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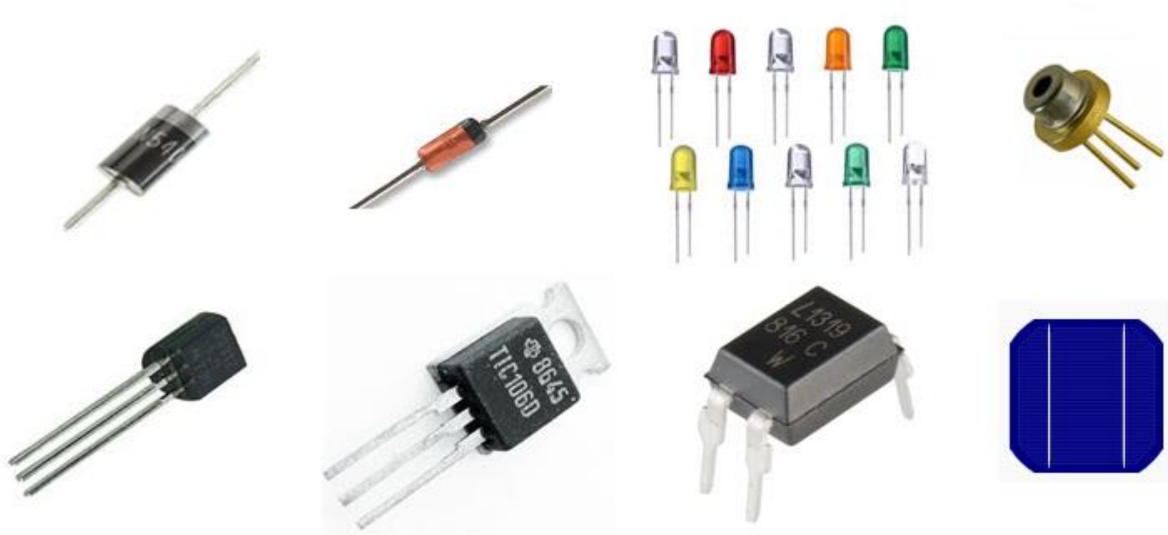
XMUT204 Electronic Design

Lecture 1b – Microfabrication of Semiconductor Devices

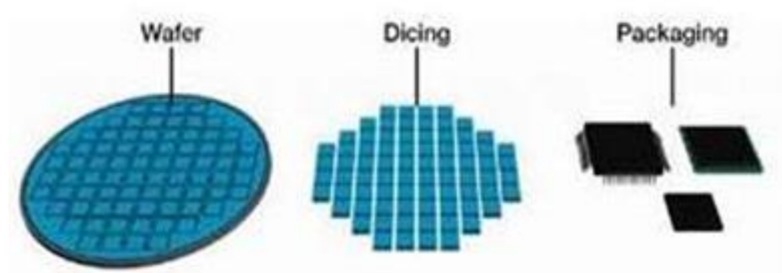
Overview

1. Microfabrication of semiconductor devices.
2. Materials for semiconductor devices.
3. Types of semiconductor devices.
4. Manufacturing of semiconductor devices.

1. Microfabrication of Semiconductor Devices

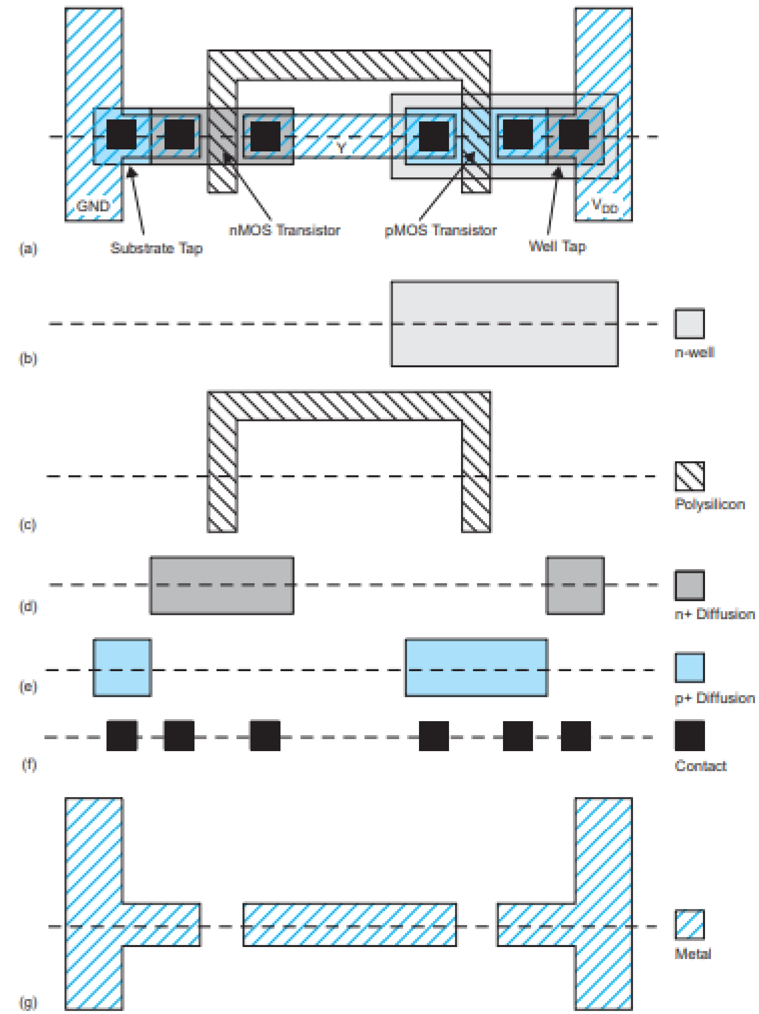


- Chips of the semiconductor devices are fabricated using a set of chemical and electrochemical processes which is called microfabrication.



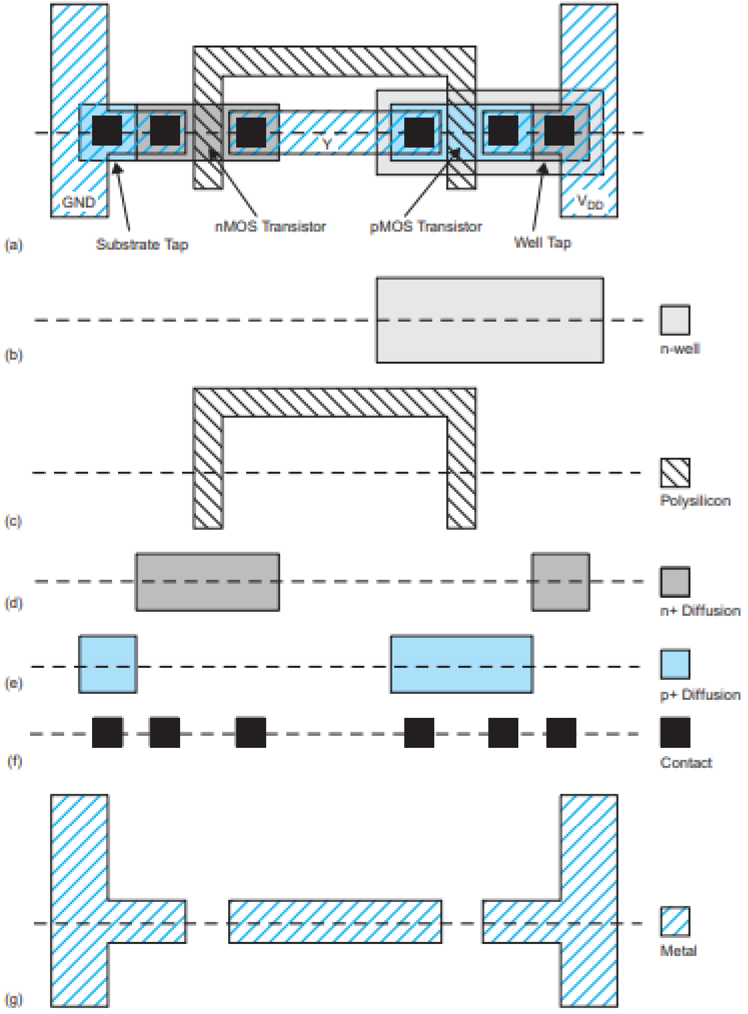
1. Microfabrication of Semiconductor Devices (cont.)

- Basic steps of microfabrication:
  a. Oxidize for Si and O_2 to react and become SiO_2.
  b. Apply photoresist for lights passing through where the well should be.
  c. Remove photoresist with mask.
  d. HF acid eats oxide but not photoresist.

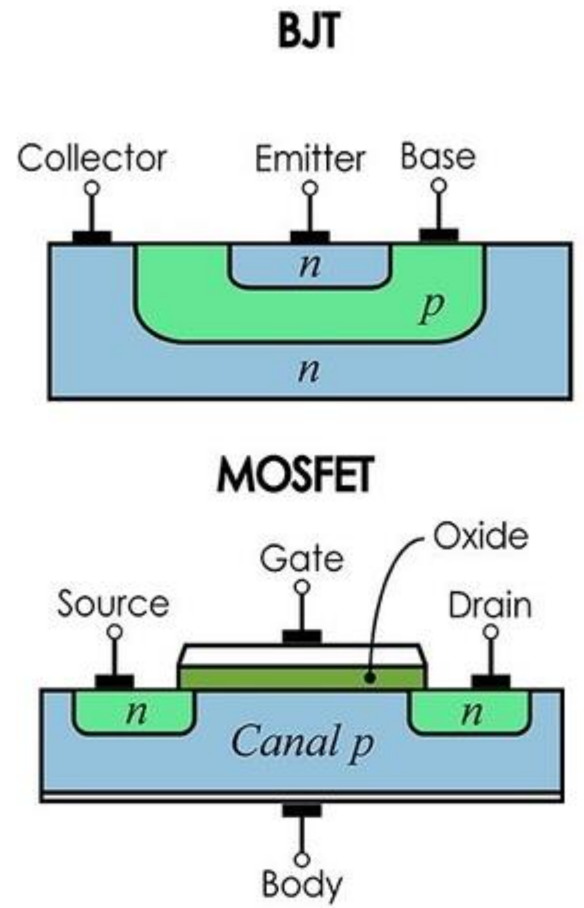


1. Microfabrication of Semiconductor Devices (cont.)

- Basic steps of microfabrication:
  - e. Pirana acid eats photoresist.
  - f. Ion implantation (diffusion, wells of dopants).
  - g. Vapour deposition (polysilicon layer).
  - h. Plasma etching (metal of contacts and bridges).



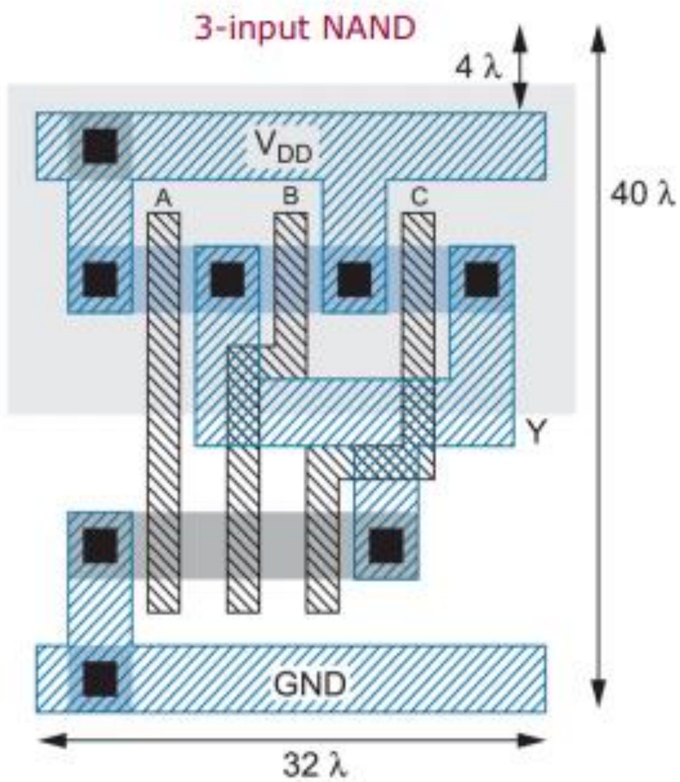
1. Microfabrication of Semiconductor Devices (cont.)

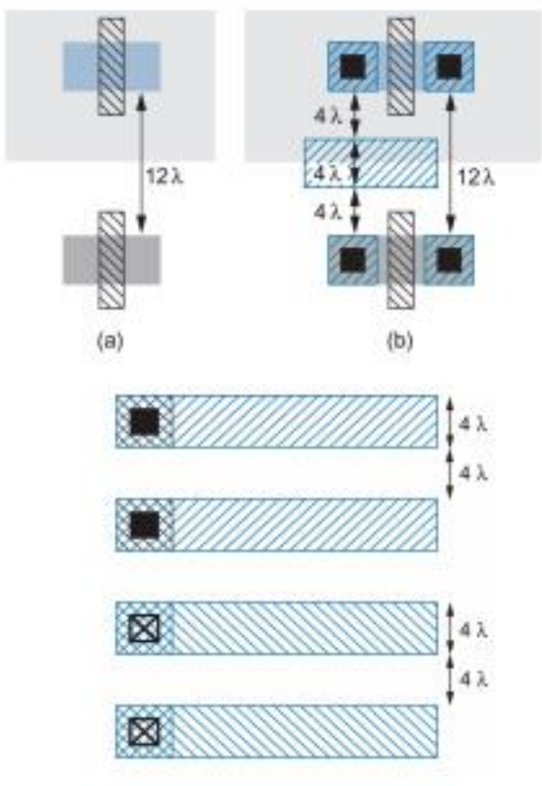


- All semiconductor devices are manufactured as a series of very thin, stacked layers on some substrate material (normally silicon dioxide).
- Each layer is created from a different mask, and different layers can be made of different materials.
- The masks used to create each layer are basically like a 1-bit bitmap: they have a grid of squares (similar to pixels) that are either "on" or "off".

1. Microfabrication of Semiconductor Devices (cont.)

- Layout of the mask of semiconductor devices.



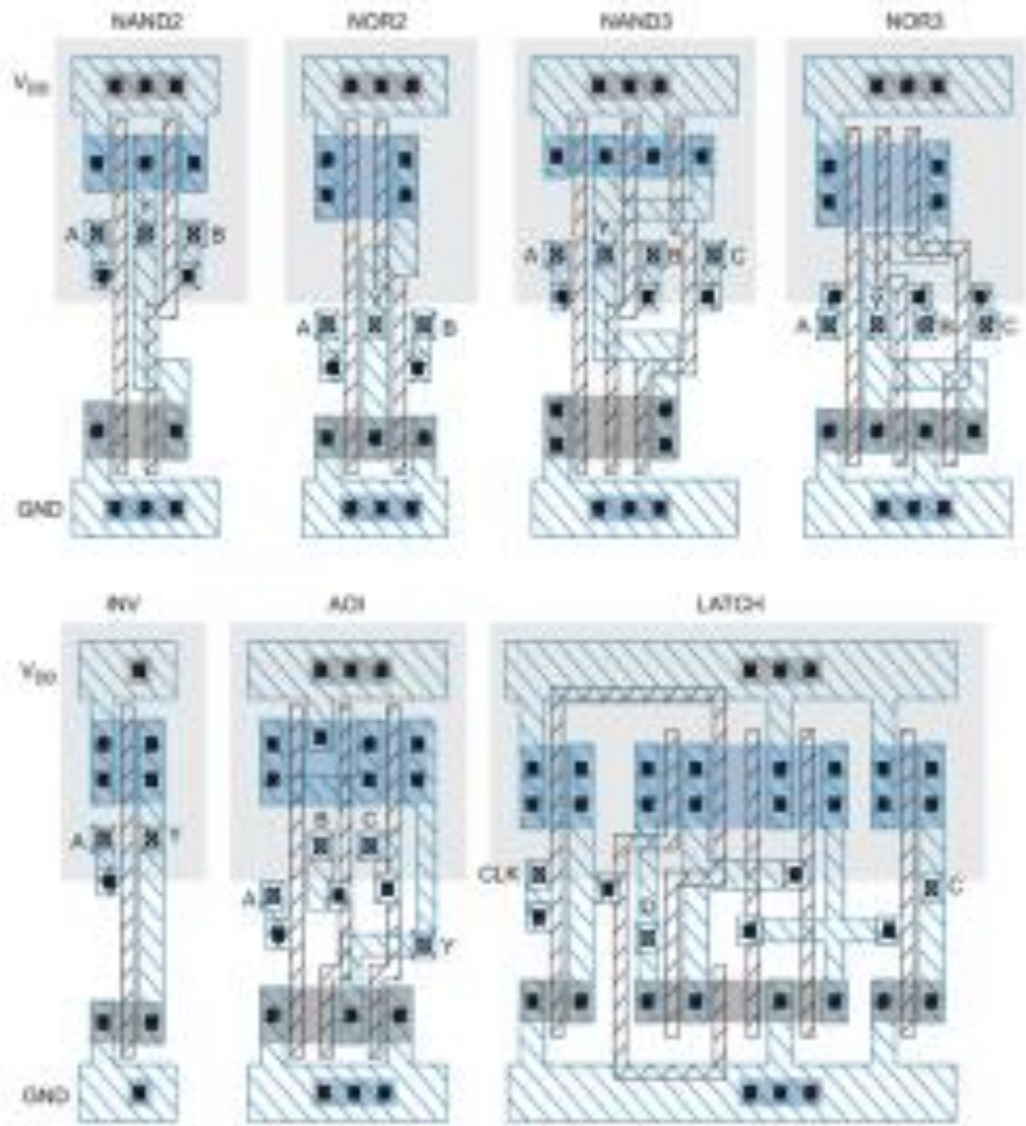


1. Microfabrication of Semiconductor Devices (cont.)

- The process size defines lambda, which is how large each of those squares will be on the chip.
- The properties of semiconductor devices, like other electronic devices, are based on the relative sizes of their dimensions.
- Functionalities, features and characteristics of the semiconductor device are built up from the smaller units on the chip i.e. a simple diode is made up of a unit made of p-n materials and a simple transistor is made up of pnp or npn materials.
- Larger or more complex functionalities are simply combinations of these smaller units.

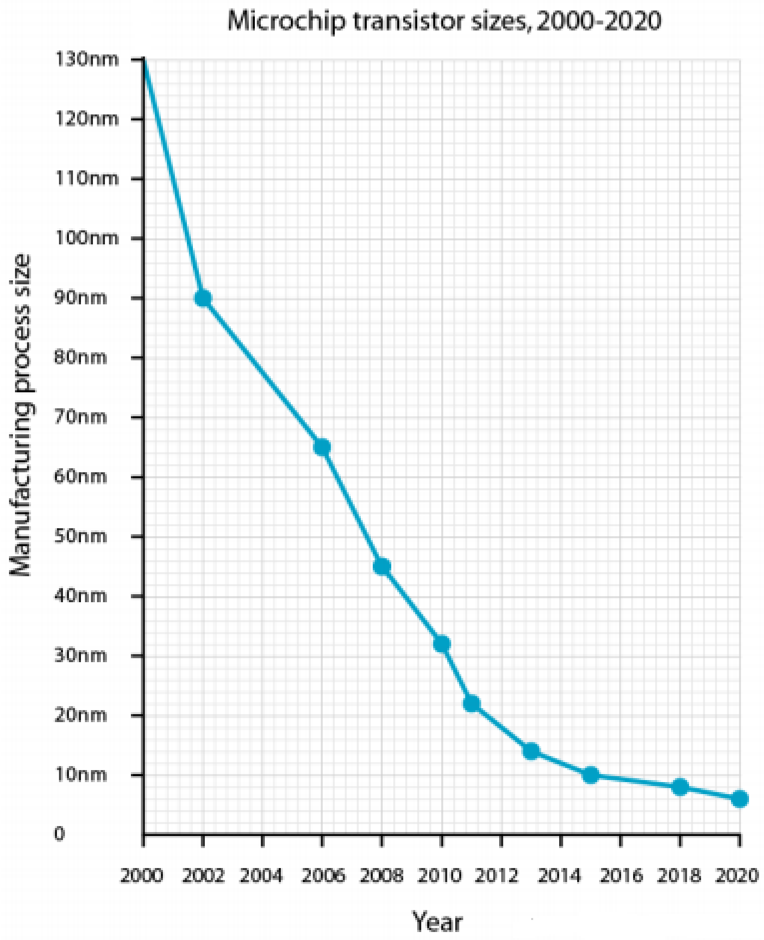
1. Microfabrication of Semiconductor Devices (cont.)

- Smaller groups of functionalities combined to make bigger/complex functionalities.
- Elements cell libraries (snap together) i.e. gates, latch, etc.



1. Microfabrication of Semiconductor Devices (cont.)

- Trend of the sizes of manufacturing process of integrated circuit.
- Note that in year 2000, the size of a transistor is 130 nm.
- In year 2020, it is less than 10 nm.

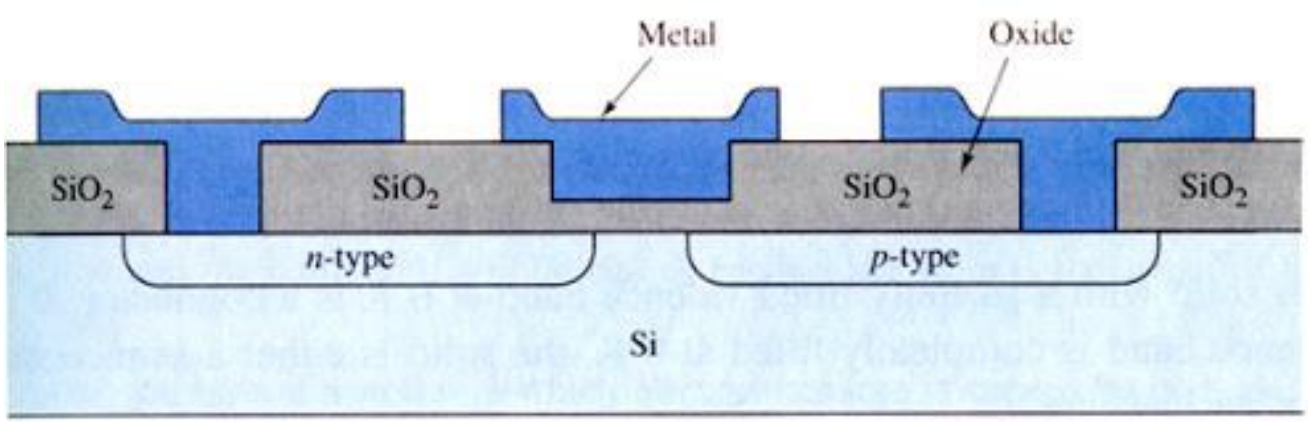


2. Materials for Semiconductor Devices

- *Insulators* – Materials which block or resist the flow of electric current. An example of an insulator is Silicon Dioxide (SiO_2) which has a resistivity of $10^{14} – 10^{16}$ Ω-cm.
- *Conductors* – Materials which readily support the flow of electric current. An example of a conductor is Aluminum which has a resistivity of 2.7×10^{-6} Ω-cm.
- *Semiconductors* – A material which can be made to act as an insulator or act as a conductor. An example of a semiconductor is Silicon with an intrinsic resistivity of 2.3×10^5 Ω-cm and doped Silicon can have resistivity down to 1×10^{-4} Ω-cm.

2. Materials for Semiconductor Devices (cont.)

- Materials in a given semiconductor device i.e. MOS transistor:
  a. Metal – Conductor material.
  b. SiO_2 – Insulator material.
  c. n-type and p-type doped Si - Active components material.



2. Materials for Semiconductor Devices (Insulator)

Insulators:

- Silicon Dioxide (SiO_2) – The most common insulator in Silicon Integrated Circuits. Silicon Dioxide is a good barrier materials with excellent electrical properties.
- Silicon Nitride (Ni_3N_4) – Frequently used as a barrier or final passivation layer for Silicon Integrated Circuits. Silicon Nitride is an excellent barrier, although Silicon Nitride exhibits too much stress to be in direct contact with Silicon.

2. Materials for Semiconductor Devices (Conductor)

Conductor:

- Aluminium – Most frequently used conductor for Silicon Integrated Circuits.
- Titanium, Cobalt, Nickel and Platinum – Metals commonly used to form silicide contacts to Silicon.
- Tungsten – Used for plug filling.
- Titanium Nitride – Used as a barrier layer to prevent metal from interacting or to prevent metals and silicon from interacting.
- Copper – Now used as a conductor.

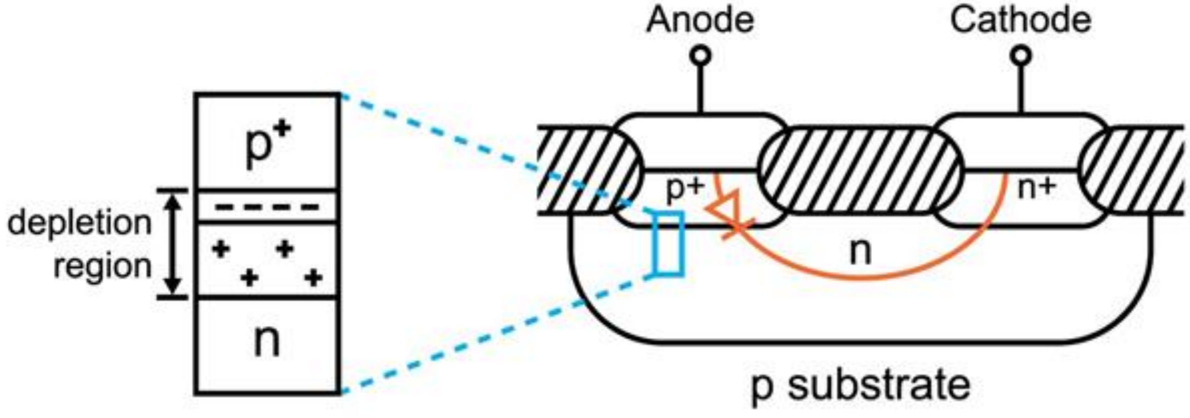
2. Materials for Semiconductor Devices (Active Components)

Active components:

- These are such as diodes and transistors can be used to control the direction of current flow.
- PN junction diodes are formed when there is a region of n-type semiconductor adjacent to a region of p-type semiconductor.
- A difference in charge at the PN junction creates a depletion region that results in a barrier voltage that must be overcome before a diode can be operated.
- A bias voltage can be configured to have a reverse bias, with little or no conduction through the diode, or with a forward bias, which permits current flow.

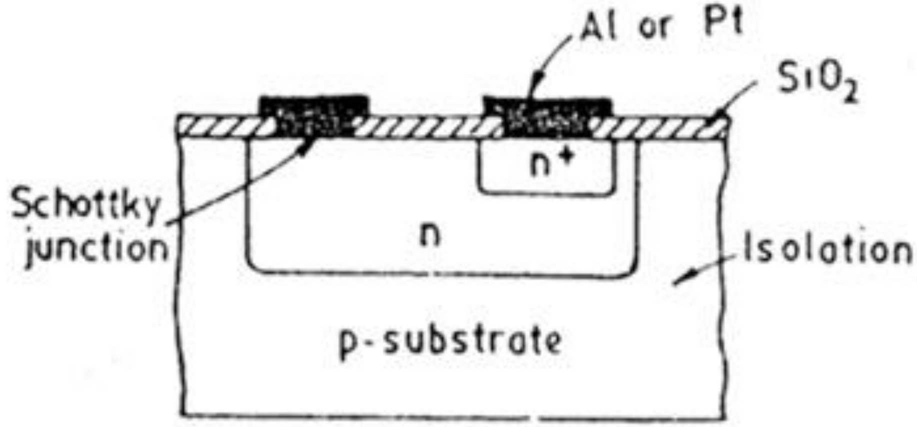
3. Types of Semiconductor Devices (Diode)

- A diode is formed when p-type semiconductor material is integrated with a lightly doped n- type semiconductor material.



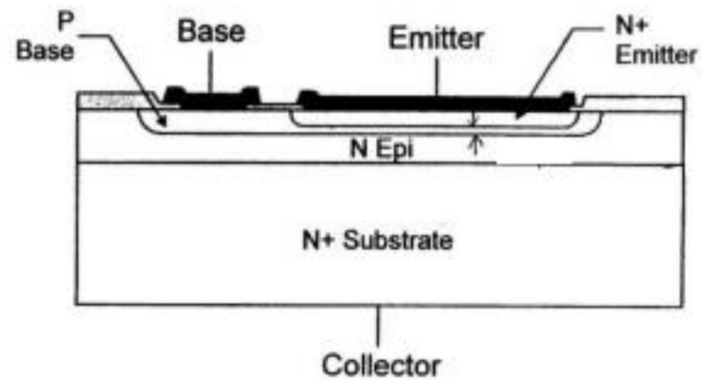
3. Types of Semiconductor Devices (Schottky Diode)

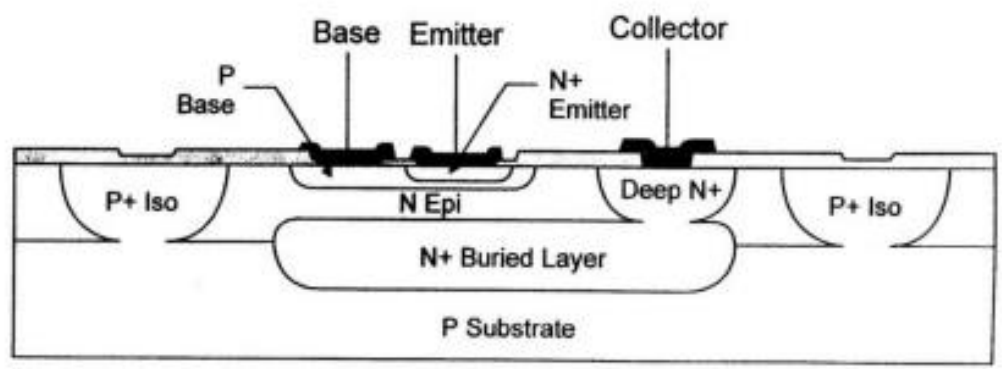
- A Schottky diode is formed when metal is brought in contact with a lightly doped n- type semiconductor material.
- This diode is used in faster and more power efficient analogue electronic circuits.



3. Types of Semiconductor Devices (BJT)

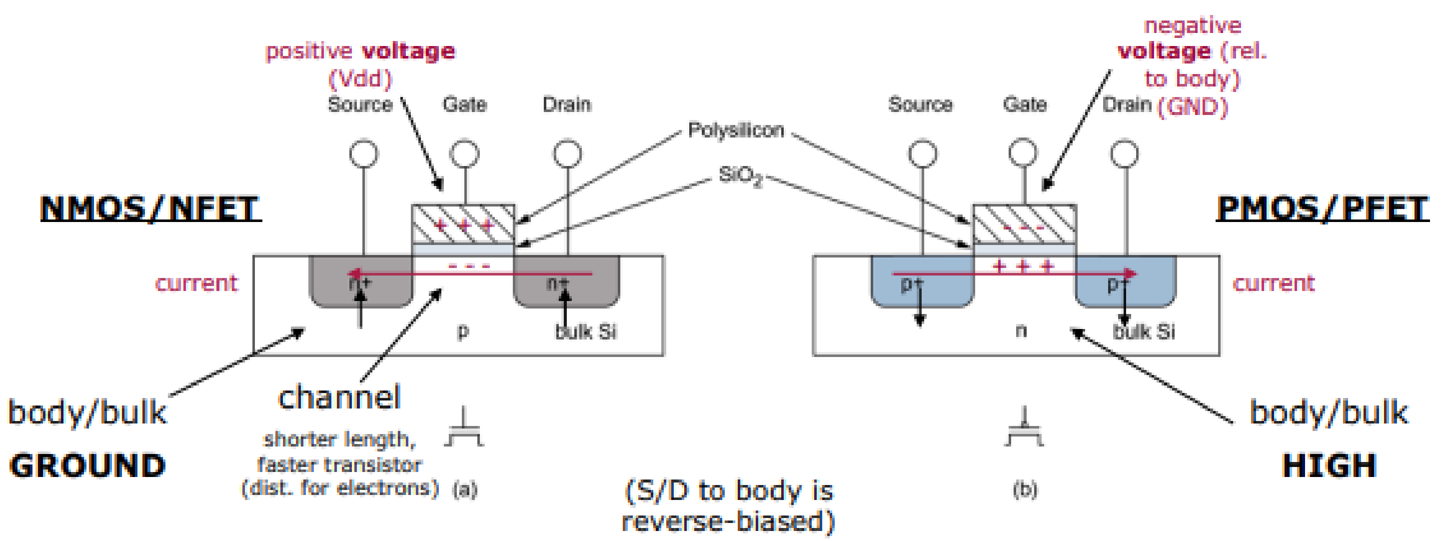
- The bipolar junction transistor (BJT) has two/three electrodes and two pn junctions.
- A BJT is configured as an npn or pnp transistor and biased for conduction mode.
- It is a current amplifying device.





3. Types of Semiconductor Devices (MOSFET)

- The field-effect transistor (FET), a voltage-amplifying device, is more compact and power efficient than BJT devices.
- A thin gate oxide located between the other two electrodes of the transistor insulates the gate on the MOSFET.



3. Types of Semiconductor Devices (MOSFET - cont.)

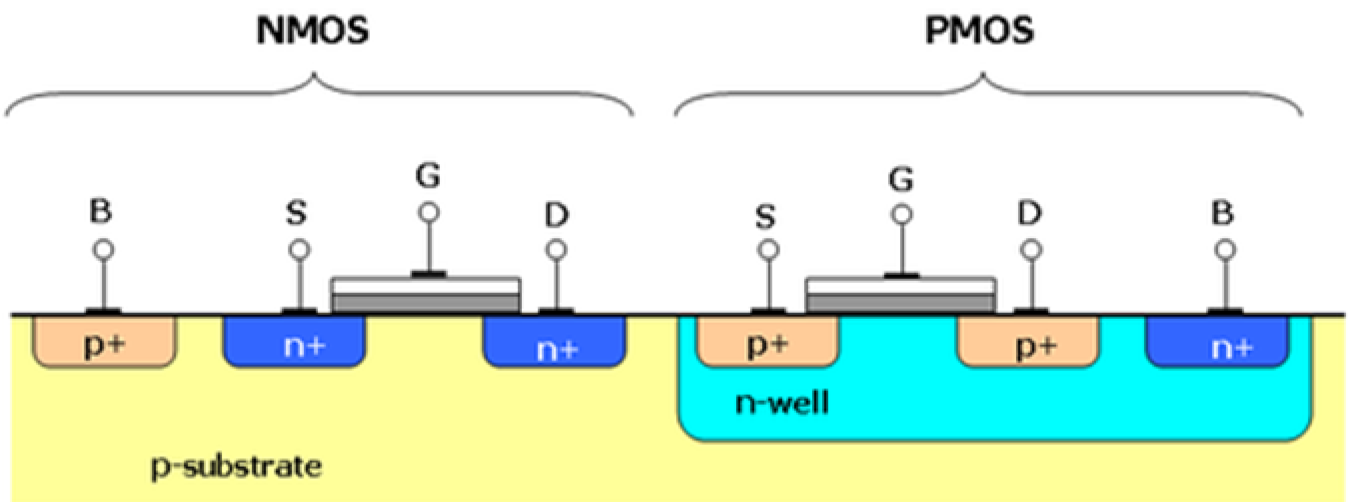
- There are two categories of MOSFETs, nMOS (n-channel) and pMOS (p-channel), each which is defined by its majority current carriers.
- There is a biasing scheme for operating each type of MOSFET in conduction mode.
- Biasing provided necessary voltage or current (depending on the types of transistor) to sufficiently turn on and off the transistor.
- We will cover this biasing topic in subsequent topics in the course for BJT and FET type transistors.

3. Types of Semiconductor Devices (BJT vs. MOSFET)

- MOS is simpler to produce than Bipolar. The minimum number of masks to make Bipolar is seven, and the minimum number of masks to make MOS is five.
- MOS requires less drive current. MOS devices are voltage controlled with high impedance inputs. Bipolar devices are current controlled with low impedance input.
- MOS dissipates less power. This is particularly true of CMOS logic which only draws power when switching states.
- MOS devices are simpler to isolate and can be packed more tightly. As we have seen, MOS has become the dominant technology.

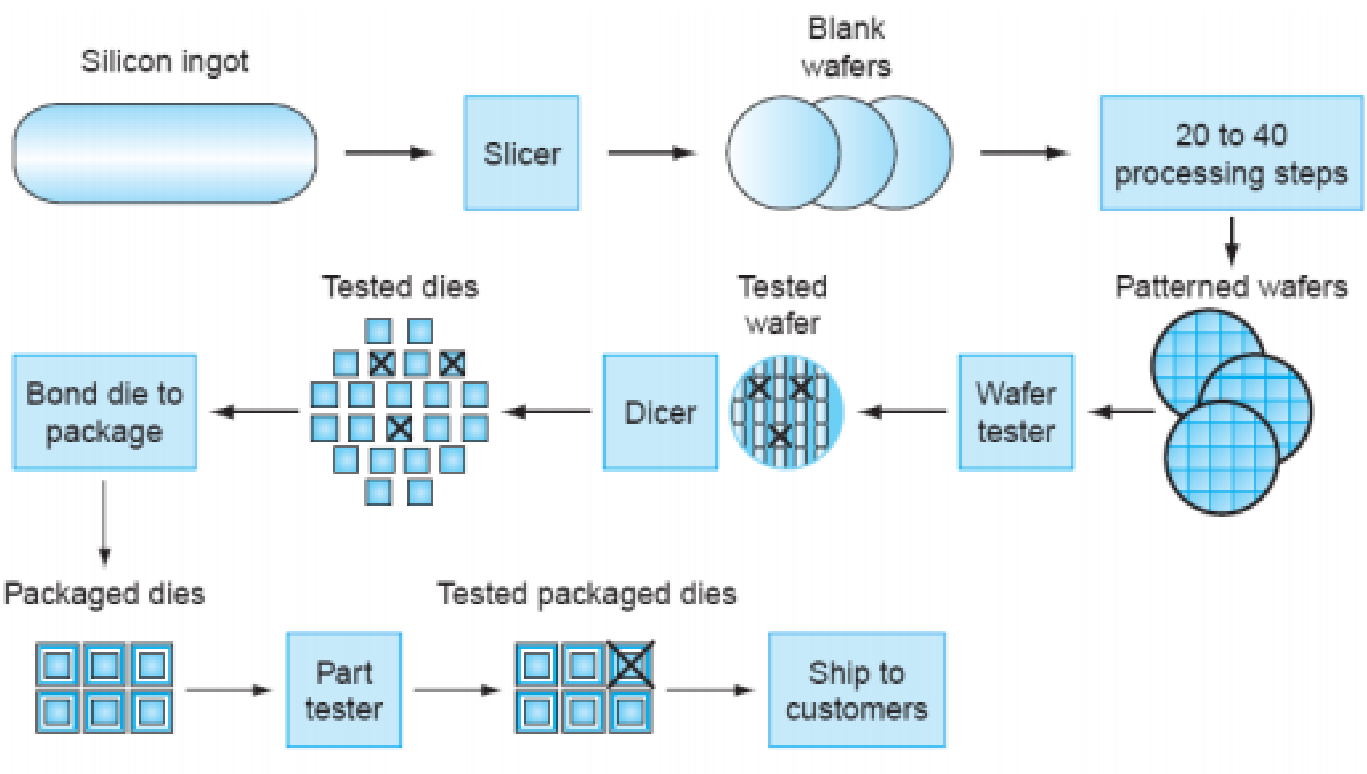
3. Types of Semiconductor Devices (CMOS)

- CMOS is a type of MOSFET (metal–oxide–semiconductor field-effect transistor) fabrication process that uses complementary and symmetrical pairs of p-type and n-type MOSFETs for logic functions.
- CMOS technology is used for constructing integrated circuit (IC) chips.



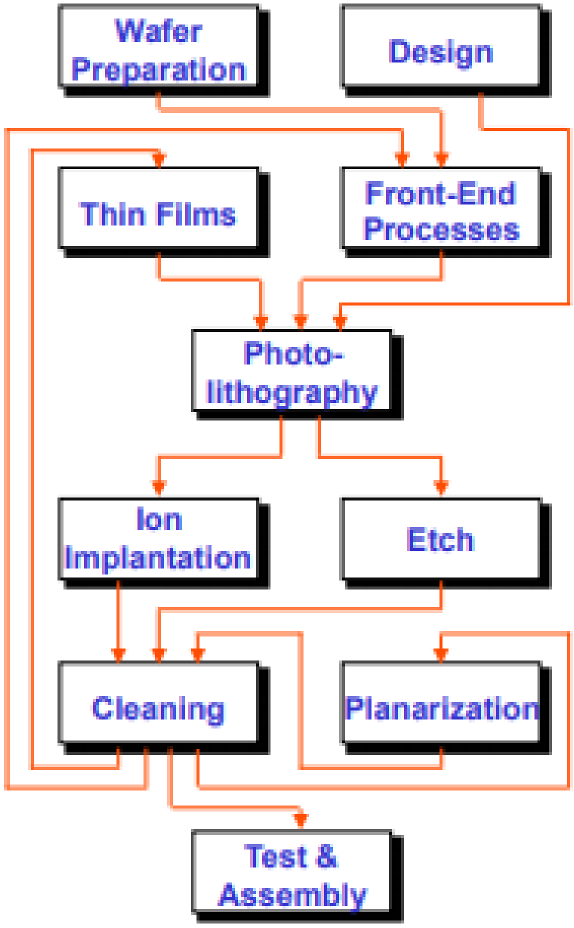
4. Manufacturing of Semiconductor Devices

- Flows of processes in the manufacturing of Integrated Circuit.



4. Manufacturing of Semiconductor Devices (cont.)

- Semiconductor manufacturing process:
  a. Design.
  b. Wafer preparation.
  c. Front-end processes.
  d. Photolithography.
  e. Etch.
  f. Cleaning.
  g. Thin films.
  h. Ion implantation.
  i. Planarization.
  j. Test and assembly.



Example for Tutorial:

1. Describe the processes involved in the silicon wafer manufacturing. [2 marks]
2. Describe the commonly found steps for manufacturing typical semiconductor devices. [5 marks]