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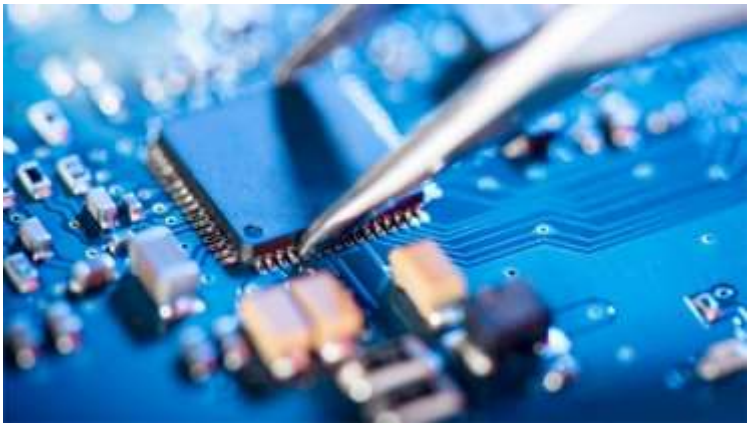
SEMICONDUCTORS AND ELECTRONIC DEVICES

Chapter: - 14th



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Semiconductors and Electronic devices
Chapter: - 14th

I. Classification of metals (conductors), Insulators and Semiconductors: -

Conductors can be classified based on their electrical conductivity and resistivity. Electrical conductivity is a measure of how well a material conducts electricity, while resistivity is a measure of how much a material opposes the flow of electric current. Here's a classification of basic conductors based on these properties:

1. **Good Conductors**:
   - These materials have high electrical conductivity and low resistivity.
   - Examples include metals such as copper, silver, gold, aluminum, and most alloys.
   - These materials allow electric current to flow easily through them with minimal resistance.

2. **Poor Conductors (Insulators)**:
   - These materials have low electrical conductivity and high resistivity.
   - Examples include rubber, glass, plastic, and wood.
   - These materials do not allow electric current to flow easily through them and offer high resistance to the flow of electricity.

3. **Superconductors**:
   - These materials exhibit zero electrical resistance below a critical temperature.
   - Examples include certain metals (e.g., niobium, lead) and ceramic compounds (e.g., yttrium barium copper oxide).
   - Superconductors allow electric current to flow indefinitely without any loss of energy due to resistance.

4. **Semiconductors**:
   - These materials have conductivity and resistivity values between those of conductors and insulators.
   - Examples include silicon, germanium, and certain metal oxides.
   - Their conductivity can be significantly altered by introducing impurities or applying an external electric field. They find extensive use in electronics and semiconductor devices.

Type of semiconductors:

(a) Elemental Semiconductors:
   - Elemental semiconductors consist of a single element in the crystal lattice.
   - The most common elemental semiconductors are **silicon (Si) and germanium (Ge).**

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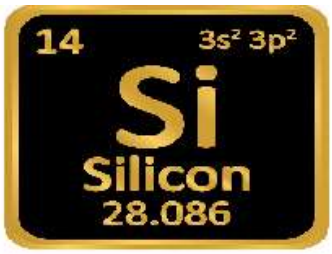

- Silicon is the most widely used semiconductor material in electronic devices due to its abundance, stable properties, and mature manufacturing processes.
- Germanium was historically important in the development of semiconductor technology but has been largely replaced by silicon in most applications due to its higher sensitivity to temperature variations.

(b) Compound Semiconductors:

- Compound semiconductors are composed of two or more elements from different groups in the periodic table.
- Compound semiconductors offer unique properties and are used in specialized applications.
- Examples of compound semiconductors include:

a) **Gallium Arsenide (GaAs)**: Used in high-frequency applications like microwave devices, infrared LEDs, and solar cells.
b) **Gallium Nitride (GaN)**: Used in high-power and high-frequency electronics, such as LEDs, laser diodes, and power amplifiers.
c) **Indium Phosphide (InP)**: Used in high-speed electronics and optoelectronic devices, such as high-frequency transistors and photodetectors.
d) **Cadmium Sulfide (CdS)**: Used in photocells, photovoltaic cells, and thin-film transistors.
e) **Zinc Selenide (ZnSe)**: Used in optical components and infrared optics.

These classifications based on elemental or compound composition highlight the diverse range of semiconductor materials available and their suitability for various applications in electronics, optoelectronics, and photovoltaics.

II. Energy Bands in solids: -

1. **Definition**: In a crystal lattice, due to the interaction between atoms, the valence electrons are shared among multiple atoms. This sharing leads to the formation of closely spaced energy levels, known as energy bands.

2. **Energy Band**:
   - Formed due to continuous energy variation in different energy levels.

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- Arises from the unique positions of electrons inside the crystal, resulting in different surrounding charge patterns for each electron.

3. **Valence Band**:
   - Comprises the energy levels of valence electrons.
   - Can be partially or completely filled with electrons.
   - Always occupied by electrons and never empty.

4. **Conduction Band**:
   - Lies above the valence band.
   - At room temperature, it is either empty or partially filled with electrons.
   - Electrons in this band can gain energy from an external electric field and contribute to electric current.

Key Points:

- Valence band: Lower band, contains valence electrons, always occupied.
- Conduction band: Upper band, may be empty or partially filled, electrons can contribute to current.
- Energy bands are formed due to interactions between atoms, leading to shared valence electrons and the emergence of continuous energy levels.

III. Energy Band Gap

- **Definition**: The energy band gap (E_g) is the minimum energy required to shift electrons from the valence band to the conduction band in a material. It represents the energy difference between the bottom of the conduction band (CB) and the top of the valence band (VB).

  E_g = (CB) min - (VB) max

- **Calculation**: It can be calculated by subtracting the maximum energy of the valence band from the minimum energy of the conduction band.

IV. Fermi Energy

- **Definition**: Fermi energy (E_f) is the maximum energy possessed by free electrons in a material at absolute zero temperature (0 K). It is a fundamental property of the material and varies from one material to another.

- **Role**: Fermi energy determines the behavior of electrons in a material, particularly in determining its electrical conductivity and other electronic properties.

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Relation to Radiation Wavelength

- **Formula**: If λ is the wavelength of the radiation used to shift electrons from the valence band to the conduction band, then the energy band gap (E_g) can be calculated using the formula:

$$E_g = hb = hc/\lambda$$

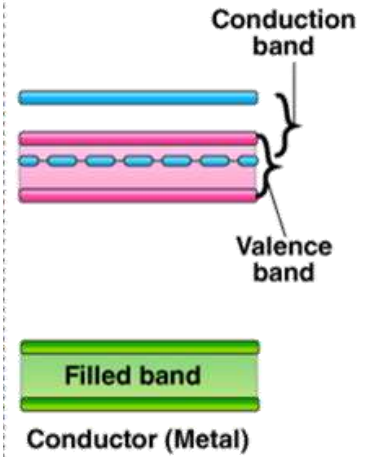
Where:

  - h is Planck's constant.
  - c is the velocity of light.
- **Variation**: The energy gap varies for different materials, depending on their composition and structure. Materials with wider band gaps are insulators or semiconductors, while those with narrower band gaps are usually conductors.

V. Differences between Conductor, Insulator, and Semiconductor based on Energy Bands:

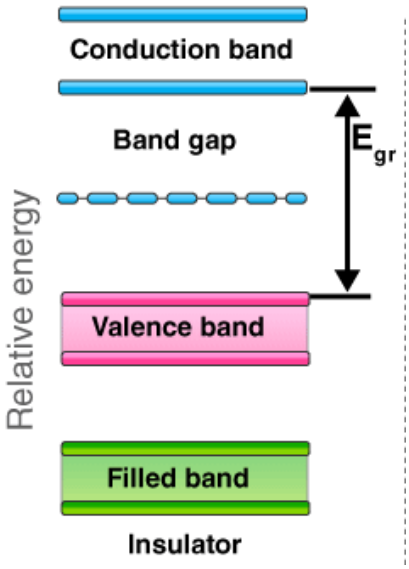
1. Conductor:

- **Energy Bands**: In a conductor, there is either no energy gap between the conduction band and valence band, or they overlap.
- **Valence Band and Conduction Band**: The valence band may not be fully filled, and the conduction band may be partially filled with electrons.
- **Behavior of Electrons**: Electrons from below the Fermi level can easily shift to higher energy levels in the conduction band and behave as free electrons with the application of a small external energy source.
- **Example**: Metals typically exhibit these characteristics, where electrons move freely and contribute to electrical conduction.



2. Insulator:

- **Energy Bands**: In an insulator, there is a large energy gap between the valence band (completely filled) and the conduction band (completely empty).
- **Valence Band and Conduction Band**: Valence band is completely filled with electrons, and the conduction band is completely empty.
- **Behavior of Electrons**: Due to the large energy gap, electrons cannot overcome it even with energy from



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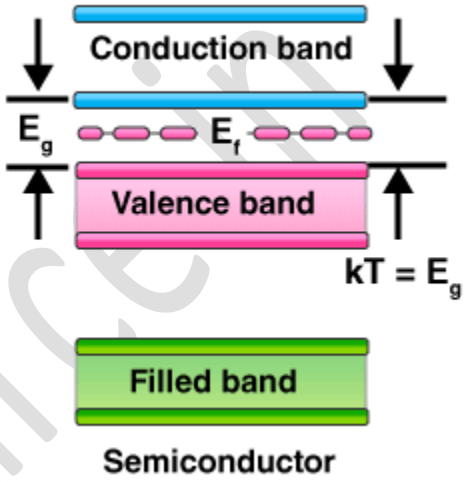
external sources, thus preventing electrical conduction.

- **Example**: Materials like diamond or glass are insulators due to their high resistance to electrical flow.

3. **Semiconductor:**
   - **Energy Bands**: In a semiconductor, the valence band is completely filled, but the conduction band is empty or only partially filled. The energy gap between the two bands is relatively small compared to insulators.
   - **Behavior of Electrons**: At room temperature, some electrons from the valence band can acquire enough thermal energy to jump to the conduction band, where they can move freely and contribute to conductivity, though to a lesser extent compared to conductors.



   - **Example**: Silicon and germanium are common semiconductor materials used in electronics due to their ability to conduct electricity under certain conditions.

VI. Semiconductors: Characteristics and Types

Characteristics:

- **Intermediate Conductivity**: Semiconductors exhibit conductivity levels between those of metals and insulators.
- **Narrow Energy Gap**: They possess a narrow energy gap (~1 eV) between the valence band and the conduction band.
- **Thermal Excitation**: At room temperature, some valence electrons acquire enough thermal energy to move into the conduction band.
- **Electrons and Holes**: The movement of electrons creates holes (vacancies) in the valence band, which behave like positive charges.
- **Conductivity Mechanism**: Semiconductors conduct electricity through the movement of both electrons in the conduction band and holes in the valence band.

Types of Semiconductors:

1. **Intrinsic Semiconductors**:
   - Also known as undoped or i-type semiconductors.
   - Pure semiconductor materials without significant impurities.
   - Thermally generated charge carriers determine conductivity.
   - Number of excited electrons equals the number of holes.

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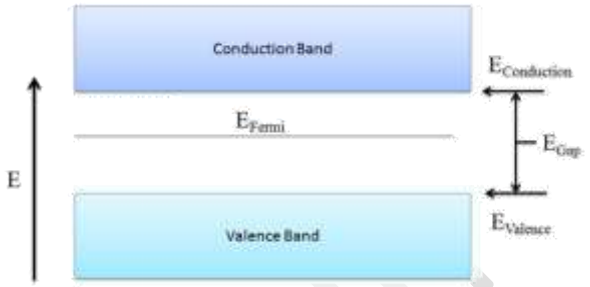
- Energy gap typically around 0.72 eV.
- Fermi energy level lies at the center of the conduction and valence bands.
- Conductivity arises from thermally excited electrons and holes.
- Under the action of an electric field, holes move towards negative potential giving hole current I_h. The total current I is the sum of the electron current I_e, and the hole current I_h. The drift velocity of(v_e) electrons is greater than that of holes(v_h).



$$I = I_e + I_h$$

- Example: Pure silicon or germanium.

2. Extrinsic Semiconductors:

- Contain impurity atoms intentionally added during fabrication.
- Process known as doping.
- Doping alters the number of mobile charge carriers significantly.
- **Two main types of extrinsic semiconductors:**

(a) n-type Semiconductors:

- Doped with donor impurities (e.g., phosphorus).
- Introduce extra electrons, increasing conductivity.

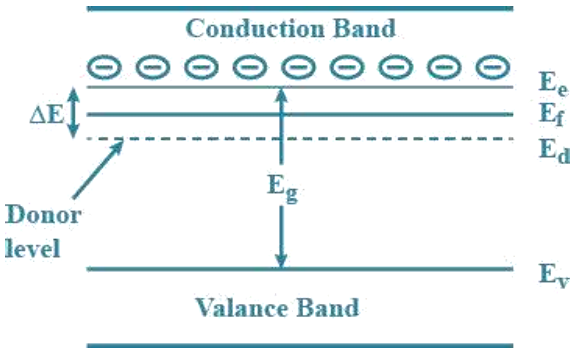
(b) p-type Semiconductors:

- Doped with acceptor impurities (e.g., boron).
- Create holes in the valence band, enhancing conductivity.

Summary: Semiconductors bridge the gap between conductors and insulators, exhibiting unique electrical properties due to their narrow energy gap. They are vital in modern electronics and come in intrinsic and extrinsic forms, each with distinct conductivity mechanisms and applications.

VII. <u>n- Type Semiconductors: -</u>

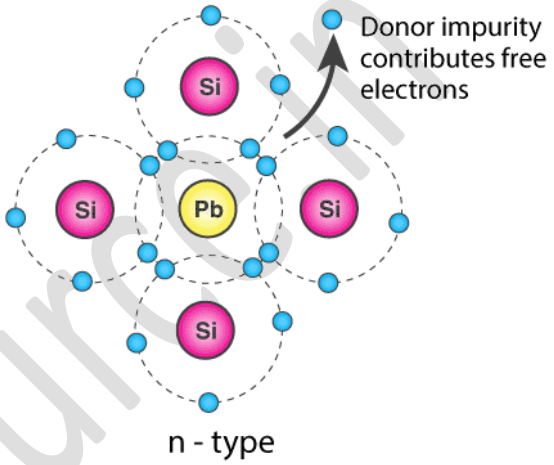
When silicon (Si) or germanium (Ge) is doped with a pentavalent element, such as phosphorus (P) or arsenic (As), four of the five valence electrons of the dopant atom form covalent bonds with the neighbouring silicon atoms, leaving one extra electron. This extra electron is weakly bound to the dopant atom



and requires very little energy **(around 0.01 eV for Ge and 0.05 eV for Si)** to become free.

These extra electrons are essentially donated by the dopant atoms and are referred to as donor electrons. They are almost free to move within the crystal lattice of the semiconductor. Consequently, the conduction within the semiconductor primarily occurs through the movement of these negatively charged donor electrons.

At room temperature, some covalent bonds in the semiconductor lattice break due to thermal energy, generating additional free electrons and holes. However, the number of free electrons is significantly greater than the number of holes due to the presence of donated electrons from the dopant atoms. Mathematically, this is expressed as $n_e >> n_h$, resulting in a much higher electron concentration compared to hole concentration. Therefore, the conductivity of n-type semiconductors is primarily governed by the movement of electrons.



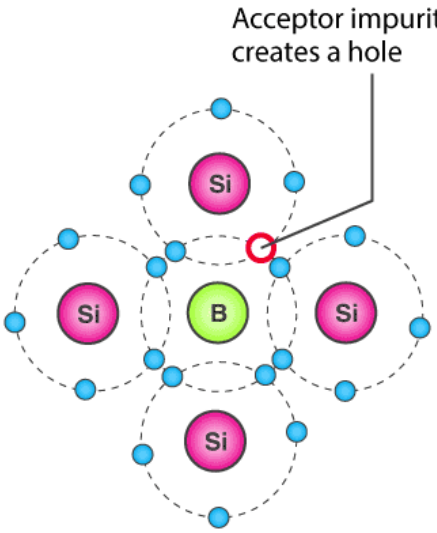
n - type

In n-type semiconductors, electrons are considered majority carriers, as their concentration is significantly higher than that of holes, which are referred to as minority carriers. The conductivity of n-type semiconductors can be represented as $\sigma = n_e \mu_e$, where σ is conductivity, n_e is the electron concentration, μ_e is the electron mobility, and e is the elementary charge.

VIII. P – Type Semiconductor: -

In a p-type semiconductor, doping is carried out with trivalent impurity atoms, which possess three valence electrons in their outer shell. Examples of such trivalent atoms include indium, aluminium, and boron. When these impurity atoms are introduced into the semiconductor lattice, each atom forms covalent bonds with four neighbouring silicon atoms. However, since the impurity atom only contributes three electrons to the bond, one bond remains incomplete, creating a deficiency of one electron.

To satisfy this need for an additional electron for proper covalent bonding, an electron from a nearby covalent bond in the silicon lattice moves to fill the incomplete bond with the impurity atom.



p - type

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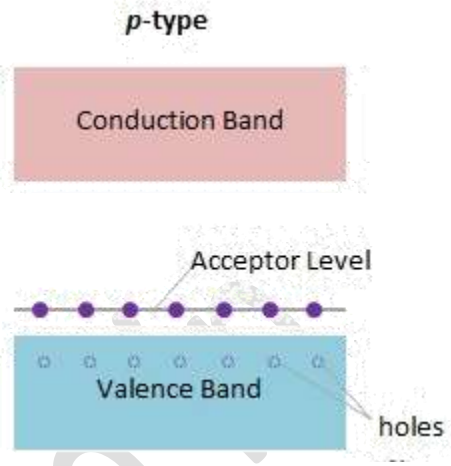

Consequently, the impurity atom becomes ionized, acquiring a negative charge due to the extra electron. This process creates a vacancy or hole in the silicon lattice where the electron was originally located.

As electrons continue to move to fill these holes, new holes are created in the lattice. In a p-type semiconductor, the movement of these holes contributes to the flow of electric current. Since holes are positively charged, the conductivity in p-type semiconductors is predominantly governed by the movement of these positively charged carriers.

At room temperature, some covalent bonds in the semiconductor lattice break due to thermal energy, generating additional free electrons and holes. However, in p-type semiconductors, the concentration of electrons is very low compared to the concentration of holes. This is expressed as $p \gg n$, indicating that the majority of charge carriers are holes, and electrons are the minority carriers. Therefore, in p-type semiconductors, holes are considered the majority carriers, and electrons are the minority carriers.

The conductivity of p-type semiconductors can be represented as $\sigma = \mu_h pe$, where σ is conductivity, μ_h is the hole mobility, p is the hole concentration, and e is the elementary charge.

IX. Important points about n-type and p-type of semiconductor: -

Characteristic	N-Type Semiconductor	P-Type Semiconductor
Dopant Type	Pentavalent dopant (e.g., Phosphorus, Arsenic)	Trivalent dopant (e.g., Boron, Gallium)
Majority Charge Carriers	Electrons	Holes
Minority Charge Carriers	Holes	Electrons
Electrical Conductivity	High	Low
Conductivity Mechanism	Electrons are the primary carriers due to excess electrons	Holes are the primary carriers due to deficiency of electrons
Doping Concentration	High (due to excess electrons from dopant atoms)	Low (due to scarcity of electrons from dopant atoms)

Fermi Level Position	Closer to the conduction band	Closer to the valence band
Band Structure	Conduction band is populated; valence band is empty	Valence band is populated; conduction band is empty
Symbol	n	p

X. Difference between intrinsic and extrinsic semiconductor

Characteristic	Intrinsic Semiconductor	Extrinsic Semiconductor
Doping	No intentional doping	Intentionally doped with impurities
Carrier concentration	Low carrier concentration	Higher carrier concentration due to doping
Electrical conductivity	Low conductivity	Higher conductivity due to added impurities
Fermi level	At mid-bandgap energy level	Shifted towards the donor or acceptor levels
Temperature effect	Conductivity increases with temperature	Conductivity may increase or decrease with temperature depending on doping type
Examples	Pure silicon, pure germanium	Silicon doped with phosphorus (N-type); Silicon doped with boron (P-type)

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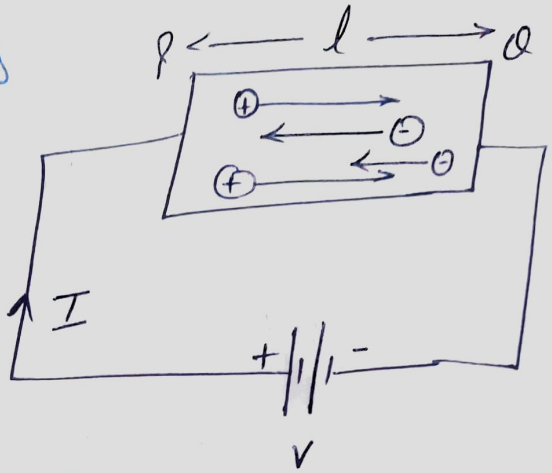
Electric Current in Intrinsic Semiconductor :-

There are two types of charges free electron (-e) and Holes (+e). The movement of these two charges causes electric current.



ie $I = I_e + I_h$ ——— (1)

I = Total Current

I_e = Current due to electrons

and I_h = Current due to Holes

Consider a stub PQ of an intrinsic semiconductor of length (l) and area of cross-section (A) Connected to a battery of potential difference V (Volt).

due to potential difference, holes drift toward the negative terminal giving (I_h) Hole current and electron drift toward the positive terminal giving (I_e) electron current.

Here n_h = number density of Holes

Al = Volume of semiconductor

e = Charge on the Semiconductor

Charge in semiconductor ($q_h = n_h Ale$)

Now current

$$I_h = \frac{q_h}{t} = \frac{n_h A l e}{t}$$

But $\frac{l}{t}$ = drift velocity (v_h)

$$\boxed{I_h = n_h A v_h e} \quad \text{— (II)}$$

Similarly current due to electrons

$$\boxed{I_e = n_e A v_e (-e)} \quad \text{— (III)}$$

Using equation (II) and (III) in (I)

$$I = n_h A v_h e + n_e A v_e (-e)$$

(-ve) Sign shows the direction of electric current due to electrons.

$$\boxed{I = Ae (n_h v_h + n_e v_e)}$$

Note :- In semiconductor current is due to both electrons and holes But In Metals current is only due to electrons.

⇒ Electrical Conductivity of Semiconductor :-

Electric current In intrinsic semiconductor

$$I = Ae[n_h v_h + n_e v_e]$$

$$\frac{I}{A} = e\left[n_h v_h + n_e v_e\right] \quad \text{——} (1)$$

The electric field across the semiconductor

$$E = \frac{V}{l}$$

using $R = \frac{\rho l}{A}$ ie $l = \frac{RA}{\rho}$, we get

$$E = \frac{V}{\frac{Rl}{\rho}} = \frac{V\rho}{Rl}$$

Here $\left[\frac{V}{R} = I\right]$

$$E = \frac{I\rho}{A} \Rightarrow \left[\frac{E}{\rho} = \frac{I}{A}\right] \quad \text{——} (II)$$

using (II) in (I)

$$\frac{E}{\rho} = e\left[n_h v_h + n_e v_e\right]$$

$$\frac{1}{\rho} = e\left[n_h \frac{v_h}{E} + n_e \frac{v_e}{E}\right]$$

$\frac{v_h}{E} = \mu_h$ mobility of holes

$\frac{v_e}{E} = \mu_e$ mobility of electron

$$\frac{1}{\rho} = e\left[n_h \mu_h + n_e \mu_e\right]$$

$$\sigma = e[n_h \mu_h + n_e \mu_e]$$

↳ Conductivity of Intrinsic Semiconductor

$$\rho = \frac{1}{e[n_h \mu_h + n_e \mu_e]}$$

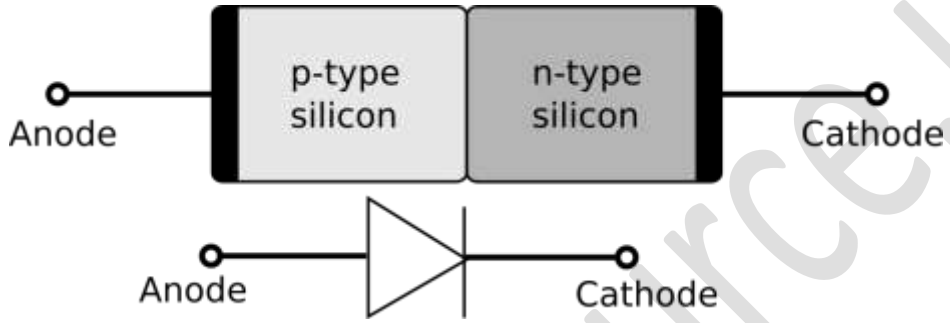
↳ Resivity of Intrinsic Semiconductor

Here $n_h = n_e = n_i$ (Intrinsic Semiconductor)

$$\boxed{\sigma = e n_i [\mu_h + \mu_e]}$$

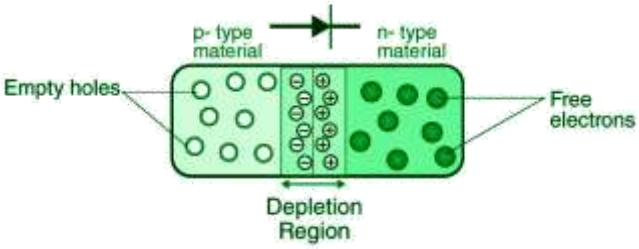
XI. P-N Junction Diode: -

A p-n junction is an arrangement made by a close contact of n-type semiconductor and p-type semiconductor. There are various methods of forming p-n junction diode. In one method, an n-type germanium crystal is cut into thin slices called wafers. An Aluminium film is laid on an n-type wafer, which is then heated in an oven at a temperature of about 600°C. Aluminium then diffuses into the surface of wafer. In this way, ap-n junction is formed.



Formation of Depletion in P-N Junction diode: -

- In an n-type semiconductor, the concentration of electrons is higher than the concentration of holes, and vice versa in a p-type semiconductor.
- Formation of a p-n junction occurs when p-type and n-type semiconductors are joined, resulting in a concentration gradient across the junction.



- Due to this concentration gradient, holes diffuse from the p-side to the n-side, while electrons diffuse from the n-side to the p-side.
- The diffused charge carriers combine near the junction, neutralizing each other.
- Near the junction, positive charge accumulates on the n-side and negative charge on the p-side.
- The establishment of the junction sets up a potential difference across it, creating an internal electric field directed from the n-side to the p-side.
- Equilibrium is achieved when this electric field becomes strong enough to halt further diffusion of majority charge carriers, while allowing minority carriers to diffuse across the junction.

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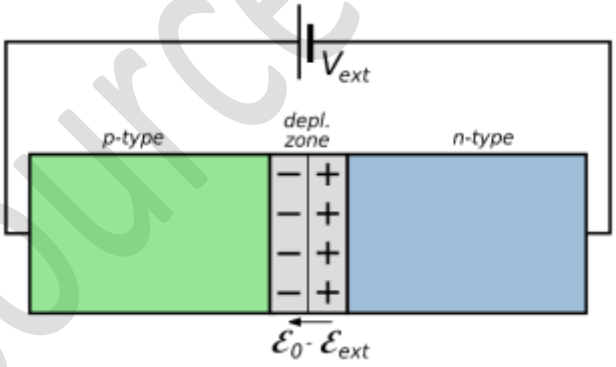
- The region on either side of the junction, depleted of mobile charge carriers, is known as the depletion region or depletion layer, with a typical width of around 10^{-6} meters.
- The potential difference developed across the depletion region is termed the potential barrier, which depends on the dopant concentration and temperature of the semiconductor material.

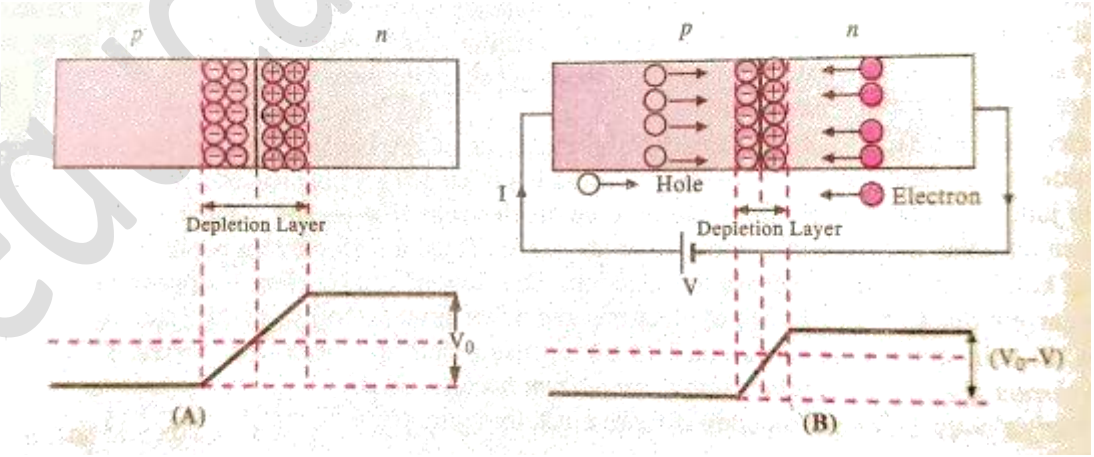
XII. P-n junction diode under forward bias: -

When the positive terminal of a cell or a battery is connected to p-region and the negative terminal of the cell/battery is connected to the n-region of the junction diode, then the p-n junction diode is said to be forward biased.



How forward biasing works and its effects on the p-n junction diode:

1. **Reduction of Barrier Potential:** When a forward voltage is applied, it reduces the potential barrier present at the junction between the p and n regions. This barrier, known as the built-in potential **(V_0),** normally prevents significant current flow across the junction. The forward bias voltage reduces this barrier potential, allowing charge carriers to cross the junction more easily.
2. **Thinning of Depletion Region**: The applied forward voltage causes the depletion region thin, the region depleted of majority charge carriers near the junction, to decrease in width. This thinning of the depletion region further facilitates the movement of charge carriers across the junction.



3. **Decrease in Junction Resistance**: Forward biasing significantly lowers the resistance of the p-n junction, enabling a much higher flow of current compared to reverse bias.

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4. **Minority Carrier Injection**: With the reduction in the barrier potential, majority charge carriers (holes in the p-region and electrons in the n-region) gain sufficient energy to overcome the barrier and move across the junction. This phenomenon is known as ***minority carrier injection***. These minority carriers contribute to the flow of current across the diode.

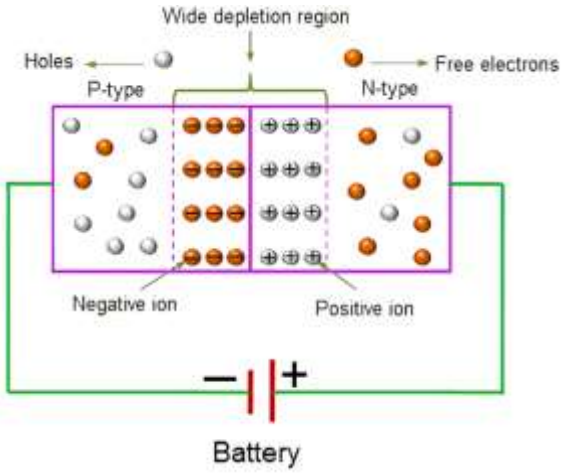
5. **Diffusion Current**: The injected minority carriers diffuse into the opposite region due to the concentration gradient. This diffusion process creates diffusion currents: a diffusion electron current **(I_e)** due to the movement of electrons from the n to the p-region, and a diffusion hole current **(I_h)** due to the movement of holes from the p to the n-region.

6. **Total Current**: The total current flowing through the diode is the sum of the diffusion electron current **(I_e)** and the diffusion hole current **(I_h)**, as expressed by the equation

$$I = I_e + I_h$$

XIII. Reverse Bias in a p-n Junction Diode:

1. **Definition of Reverse Bias:**
   - Reverse bias occurs in a p-n junction diode when the positive terminal of a cell or battery is connected to the n-side and the negative terminal is connected to the p-side of the diode.



2. **Barrier Potential Increase:**
   - When a cell is connected in reverse bias, a potential difference *V* is applied across the diode, increasing the effective barrier potential **(*Vo*+*V*)**.
   - Consequently, the thickness of the depletion layer also increases.

3. **Increased Junction Resistance:**
   - Reverse bias leads to an increase in junction resistance.
   - Majority carriers in the p-region and n-region are attracted away from the junction by the applied voltage, reducing the flow of current.

4. **Halted Majority Carrier Movement:**
   - Both holes in the p-region and electrons in the n-region are prevented from crossing through the junction due to the drift induced by the applied reverse bias.

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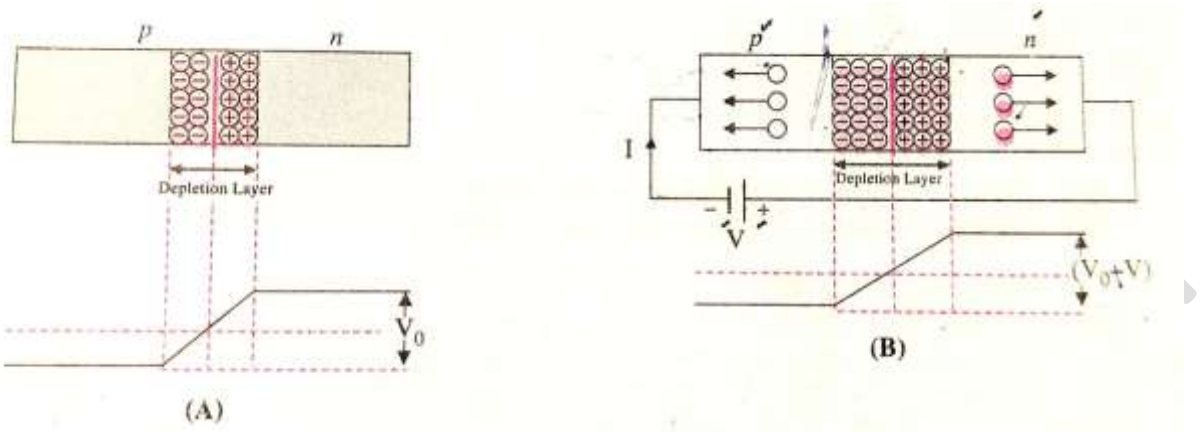
- As a result, the flow of current in the diode is significantly reduced, approaching near zero.



5. **Saturation Current:**
   - A small saturation current exists due to the sweep of minority carriers in both the p-region and n-region.
   - This current remains relatively unaffected by the increase in applied reverse voltage but increases with temperature.

6. **Breakdown Phenomenon:**
   - If the reverse bias voltage is increased to a high value, covalent bonds near the junction may break down.
   - This breakdown results in the liberation of a large number of electron-hole pairs, causing an abrupt increase in reverse current.
   - The voltage at which breakdown occurs is termed as the breakdown voltage (breakdown).

7. **Consequences of Breakdown:**
   - Breakdown can lead to a very high reverse current, potentially damaging or destroying the diode due to overheating.
   - It is crucial to operate the diode within its specified voltage limits to avoid breakdown and ensure proper functionality.

Notes: -

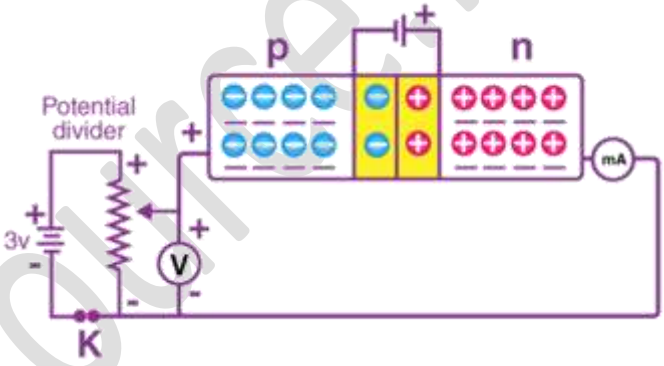
(a) In Forward biasing the thickness of the depletion layer and the junction resistance decreases.

(b) In reversed biasing the thickness of the depletion layer and junction resistance is increases.

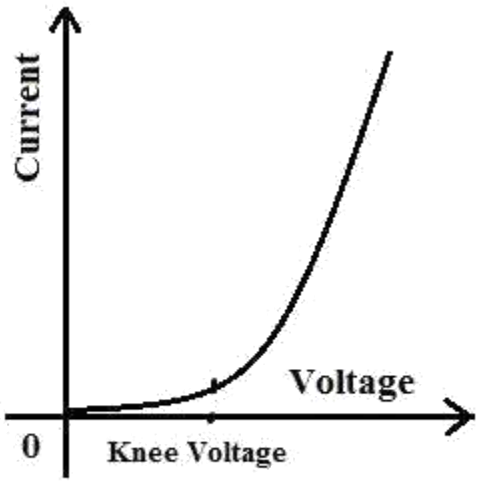
XIV. Characteristics of P-N junction diode: -

(a) Forward Bias Characteristic: -

1. **Zero Bias Condition:**
   - When the battery voltage is zero, the diode does not conduct, and the diode current remains at zero.
2. **Initiation of Forward Bias:**
   - As the forward battery voltage (*V*) increases, the barrier potential across the diode decreases.
   - A small forward current begins to flow as a result.



3. **Gradual Increase in Forward Current:**
   - Initially, the forward current increases slowly with the increase in battery voltage.
4. **Rapid Increase at Knee Voltage:**
   - As the battery voltage continues to increase, there comes a point where the forward current starts increasing rapidly.
   - This voltage is termed as the knee voltage (V_k), threshold voltage, or cutoff voltage.
   - For germanium diodes, the knee voltage is approximately 0.7 V, while for silicon diodes, it is around 0.2 V.
5. **Behavior After Knee Voltage:**
   - Beyond the knee voltage, the junction diode behaves almost like a conductor.
   - The diode exhibits a sharp increase in conductivity, allowing a significant flow of current.
6. **Linear Variation of Current:**
   - After reaching the knee voltage, the variation of current with the applied voltage across the junction diode becomes almost linear.
   - This linear relationship between voltage and current indicates a consistent and predictable behavior of the diode in the forward bias region.



Forward Characteristics

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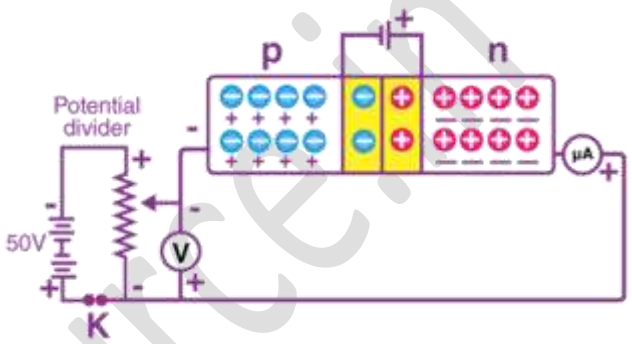
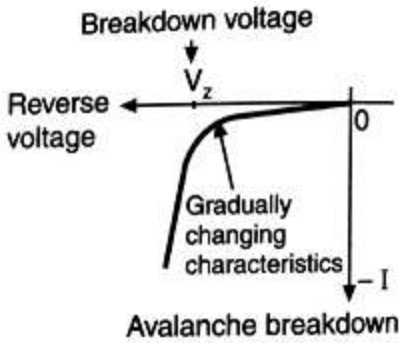
(b) Reverse Bias Characteristics:

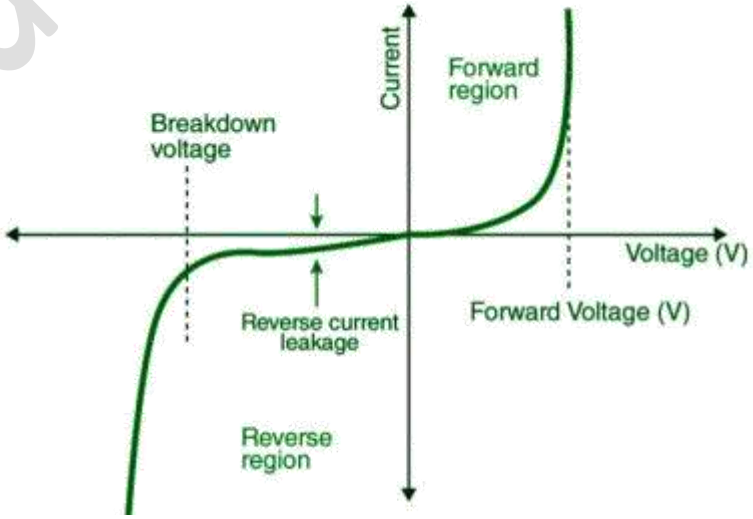
- **Minority Charge Carrier Flow:** In reverse bias, the applied voltage facilitates the movement of minority charge carriers (minority carriers) across the junction. This results in a very small current flowing across the junction.
- **Internal Potential Barrier:** The motion of minority charge carriers is aided by the internal potential barrier within the diode. Consequently, nearly all minority carriers are able to cross the junction.
- **Reverse Saturation Current:** The small reverse current remains nearly constant over a wide range of reverse bias voltages. This voltage-independent current is termed as reverse saturation current. It increases only slightly with increasing voltage, forming the "OC" (Open Circuit) portion of the characteristic graph.



- **Breakdown Voltage:** At high reverse voltages, the minority carriers acquire very high velocities due to the strong electric field. This can lead to collisions that break down covalent bonds, generating more charge carriers.
- **Chain Reaction:** The breakdown of covalent bonds initiates a chain reaction, resulting in the generation of a large number of charge carriers. This cascade effect leads to a significant increase in the reverse current.



- **Avalanche Breakdown:** When the reverse bias voltage equals the breakdown voltage, the reverse current through the junction increases rapidly. This situation is referred to as avalanche breakdown. If this current exceeds the rated value of the p-n junction, excessive heating can occur, potentially damaging the junction.



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XV. Application of Junction Diode as Rectifier: -

A device which converts alternating current (a.c.) into direct current (d.c.) is known as rectifier.

The process of converting a.c. into d.c, is known as rectification.

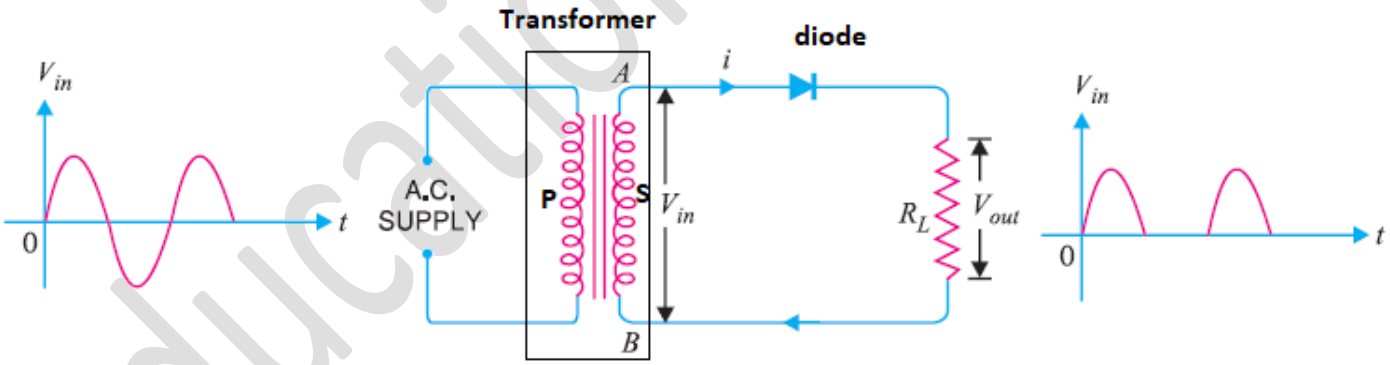
Principle of Operation:

- A junction diode conducts electricity in only one direction: *when it is forward biased.*
- When reverse biased, the diode blocks the flow of current effectively acting as an open circuit.

(a) Junction Diode as Half wave Rectifier: -

Working of Half-Wave Rectifier:

1. **Input Stage**:
   - Alternating current (AC) from a source is provided as input.
   - This AC input is typically sinusoidal, with both positive and negative half cycles.
2. **Transformer**:
   - The AC input is usually fed into the primary coil (P) of a transformer.
   - The transformer down the input voltage and provides isolation between input and output circuits.
   - The secondary coil (S) induces a voltage across it due to mutual induction when AC flows through the primary coil.



3. **Diode Connection**:
   - The secondary coil is connected to the junction diode through a load resistance (RL).
   - The load resistance serves to limit the current flowing through the circuit and acts as the load for the rectifier.
4. **Positive Half-Cycle**:
   - During the positive half-cycle of the input AC signal, the upper end of the secondary coil becomes positive, and the lower end becomes negative due to induced electromotive force (emf).

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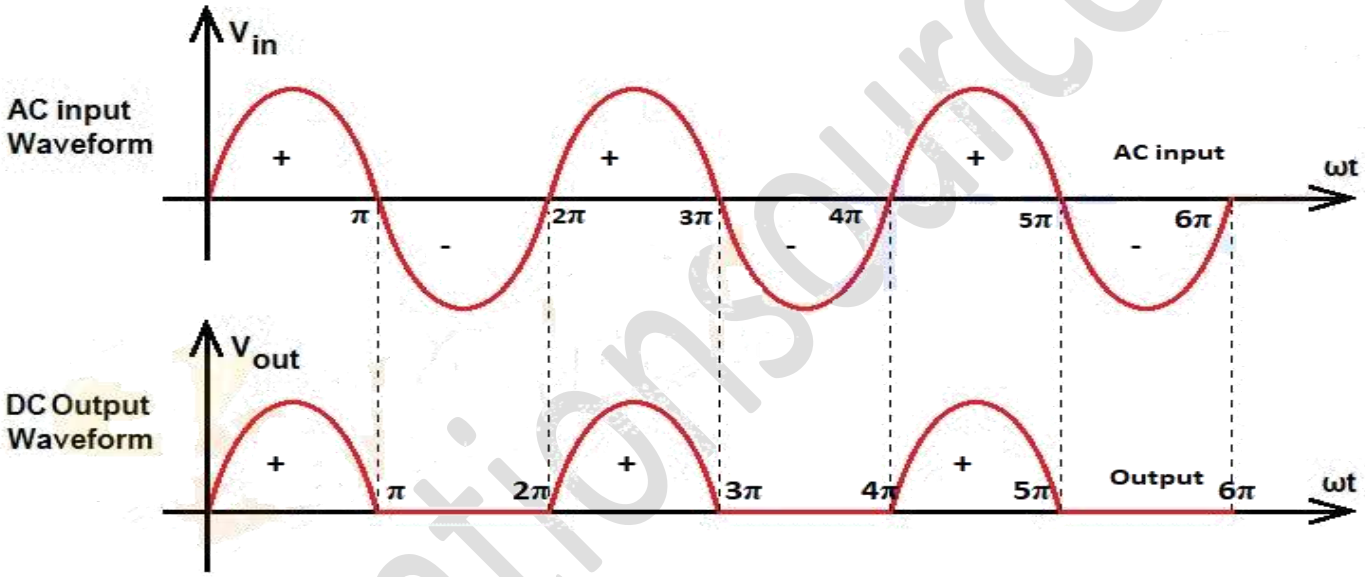
- These forward biases the junction diode, allowing current to flow through the diode and the load resistance RL.
- The output voltage is obtained across the load resistance RL during this period.

5. **Negative Half-Cycle**:
   - Conversely, during the negative half-cycle of the input AC signal, the polarity across the secondary coil reverses.
   - The upper end becomes negative, and the lower end becomes positive, which reverse biases the junction diode.
   - As a result, the diode blocks current flow, and no output is obtained across the load resistance RL during this period.



Advantages:

- Simple circuit design.
- Requires inexpensive components.
- Suitable for low-power applications.

Disadvantages:

1. **Discontinuous Output**:
   - The rectified output is not continuous; it only represents one half of the input waveform.
   - This leads to lower efficiency compared to full-wave rectification.
2. **Pulsating DC Output**:
   - The output obtained is pulsating DC, which means it contains AC components or ripples.
   - This may require additional filtering to obtain a smoother DC output.

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Expression for Output DC Voltage:

Output D.C. Voltage = Mean load current X Load resistance

$$V_{d.c.} = I_{d.c.} + R_L$$

But $I_{d.c.} = {}^{I_o}/_{\pi}$, Where I_o is the maximum value of the secondary half wave Current.

$$V_{d.c.} = {}^{I_o}/_{\pi} + R_L$$

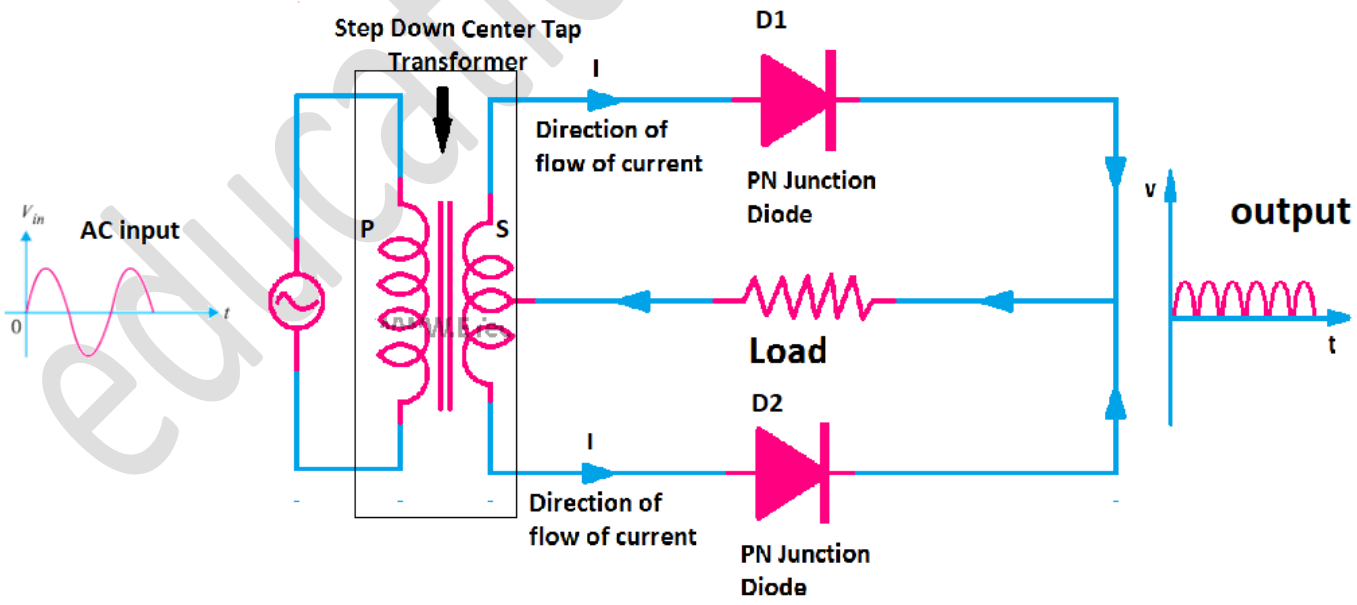
(b) Full Wave Rectifier: - Full wave rectifier convert both halves of a.c. input signal to d.c. output.

Principle:

- A full wave rectifier converts both halves of the AC input signal into DC output.

Circuit Diagram:

- The circuit consists of a transformer, two diodes (D1 and D2), and a load resistance (RL).
- The p-regions of both diodes are connected to the two ends of the secondary coil of the transformer.
- The load resistance RL is connected between the common point of n-regions of the diodes and the central tapping of the secondary coil.



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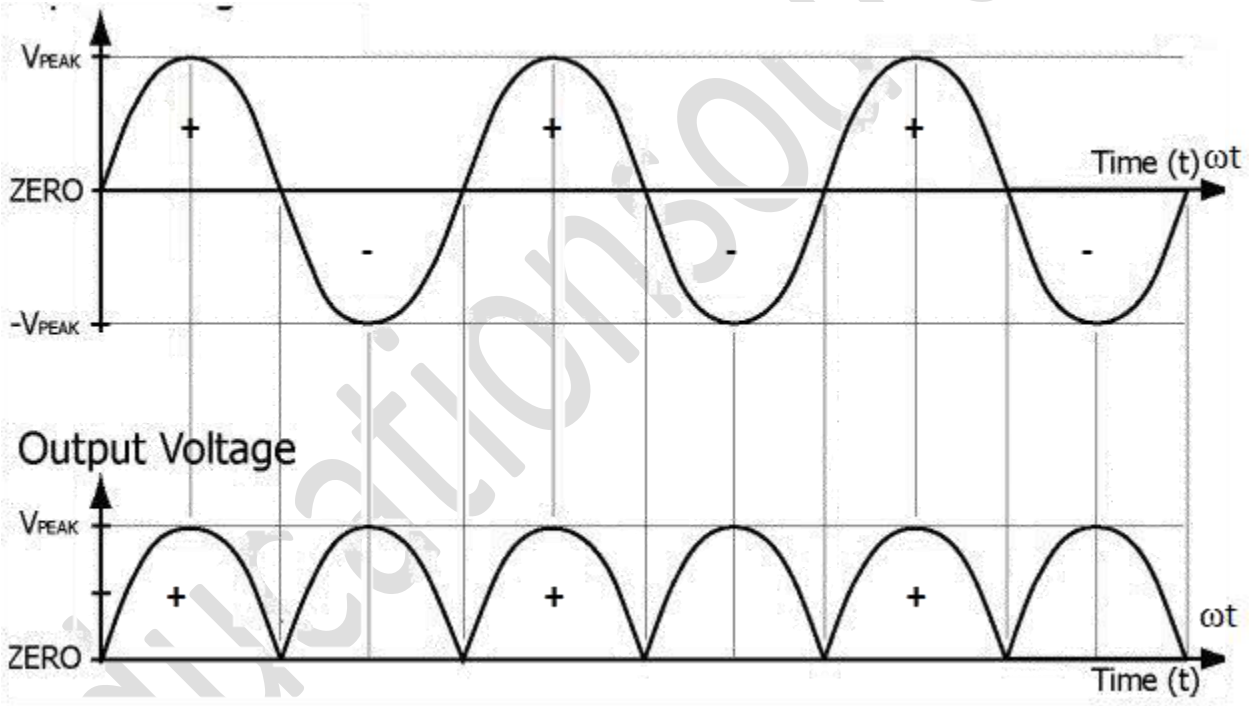
Working:

1. **Positive Half-Cycle**:
   - During the positive half-cycle of the input AC signal, the upper end of the secondary coil becomes positive, and the lower end becomes negative due to induced emf.
   - Diode D1 is forward biased, allowing current to flow through the circuit, generating an output voltage across RL.
   - Diode D2 is reverse biased and does not conduct.
2. **Negative Half-Cycle**:
   - During the negative half-cycle of the input AC signal, the polarity across the secondary coil reverses.
   - Now, diode D1 is reverse biased, and diode D2 is forward biased.
   - Current flows through diode D2 in the opposite direction, generating an output voltage across RL.



Advantage:

- Continuous output, leading to higher efficiency compared to half-wave rectifiers.

Disadvantages:

- Output is still pulsating DC, requiring additional filtering for smoother output.

Expression for Output d.c. Voltage: -

Output D.C. Voltage = Mean load current X Load resistance

$$V_{d.c.} = I_{d.c.} + R_L$$

But $I_{d.c.} = {}^{2I_o}/_{\pi}$, Where I_o is the maximum value of the secondary half wave Current.

$$V_{d.c.} = {}^{2I_o}/_{\pi} + R_L$$

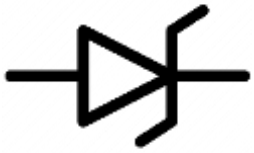
XVI. Zener diode: -

Definition:

- A Zener diode is a specially doped p-n junction diode designed to operate in the breakdown region without getting damaged.
- It is commonly used as a voltage regulator due to its ability to maintain a constant voltage across its terminals.

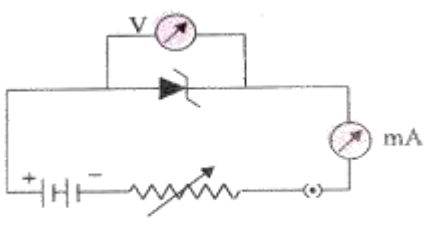
Characteristics:

1. **Symbolic Representation**:
   - The symbol for a Zener diode resembles that of a standard diode with an additional zigzag line across it, indicating its breakdown characteristics.

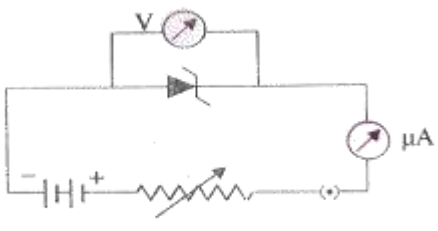


2. **Breakdown Voltage (V_z)**:
   - The breakdown voltage or Zener voltage (V_z) depends on the doping concentration.
   - Both the n and p regions of the Zener diode are heavily doped, resulting in a thin depletion layer.
   - The thin depletion layer leads to a high electric field, known as the ionizing field, even for small applied voltages.

3. **Volt-Ampere(V-I) Characteristics**:
   - The characteristics of a Zener diode can be studied through its volt-ampere (V-I) curve.
   - The circuit diagrams for studying the characteristics of a Zener diode in forward biased and reverse biased modes respectively.



(a) Forward Biased



(b) Reverse Biased

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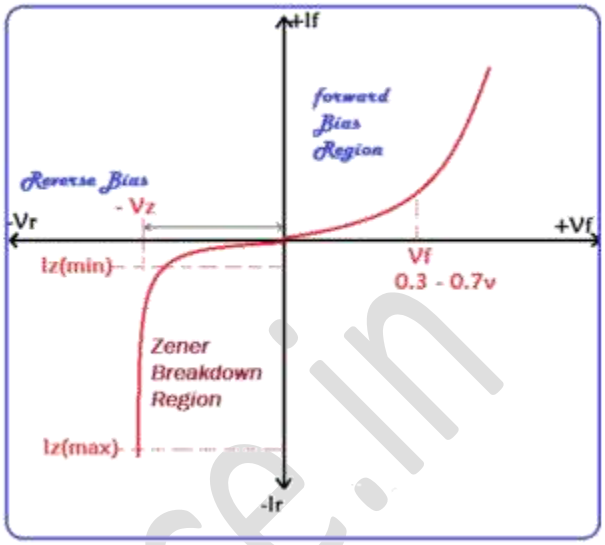
4. **Operation**:
    - In forward biasing the Zener diode behave like an ordinary diode.
    - In reverse bias, the Zener diode operates in the breakdown region.
    - The current through the Zener diode is limited by an external resistor in the circuit.
    - The Zener voltage **(V_z)** remains relatively constant even for large changes in reverse current, providing voltage regulation.



Applications:

- **Voltage Stabilizers**:
    - The ability of the Zener diode to maintain a constant voltage across its terminals makes it suitable for voltage stabilization applications.
    - Zener diodes are widely used in voltage regulator circuits to provide a stable output voltage despite fluctuations in the input voltage.

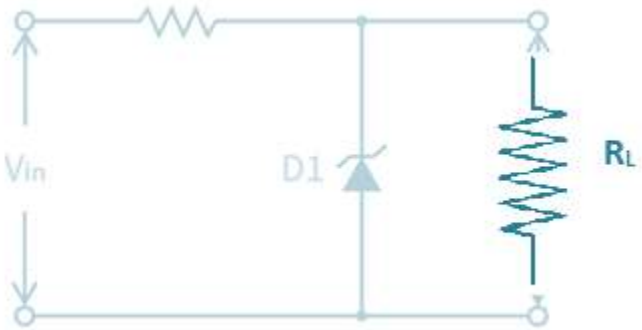
➢ **Zener Diode as a Voltage Regulator**

Principle:

- A Zener diode can be employed as a voltage regulator or stabilizer to maintain a constant output voltage even when the input voltage fluctuates widely.

Circuit Diagram:

- The circuit utilizes a Zener diode connected across the fluctuating voltage source via a dropping resistor (R_s).
- The constant voltage output is obtained across the load resistance (**R_L**).



Working:

1. **Voltage Increase**:
    - When the input voltage rises, the resistance of the Zener diode decreases.
    - Consequently, the current through the diode increases substantially.
    - This results in a significant voltage drop across the dropping resistor (R_s), maintaining the output voltage across it at the desired value.

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2. **Voltage Decrease**:
   - Conversely, if the input voltage decreases, the current through the diode decreases as well.
   - As a result, only a small voltage drop occurs across the dropping resistor (R_s).
   - However, the output voltage across R_L remains constant at the desired value.
3. **Voltage Regulation**:
   - Despite fluctuations in the input voltage, the Zener diode ensures that the output voltage across R_1 remains constant.
   - Thus, the circuit provides a stable output voltage, making the Zener diode act as a voltage regulator.

Q1: Why does reverse current suddenly increase at the reverse breakdown voltage? What is internal field emission?

Ans: - As the voltage across the junction increases, the electric field strength intensifies significantly. This heightened electric field exerts a force on minority carriers and valence electrons within the p-side, compelling them to depart from their parent atoms and traverse the junction towards the n-side. This emission of electrons is referred to as internal field emission or field ionization.

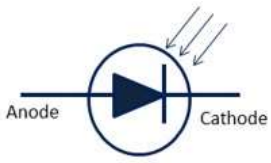
XVII. Optoelectronic Junction diode: -

The junction diode which conducts when charge carriers are generated by the photons i.e., light incident on it is known as optoelectronic junction device.

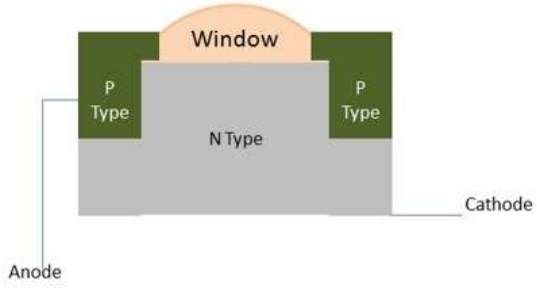
(a) Photo Diode

Definition:

- A photo diode is a reverse biased p-n junction diode designed with a transparent window, allowing it to respond to light.
- When illuminated with light, the reverse diode current varies linearly with the light flux.



Symbol of Photo Diode



Construction:

- Enclosed in a clear plastic envelope, allowing light to fall on the surface facing the diode.
- Other faces of the plastic may be enclosed in a metallic case.
- The output voltage is taken across the load resistance R_L.

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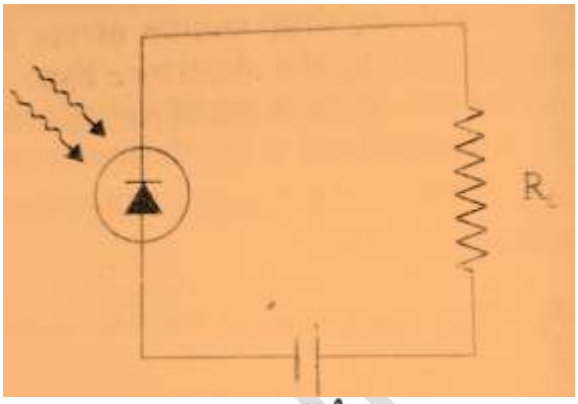
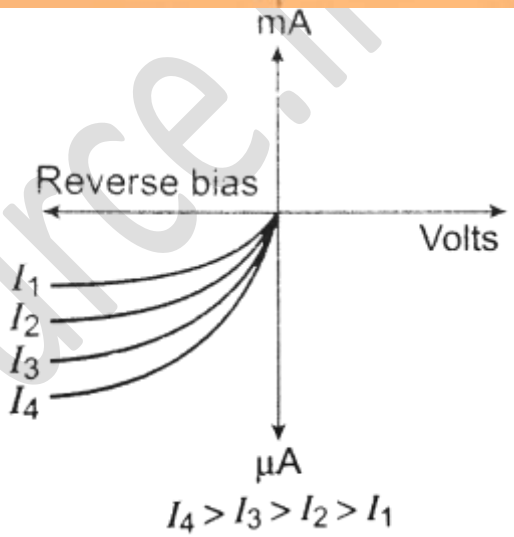
Symbolic Representation:

- The symbol for a photo diode resembles that of a standard diode, with an arrow pointing towards the diode indicating the direction of the current flow.



Characteristics:

- **Dark Current (I_0)**:
  - When reverse biased, a constant current known as the dark current or saturation current (I_0) flows due to thermally generated minority carriers.



- **Light Induced Current (I_s)**:
  - When light of energy (hv) greater than the energy gap (E_g) of the semiconductor falls on the diode, additional electron-hole pairs are generated.
  - These electron-hole pairs contribute to an additional current (I_s) flowing in addition to the dark current (I_o).
  - The total reverse current (I) in the circuit is given

$$\boldsymbol{I = I_o + I_s}$$

where $\boldsymbol{I_s}$ is proportional to the intensity of the incident light.

- **Volt-Ampere Characteristics**:
  - The variation of the photo diode current with the reverse voltage is known as its volt-ampere characteristics.
  - The characteristics show an increase in the total reverse current with an increase in the intensity of incident light.

Uses of Photo Diodes:

1) Used to detect the intensity of radiation.
2) Utilized in light-operated switches.
3) Employed in optical communication equipment.
4) Used for fast reading of film soundtracks and tapes.
5) Integrated into logic circuits.
6) Utilized as optical demodulators.

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Q1: Why is a photo diode used in reverse bias as a photo detector?

OR

Current in forward bias is in mA and in reverse bias it is in up. Why is then photodiode operated in reverse bias?

Ans: - Photo-diodes are typically employed in reverse bias mode despite the fact that the forward bias current surpasses the reverse bias current by a significant margin. The primary function of a photo-diode is to detect incident photo radiation. Under forward bias conditions, the current arises predominantly from the diffusion of majority carriers across the junction, with minority carriers playing a minimal role in the forward current. Conversely, under reverse bias, the current is primarily driven by the diffusion of minority carriers through the junction. Variations in light intensity affect the minority carrier-based reverse current more profoundly than the forward current, which relies on minority carriers to a lesser extent. Therefore, a photo-diode is utilized in reverse bias to optimize its sensitivity to light variations.

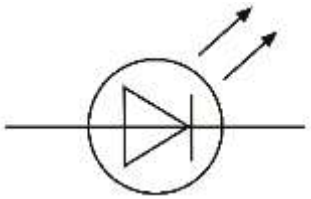
(b) Light Emitting Diode (LED): -

Definition:

- A light emitting diode (LED) is a heavily doped p-n junction diode designed to emit spontaneous radiation when forward biased, converting electrical energy into light energy.

Symbolic Representation:

- The symbol for an LED resembles that of a standard diode, with two arrows pointing away from the diode, indicating the emission of light energy.



Construction:

- LEDs are made of either elemental semiconductors like germanium (Ge) and silicon (Si) or compound semiconductors like gallium arsenide (GaAs) and gallium arsenide phosphide (GaAsP).
- Elemental semiconductor LEDs emit infrared (heat) radiation, while compound semiconductor LEDs emit light of different wavelengths.

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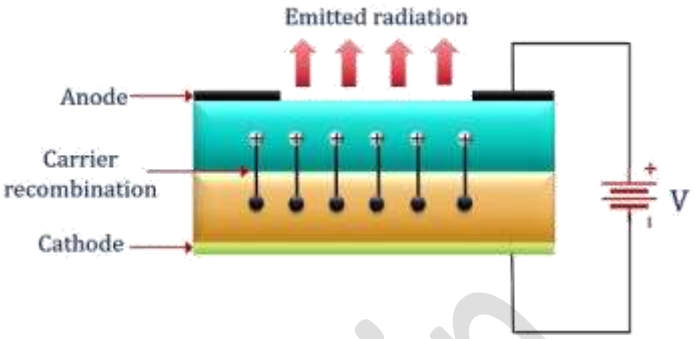

Theory:

- When a p-n junction diode is forward biased, electrons injected into the p-side of the junction fall from the conduction band to the valence band and recombine with holes.
- This recombination process releases energy in the form of visible light, a phenomenon known as electro-luminescence.

Characteristics:

- The voltage-current (V-I) characteristics of LEDs are similar to that of elemental semiconductors like silicon diodes.
- However, the forward voltage of LEDs is much higher than that of silicon diodes, and they can be damaged by low reverse voltages (e.g., 5V).

Advantages of LED:

1) LEDs are easily manufactured and have low production costs.
2) LEDs operate at lower voltages compared to incandescent bulbs.
3) LEDs have a longer operational lifespan compared to incandescent bulbs.
4) LEDs can be switched on and off rapidly, making them suitable for use as blinkers.
5) LEDs require no warm-up time and provide instant illumination.
6) LEDs consume significantly less power compared to incandescent bulbs.
7) LEDs can emit monochromatic light as well as white light.

Uses of LED:

1) Used as indicator lights in various electronic devices.
2) Utilized in digital displays in watches, calculators, and electronic signage.
3) Infrared LEDs are used in burglar alarms and remote-control systems.
4) Employed as blinkers in automotive applications.
5) Used for decorative lighting purposes in various settings.
6) Utilized as night lamps and in torches for illumination in low-light conditions.

(c) <u>Solar Cell or Photovoltaic Device</u>

Definition:

- A solar cell, also known as a photovoltaic device, is a special p-n junction diode designed to convert solar energy (sunlight) into electrical energy.

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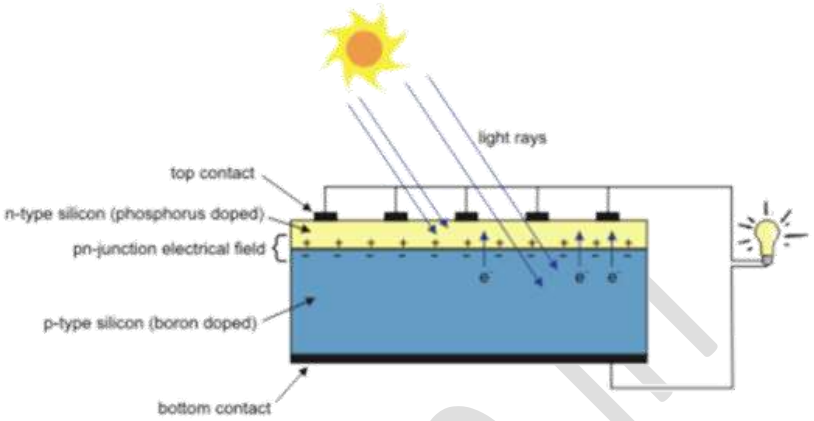
Construction:

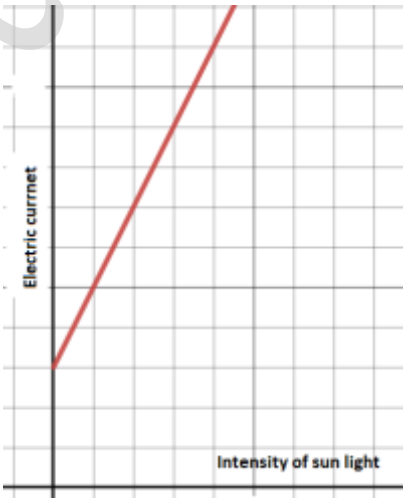
- Solar cells consist of a p-n junction diode, where the n-region is very thin and the p-region is thick to enhance light absorption.
- The junction surface of these diodes is kept large to capture maximum radiation.
- Nickel-plated contacts are connected through a load resistance to extract electrical energy.



Working:

1) Generation of Electron-Hole Pairs:

When solar energy or light energy falls on the solar cell, electron-hole pairs are generated in both the n-region and p-region of the junction diode.

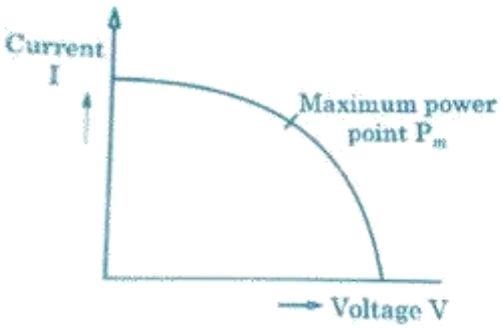


2) The electrons from p-region diffuse through the junction to n-region and holes from n-region diffuse through the junction to the p-region due to electric field of depletion layer. Thus, holes and electrons are separated out. For better hole electron separation under the effect of junction field it is required that photo emission takes place in the junction area only.

3) If p-n junction diode is open circuited, then holes and electrons will collect or accumulate on the two sides of the junction: This gives rise to an open circuit voltage Vo. When an external resistance is connected across the junction diode, electric current flows through the circuit. The electric current in the circuit increases with the increase in the intensity of sunlight.

4) V-I Characteristics:

- A typical V-I characteristic of a solar cell is shown in Figure
- V_o represents the open-circuit voltage of the solar cell, and I_s the maximum current (short-circuit current) that can be drawn from the cell.



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- The curve is available in the fourth quadrant because the current I_s supplied by the cell and not drawn by the cell.

Uses of Solar Cell:

1. **Street Lights**:
    - Solar cells are used in street lights powered by solar energy.
2. **Solar Heaters**:
    - Utilized in solar heaters for water heating applications.
3. **Space Applications**:
    - Used in power supply systems of satellites and space vehicles.
4. **Calculators**:
    - Integrated into calculators and other portable electronic devices.

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