Semiconductor Materials, Energy Level Diagrams and p–n Junction

Small gaps → Big possibilities!

1. Semiconductor Materials

Semiconductors are materials whose **conductivity is between** that of insulators and conductors. Their conductivity can be controlled by temperature, light or impurities.

Common Semiconductor Materials

- Silicon (Si) – most widely used
- Germanium (Ge) – high speed, high sensitivity
- Gallium Arsenide (GaAs) – used in LEDs, solar cells
- Indium Phosphide (InP) – high frequency devices

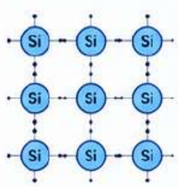
Why are they special?

- ✔ They have a small energy gap (band gap).
- ✔ They can be made more conductive by adding impurities (doping).
- ✔ They are the building blocks of devices like diodes, transistors, solar cells, LEDs etc.

Intrinsic vs Extrinsic

Intrinsic (Pure)

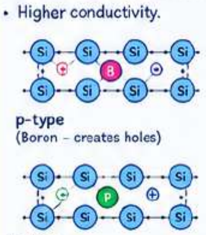
- No impurity added.
- Few free electrons and holes.
- Lower conductivity.



Pure silicon crystal

Extrinsic (Doped)

- Impurities added (e.g. Boron or Phosphorus).
- More free charge carriers.
- Higher conductivity.



p-type (Boron – creates holes)

n-type (Phosphorus – creates electrons)

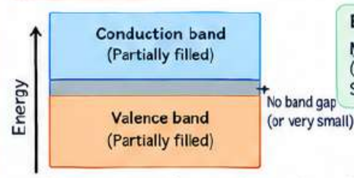
Quick Comparison

Property	Conductor	Semiconductor	Insulator
Band gap	None / very small	Small (~1 eV)	Large (>3 eV)
Conductivity	High	Moderate	Very low
Examples	Metals	Si, Ge, GaAs	Glass, Rubber

2. Energy Level Diagrams

In a solid, atoms come close together and their energy levels form bands.

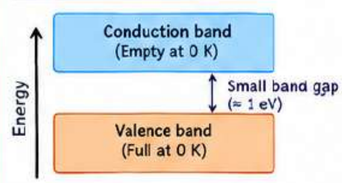
(a) Conductor



Example:
Metals
(e.g. Copper, Silver, Aluminium)

- Electrons can easily move from valence band to conduction band, so conductivity is high.

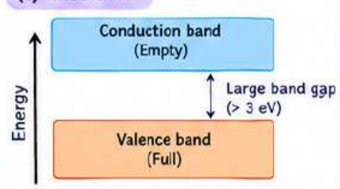
(b) Semiconductor



Example:
Si (1.1 eV)
Ge (0.7 eV)

- At room temperature, some electrons gain energy and jump to the conduction band.
- This creates electron–hole pairs.

(c) Insulator



Example:
Glass, Rubber, Diamond

- Very few electrons can jump to conduction band, so conductivity is very low.

Key Point:
The size of the band gap decides how easily electrons can move and thus the material's conductivity.

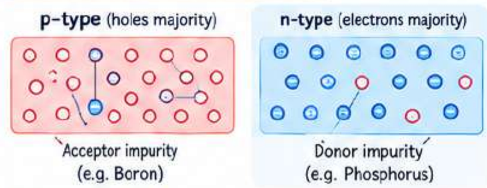
Remember

- More doping → higher conductivity.
- Temperature ↑ → more carriers in semiconductors.
- Light → can also create electron–hole pairs (photoconductivity).
- p–n junction → forms the heart of a diode.

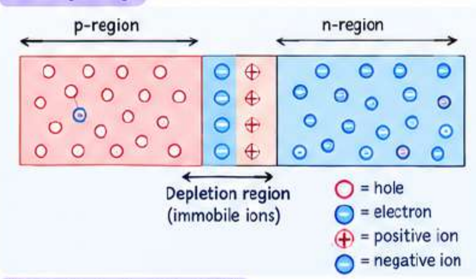
3. p–n Junction

A **p–n junction** is formed by joining a **p-type** and an **n-type** semiconductor. It is the basic building block of diodes, transistors and many electronic devices.

(a) Formation of p–n Junction

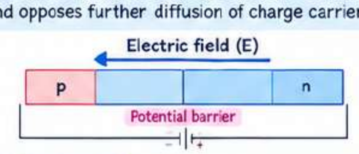


After joining



(b) Built-in Electric Field

Due to the uncovered ions, an electric field is created across the junction. It points from n to p and opposes further diffusion of charge carriers.



(c) What happens?

Forward bias
(p to +, n to –)

- Reduces barrier.
- Allows current to flow.
- Diode conducts.

Reverse bias
(p to –, n to +)

- Increases barrier.
- Blocks current.
- Diode does not conduct (only small leakage).

From atoms to devices... Semiconductors make modern technology possible!

Semiconductor Materials
– Energy Level Diagrams and p-n Junction –

1. Introduction

- Semiconductors are materials whose electrical conductivity lies between that of conductors and insulators.
- Their conductivity can be controlled by adding **impurities**, temperature or light.
- They are the basic building blocks of modern electronic devices like diodes, transistors, solar cells, LEDs etc.

Why are they important?

- ✔ They have a small energy gap (band gap).
- ✔ They can be made more conductive by doping (adding impurities).
- ✔ They form the heart of modern electronics and renewable energy devices.

Key Properties

- Intermediate conductivity (between metals and insulators).
- Negative temperature coefficient of resistance.
- Can be doped to make n-type or p-type.
- Sensitive to light, heat and electric fields.

2. Semiconductor Materials

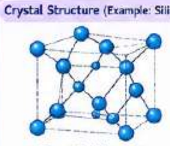
Common semiconductors (elemental and **compound**):

- **Elemental:** Silicon (Si), Germanium (Ge)
- **Compound:** Gallium Arsenide (GaAs), Indium Phosphide (InP), Gallium Nitride (GaN), Cadmium Telluride (CdTe) etc.

Typical band gap values

Material	Band gap (eV) (approx.)
Si (Silicon)	1.1
Ge (Germanium)	0.66
GaAs	1.42
InP	1.34
GaN	3.4
CdTe	1.5

Crystal Structure (Example: Silicon)



Diamond cubic structure
(each Si atom is covalently bonded to 4 neighbours)

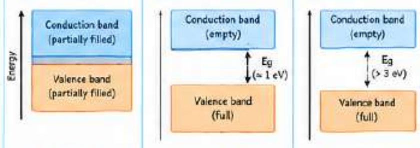
Types of Semiconductors

- ✔ **Elemental:** Si, Ge (Group IV)
- ✔ **Compound:** GaAs (Group III–V), InP (Group III–V), GaN (Group III–V), CdTe (Group II–VI) etc.

3. Energy Level Diagrams

In a solid, atoms are very close to each other and their individual energy levels split into large numbers of closely spaced levels, forming energy bands.

3.1 Energy Bands in Solids

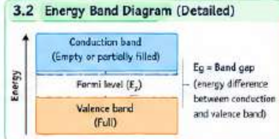


(a) Bands overlap or are very close. No band gap.

(b) Small band gap (≈ 0.5 – 1.5 eV).

(c) Large band gap (> 3 eV).

3.2 Energy Band Diagram (Detailed)



3.3 Fermi Level

- It is the energy level at which the probability of finding an electron is 1/2 at absolute zero.
- In intrinsic semiconductors, the Fermi level lies near the middle of the band gap.
- Doping shifts the Fermi level towards the conduction band (n-type) or valence band (p-type).

Key Points

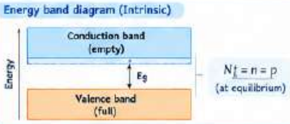
- **Conduction band** – higher energy, empty (or partially filled).
- **Valence band** – lower energy, full.
- **Band gap (Eg)** – energy required to move an electron from valence to conduction band.
- At room temperature, some electrons gain enough energy to jump to conduction band, leaving holes in the valence band.

4. Intrinsic and Extrinsic Semiconductors

4.1 Intrinsic Semiconductor

- Pure semiconductor (no intentional impurities).
- At 0 K, valence band is full and conduction band is empty.
- At room temperature, some electrons gain energy and create electron-hole pairs.
- Electron concentration (n) = hole concentration (p).
- Example: Pure Si, Ge.

Energy band diagram (Intrinsic)



$N_i = n = p$ (at equilibrium)

Comparision of n-type and p-type

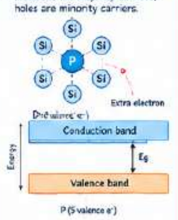
Property	n-type	p-type
Impurity (dopant)	Donor (Group V)	Acceptor (Group III)
Majority carrier	Electrons	Holes
Minority carrier	Holes	Electrons
Conductivity	Higher	Lower (than n-type)
Fermi level	Closer to conduction band	Closer to valence band

4.2 Extrinsic Semiconductor (Doped)

Small amount of impurity atoms are added to increase conductivity and control the type of charge carriers.

(a) n-type (Donor impurity)

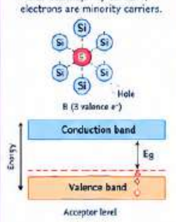
- Pentavalent impurity (Group V) (e.g., Phosphorus, Arsenic, Antimony).
- Adds extra electron (donor level).
- Electrons are majority carriers; holes are minority carriers.



n-type

(b) p-type (Acceptor impurity)

- Trivalent impurity (Group III) (e.g., Boron, Aluminium, Gallium)
- Creates a hole (acceptor level)
- Holes are majority carriers; electrons are minority carriers.



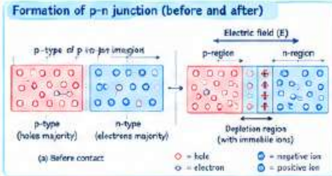
p-type

5. p-n Junction

5.1 Formation of p-n Junction

- A p-type and an n-type semiconductor are joined together to form a p-n junction.
- Due to the concentration gradient, electrons and holes diffuse across the junction.
- This creates a depletion region (no mobile charge carriers) and an internal electric field.

Formation of p-n junction (before and after)



5.2 Potential Barrier and Depletion Region

- The uncovered ions create an electric field from n to p.
- This field opposes further diffusion of charge carriers.
- A potential barrier is formed (about 0.3 V for Ge, fe, ~0.7 V for Si).
- The depletion region is typically 0.1 – 1 μm.

5.3 p-n Junction in Forward and Reverse Bias

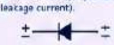
(a) Forward Bias
(p to +, n to –)

- Reduces the barrier.
- Narrows the depletion region.
- Allows current to flow.

Current flows (large).

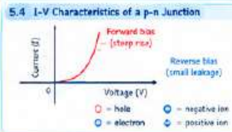
(b) Reverse Bias
(p to –, n to +)

- Increases the barrier.
- Widens the depletion region.
- Blocks current (only small leakage current).



Very small current (leakage).

5.4 I-V Characteristics of a p-n Junction



Applications

- ✔ Diodes (rectification)
- ✔ LEDs (light emission)
- ✔ Solar cells (photovoltaic effect)
- ✔ Transistors (amplification and switching)

Remember

- p-n junction is the building block of most semiconductor devices.
- The depletion region and electric field are key to its operation.
- By controlling the bias, we can allow or stop current flow.

From atoms to devices... Semiconductors make modern technology possible!