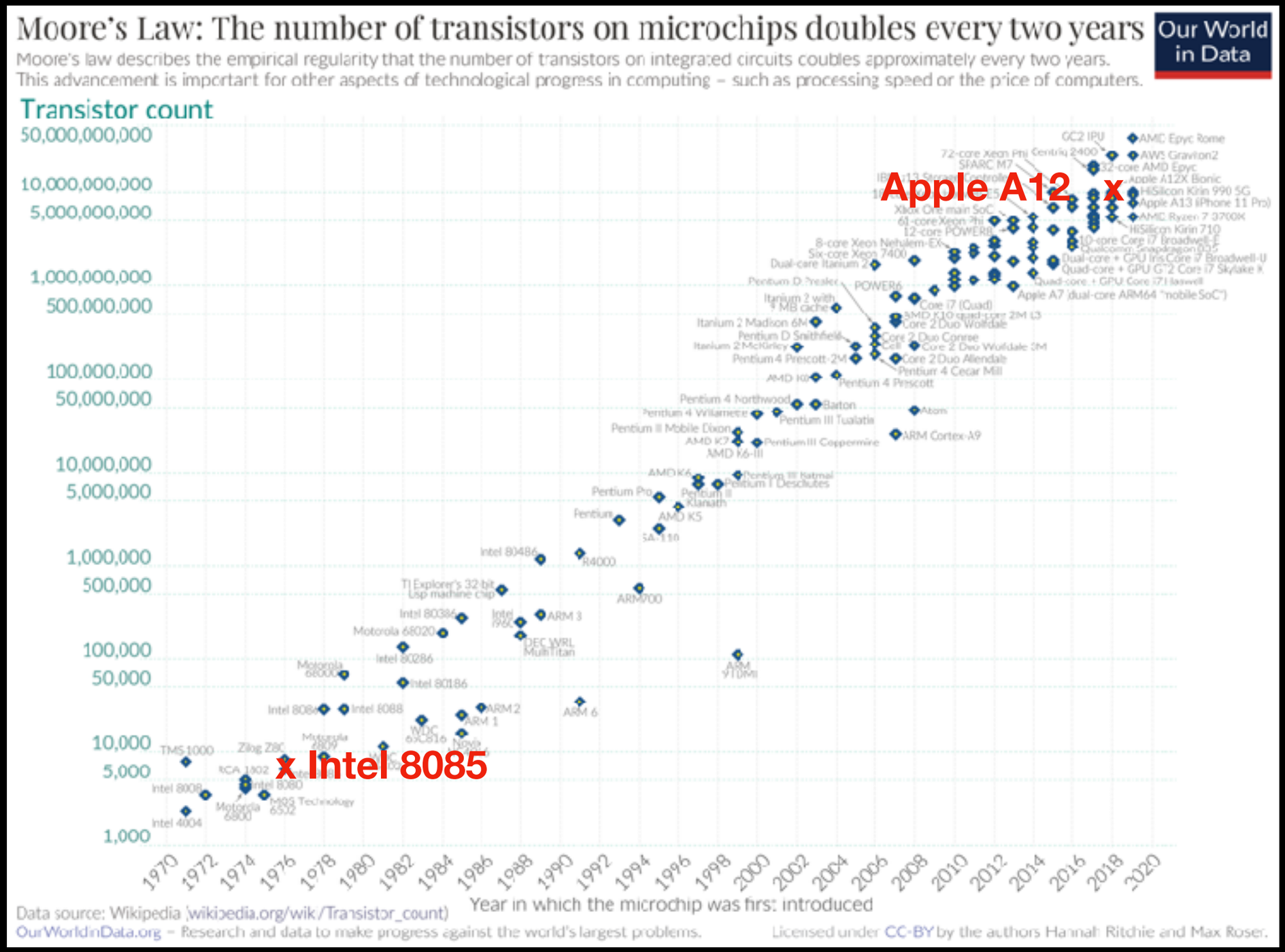
Integrated Circuit Design



Processor Transistor Count

Integrated Circuit Design

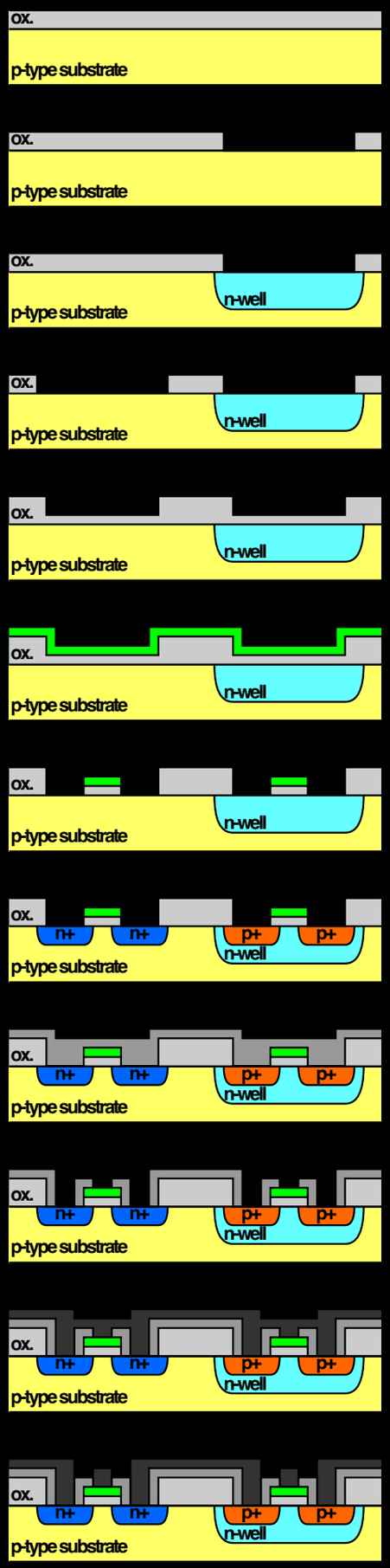
MOSFET scaling (process nodes)	
20 μm	1968
10 μm	1971
6 μm	1974
3 μm	1977
1.5 μm	1981
1 μm	1984
800 nm	1987
600 nm	1990
350 nm	1993
250 nm	1996
180 nm	1999
130 nm	2001
90 nm	2003
65 nm	2005
45 nm	2007
32 nm	2009
28 nm	2010
22 nm	2012
14 nm	2014
10 nm	2016
7 nm	2018
5 nm	2020
3 nm	2022
2 nm	~ 2024



Fabrication Process

Integrated Circuit Design

Simplified process of fabrication of a CMOS inverter on p-type substrate in semiconductor micro fabrication.



1. Grow field oxide
2. Etch oxide for pMOSFET
3. Diffuse n-well
4. Etch oxide for nMOSFET
5. Grow gate oxide
6. Deposit polysilicon
7. Etch polysilicon and oxide
8. Implant sources and drains
9. Grow nitride
10. Etch nitride
11. Deposit metal
12. Etch metal

Video shown in Meeting

Integrated Circuit Design

- https://www.computerhistory.org/revolution/digital-logic/12/288/2220
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Questions?