Chapter 1

Semiconductor Diode (6hr)

Introduction to Semiconductors

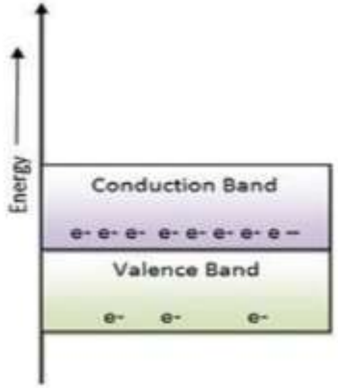
- **Semiconductor** are materials whose electrical conductivity lies between **conductor** and an **insulator**.

- Electrical Conductivity: Level to which a material conducts electricity.
- **Conductor**: allows the current to flow through it with the application of voltage like copper.
- **Insulator**: **Do not allows** the current to flow through it with the application of voltage like Glass.

Energy band diagram of materials

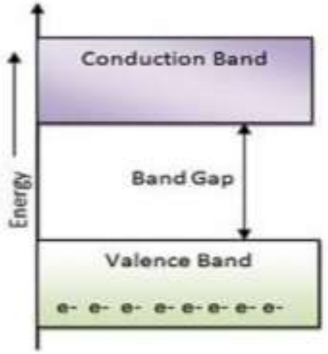
- **Conductor**: have a very small energy gap

➢ Result: current flows easily



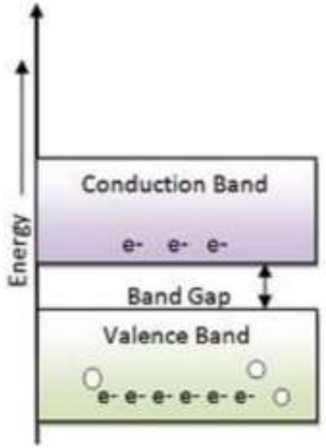
- **Insulator**: have a large energy gap

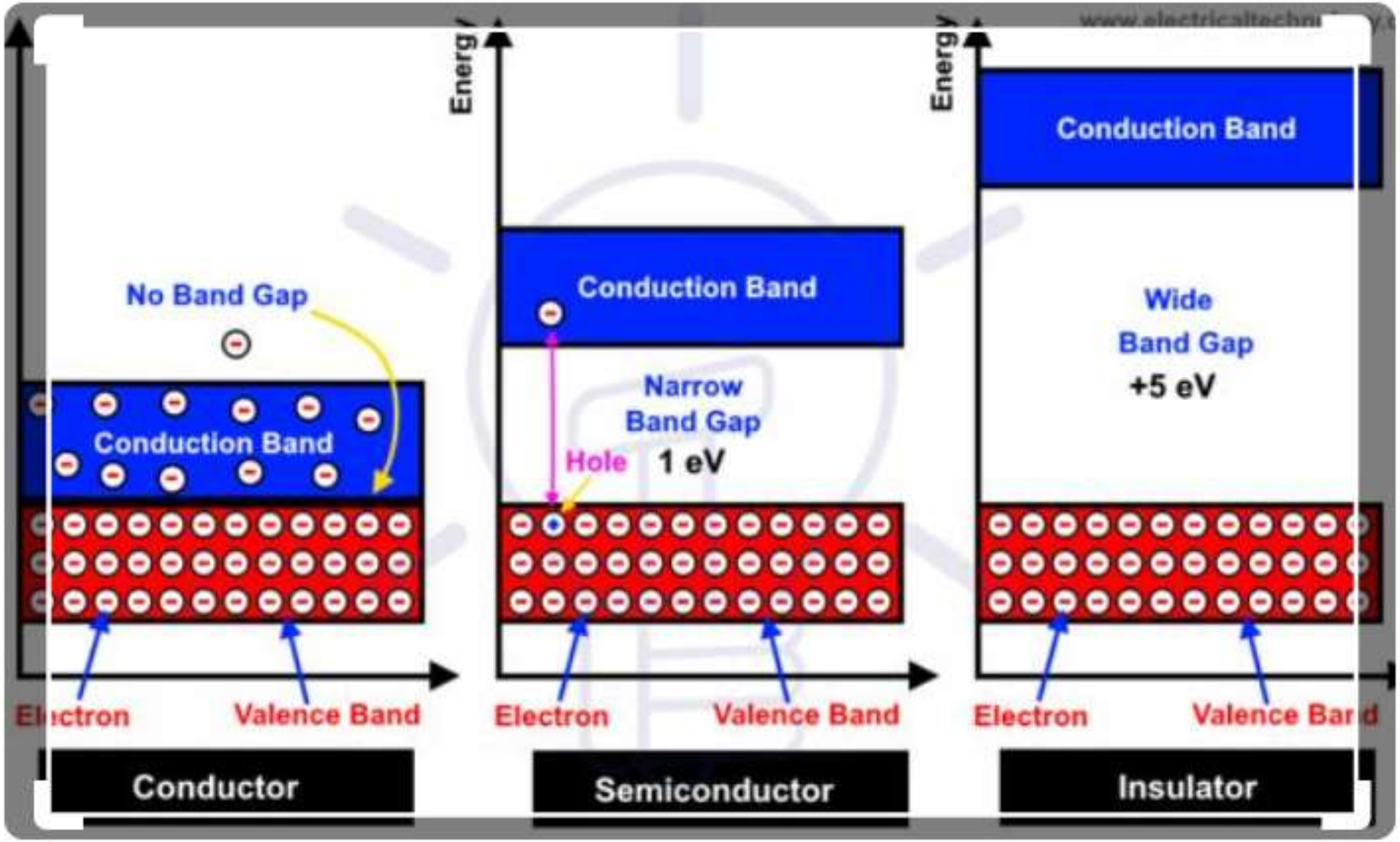
➢ Result: no current flows



- **Semiconductor**: have a medium energy gap

➢ Result: only a small amount of current can flow





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Energy
No Band Gap
Conduction Band
Electron
Valence Band
Conductor
Energy
Conduction Band
Narrow
Band Gap
Hole
1 eV
Electron
Valence Band
Semiconductor
Energy
Conduction Band
Wide
Band Gap
+5 eV
Electron
Valence Band
Insulator

Bands in Energy Diagram

- Valance Band: Outermost electron orbital of an atom of material that electrons actually occupy. This is lower band. From this band electrons can jump out of, moving into the higher energy level.
- Conduction Band: This band is generally empty and high in energy. When the electrons are in these band, they have enough energy to move freely in the material. This movement of electrons creates a current.
- Energy band gap: The gap between valance band and conduction band.

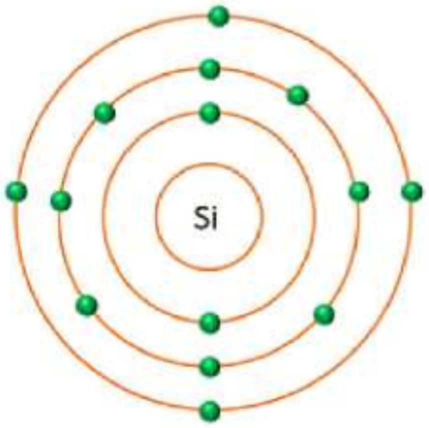
Materials having Semiconductor property

- Semiconductors are the materials which have 4 electrons in its outer most orbit and which forms crystalline structure.

➢ Silicon(Si): atomic number is 14

Number of Energy Levels: 3

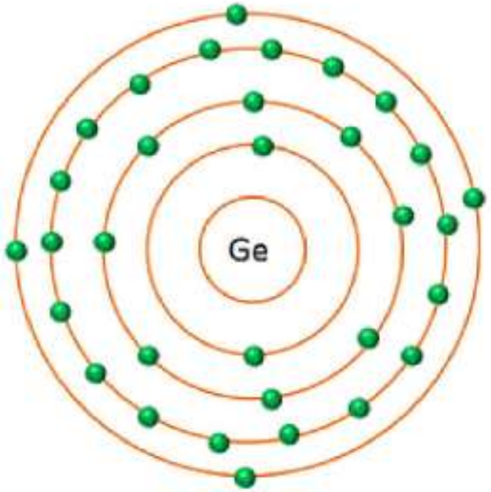
First Energy Level: 2
Second Energy Level: 8
Third Energy Level: 4



➢ Germanium(Ge): atomic number is 32

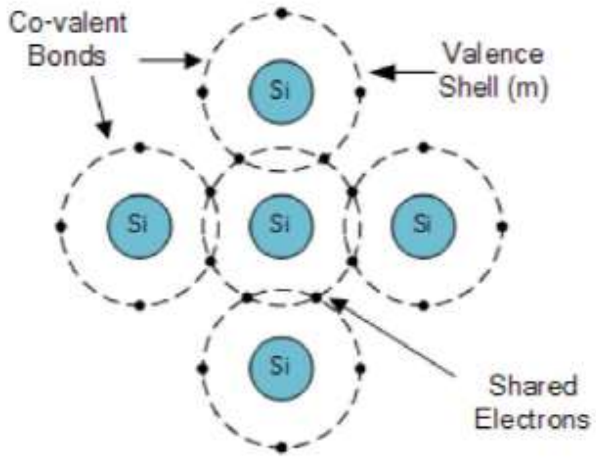
Number of Energy Levels: 4

First Energy Level: 2
Second Energy Level: 8
Third Energy Level: 18
Forth Energy Level: 4



Silicon Crystal Structure

- Silicon atoms form covalent bonds and can crystallize into a regular lattice.
- Silicon atom has four electrons in its outer most orbit which it can share in covalent bonds with its neighbors and form crystal lattice.



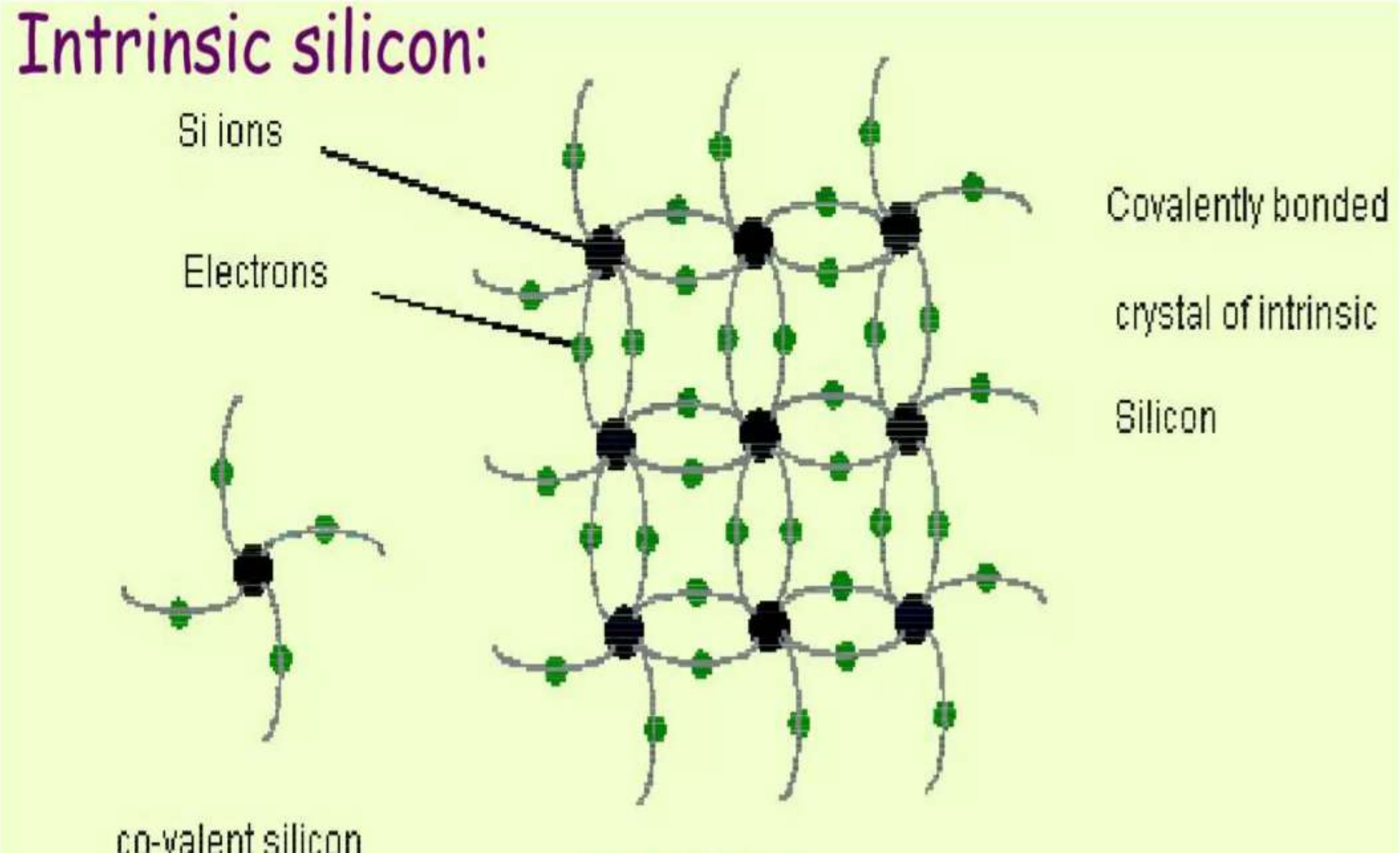
Properties of Semiconductor

- It has negative temperature coefficient of resistance, i.e., the resistance of semiconductor decreases with increase in temperature and vice versa
- The resistivity lies between insulator and conductor
- Doping increases conductivity of semiconductor
- At absolute zero, it behaves as perfect insulator
- At room temperature it behaves as conductor.

Intrinsic Semiconductors

- An intrinsic semiconductor is one which is made of the ***semiconductor material in its extremely pure form.***
- Examples of such semiconductors are: *pure germanium and silicon which have forbidden energy gaps of 0.72 eV and 1.1 eV respectively.*
- The energy gap is so small that even at ordinary room temperature; *there are many electrons which possess sufficient energy to jump across the small energy gap between the valence and the conduction bands.*
- Alternatively, ***an intrinsic semiconductor may be defined as one in which the number of conduction electrons is equal to the number of holes.***

Intrinsic Semiconductors



Extrinsic Semiconductors

("doped semiconductor")

- semiconductor with *small admixture of trivalent or pentavalent atoms.*
- Those intrinsic semiconductors to which some suitable *impurity or doping agent or doping* has been added in *extremely small amounts* (about 1 part in 108) are called ***"Extrinsic or Impurity semiconductors".***

TYPES OF EXTRINSIC SEMICONDUCTOR

- Depending on the type of doping material used, extrinsic semiconductors can be sub-divided into two classes:

- ❑ **N-type semiconductors (donor)**
- ❑ P-type semiconductors (acceptor)

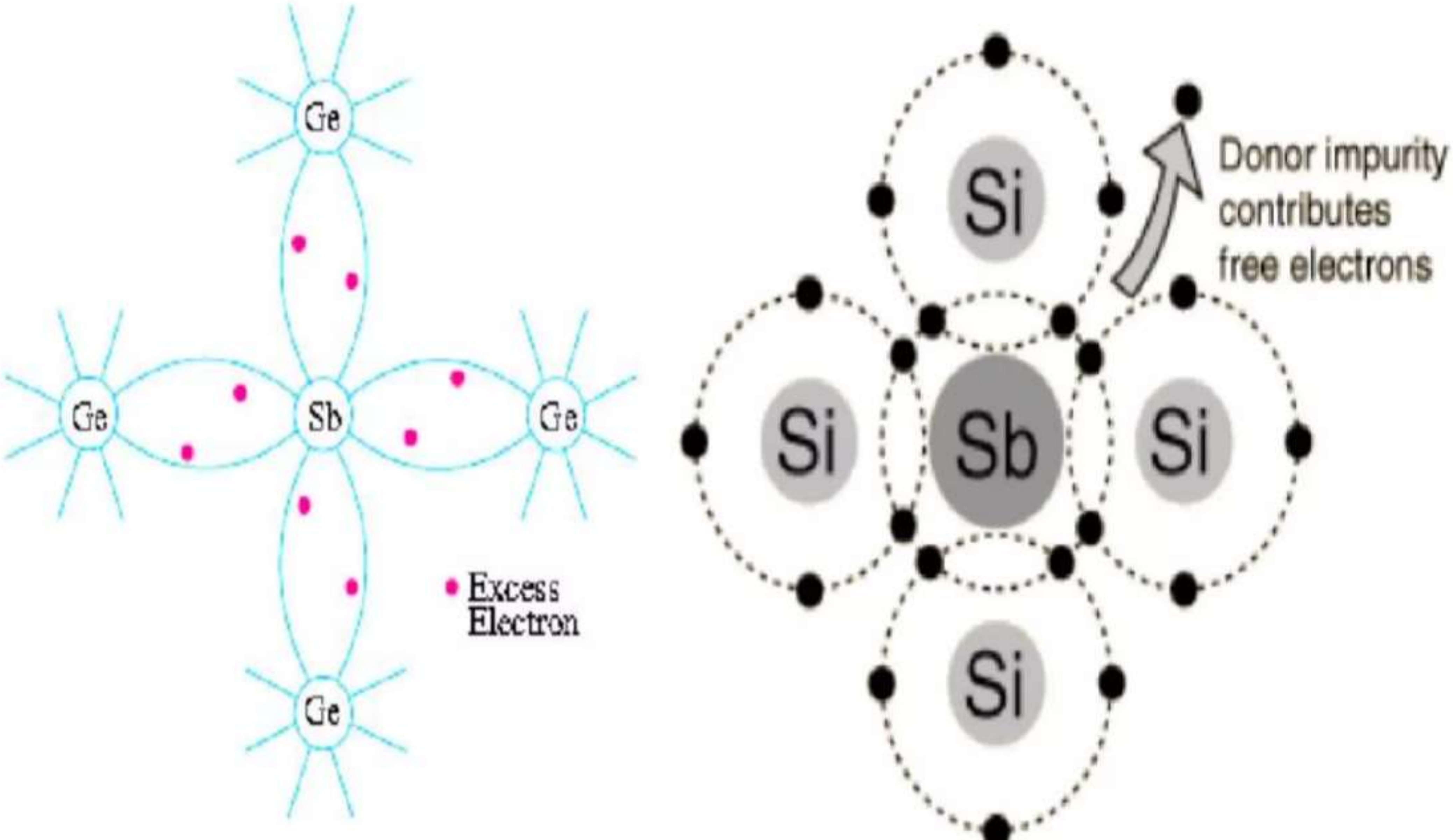
N-type Extrinsic Semiconductor

- This type of semiconductor is obtained when a **Pentavalent material** like **antimony (Sb)** is added to **pure silicon crystal.**
- **dopant with 5 valence electrons. 4 electrons used for covalent bonds with surrounding Si atoms.**
- each antimony atom forms covalent bonds with the surrounding four silicon atoms with the help of four of its five electrons.
- **The fifth electron is loosely bound to the antimony atom.** it is mobile charge carrier. **This electron needed only small amount of energy to lift it into conduction band (0.05 eV in Si).** which improves the conduction ability to some extent.

N-type Extrinsic Semiconductor

- Hence, **it can be easily excited from the valence band to the conduction band by the application of electric field or increase in thermal energy.**
- The resultant material is known as an n-type semiconductor.
- It is seen from the above description that in N-type semiconductors, ***electrons are the majority carriers while holes constitute the minority carriers.*** has conduction electrons, no holes.
- e.g.of dopant with 5 valence electrons P, As, Sb

N-type Extrinsic Semiconductor



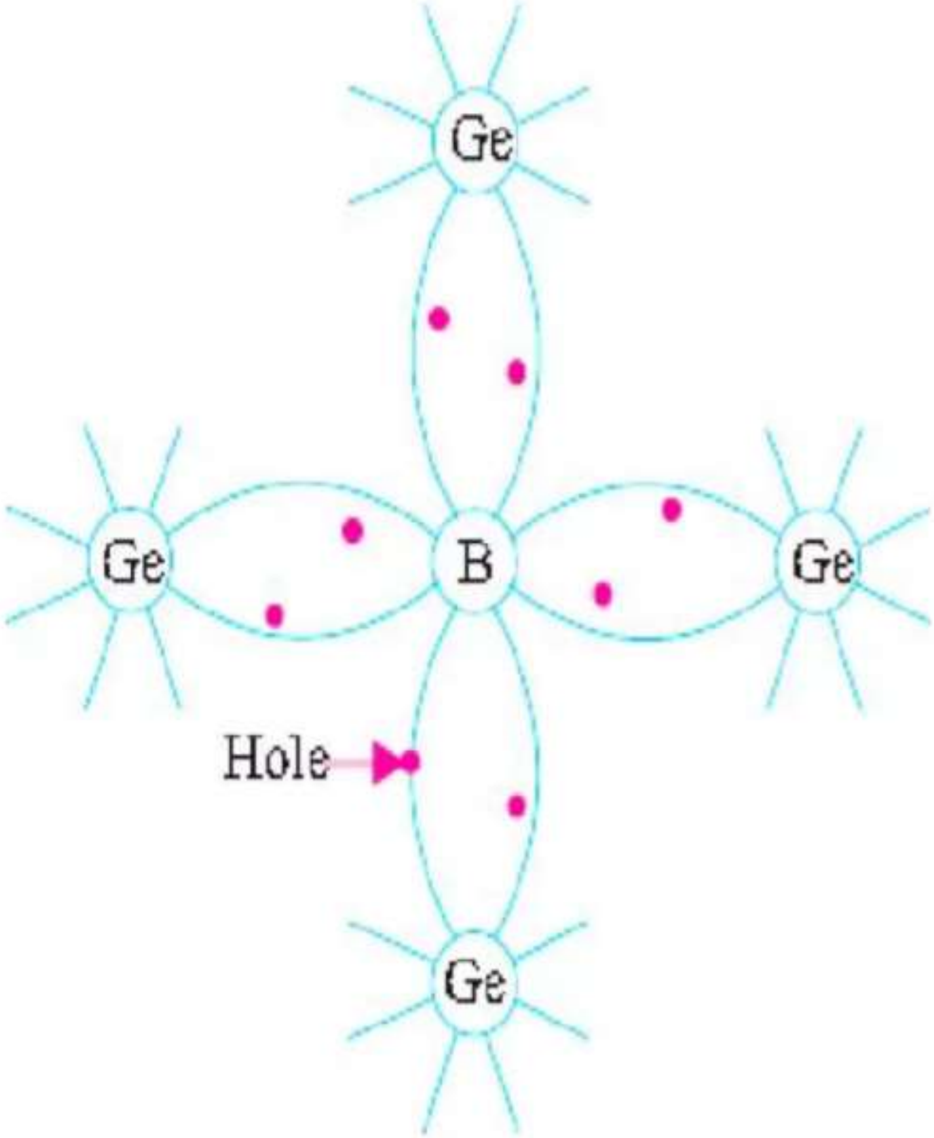
P-type Extrinsic Semiconductor

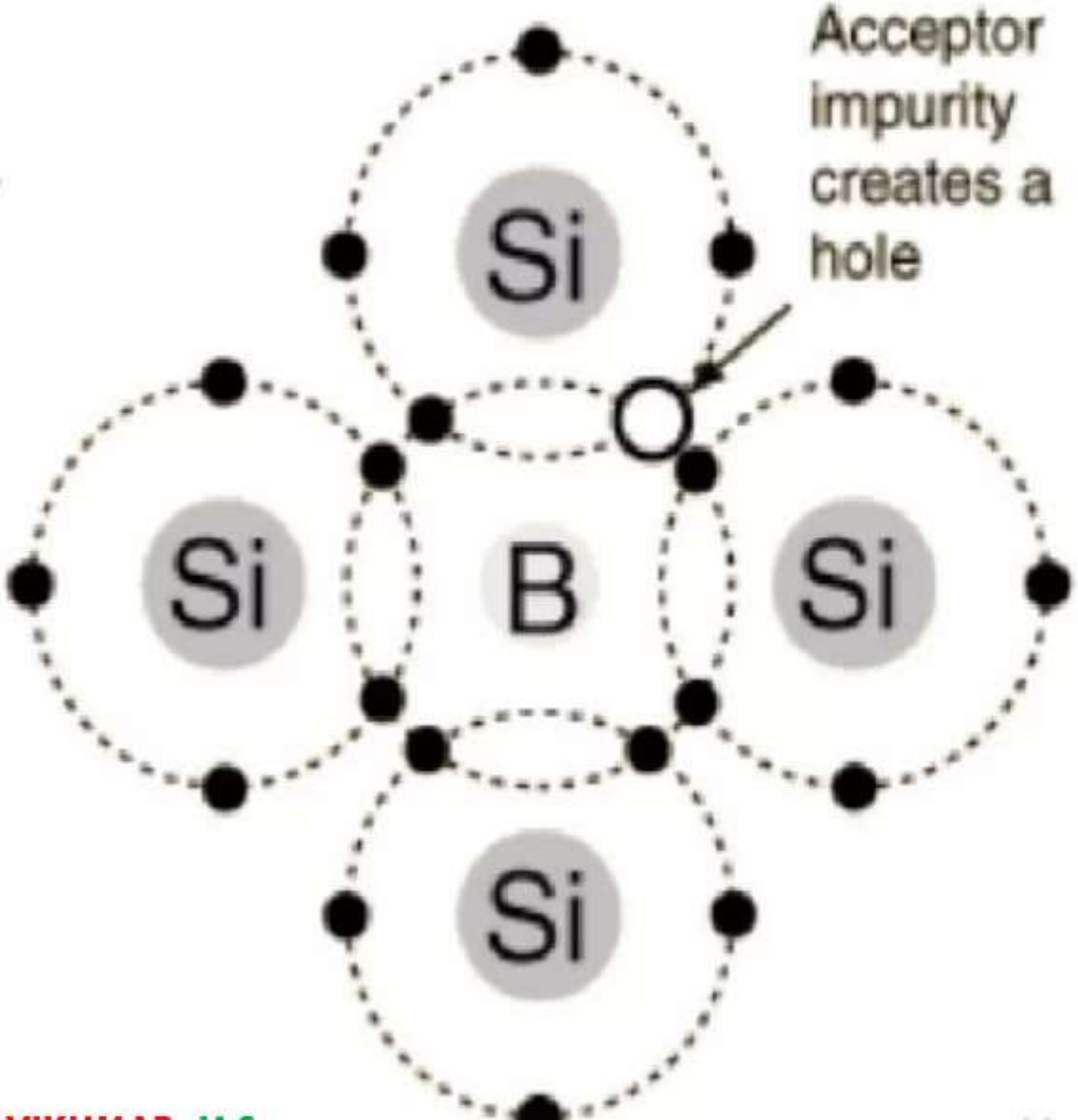
- This type of semiconductor is obtained when traces of a **trivalent like boron (B)** are added to a **pure germanium crystal.**
- **dopant with 3 valence electrons** (e.g. B, Al, Ga, In)
- **only 3 of the 4 covalent bonds filled** and **vacancy in the fourth covalent bond is hole.**
- In this case, the three valence electrons of boron atom form covalent bonds with four surrounding germanium atoms but one bond is left incomplete and gives rise to a hole.
- **hole is left free as a mobile charge carrier,** which improves the conduction ability to some extent.

P-type Extrinsic Semiconductor

- Thus, boron which is called an acceptor impurity causes as many positive holes in a germanium crystal as there are boron atoms there by producing a P-type (P for positive) extrinsic semiconductor.
- **In this type of semiconductor, conduction is by the movement of holes in the valence band.**
- The resultant material is known as a p-type semiconductor.
- Examples for trivalent dopant B, Al, Ga, In

P-type Extrinsic Semiconductor





1-4 Conduction in Semiconductor

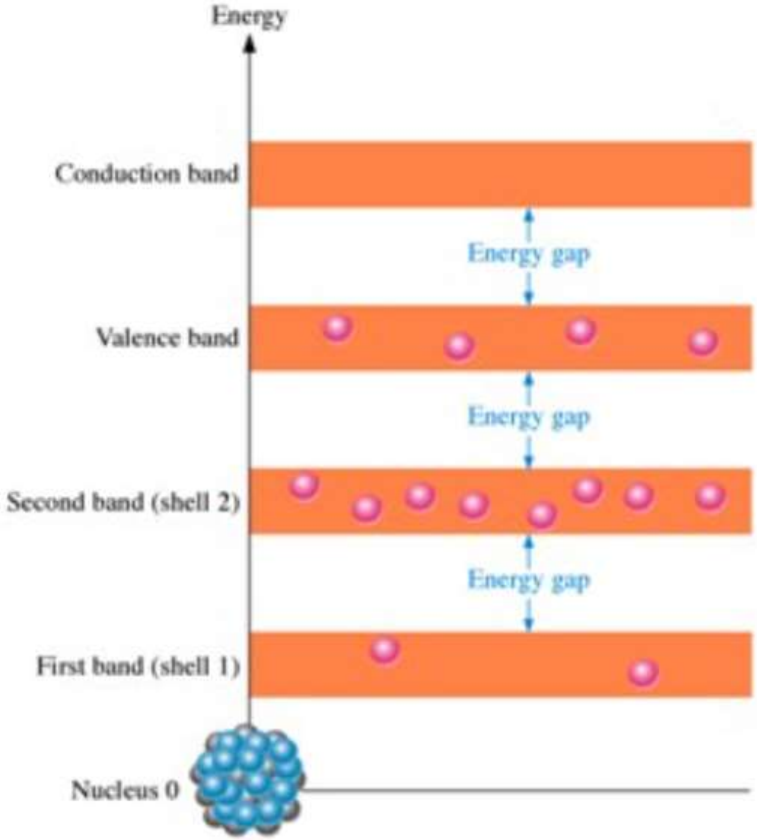


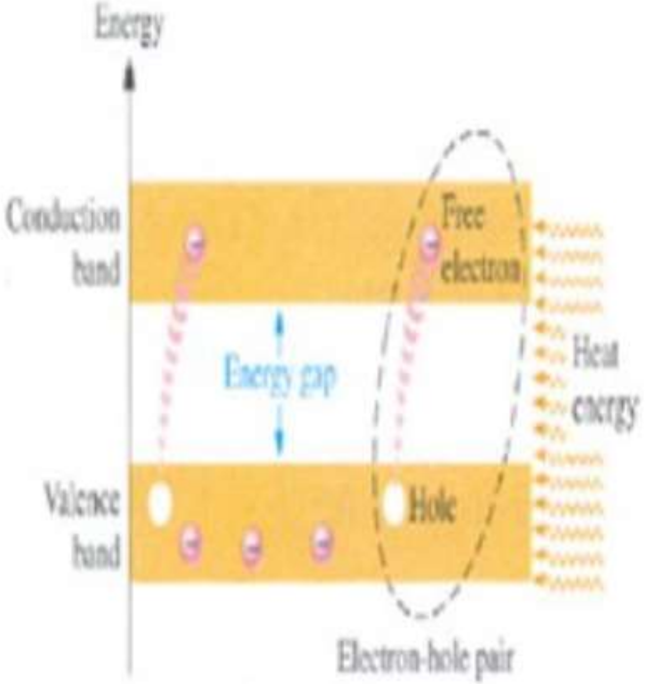
Figure 1-10 Energy band diagram for a pure (intrinsic) silicon crystal with unexcited (no external energy such as heat) atoms. There are no electrons in the conduction band. This condition occurs only at a temperature of absolute 0 Kelvin.

Conduction Electrons and Holes

- When an electron jumps to the conduction band, a *vacancy* is left in the vallence band, this vacancy is called a *hole* and the electron is said to be in an *excited state*.

- *Recombination* occurs when a conduction-band electron after within a few microseconds of becoming a free, loss its energy and falls back into a hole in the valence band.

- The energy given up by the electron is in the form of *light* and/or *heat*.



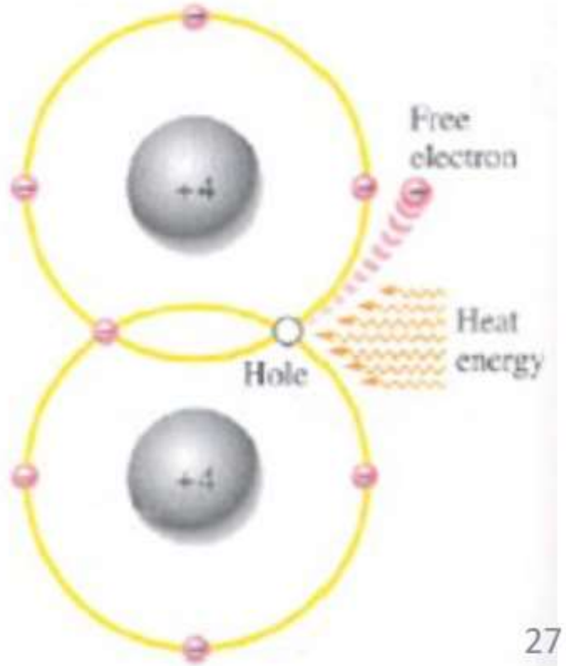


Fig.1-11: Creation of electron-hole pairs in a Si atom. (a) energy diagram, and (b) bonding diagram

Electron Current

- At the temperature room, at any instant, a number of free electrons that are unattached to any atom drift randomly throughout the material. This condition occurs when no voltage is applied across a piece of intrinsic Si (as illustrated in Fig. 12).

- When a voltage is applied across the piece of intrinsic Si, as shown in Fig. 13, the thermally generated free electrons in the conduction band, which are free to move, are now easily attracted toward the positive end.

- The movement of free electrons in a semiconductive material is called *electron current*.

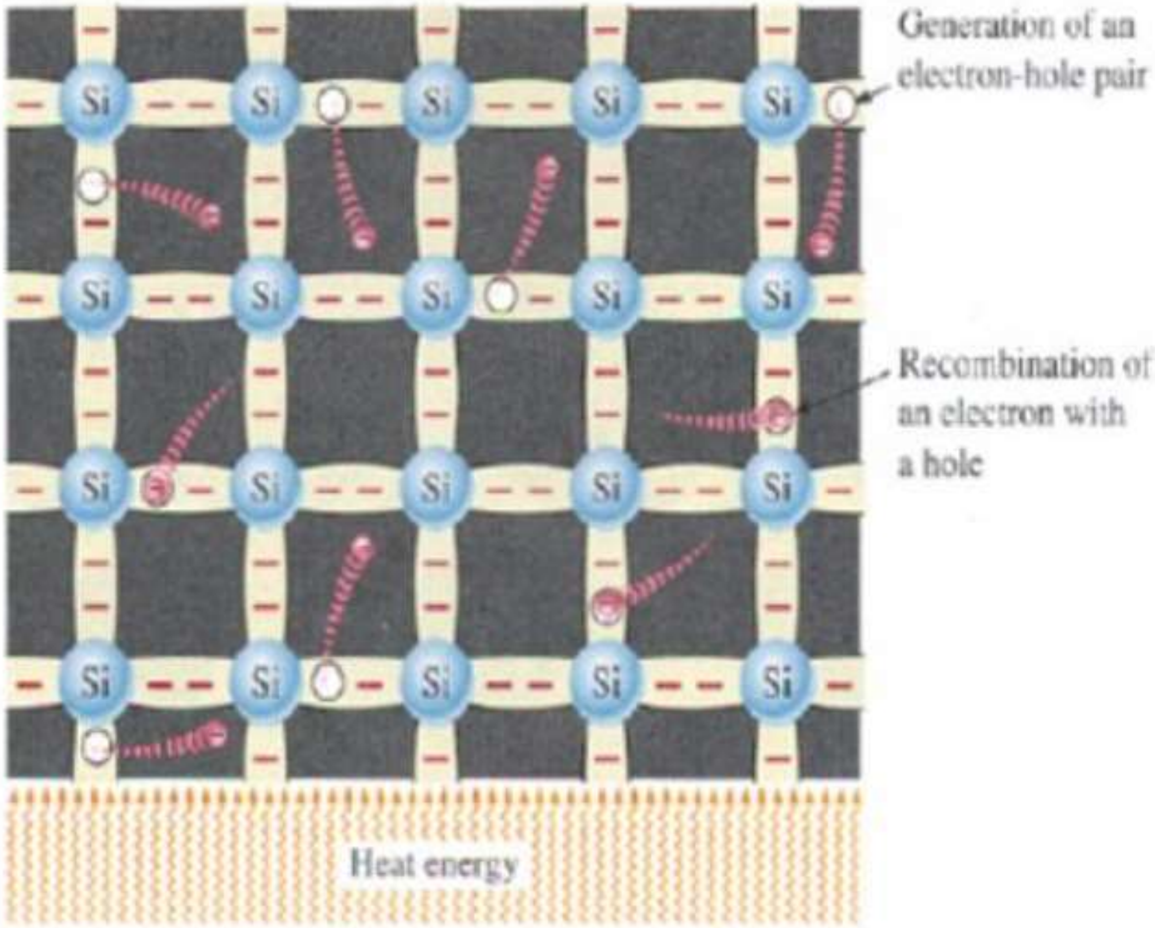


Fig .12: Free electrons are being generated continuously while some recombine with holes

Hole Current

- At the same time, there are also an equal number of holes in the valence band created by electrons that jump into the conduction band (Fig. 13).
- Electron remaining in the valence band are still attached to the atom – not free to move like free electron.
- However, valence electron can move into nearby hole – leaving another hole it comes from
- Thus, hole has moved from one place to another in the opposite direction.
- The movement of electrons in a valence band is called ***hole current*** .

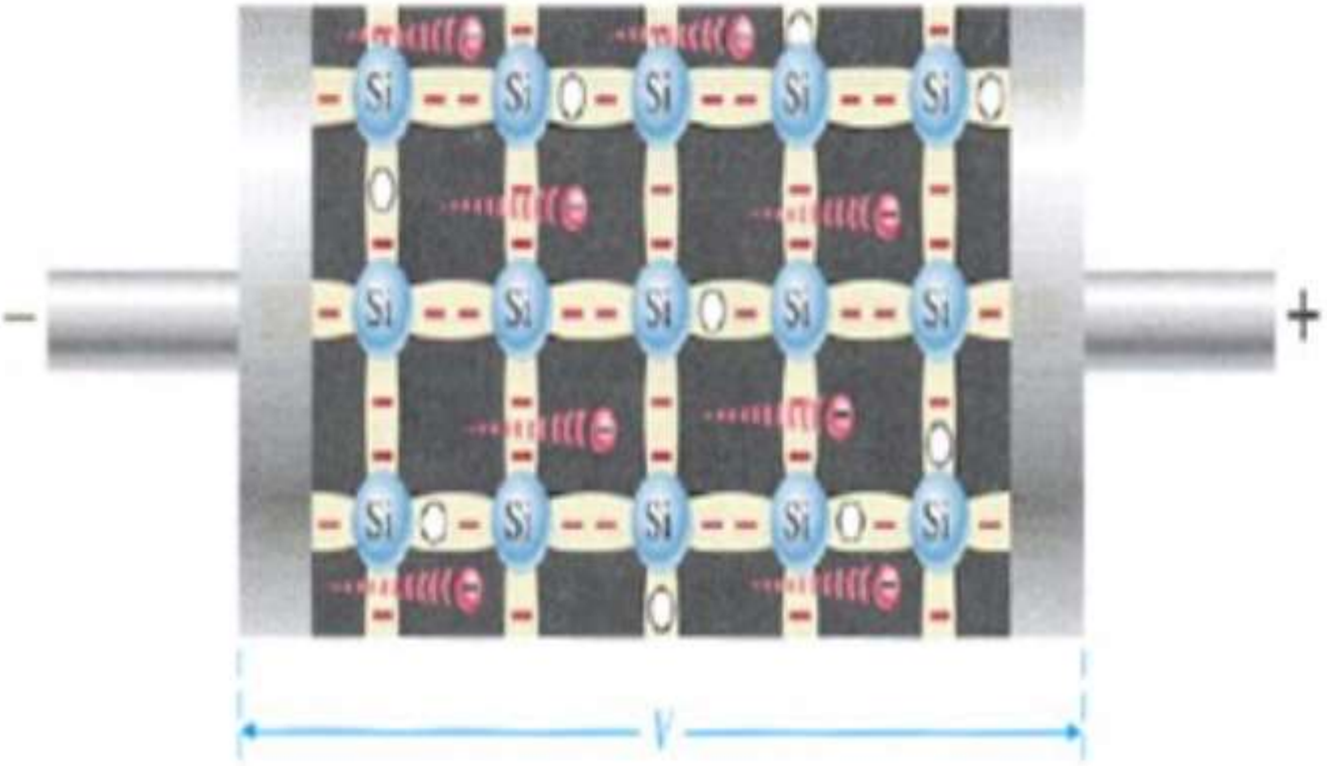
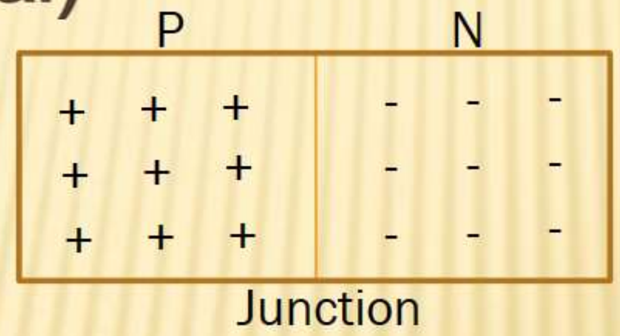


Fig. 13: Free electrons are attracted toward the positive end

P-N JUNCTION

- Single piece of SC material with half n-tpye and half p-type
- The plane dividing the two zones is called junction (plane lies where density of donors and acceptors is equal)

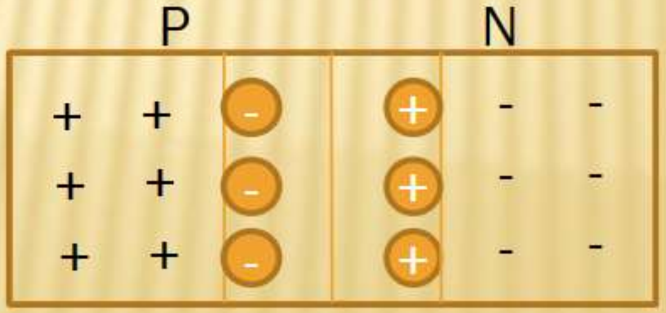


- Three phenomenas take place at the junction
  - Depletion layer
  - Barrier potential
  - Diffusion capacitance

P-N JUNCTION

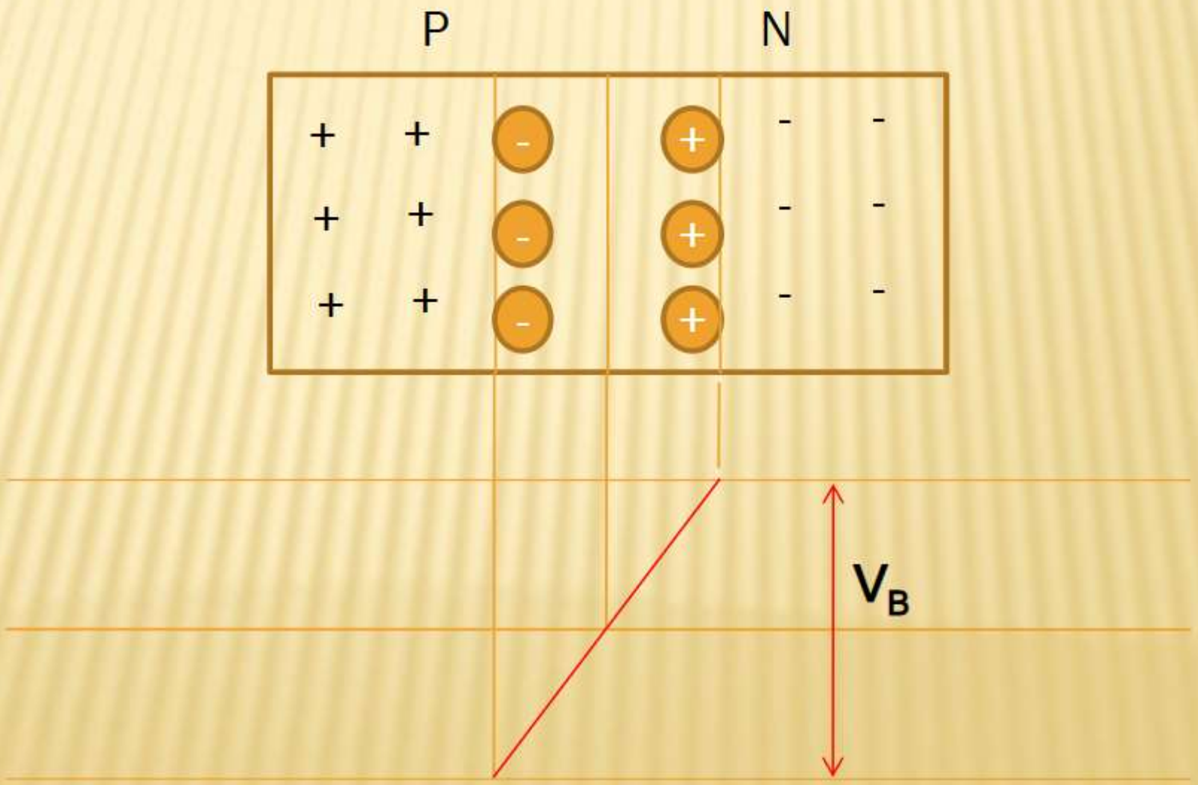
- Formation of depletion layer
  - Also called Transition region
  - Both sides of the junction
  - Depleted of free charge carriers
  - Density gradient across junction (due to greater difference in number of electrons and holes)-Results into carrier diffusion
  - Diffusion of holes (from p to n) and electrons (from n to p)
  - Diffusion current is established
  - Devoid of free and mobile charge carriers (depletion region)
  - **It seems that all holes and electrons would diffuse!!!**

- But this does not happen
- There is formation of ions on both sides of the junction
- Formation of fixed +ve and –ve ions- parallel rows of ions
- Any free charge carrier is either
  - Diffused by fixed ions on own side
  - Repelled by fixed ions of opposite side
- Ultimately depletion layer widens and equilibrium condition reached



BARRIER VOLTAGE

- Inspite of the fact that depletion region is cleared of charge carriers, there is establishment of electric potential difference or Barrier potential (V_B) due to immobile ions



- V_B for Ge is 0.3eV and 0.7eV for Si
- Barrier voltage depends on temperature
- V_B for both Ge and Si decreases by about 2 mV/ ^0C

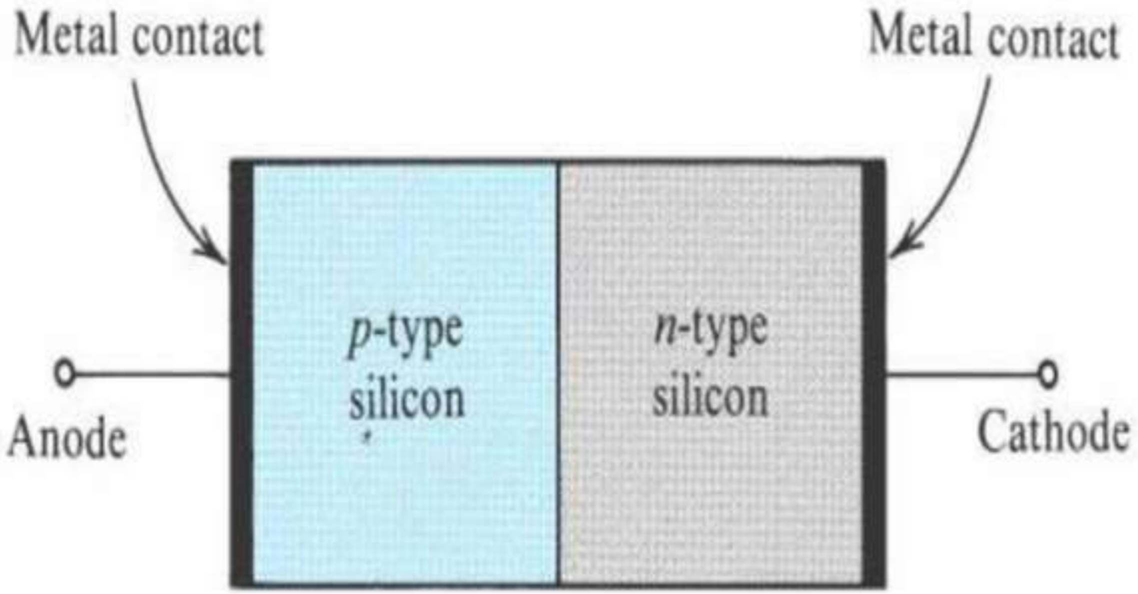
  Therefore $\Delta V_B = -0.002\ \Delta t$

  where Δt is the rise in temperature
- V_B causes the drift of carriers through depletion layer. Hence barrier potential causes the drift current which is equal and opposite to diffusion current when final equilibrium is reached- Net current through the crystal is zero

Introduction: Diode

- The diode is the simplest and most fundamental nonlinear circuit element.
- Just like resistor, it has two terminals.
- Unlike resistor, it has a nonlinear current-voltage characteristics.
- Its use in rectifiers is the most common application.

Physical Structure of Diode



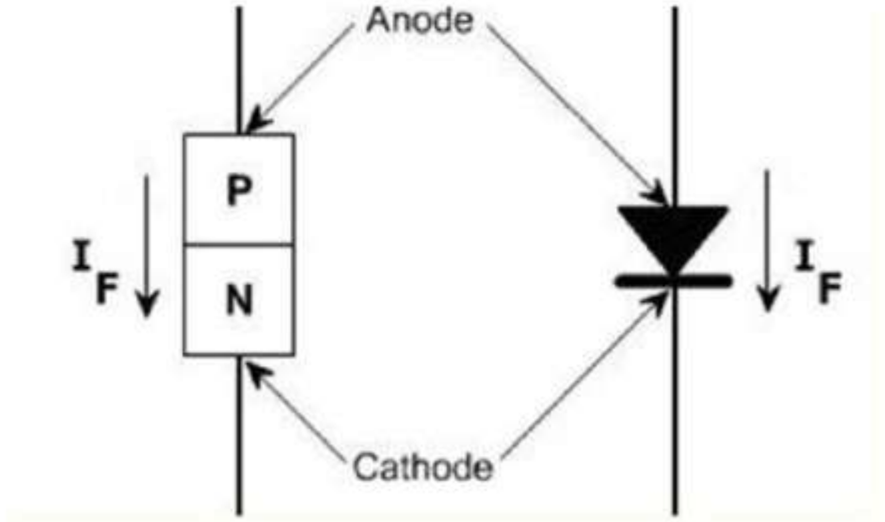
Diodes are formed by joining the N-type and P-type semiconductors

Diode is an electronic device which allows current to flow only in one direction

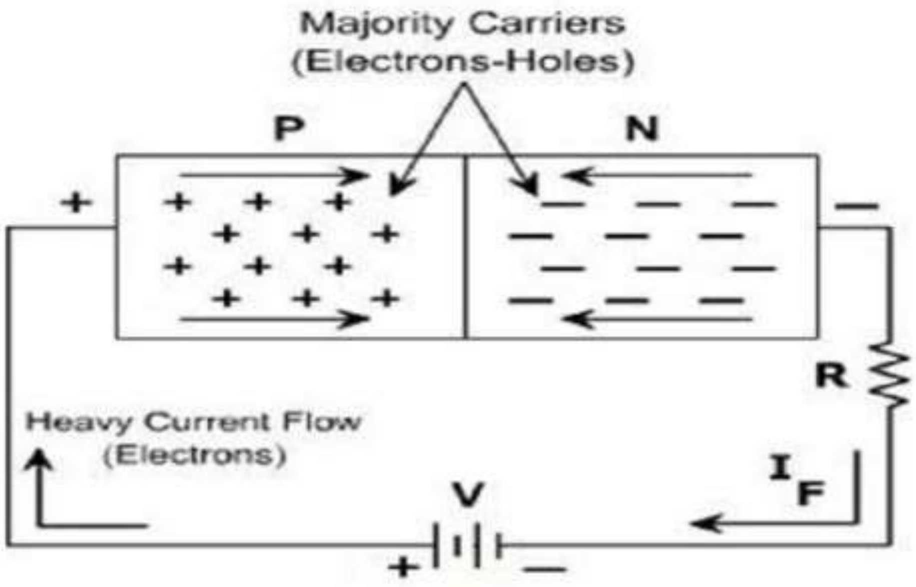
The voltage applied to the semiconductor diode is referred to as bias voltage.

Types of bias voltages:

- Forward Bias
- Reverse Bias

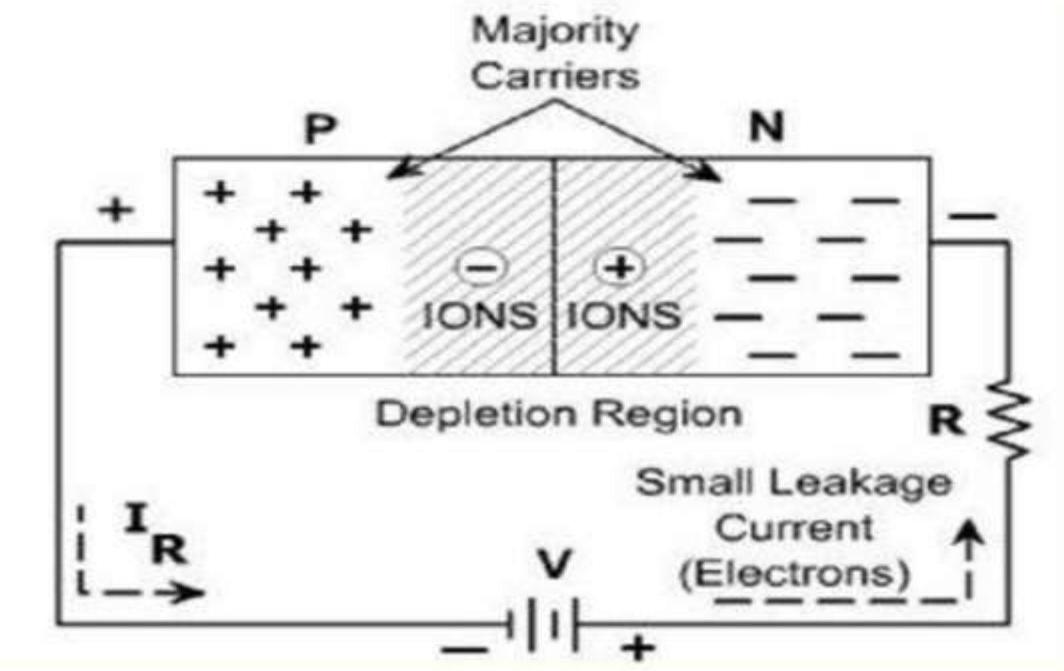


Forward Bias



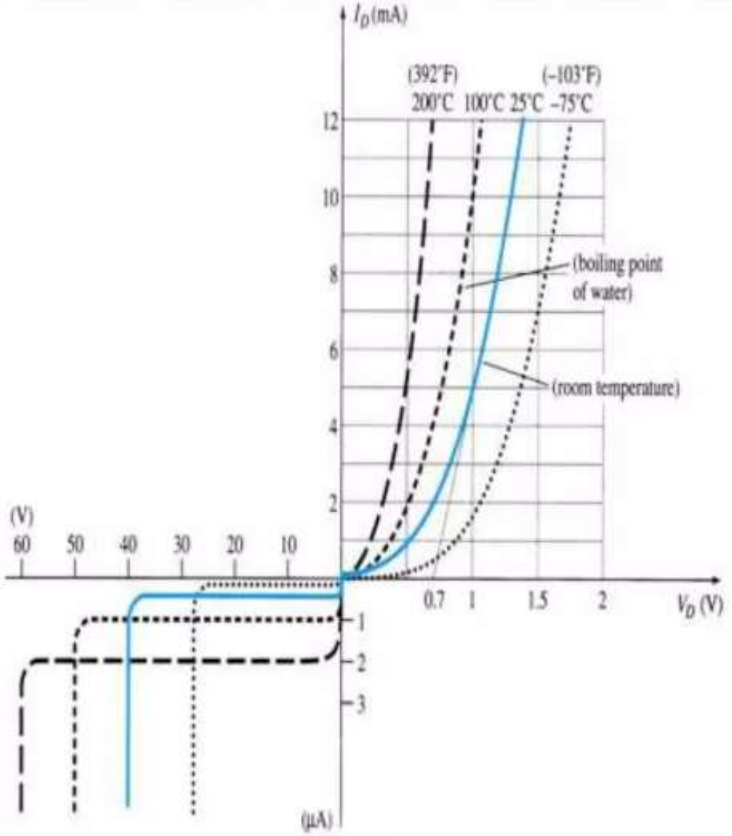
- A forward biased diode conducts current in the forward direction
- A forward biased diode conducts current as long as a high external bias voltage with correct polarity is applied

Reverse Bias



Extremely small current flows through the diode during reverse biasing. The minority carriers are forced towards the junction where they combine and support an extremely small current

Temperature Effects



Variation in Si diode characteristics with temperature change

- In the forward bias region the characteristics of a Si diode shift to the left at a rate of 2.5 mv per centigrade degree increase in temperature
- The reverse saturation current I_s will just about double in magnitude for every 10°C increase in temperature.
- The reverse breakdown voltage of a semiconductor diode will increase or decrease with temperature depending on the zener potential
- At room temperature Si and GaAs have relatively small reverse saturation current

$$I_D = I_S\left(e^{\frac{qV_D}{nkT}} - 1\right)$$

Ideal Diode Equation

Where

I_D and V_D are the diode current and voltage, respectively

q is the charge on the electron

n is the ideality factor: n = 1 for indirect semiconductors (Si, Ge, etc.)

n = 2 for direct semiconductors (GaAs, InP, etc.)

k is Boltzmann's constant

T is temperature in Kelvin

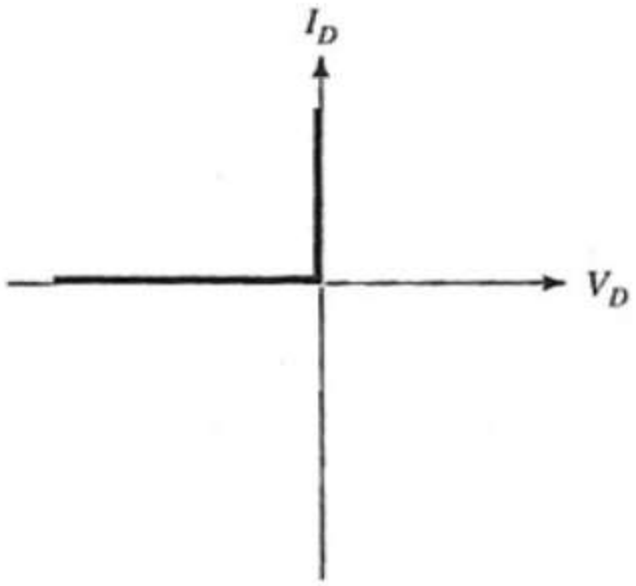
kT/q is also known as V_{th}, the thermal voltage. At 300K (room temperature), kT/q = 25.9mV

$$\mathbf{I_D = I_S(e^{V_D/\eta V_T} - 1)}$$

Ideal and piecewise linear model of diode

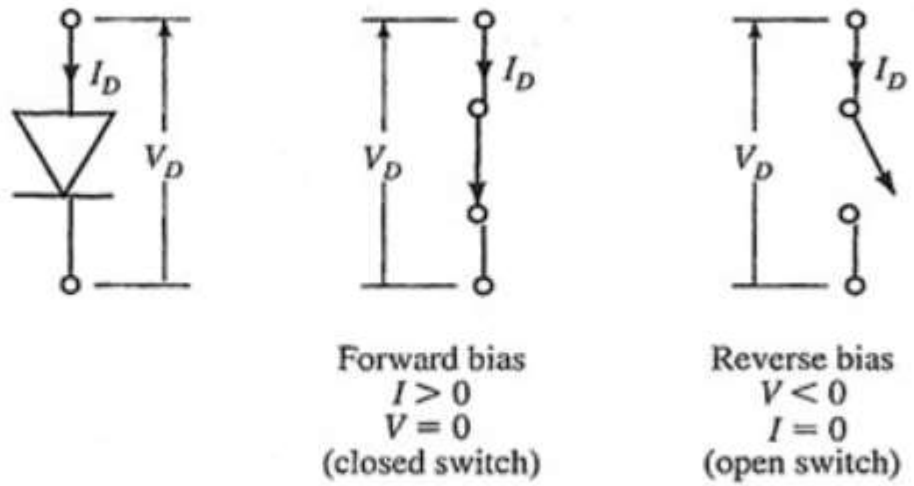
Ideal Diode

- Idealized two terminal device which passes current in one direction (zero resistance) and passes no current in the opposite direction (infinite resistance).
- Its v-i plot, which shows the relationship of the voltage across the diode and the current flowing through it, contains a discontinuity.



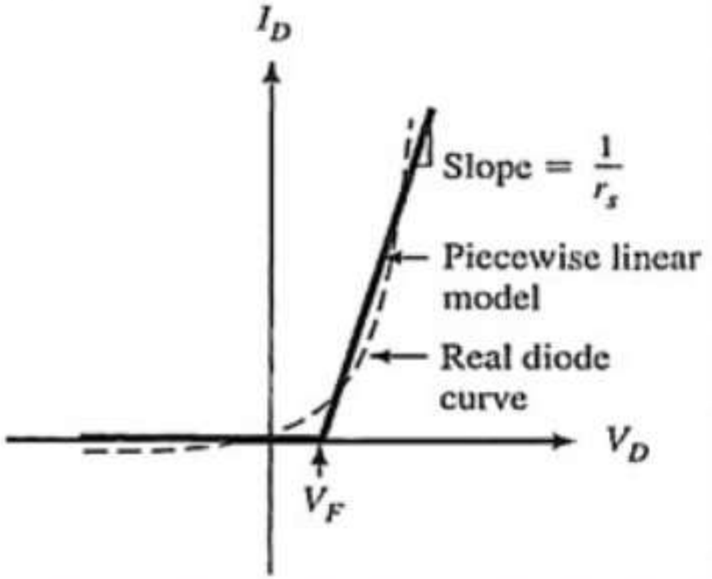
Ideal Diode

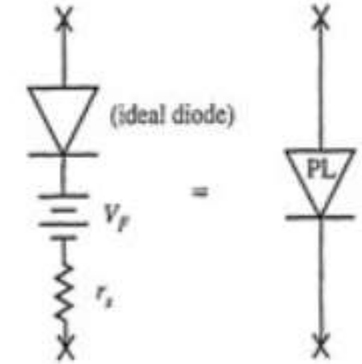
- If the diode is forward biased then the ideal diode conducts current as a closed switch.
- If the diode is reverse biased then the ideal diode will not conduct current, and it will appear as an open switch.



Piecewise Linear Model

- The real diode can be approximated by a model which uses two connected line segments.
- Note that the turn on voltage, V_F, marks the point where the two line segments meet.

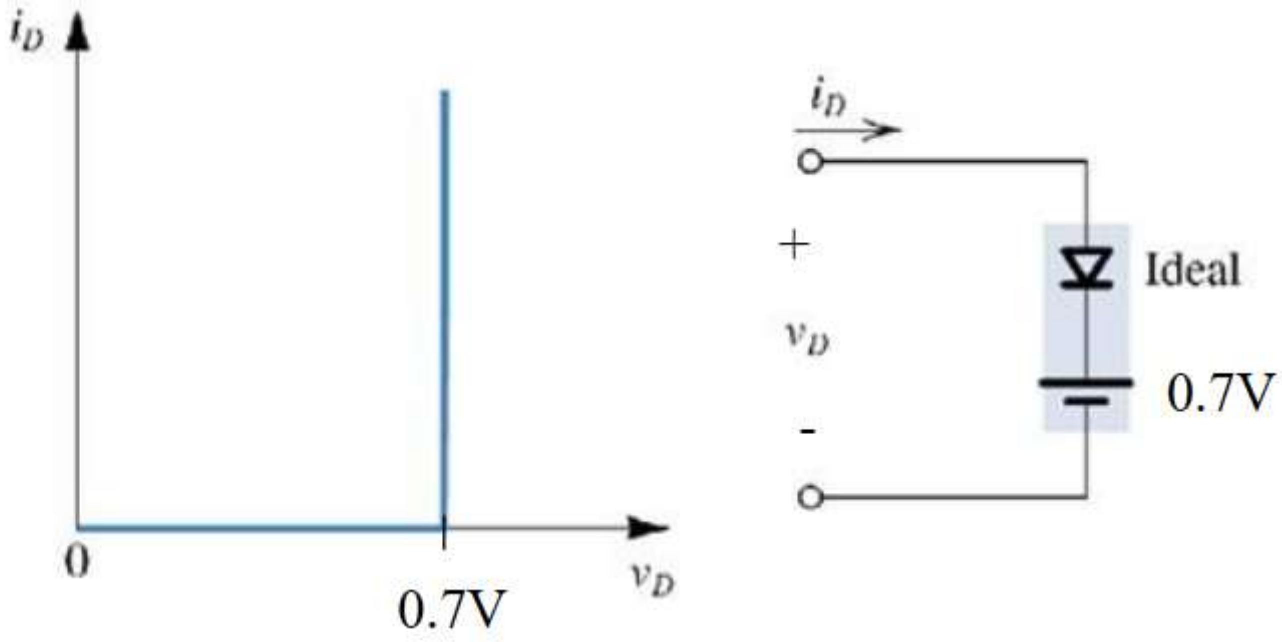




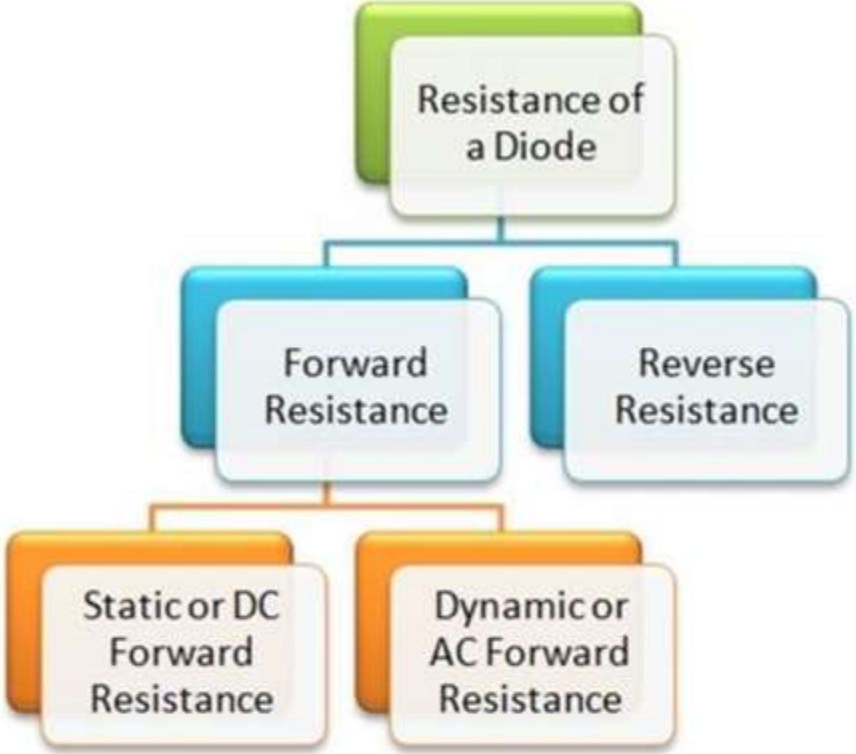
Slope= dy/dx
= $1/r_d$ = I_D/V_D

Constant-voltage drop model

I-V characteristics and equivalent circuit



Diode resistance



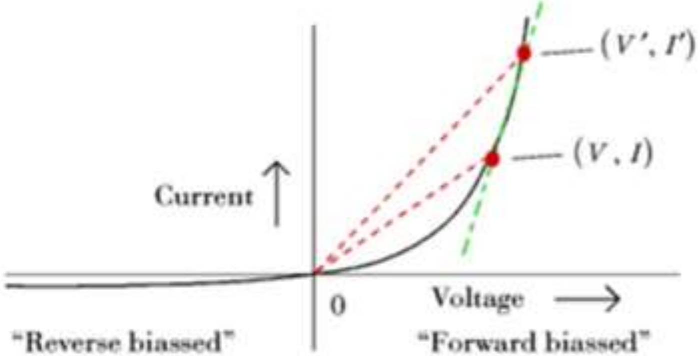
- The resistance of a diode is non-zero and finite, as diode is not a perfect conductor nor it is perfect insulator.
- The resistance of a diode will change depending on the region of characteristics it is operating in, due to the nonlinear shape of the characteristic curve.
- The resistance of a diode is also defined depending on whether it is operating in DC or AC condition as:
  - **DC or Static resistance**
  - **AC or Dynamic resistance**

Diode resistance …

❑ DC or Static resistance

- ❖ When a DC voltage is applied to the diode, a DC current will flow through it and the operating point on the characteristic curve of the diode will not change its position with time.
- ❖ The resistance of a diode at the operating point can be given by the ratio of V_F and I_F,

i.e $R_D = \frac{V_F}{I_F}$

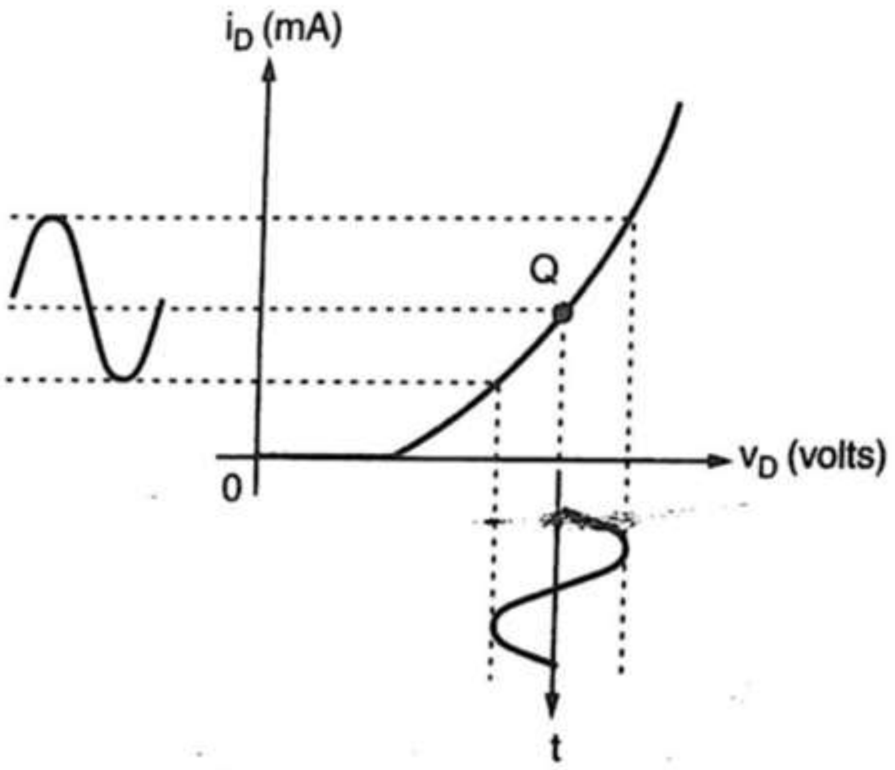


- ❖ This resistance offered by the diode to the DC operating conditions is called as **DC or Static resistance**
- ❖ The dc resistance at the knee and below will be greater than the resistance obtained in the vertical rise section of the characteristics curve.
- ❖ In general higher the current through a diode, the lower is the DC resistance

Diode resistance …

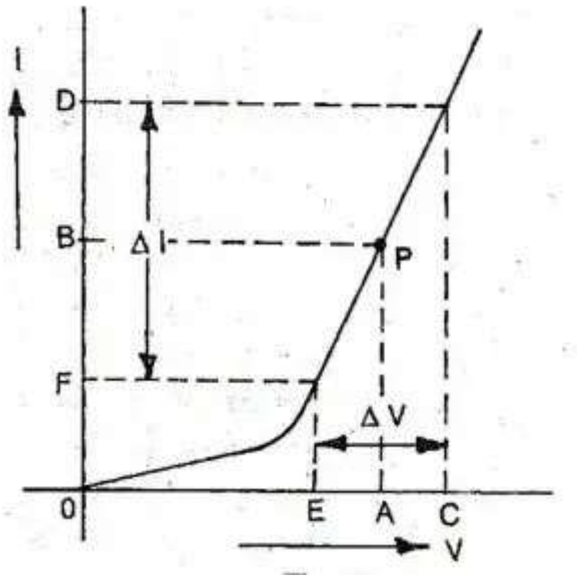
AC or Dynamic resistance

- When an AC voltage rather than a DC voltage is applied to a diode, the situation is altogether different.
- The operating point of the diode does not remain fixed. Its position will keep changing continuously, due to change in the input voltage.
- The varying input will move the instantaneous operating point up and down a region of the characteristic.



(b) Variation in diode current due to ac voltage

Formula of AC resistance or Dynamic Resistance of Diode



Dynamic resistance

$$= \frac{\text{Change in Voltage}}{\text{Change in Current}}$$

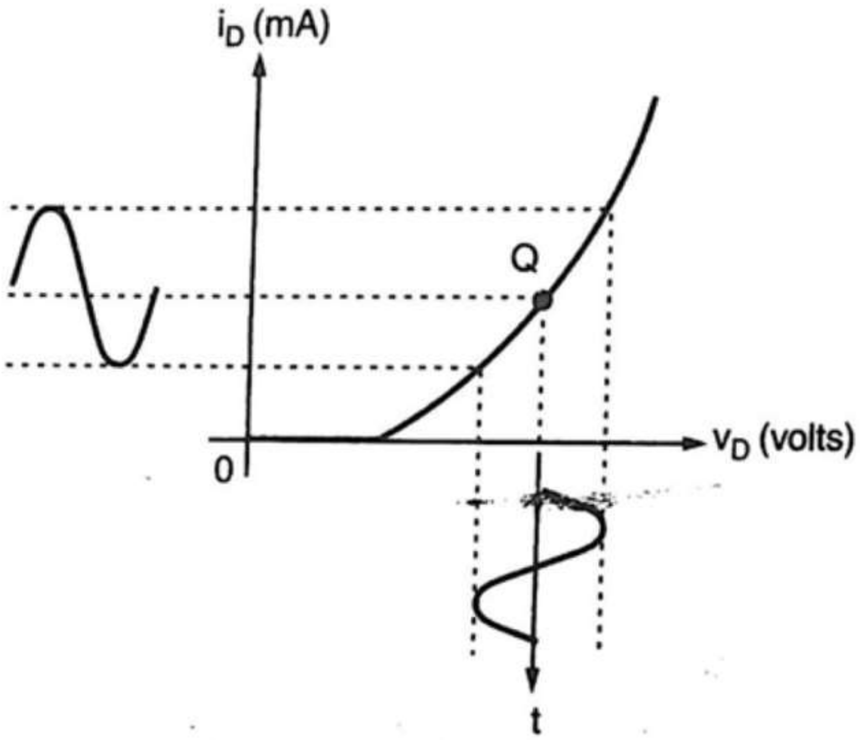
Or,

$$\boxed{R_d = \frac{\Delta V}{\Delta I}}$$

Hence, the dynamic resistance will be reciprocal of slope.

Diode resistance …

- With no applied varying signal, the point of operation would be the Q-point (Quiescent), determined the applied dc levels
- A straight line drawn tangent to the curve through the Q-point will define a particular change in vltage and current that can be used to determine the ac or dynamic resistance for the region of the diode characteristics



(b) Variation in diode current due to ac voltage

We have,

$$I_D = I_s\left(e^{V_D/\eta V_T} - 1\right)$$

$$I_D = I_s e^{V_D/\eta V_T} - I_s \qquad (1)$$

$$\frac{dI_D}{dV_D} = I_s \frac{d}{dV_D}\left(e^{V_D/\eta V_T}\right) - \frac{d}{dV_D}(I_s)$$

$$\frac{dI_D}{dV_D} = \frac{\boxed{I_s e^{V_D/\eta V_T}}}{\eta V_T} \quad (I_D + I_s)$$

$$= \frac{1}{\eta V_T}(I_D + I_s)$$

$$I_D \gg I_s$$

$$\frac{dI_D}{dV_D} = \frac{I_D}{\eta V_T} = 1/\, r_d$$

Where value of Thermionic emission is 1 or 2 .

On solving we get dynamic resistance of diode r_d.

Expression for the AC or Dynamic resistance

The dynamic resistance has already been defined as under:

$$r = \frac{1}{\text{Slope of V-I characteristics}} = \frac{1}{[dI/dV]} \quad ...(3.29)$$

Now, we have

$$I = I_o\left[e^{V/\eta V_T} - 1\right] \quad ...(3.30)$$

Taking the derivative with respect to V, we get,

$$\frac{dI}{dV} = I_o\left[\frac{1}{\eta V_T} e^{V/\eta V_T}\right] = \frac{I_o e^{V/\eta V_T}}{\eta V_T} \quad ...(3.31)$$

Substituting this into equation (3.29), we get,

$$r = \frac{1}{[dI/dV]} = \frac{\eta V_T}{I_o e^{V/\eta V_T}} \quad ...(3.32)$$

But from equation (3.30), we get,

$$I = I_o e^{V/\eta V_T} - I_o \quad ...(3.33)$$

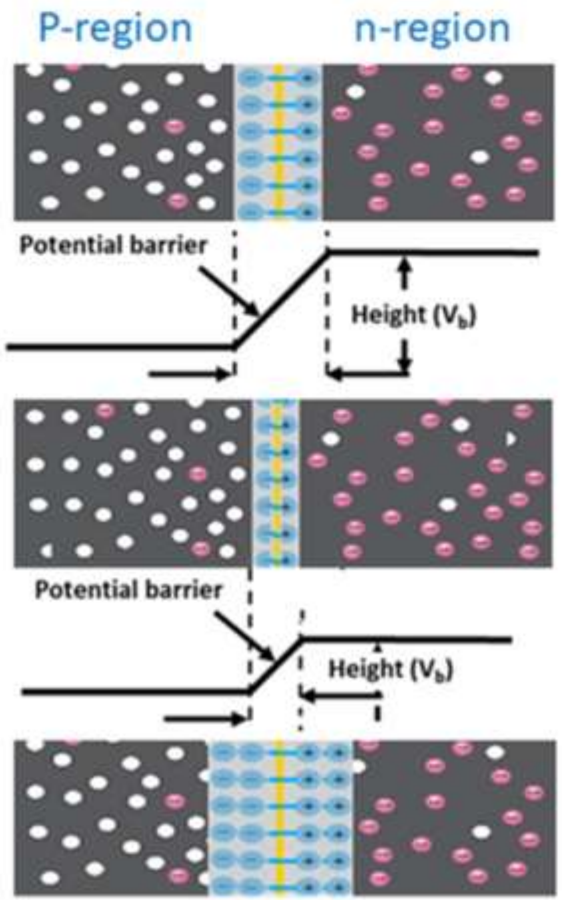
$$\text{or } I_o e^{V/\eta V_T} = I + I_o \quad ...(3.34)$$

Substituting this into equation (3.32), we get,

$$r = \frac{\eta V_T}{I + I_o} \quad ...(3.35)$$

This is the required expression for the dynamic resistance of diode.

Capacitances in diode



- We know that during the formation of PN junction, a layer of positive and negative impurity ions is formed in either side of junction, to form depletion region, space charge region or transition region.
- The depletion region act as a dielectric (non-conductive) medium between P and N region. P-and N region has low resistance.
- Therefore, these regions act as two plates of a capacitor, separated by dielectric.
- In PN junction diode we can observe capacitance effects i.e., at both forward and reverse bias region.

- In reverse bias region >>> **The transition or depletion region or space charge or junction region capacitance (C_T)**
- In forward bias region >>> **The diffusion or storage capacitance (C_D)**

Junction capacitances and its effects …

In reverse bias region >>> **The transition or depletion region or space charge or junction region capacitance (C_T)**

- We know, in a basic capacitor, the capacitance is directly proportional to the size of electrodes or plates and inversely proportional to the distance between two plates. i.e., $C = \varepsilon \frac{A}{W}$ ε = Permittivity of the semiconductor, A = Area of plates or p-type and n-type regions, W = Width of depletion region
- The capacitance at the depletion region changes with the change in applied voltage. When reverse bias voltage applied to the p-n junction diode is increased, a large number of holes (majority carriers) from p-side and electrons (majority carriers) from n-side are moved away from the p-n junction. As a result, the width of depletion region increases whereas the size of p-type and n-type regions (plates) decreases.
- We know that capacitance means the ability to store electric charge. The p-n junction diode with narrow depletion width and large p-type and n-type regions will store large amount of electric charge whereas the p-n junction diode with wide depletion width and small p-type and n-type regions will store only a small amount of electric charge. Therefore, the capacitance of the reverse bias p-n junction diode decreases when voltage increases.

The diffusion or storage capacitance and its effects ...

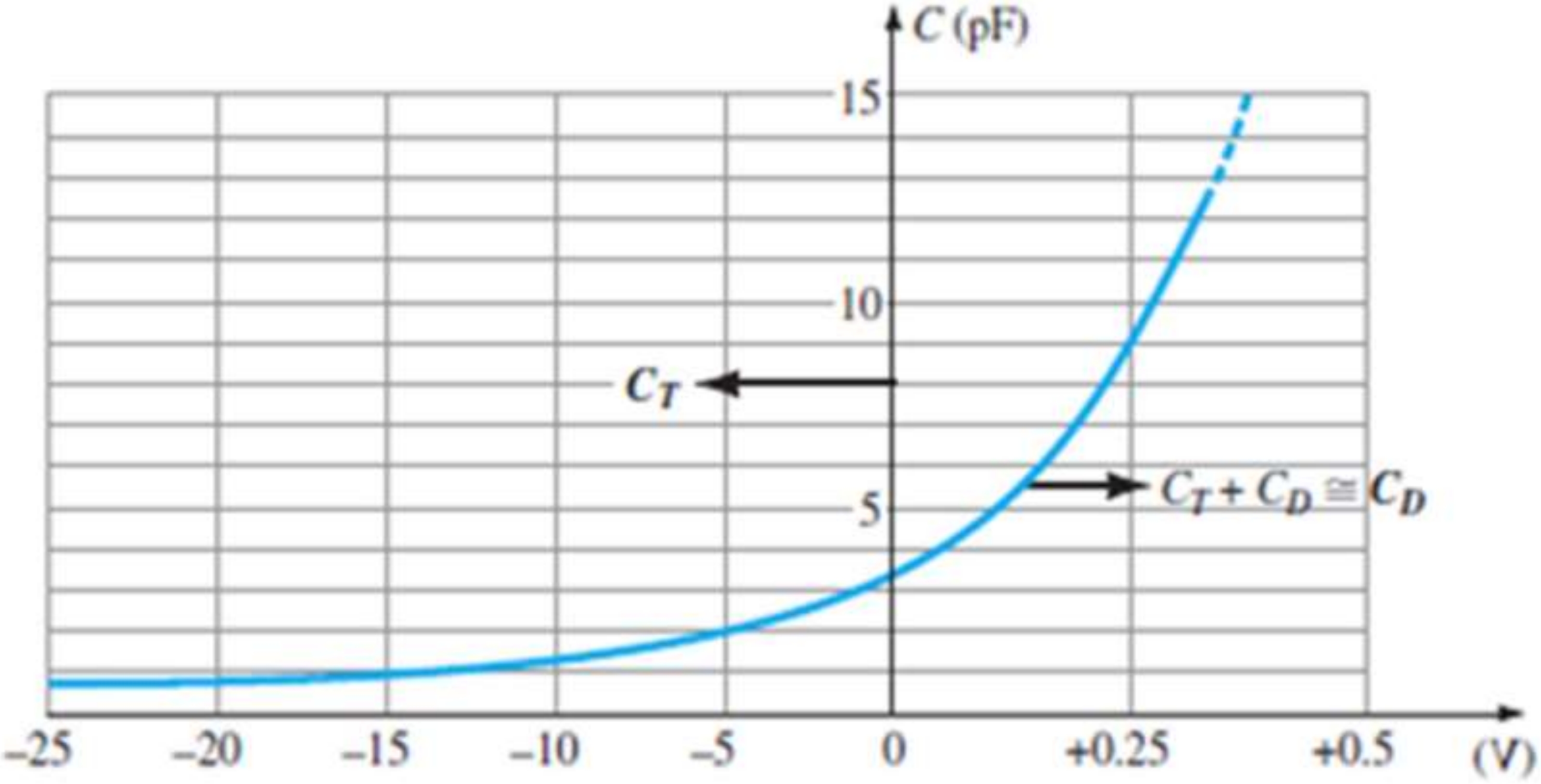
In forward bias region >>> **The diffusion or storage capacitance (C_D)**

- In a forward biased diode, diffusion capacitance is much larger than the transition capacitance. Hence, diffusion capacitance is considered in forward biased diode.
- The diffusion capacitance occurs due to stored charge of minority electrons and minority holes near the depletion region.
- When forward bias voltage is applied to the p-n junction diode, electrons (majority carriers) in the n-region will move into the p-region and recombines with the holes. In the similar way, holes in the p-region will move into the n-region and recombines with electrons. As a result, the width of depletion region decreases.
- The electrons (majority carriers) which cross the depletion region and enter into the p-region will become minority carriers of the p-region similarly; the holes (majority carriers) which cross the depletion region and enter into the n-region will become minority carriers of the n-region.

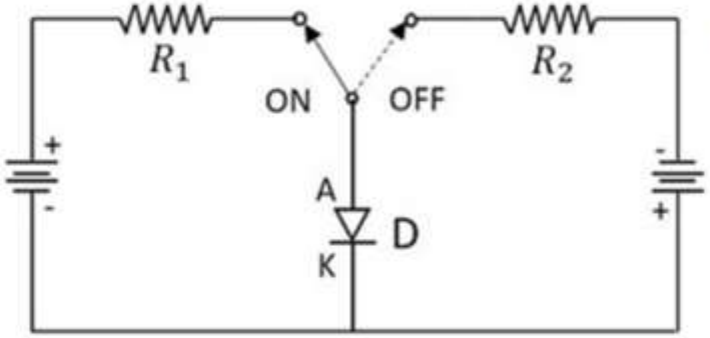
The diffusion capacitance and its effects ...

- A large number of charge carriers, which try to move into another region will be accumulated near the depletion region before they recombine with the majority carriers. As a result, a large amount of charge is stored at both sides of the depletion region.
- The accumulation of holes in the n-region and electrons in the p-region is separated by a very thin depletion region or depletion layer. This depletion region acts like dielectric or insulator of the capacitor and charge stored at both sides of the depletion layer acts like conducting plates of the capacitor.
- Diffusion capacitance is directly proportional to the electric current or applied voltage. If large electric current flows through the diode, a large amount of charge is accumulated near the depletion layer. As a result, large diffusion capacitance occurs.
- In the similar way, if small electric current flows through the diode, only a small amount of charge is accumulated near the depletion layer. As a result, small diffusion capacitance occurs.
- When the width of depletion region decreases, the diffusion capacitance increases. The diffusion capacitance value will be in the range of nano farads (nF) to micro farads (μF).

Capacitances in diode and its effect



Diode switching times

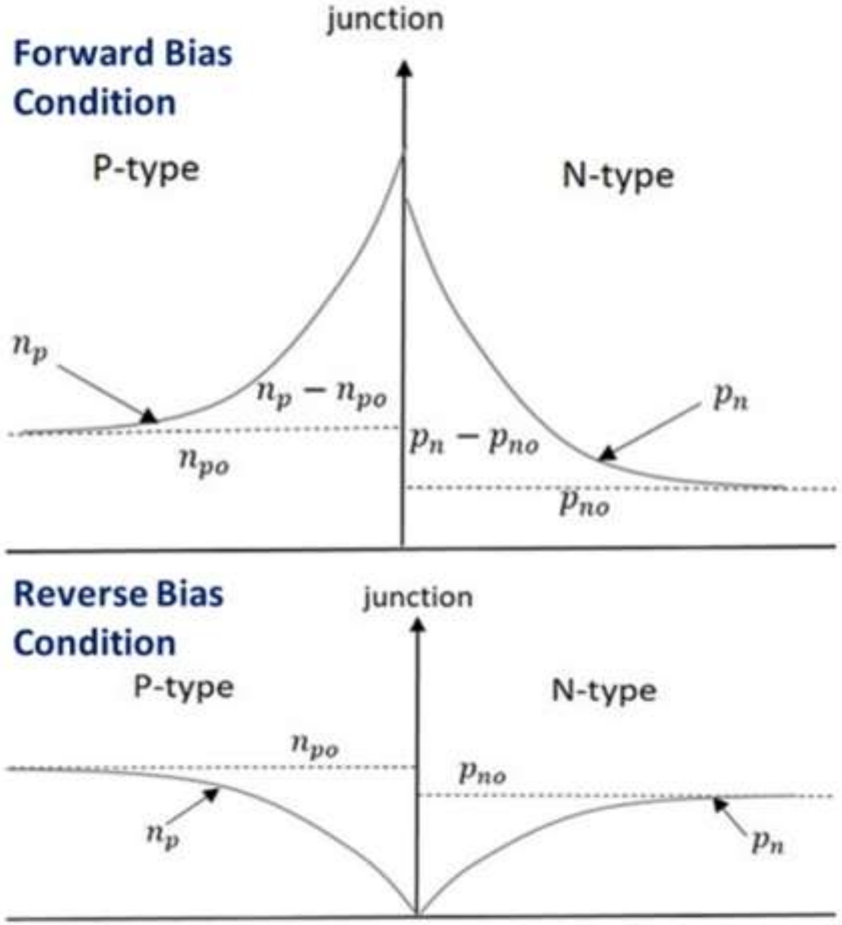


Switching circuit using Diode

- A switching diode has a PN junction in which P-region is lightly doped and N-region is heavily doped. The above circuit symbolizes that the diode gets ON when positive voltage forward biases the diode and it gets OFF when negative voltage reverse biases the diode.
- While changing the bias conditions, the diode undergoes a **transient response**. The response of a system to any sudden change from an equilibrium position is called as **transient response**.
- The sudden change from **forward to reverse** and from **reverse to forward** bias, affects the circuit. The time taken to respond to such sudden changes is the important criterion to define the effectiveness of an electrical switch.
- The time taken before the diode recovers its **steady state** is called as **Recovery Time**.
  - The time interval taken by the diode to switch from reverse biased state to forward biased state is called as **Forward Recovery Time**
  - The time interval taken by the diode to switch from forward biased state to reverse biased state is called as **Reverse Recovery Time**.

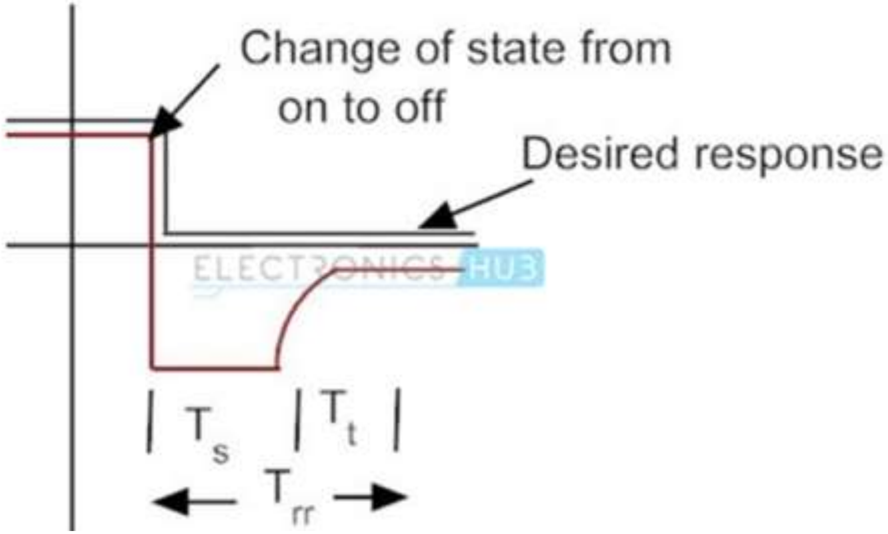
Reverse Recovery Time

- We know that in the forward bias there are large numbers of electrons from N region material move toward P region and are large numbers of holes from P region material move toward N region.
- There is also minority charge carriers in each region.
- If applied voltage is reversed to establish a reverse-bias situation, we observe ideal that the diode change instantaneously from the conduction state to the non-conduction state.



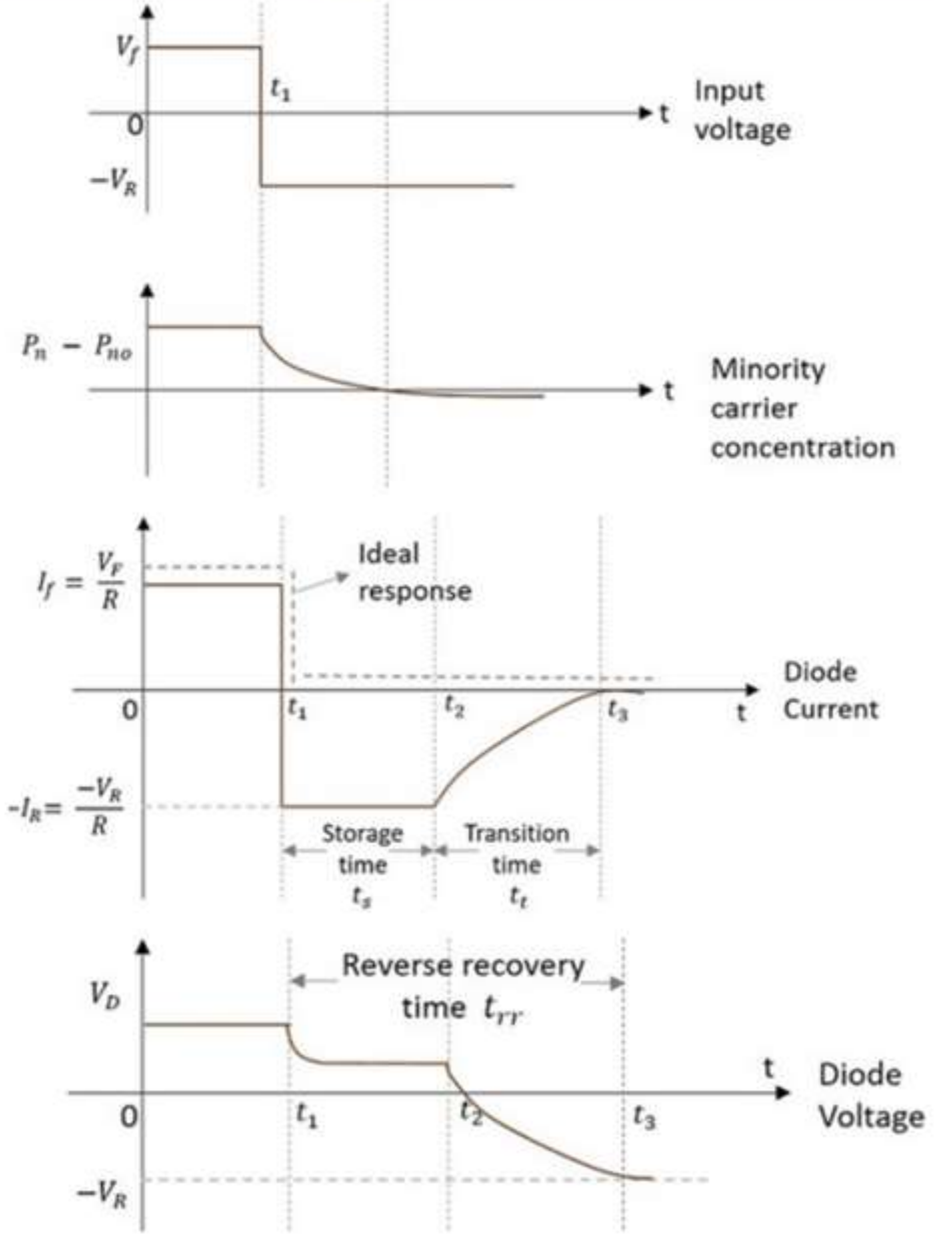
Reverse Recovery Time ...

- However, because of the large number of minority carriers in each region, the diode current will simply reverse as shown in figure and stay at measurable level for the period of time T_s (storage time) required for the minority carriers to return to their majority carrier state in the opposite region
- Eventually, when this storage phase passed, the current will reduce in level to that associated with the non-conduction state. This second period of time is transition time (T_t).
- **The reverse recovery time (T_{rr})** is given as $T_s + T_t$



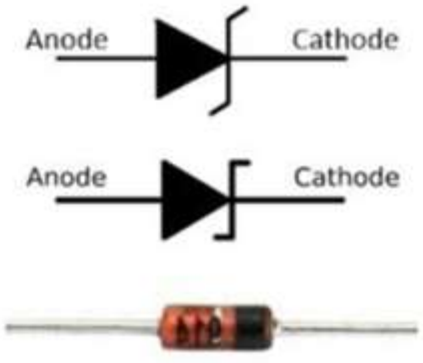
- The reverse recovery time is very important in high speed switching application. The value range from pico second (10^{-12}) to micro second (10^{-6})

Reverse Recovery Time ...

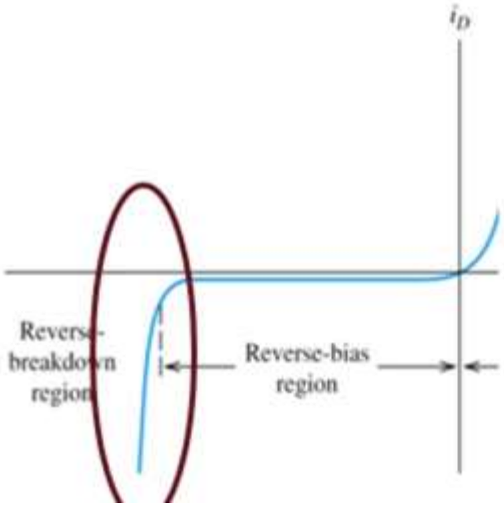


Construction, characteristics and applications of Zener diode

- ❑ Zener diode is also called a voltage-reference, voltage regulator or breakdown diode.
- ❑ ***Zener diode*** is designed for operation in the reverse-breakdown region.
- ❑ The *breakdown voltage* is controlled by the doping level *(-1.8 V to -200 V)*.
- ❑ Breakdown occurs by two mechanism: **Avalanche** and **Zener effect**
- ❑Avalanche effect due to multiplication of electron whereas Zener effect is due to electric field.
- ❑ The major application of Zener diode is to provide an output reference that is stable despite changes in input voltage – power supplies, voltmeter,...



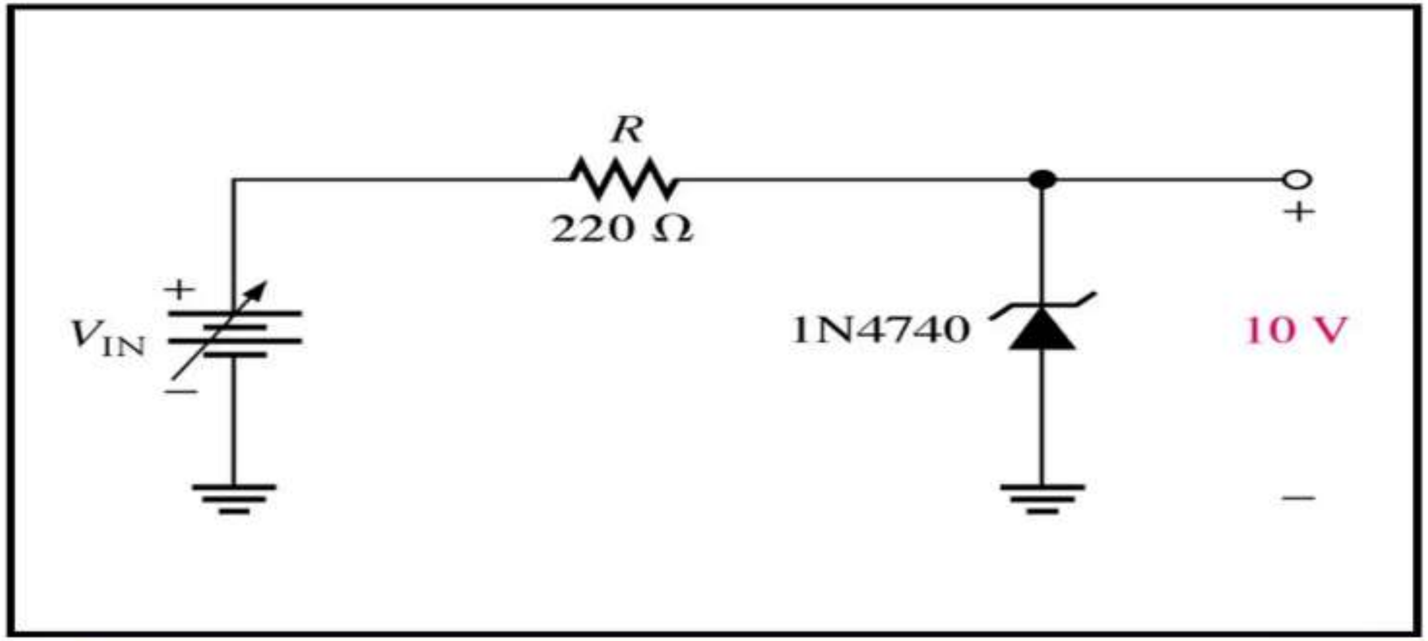
Zener diode symbol

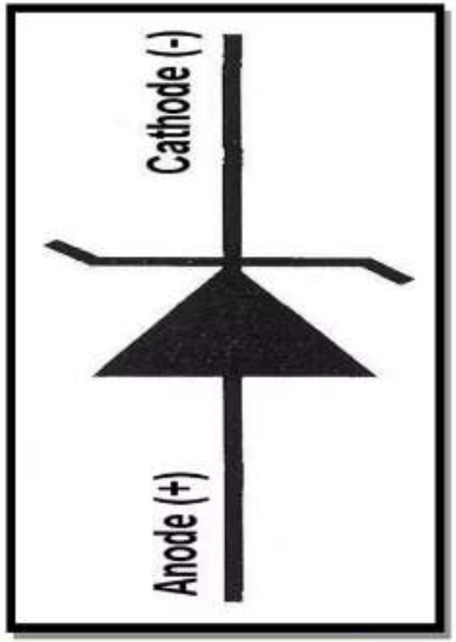


Construction, characteristics and applications of Zener diode

- The Zener diode is a Silicon PN junction device, which differ from a rectifier diode, in the sense, that it is operated in the reverse breakdown region.
- The breakdown voltage of a zener diode is set by carefully controlling the doping level during the manufacture. Both P and N side of junction is heavily doped, which make thin depletion width and consequently, high electric field in low voltage
- The zener breakdown voltage of the zener diode is depends on the amount of doping applied. If the diode is heavily doped, zener breakdown occurs at low reverse voltages. On the other hand, if the diode is lightly doped, the zener breakdown occurs at high reverse voltages. Zener diodes are available with zener voltages in the range of 1.8V to 400V.

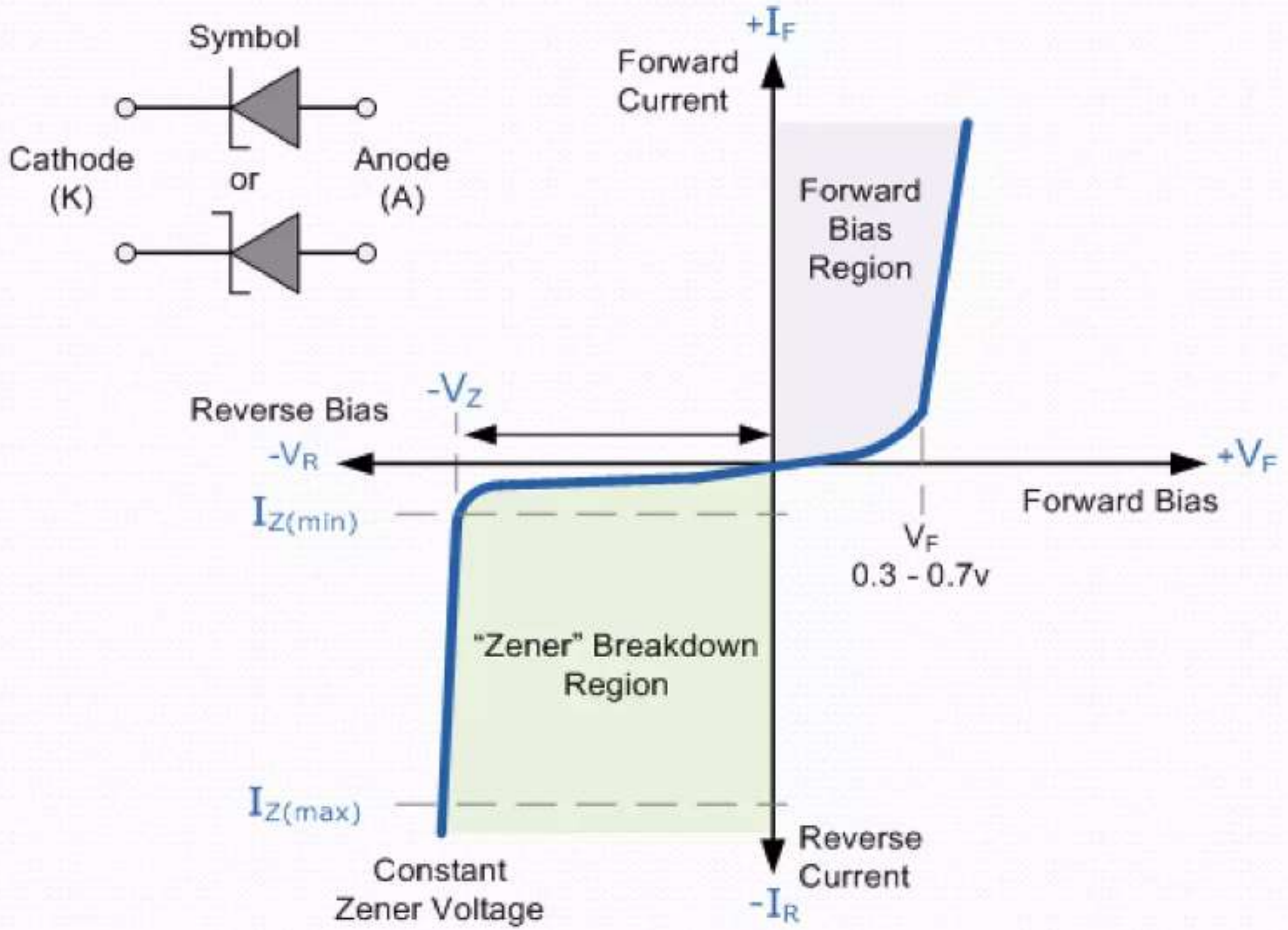
The **zener diode** is a silicon pn junction devices that differs from rectifier diodes because *it is designed for operation in the reverse-breakdown region*. The breakdown voltage of a zener diode is set by carefully controlling the level during manufacture. The basic function of **zener diode** is to maintain a specific voltage across it's terminals within given limits of line or load change. Typically it is used for providing a stable reference voltage for use in power supplies and other equipment.





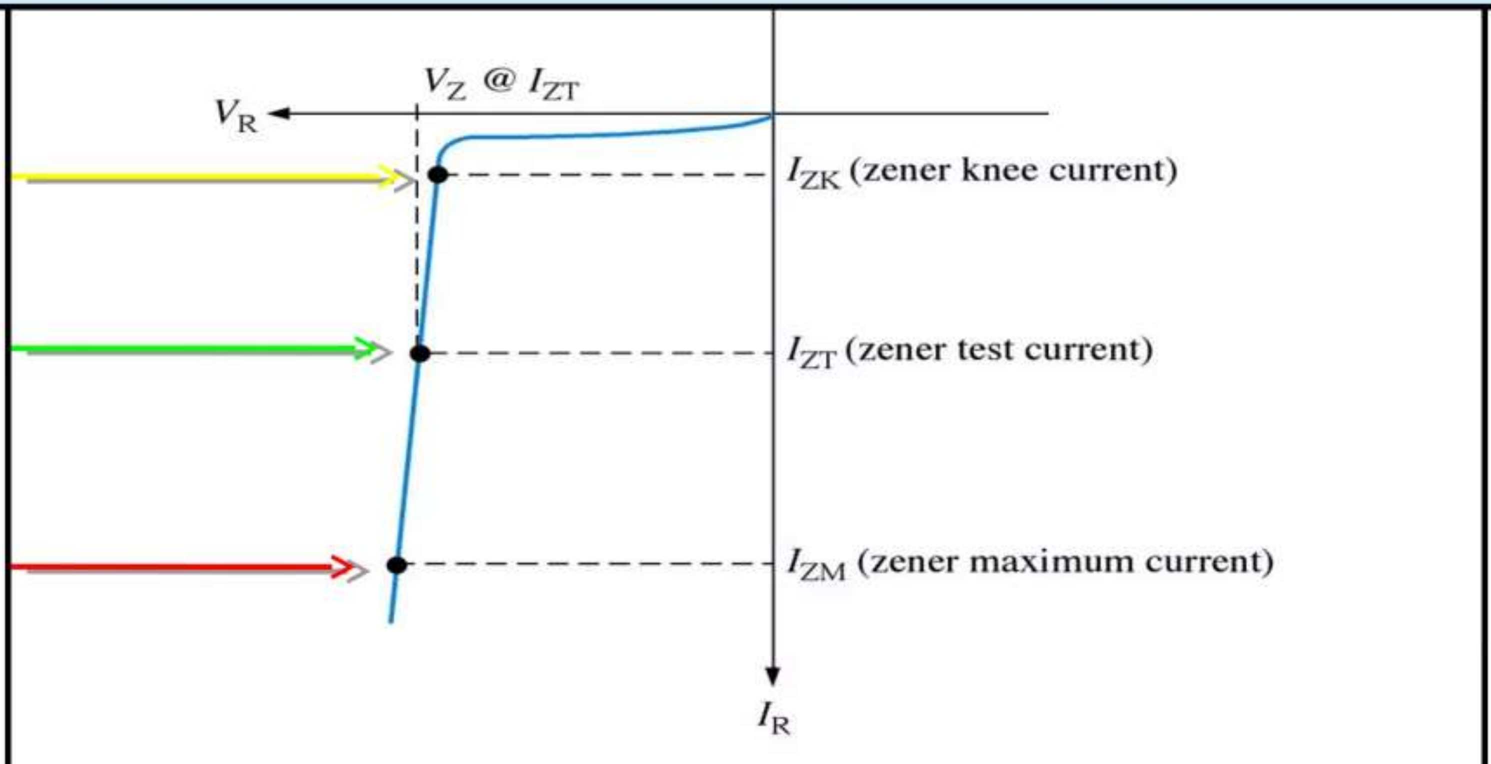
This particular zener circuit will work to maintain 10 V across the load.

- Notice that as the reverse voltage is increased the leakage current remains essentially constant until the breakdown voltage is reached where the current increases dramatically.



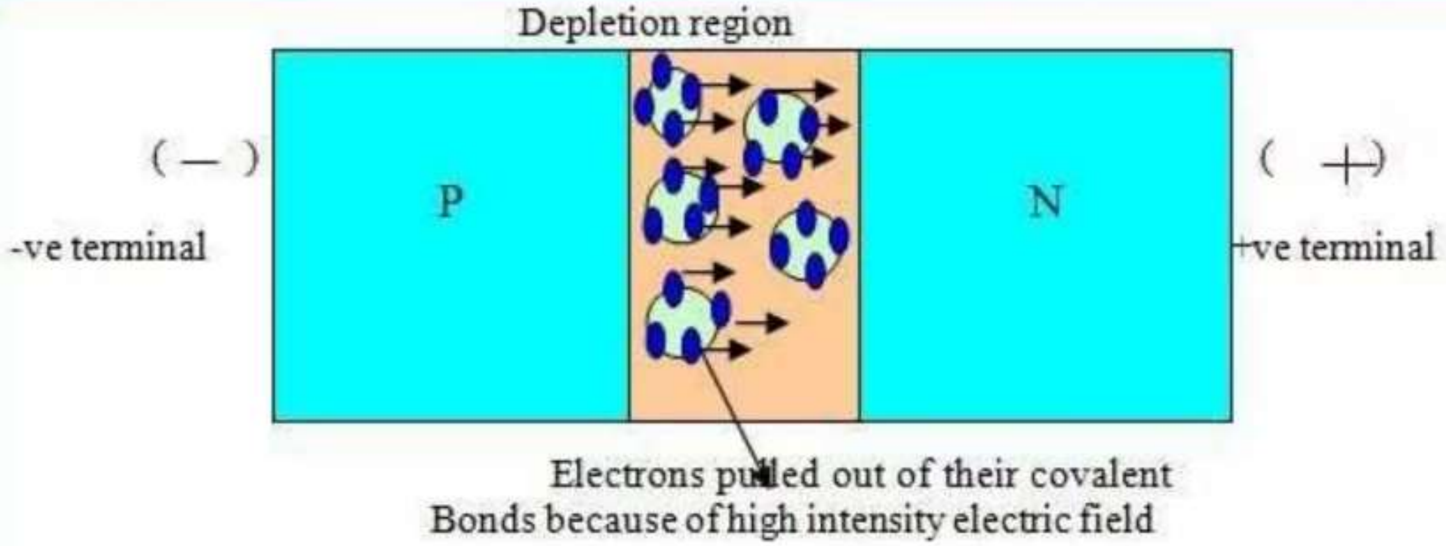
Breakdown Characteristics

Figure shows the reverse portion of a zener diode's characteristic curve. As the reverse voltage (V_R) is increased, the reverse current (I_R) remains extremely small up to the "knee" of the curve. The reverse current is also called the zener current, I_Z. At this point, the breakdown effect begins; the internal zener resistance, also called zener impedance (Z_Z), begins to decrease as reverse current increases rapidly.



Zener breakdown

- The Zener effect is a type of electrical breakdown in a reverse biased p-n diode in which the electric field enables tunneling of electrons from the valence to the conduction band of a semiconductor, leading to a large number of free minority carriers, which suddenly increase the reverse current.



Zener breakdown in Zener diode

Advantage and application zener diode

Advantages of zener diode

- Power dissipation capacity is very high
- High accuracy
- Small size
- Low cost

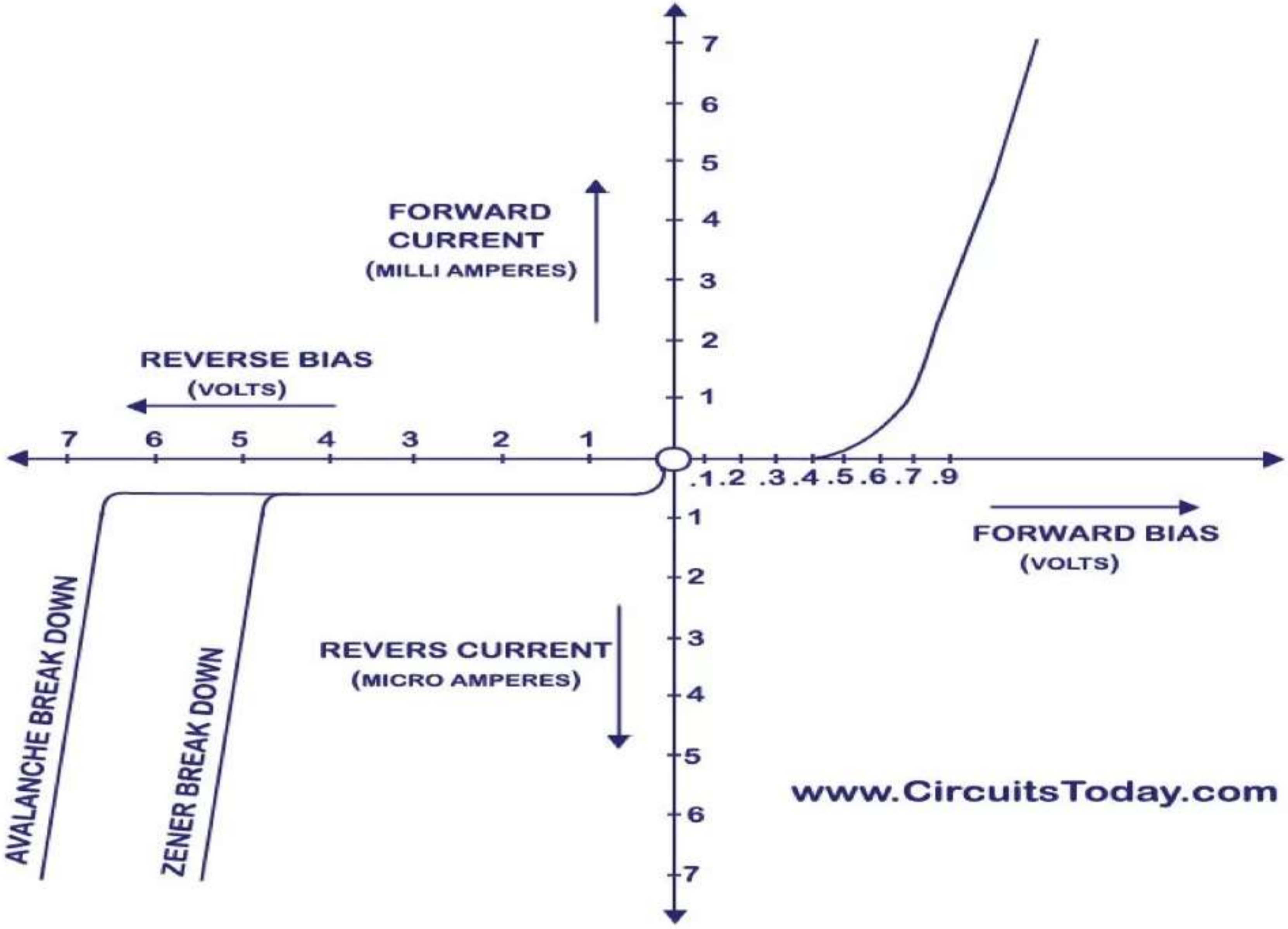
Applications of zener diode

- It is normally used as voltage reference
- Zener diodes are used in voltage stabilizers or shunt regulators.
- Zener diodes are used in switching operations
- Zener diodes are used in clipping and clamping circuits.
- Zener diodes are used in various protection circuits

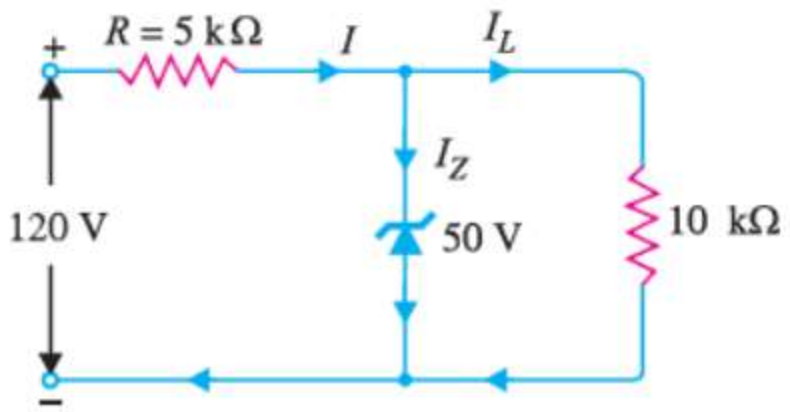
DIFFERENCE BETWEEN ZENER AND AVALANCHE BREAKDOWN

Zener Breakdown	Avalanche breakdown
1.This occurs at junctions which being heavily doped have narrow depletion layers	1. This occurs at junctions which being lightly doped have wide depletion layers.
2. This breakdown voltage sets a very strong electric field across this narrow layer.	2. Here electric field is not strong enough to produce Zener breakdown.
3. Here electric field is very strong to rupture the covalent bonds thereby generating electron-hole pairs. So even a small increase in reverse voltage is capable of producing Large number of current carriers.	3. Her minority carriers collide with semi conductor atoms in the depletion region, which breaks the covalent bonds and electron-hole pairs are generated. Newly generated charge carriers are accelerated by the electric field which results in more collision and generates avalanche of charge carriers. This results in avalanche breakdown.
4. Zener diode exhibits negative temp: coefficient. Ie. breakdown voltage decreases as temperature increases.	4. Avalanche diodes exhibits positive temp: coefficient. i.e breakdown voltage increases with increase in temperature.

PN JUNCTION BREAKDOWN CHARACTERISTICS



Q1. For the circuit shown in Fig.1 (i), find : (i) the output voltage (ii) the voltage drop across series resistance (iii) the current through zener diode.



Q2. For the circuit shown in Fig. 2 (i),find the maximum and minimum values of zener diode current.

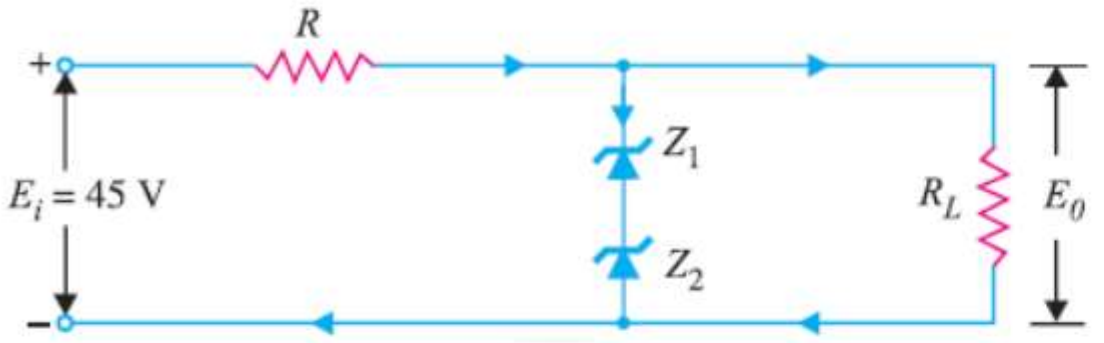
Maximum zener current: The zener will conduct maximum current when the input voltage is maximum i.e. 120 V. Under such conditions :

$$\begin{aligned}
\text{Voltage across } 5\text{ k}\Omega &= 120 - 50 = 70\text{ V} \\
\text{Current through } 5\text{ k}\Omega,\ I &= \frac{70\text{ V}}{5\text{ k}\Omega} = 14\text{ mA} \\
\text{Load current, } I_L &= \frac{50\text{ V}}{10\text{ k}\Omega} = 5\text{ mA} \\
\text{Applying Kirchhoff's first law, } I &= I_L + I_Z \\
\therefore \qquad \text{Zener current, } I_Z &= I - I_L = 14 - 5 = \mathbf{9\text{ mA}}
\end{aligned}$$

Minimum Zener current: The zener will conduct minimum current when the input voltage is minimum i.e. 80 V. Under such conditions, we have,

$$\begin{aligned}
\text{Voltage across } 5\text{ k}\Omega &= 80 - 50 = 30\text{ V} \\
\text{Current through } 5\text{ k}\Omega,\ I &= \frac{30\text{ V}}{5\text{ k}\Omega} = 6\text{ mA} \\
\text{Load current, } I_L &= 5\text{ mA} \\
\therefore \qquad \text{Zener current, } I_Z &= I - I_L = 6 - 5 = \mathbf{1\text{ mA}}
\end{aligned}$$

Q6. The circuit of Fig. 6 uses two zener diodes, each rated at 15 V, 200 mA. If the circuit is connected to a 45-volt unregulated supply, determine :(i) The regulated output voltage (ii) The value of series resistance R.



$$\text{Current rating of each zener, } I_Z = 200 \text{ mA}$$

$$\text{Voltage rating of each zener, } V_Z = 15 \text{ V}$$

$$\text{Input voltage, } E_i = 45 \text{ V}$$

(*i*) $$\text{Regulated output voltage, } E_0 = 15 + 15 = \mathbf{30\ V}$$

(*ii*) $$\text{Series resistance, } R = \frac{E_i - E_0}{I_Z} = \frac{45 - 30}{200 \text{ mA}} = \frac{15 \text{ V}}{200 \text{ mA}} = \mathbf{75\ \Omega}$$

Construction, characteristics and applications of Schottky Diode

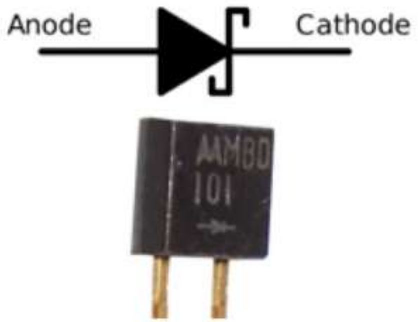
Schottky diode definition

❑ Schottky diode is a metal-semiconductor junction diode that has less forward voltage drop than the P-N junction diode and can be used in high-speed switching applications.

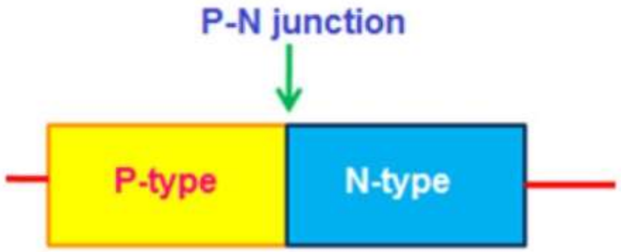
What is a Schottky diode?

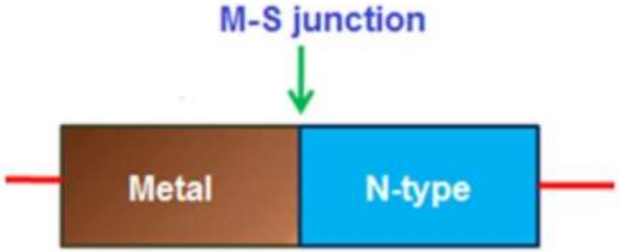
❑ In Schottky diode, metals such as aluminum or platinum replace the P-type semiconductor. The Schottky diode is named after German physicist Walter H. Schottky.

❑ Schottky diode is also known as Schottky barrier diode, surface barrier diode, majority carrier device, hot-electron diode, or hot carrier diode. Schottky diodes are widely used in radio frequency (RF) applications.



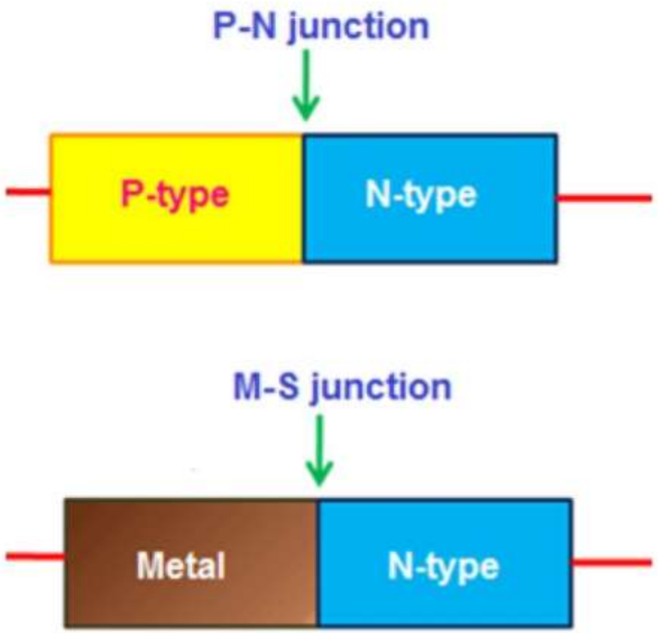
Schottky diode symbol





Construction, characteristics and applications of Schottky Diode ...

- When aluminum or platinum metal is joined with N-type semiconductor, a junction is formed between the metal and N-type semiconductor. This junction is known as a metal-semiconductor junction or M-S junction. A metal-semiconductor junction formed between a metal and n-type semiconductor creates a barrier or depletion layer known as a Schottky barrier.
- Schottky diode can switch on and off much faster than the p-n junction diode. Also, the Schottky diode produces less unwanted noise than p-n junction diode. These two characteristics of the Schottky diode make it very useful in high-speed switching power circuits.



Difference between schottky diode and P-N junction diode

- In Schottky diode, the free electrons carry most of the electric current. Holes carry negligible electric current. So Schottky diode is a unipolar device. In P-N junction diode, both free electrons and holes carry electric current. So P-N junction diode is a bipolar device.
- The reverse breakdown voltage of a Schottky diode is very small as compared to the p-n junction diode.
- In Schottky diode, the depletion region is absent or negligible, whereas in p-n junction diode the depletion region is present.
- The turn-on voltage for a Schottky diode is very low as compared to the p-n junction diode.
- In Schottky diode, electrons are the majority carriers in both metal and semiconductor. In P-N junction diode, electrons are the majority carriers in n-region and holes are the majority carriers in p-region.

Advantages of Schottky diode

Low junction capacitance

- We know that capacitance is the ability to store an electric charge. In a P-N junction diode, the depletion region consists of stored charges. So there exists a capacitance. This capacitance is present at the junction of the diode. So it is known as junction capacitance.
- In Schottky diode, stored charges or depletion region is negligible. So a Schottky diode has a very low capacitance.

Fast reverse recovery time

- The amount of time it takes for a diode to switch from ON state to OFF state is called reverse recovery time.
- In order to switch from ON (conducting) state to OFF (non-conducting) state, the stored charges in the depletion region must be first discharged or removed before the diode switch to OFF (non-conducting) state.
- The P-N junction diode do not immediately switch from ON state to OFF state because it takes some time to discharge or remove stored charges at the depletion region. However, in Schottky diode, the depletion region is negligible. So the Schottky diode will immediately switch from ON to OFF state.

Advantages of Schottky diode

High current density

- We know that the depletion region is negligible in Schottky diode. So applying is small voltage is enough to produce large current.

Low forward voltage drop or low turn on voltage

- The turn on voltage for Schottky diode is very small as compared to the P-N junction diode. The turn on voltage for Schottky diode is 0.2 to 0.3 volts whereas for P-N junction diode is 0.6 to 0.7 volts. So applying a small voltage is enough to produce electric current in the Schottky diode.

High efficiency

Schottky diodes operate at high frequencies.

Schottky diode produces less unwanted noise than P-N junction diode.