Electronic Devices (Semiconductor Electronics)

Electronic devices are the building blocks of modern technology. Unlike vacuum tubes, which are bulky and consume high power, semiconductor devices are small, consume low power, and are highly reliable.

I. Energy Bands in Solids (Qualitative Idea)

In an isolated atom, electrons have discrete energy levels. However, in a solid, atoms are closely packed, and these discrete levels spread out into **energy bands** due to the interaction between neighbouring atoms.

1. **Valence Band (VB):** The energy band occupied by valence electrons. It is the highest occupied band and can be completely or partially filled but is never empty.
2. **Conduction Band (CB):** The next higher permitted band above the valence band. If electrons move into this band, they become free to conduct electricity.
3. **Energy Gap (E_g):** The gap between the top of the valence band and the bottom of the conduction band where no electron states exist. It is also called the **Band Gap**.

Classification based on Energy Bands:

- **Conductors (Metals):** The valence and conduction bands overlap ($E_g \approx 0$), or the conduction band is partially filled. Electrons are easily available for conduction.
- **Insulators:** The conduction band is empty, and the energy gap is very large ($E_g > 3 \text{ eV}$). Electrons cannot jump from VB to CB even with thermal excitation.
- **Semiconductors:** The energy gap is small ($E_g < 3 \text{ eV}$). At 0 K, they behave as insulators, but at room temperature, some electrons gain enough energy to jump into the conduction band.
  - For Silicon (Si): $E_g \approx 1.1 \text{ eV}$
  - For Germanium (Ge): $E_g \approx 0.7 \text{ eV}$

II. Intrinsic and Extrinsic Semiconductors

1. Intrinsic Semiconductors

These are pure semiconductors (like pure Si or Ge) with no impurities.

- The number of free electrons (n_e) in the conduction band is exactly equal to the number of holes (n_h) in the valence band. $n_e = n_h = n_i$ where n_i is the **intrinsic carrier concentration**.
- Conduction is poor at room temperature.

2. Extrinsic Semiconductors

To increase conductivity, a small amount of a suitable impurity is added to the pure semiconductor in a process called **doping**. The resulting material is an **extrinsic semiconductor**.

- **n-type Semiconductor:**
  - **Dopant:** Pentavalent elements (5 valence electrons) like Phosphorus (P), Arsenic (As), or Antimony (Sb).
  - **Mechanism:** Four electrons bond with the Si atoms, and the fifth

becomes a free conduction electron. The dopant is called a **Donor**.
  - **Majority Carriers:** Electrons ($n_e \gg n_h$).

- **p-type Semiconductor:**
  - **Dopant:** Trivalent elements (3 valence electrons) like Boron (B), Aluminum (Al), or Indium (In).
  - **Mechanism:** The impurity creates a vacancy or "hole" that can accept an electron from the valence band. The dopant is called an **Acceptor**.
  - **Majority Carriers:** Holes ($n_h \gg n_e$).

Mass Action Law: For any semiconductor in thermal equilibrium: $n_e n_h = n_i^2$

III. p-n Junction and Semiconductor Diode

A **p-n junction** is formed when a p-type semiconductor is joined to an n-type semiconductor.

1. **Formation Process:**
   - **Diffusion:** Electrons from the n-side diffuse to the p-side, and holes from the p-side diffuse to the n-side.
   - **Depletion Region:** A region near the junction becomes depleted of free charge carriers, leaving behind immobile ion cores (positive on the n-side, negative on the p-side).
   - **Barrier Potential (V_0):** The internal electric field created by these ions opposes further diffusion.
2. **Semiconductor Diode:** A p-n junction with metallic contacts provided at the ends for external connections.

IV. I-V Characteristics of a p-n Junction Diode

1. Forward Bias

- **Connection:** Positive terminal of the battery to the p-side, negative to the n-side.
- **Effect:** The external voltage opposes the barrier potential, **decreasing the width of the depletion region**.
- **Current:** Once the external voltage exceeds the "Knee Voltage" (barrier potential), current increases exponentially. $V > V_{knee} \implies \text{Large Forward Current}$

2. Reverse Bias

- **Connection:** Positive terminal to the n-side, negative to the p-side.
- **Effect:** The external voltage supports the barrier potential, **increasing the width of the depletion region**.
- **Current:** Only a very small **reverse saturation current** flows due to minority carriers.
- **Breakdown:** If the reverse voltage is increased too much, a sudden, very high current flows at the **Breakdown Voltage (V_{br})**, which may damage the diode.

V. Application: Diode as a Rectifier

Rectification is the process of converting alternating current (AC) into direct current (DC). A diode is used because it allows current to flow only in one direction (forward bias).

1. Half-Wave Rectifier

- Uses a single diode.
- **Mechanism:** During the positive half-cycle of AC, the diode is forward biased and conducts. During the negative half-cycle, it is reverse biased and does not conduct.
- **Output:** Only one half of the AC wave appears as a pulsating DC.

2. Full-Wave Rectifier

- Uses two diodes and a center-tap transformer.
- **Mechanism:**
  - In the first half-cycle, Diode D_1 is forward biased and conducts.
  - In the second half-cycle, Diode D_2 is forward biased and conducts.
- **Output:** Both halves of the AC wave are converted into pulsating DC in the same direction.
- **Efficiency:** Much higher than a half-wave rectifier.

Key Formulas for Unit 9

Concept	Formula
Intrinsic concentration	$n_e = n_h = n_i$
Mass Action Law	$n_e n_h = n_i^2$
Energy of a Photon	$E = h\nu = \frac{hc}{\lambda}$
Conductivity (Semiconductor)	$\sigma = e(n_e\mu_e + n_h\mu_h)$
Rectifier Output Frequency (Half)	$f_{out} = f_{in}$
Rectifier Output Frequency (Full)	$f_{out} = 2f_{in}$