14. SEMICONDUCTOR ELECTRONICS: MATERIALS, DEVICES AND SIMPLE CIRCUITS

Single Page Simple Synopsis

Semiconductors are materials with electrical conductivity between conductors and insulators . They are the fundamental building blocks of modern electronics—acting as tiny, reliable, and low-power switches that control the flow of electrical current.

1. **3 Types of Energy Bands:** Energy bands in solids dictate how electrical current flows .
   - **Valence Band-** contains electrons bound to atoms, and has lower energy.
   - **Conduction Band -** contains free electrons, and has higher energy.
   - **Forbidden band** - energy gap between valence band and conduction band.
   - **Bandgap (E_g):** The energy difference between the valence and conduction bands.
2. **3 Types of Materials:**
   - **Conductors:** Bands overlap; electrons flow freely. **Ex:** Copper, silver
   - **Insulators:** Large bandgap (~3eV); electrons cannot jump across. **Ex:** Wood, glass
   - **Semiconductors:** Small bandgap (~1 eV) electrons can jump at room temp. **Ex:** Si, Ge
3. **Intrinsic Vs Extrinsic Semiconductors**
   - **Intrinsic Semiconductors:** Pure semiconductor materials in their natural form (**Ex:** pure Silicon). At 0 K, they act as perfect insulators. At room temperature, thermal energy breaks some covalent bonds, creating an equal number of free electrons (negative) and holes (positive vacancy).
   - **Extrinsic Semiconductors:** Pure semiconductors intentionally mixed with tiny amounts of other elements (a process called **doping**) to drastically increase their conductivity.
   - **N-type (Negative):** Doped with pentavalent impurities (**Ex:** Phosphorus, Arsenic). This provides extra free electrons, making electrons the *majority carriers*.
   - **P-type (Positive):** Doped with trivalent impurities (**Ex:** Boron, Gallium, Indium). This creates vacancies in the bonds known as holes, making holes the *majority carriers*.
4. **Semiconductor Devices** made by joining P-type and N-type materials together.
   - **P-N Junction Diode:** A two-terminal device that allows current to flow in only one direction.
   - **Forward Bias:** Here the diode conducts electricity easily (resistance drops).
   - **Reverse Bias:** Here the diode blocks current, allowing only a tiny leakage current.
   - **Zener Diode:** A specially designed diode used as a voltage regulator in reverse bias.
   - **Special Purpose Diodes: Photodiodes** (light-to-current), Light Emitting Diodes (LEDs) (current-to-light), and Solar Cells (light-to-voltage).
   - **Transistors:** A three-terminal device (**Ex:** NPN or PNP) primarily used as an amplifier .
   - **Rectifiers:** Diodes are frequently used in simple circuits to convert AC to DC by blocking the reverse half-cycle. Two types are : Half wave rectifier & Full wave rectifier.
5. **Digital circuits:** Logic Gates that make logical decisions based on boolean algebra.
   - **Basic Gates:** OR, AND, NOT
   - **Universal Gates:** NAND, NOR

Real Life Examples

- **Si microchips** in smart phones, microscopic transistors in CPU of computers, LEDs, Solar cells, Zener diodes (to regulate power fluctuations), Phone chargers with diodes (rectifier-AC to DC), Transistors in microphones as amplifiers, logic gates in calculators.

IMP. IPE POINTS

1. **Vacancy** of electron in the covalent bond of a semiconductor is called **hole**. Hole acts as **positive charge carrier** in semiconductors.

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2. A pure semiconductor (Si or Ge) without doping is called **intrinsic semiconductor**.
   In this, $n_e = n_h$
   Where n_e = electron concentration
   n_h = hole concentration

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3. A doped semiconductor is called **extrinsic semiconductor.** In this, $n_e \neq n_h$

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4. Si or Ge doped with pentavalent impurity is called **n-type semiconductor**. In this, $n_e > n_h$.

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5. Si or Ge doped with trivalent impurity is called **p-type semiconductor**. In this, $n_e < n_h$.

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6. Relation between n_e, n_h, n_i is $n_i^2 = n_e n_h$
   where n_i = intrinsic carrier concentration

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7. The region where p-type and n-type semiconductors are in contact with each other is called **p-n junction.**

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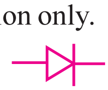
8. The device having a p-n junction is called **p-n junction diode.** Its basic property is to allow current in one direction only.
   Symbol of junction diode is 

9. The neutral region formed on either sides of the p-n junction due to diffusion of electrons and holes is called **depletion layer**. Thickness of depletion layer is of the order of 1/10 of a micrometer.

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10. The **potential drop** that exists across depletion layer to prevent the flow of electrons and holes is called **barrier potential**

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11. A diode is said to be in **forward bias** if its p-end is at positive potential and its n-end is at negative potential. In forward bias, width of the **depletion layer decreases.**

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12. A diode is said to be in **reverse bias** if its p-end is at negative potential and its n-end is at positive potential. In **reverse bias, width** of the **depletion layer increases.**

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13. The device which converts AC into DC is called **rectifier**. The process in which AC converted to DC is called rectification.

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14. The device which converts only half of the AC wave into DC is called **half wave rectifier**. Only single diode is used in it.

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15. The device which converts full AC wave into DC is called **full wave rectifier**. Two diodes are used in it.

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16. Half wave rectifier, Efficiency $\eta = \frac{0.406R_L}{r_f + R_L}$

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17. Full wave rectifier, Efficiency $\eta = \frac{0.812R_L}{r_f + R_L}$
