Semiconductor Devices

By

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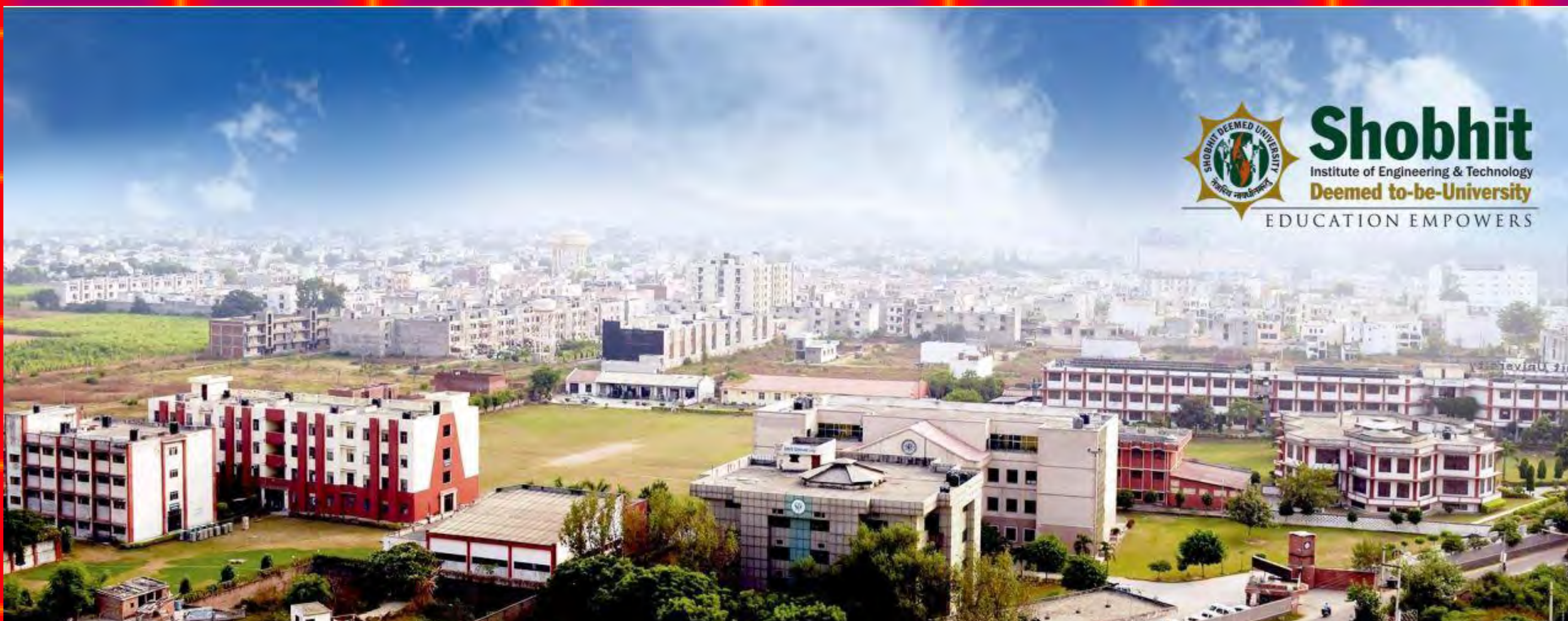


Chapter-2
Semiconductor Devices

pn Junction

It is a border between p-type & n-type semiconductor. The pn- junction itself forms the most basic semiconductor device called semiconductor diode, thus semiconductor diode and pn junction are one and the same.

Depletion layer

In pn junction diode the the free electrons on n side tend to diffuse across the junction ,when free electrons enters the p region, the free electrons recombines with hole in p region, and due to which hole disappears and free electron becomes valence electron.

Each time an electron diffuses across a junction , it creates a pair of ions , +ve ion on n side and -ve ion on p side, these pair of ions at junction is called a dipole. As no. of dipoles builds up, empty charge region is created know as depletion region.

Junction Potential width of depletion layer

Width of depletion layer is the distance measured from one side to the other side of the depletion region. Due to the presence of depletion region the electrons and holes do not i.e. depletion region acts as a barrier. Due to the presence of immobile +ve(n-side) and –ve (p-side) ions on opposite sides of the junction an electric field is created across the junction . This electric field is known as junction potential also known as barrier potential. The barrier potential for silicon is 0.7 volt whereas for germanium is 0.3 volt at 25^0C.

The Energy Hill

The barrier potential of a diode looks like an energy hill. Electrons attempting to cross the junction need to have enough energy to climb this hill. An external voltage source that forward-bias the diode gives electrons the energy required to pass through the depletion layer.

Barrier Potential & Temperature

When the junction temperature increases, the depletion layer becomes narrow & the barrier potential decreases. It will decrease approximately 2.5 mV for each ^{0}C increase.

Forward bias & Reverse bias

When an external voltage opposes the junction potential, the diode is forward biased. If the applied voltage is greater than the barrier potential, the current flows. When an external voltage aids the barrier potential, the diode is reverse biased.

Knee Voltage or Cut-in voltage

The voltage at which the forward diode current increases rapidly is known as Knee voltage or cut in voltage . Knee voltage for germanium is 0.3V & for silicon is 0.7V.

Peak Inverse voltage

The maximum reverse bais voltage that p-n diode can withstand without breaking down is known as peak inverse voltage.

Reverse saturation current

Current flowing through a diode in the reverse biased state is known as reverse saturation current (I_S). The reverse saturation current in Si increases 100 % for each 10^0C rise in temperature i.e. approximately equal to 7 % for each ^{0}C rise in temperature.

Reverse Breakdown

The reverse bais voltage above PIV leads to breakdown of voltage . The breakdown in a reverse biased diode can take place due to following effects :

1. Avalenche Breakdown
2. Zener Breakdown

Once the breakdown voltage is reached, a large number of the minority carrier suddenly appears in a depletion layer and the diode conducts heavily.

Due to large reverse voltage the velocity of the minority carrier will increase & hence kinetic energy associated with them will also increase. While travelling, these high kinetic energy carriers will collide

with the stationary atoms and impart some kinetic energy to the valence electrons present in the covalent bonds. Due to additionally acquired energy, these valence electrons collide with further atoms bounded with covalent bonds, generating more free electrons.
The process continues in the geometric fashion, until the reverse current becomes huge. The breakdown voltage of a diode depends on how heavily doped the diode is. Normal diodes has breakdown usually greater than 50V.
The Zener breakdown occurs in high doping diodes known as **Zener diodes** , where as avalanche breakdown occurs at low doping diodes known as **Avelanche diodes** . The breakdown voltage in Zener is lesser then Avelanche breakdown voltage.

Doping $\uparrow$ Breakdown voltage $\downarrow$

Doping $\downarrow$ Breakdown voltage $\uparrow$

Capacitance of depletion layer
The accumulation of charge across the depletion region produces capacitance action ,where depletion region acts as dielectric medium of the parallel plate capacitor(p-side and n-side as a plates of capacitor)
Transition capacitance (C_T) & Diffusion capacitance (C_D) are two capacitances associated with a p-n junction diode.
Resistance of pn Junction diode
The two types of resistance associated with a p-n junction diode are

1. DC resistance
2. AC resistance

The resitance offered by the diode to the DC operating conditions is called as "DC resistance or Static resistance " denoted by R_F **.**The DC resitance of a diode at operating point can be obtained by tacking the ratio of V_F & C_D
The resistance offered by the diode to the AC operating conditions is called as "AC resistance or Dynamic resistance" denoted by r_F. AC resistance is actually the reciprocal of the slope of the forward characteristics .

$$r_F = \frac{1}{Slope\ of\ the\ characteristics}$$

Tunnel diode
Such a diode having doping level $\approx 10^{25}/m^3$ in both $P-N$ region of pn junction diode known as Tunnel diode. These diodes posses negative resistance & is useful for high-frequency circuits.
Point contact diode
It consists of a small wafer of a semiconducting crystal having an area of few square millimeter & a thickness of a fraction of mm. The crystal is soldered to a metallic base for external ohmic contact.
LED
Light emitting diode (LED) produces electromagnetic energy in the form of light widely used as an indicator on instruments, calculators and other electronic equipment. In ordinary diode energy is radiated in the form of heat but in an LED , the energy is radiated as light.

Photodiodes
Photodiode is a reverse biased P-N junction whose operation depends on the intensity of light .The incoming light produces free electrons and holes. The stronger the light, the greater the number minority carrier and the larger the reverse current.

Thermistors

A thermistor is a device which has negative temperature coefficient useful for making oscillator, amplifiers & switching devices.

Derivations

1. $\frac{\Delta V}{\Delta T}$= -2.5mV/^{0}C
2. ΔV= (-2.5mV/^{0}C) * ΔT
3. % I_S= 100% for a 10^{0}C increase
4. % I_S= 7% per ^{0}C

Long & Short Questions

Q.1. Explain the formation of depletion layer and barrier potential barrier in a p-n Junction diode. Find out the expression for the height of potential barrier and the width of depletion layer.

Or

Find out the expression for potential barrier and depletion width of a junction diode.

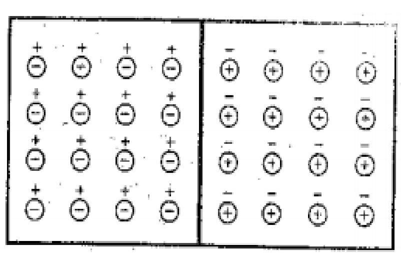
Related Short Answer Question

(i) What is Junction diode? Explain the formation of depletion layer.

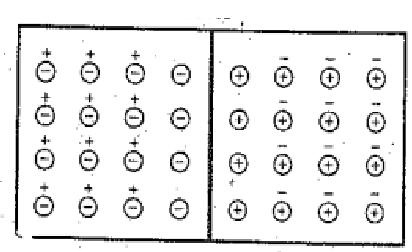
(ii) What is a P-N Junction diode ? How does a barrier field appear across a P-N Junction?

Formation of depletion layer

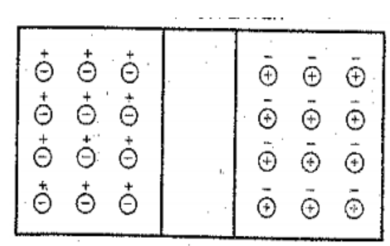
- We visualized the pentavalent atoms and free electrons n- type semiconductors as shown on the right side of fig. . Each circled plus sign represents a pentavalent atom, and each minus sign is the free electron it contributes to the semiconductor .
- A manufacturer can produce a single crystal with p-type material on one side and n-type on the other side ,the region where these materials meet known as junction diode.



Two types of semiconductors



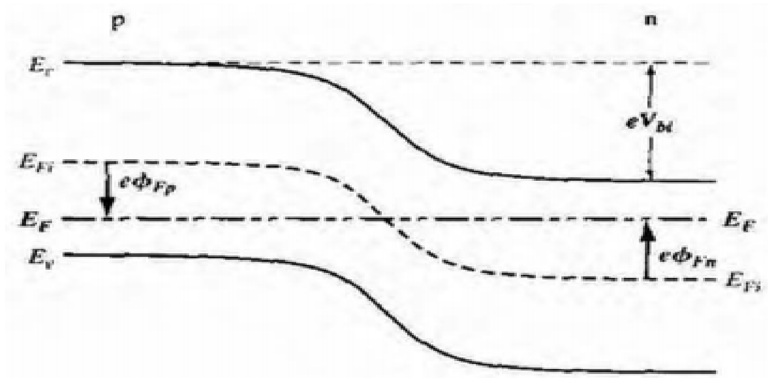
Two types of semiconductors



Creation of ions at junction

- The free electrons on n side tend to diffuse across the junction , when free electrons enters the p region, it recombines with hole, and due to which hole disappears and free electron becomes valence electron.
- Each time an electron diffuses across a junction , it creates a pair of ions , +ve ion on n side and -ve ion on p side, these pair of ions at junction is called a dipole. As no. of dipoles builds up, empty charge region is created know as depletion region.

Expression for barrier potential



Energy Band diagram of a pn junction in thermal equilibrium.

The barrier potential maintains equilibrium , so no current is produced by this voltage. The intrinsic Fermi level is equidistant from the conduction band edge through the junction, thus the built-in potential barrier can be determined as the difference between the intrinsic Fermi level in the p and n regions.

i.e. $V_{bi} = |\Phi_{Fn}| + |\Phi_{Fp}|$ (1)

In the n region, the electron concentration in the conduction band is given by

$$n_0 = n_i \exp^{-(E_C - E_F)/KT} \tag{2}$$

Where n_i& E_{Fi} are the intrinsic carrier concentration and instrinsic fermi energy resp. If Φ_{Fn} is the potential in the n –region $e\,\Phi_{Fn} = E_C - E_F$ (3)

Eq. (3) may be written as

$$n_0 = n_i \exp^{-e\Phi_{Fn}/KT} \tag{4}$$

Taking natural log both sides, setting $n_0 = N_D$

$$\ln(N_D / n_i) = -e\Phi Fn/KT \tag{5}$$

$$\Phi_{Fn} = -\frac{KT}{q} * \ln(N_D / n_i) \tag{6}$$

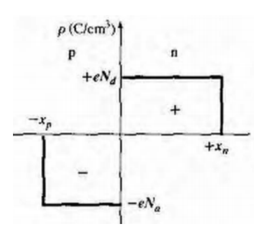
Similarly in p region , the concentration is given by

$$P_0 = N_A = n_i \exp^{-(E_F - E_V)/KT} \quad \{\text{since, } e\,\Phi_{Fp} = E_F - E_V\} \tag{7}$$

$$\Phi_{Fp} = \frac{KT}{q} * \ln(N_A / n_i) \tag{8}$$

Substituting eq. (7) & (8) in eq. (1) , we have

$$\mathbf{V_{bi}} = \frac{KT}{q} * \boldsymbol{ln}\left(\frac{N_D N_A}{n_i^2}\right) = \frac{KT}{q} * \boldsymbol{ln}\left(\frac{N_D N_A}{n_i^2}\right)$$



Expression for depletion width

Assuming that the space charge region abruptly ends in the n region at $x = x_n$ and abruptly ends in the p region at $x = x_p$, we have

Potential in n region of diode is $\Phi_n(x) = \frac{eN_D}{\epsilon}(x_n x - \frac{x^2}{2}) + \frac{eN_A}{2\epsilon_S} x_n^2$ $\quad 0 \leq x \leq x_n$ (9)

Potential in p region of diode is $\Phi_p(x) = \frac{eN_D}{\epsilon}(\frac{x^2}{2} + x_p x) + \frac{eN_A}{2\epsilon_S} x_p^2$ $\quad -x_p \leq x \leq 0$ (10)

The magnitude of potential at $x = x_n$ is equal to built in potential $\mathbf{V_{bi}}$

$$\mathbf{V_{bi}} = \frac{e}{2\epsilon}(N_D x_n^2 + N_A x_n^2) \qquad (11)$$

$$\therefore \quad x_n = \{\frac{2\epsilon V_{bi}}{\epsilon}[\frac{N_A}{N_D}][\frac{1}{N_A+N_D}]\}^{\frac{1}{2}} \qquad (12)$$

$$\because \quad \frac{X_n}{X_p} = \frac{N_A}{N_D}$$

$$x_p = \{\frac{2\epsilon V_{bi}}{\epsilon}[\frac{N_D}{N_A}][\frac{1}{N_A+N_D}]\}^{\frac{1}{2}} \qquad (13)$$

Depletion or space charge width is $W = x_n + x_p$
Using equation (12) & (13) we have

$$W = \{\frac{2\epsilon V_{bi}}{\epsilon}[\frac{N_A+N_D}{N_A N_D}]\}^{\frac{1}{2}} \qquad (14)$$

Q.2. Describe the action of forward and reverse biased p-n junction semiconductor. Draw its V-I characteristics curve and explain it.

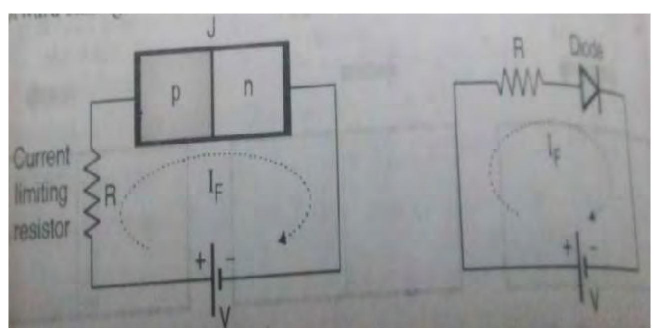
<u>**Related Short Answer Question**</u>

(i) Draw and explain the characteristics curve of a P-N Junction diode.

Forward bias

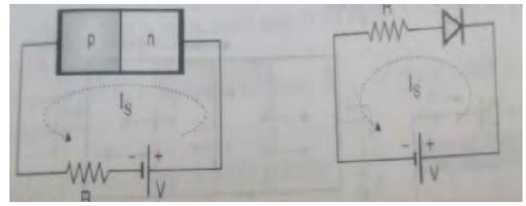
If the p- region(anode) of diode is connected to the +ve terminal of the external DC source and n-region (cathode) is connected to -ve terminal of the external DC source then the biasing is said to "forward biasing".

In forward bias width of depletion layer will reduce



Reverse Bias

If the p- region(anode) of diode is connected to the -ve terminal of the external DC source and n-region (cathode) is connected to +ve terminal of the external DC source then the biasing is said to “reverse biasing”.

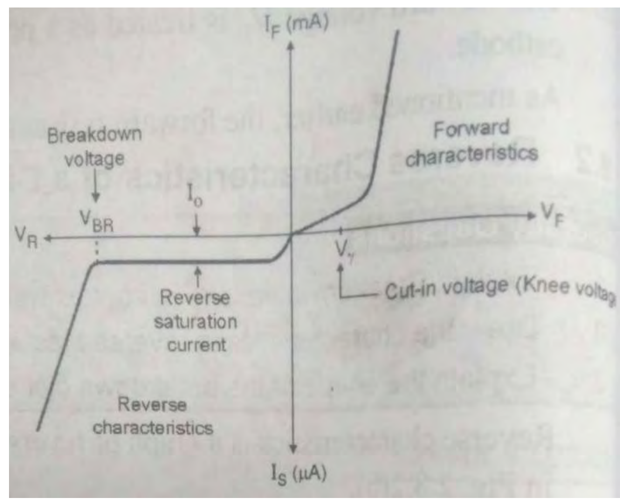


In reverse bias width of depletion layer will increase.

V-I characteristics curve

The V-I characteristics of p-n junction diode is a graph of voltage across the diode versus the current flowing through it . The V-I characteristics can be dived into two parts i.e. forward & reverse characteristics. The right side & left side of graph is forward & reverse characteristics respectively.

Forward characteristics



- When the external voltage is applied on germanium (Ge)/silicon (Si)diode, is less then 0.3/0.7 volts , the Ge/Si diode allows negligible current to flow through it know as cut in voltage & the Cut off region of V-I characteristics.
- When the external voltage is applied on germanium (Ge)/silicon (Si)diode, is more above cut in voltage, current through the diode increases suddenly.
- The voltage at which the forward diode current increases rapidly is known as cut in voltage or Knee voltage. Knee voltage for Ge is 0.3V & for Si is 0.7V.
- The Forward characteristics of Si diode shifts to the left at a rate of 2.5mV per ^{0}C increase in temperature.

Reverse characteristics

- Current flowing through a diode in the reverse biased state is known as reverse saturation current.
- As the reverse voltage is increased but below breakdown voltage(V_{BR}) , the reverse saturation current remains constant, if the temperature is constant . However when the reverse voltage is above (V_{BR}) , the large current flows
- The reverse saturation current in Si increases 100 % for each 10^{0}C rise in temperature i.e. approximately equal to 7 % for each ^{0}C rise in temperature.

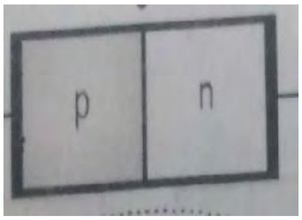
Q.3. **What is a junction diode ? What do you mean by biasing a junction diode ? Draw V-I characteristics curve of a junction diode under different biasing .**

Or

What is junction diode ? Draw its characteristic junction curve.

Junction Diode

The border b/w p-type and n-type semiconductor is called p-n junction, which has led to different inventions including diodes, transistors and integrated circuits.



Schematic of Junction diode

Symbol of Junction diode

Reaming ref. to Q.2.

Q.4. **Discuss the theory of current across p-n junction.**

Or

Obtain the current-voltage equation for a p-n junction diode.

Current across p-n junction

The current in p-n junction flows due to majority & minority carriers present in p & n type semiconductor . The net current density through junction is due to following four contributions

(a) The Current I_1 due to flow of minority electrons from p-type to n-type.
(b) The Current I_2 due to flow of majority electrons from n-type to p-type.
(c) The Current I_3 due to flow of majority holes from p-type to n-type.
(d) The Current I_4 due to flow of minority holes from n-type to p-type.

Therefore $I_{net}= (I_2+I_3) -(I_1+I_4)$

The current density for majority electrons from n-type

$$I_2= A\exp \left[\frac{-e(V_B-V)}{K_B T}\right]$$

Similary for holes $$I_3= B\exp \left[\frac{-e(V_B-V)}{K_B T}\right]$$

Hear A&B are constant, V_B is barrier and V is the applied voltage.

For no bias condition ,no net current is flowing through the circuit , hence $I_2=I_1$ and $I_3=I_4$

$\therefore \quad I_1 = A\exp\left[\frac{-eV_B}{K_B\,T}\right]$

$\Longrightarrow$ A= I_1/ Aexp $\left[\frac{-eV_B}{K_B\,T}\right]$

$\therefore \quad I_2 = I_1\exp\left[\frac{eV}{K_B\,T}\right]$

Similarly $I_3 = I_4 \exp\left[\frac{eV}{K_B\,T}\right]$

$$\therefore I_{net} = (I_1 - I_4)[\exp(\frac{eV}{K_B\,T}) - 1] = I_0[\exp(\frac{eV}{K_B\,T}) - 1]$$

This equation is known as **Schockley equation**, I_0 is called reverse saturation current.

Q.5. Explain Junction resistance & Junction Capacitance in detail.

Or

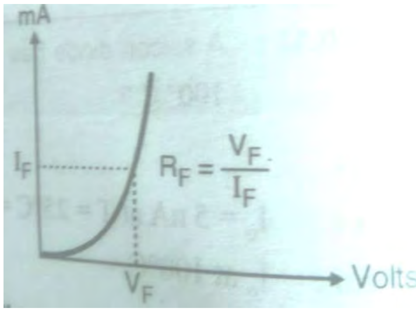
Discuss the meaning of potential barrier and junction capacitance of a P-N junction diode

Related Short Answer Question

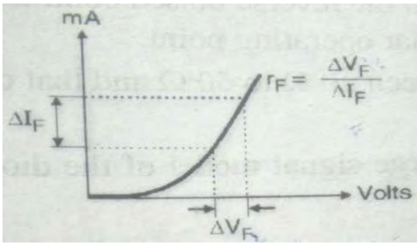
(i) Define resistance of junction diode and obtain expression for them.

The two types of resistance associated with a p-n junction diode are

1. DC resistance
2. AC resistance



- The resitance offered by the diode to the DC operating conditions is called as “DC resistance or Static resistance ” denoted by R_F
- The DC resitance of a diode at operating point can be obtained by tacking the ratio of V_F & C_D



- The resistance offered by the diode to the AC operating conditions is called as “AC resistance or Dynamic resistance” denoted by r_F.
- AC resistance is actually the reciprocal of the slope of the forward characteristics .

$$r_F = \frac{1}{Slope\ of\ the\ characteristics}$$

The two types of capacitances associated with a p-n junction diode are

1. Transition capacitance (C_T)

2. Diffusion capacitance (C_D)

- The **transient capacitance** C_T referred to as space charge capacitance or barrier capacitance or depletion region capacitance.
- C_T is not constant, depends on the magnitude of reverse voltage.
- The value of C_T is inversely proportional to the width of depletion region and the width of depletion region is directly proportional the reverse voltage.
- When the p-n junction diode is forward biased, a capacitance which is much larger then the transient capacitance is known as **diffusion capacitance** (C_D) or storage capacitance.
- The diffusion capacitance (C_D) is given by ,

$$C_D = \frac{dQ}{dV} = \frac{dI(V)}{dV} T_F \text{ , where } T_F = transist\ time$$

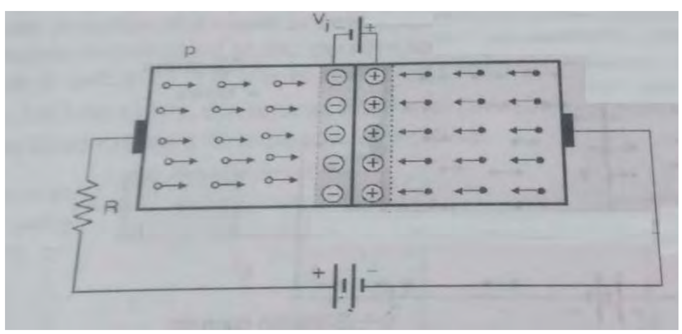
Q.6. How current flow through pn junction ? Discuss effect of biasing on the width of depletion layer

Related Short Answer Question

(i) Draw the energy level diagram with Fermi level for an unbiased, forward biased and reverse biased pn junction. Explain the effect of biasing on the width of depletion layer.

Mechanism of current flow (Forward bias)

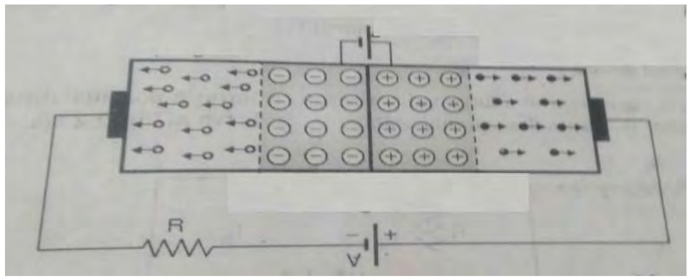
- When diode is forward bias , due to –ve terminal of external source connected to n-region, free electrons from n-side are pushed towards the p-side. Similarly the +ve end of supply will push holes from the p-side towards the n-side.
- With increase in the external supply voltage V, more and more number of holes (p-side) and electrons (n-side) start travelling towards the junction .



- The holes will start converting the negative ions into neutral atoms and the electrons will convert the positive ions into neutral atoms. As a result of this, the width of depletion region will reduce.
- Due to reduction of the depletion region width , the barrier potential will also reduce. Eventually at a particular value of V , the depletion region will collapse. There is absolutely no opposition to the flow of electron and holes.
- The large no. of majority carriers crossing the junction constitute a current called as the forward current.

- The forward current through a p-n junction diode flows due to the majority carriers and its direction of flow(conventional) is always from anode to cathode.
- There is a potential drop across the conducting forward biased diode denoted by V_F equal to 0.7V for silicon & 0.3V for germanium diode.
- The forward voltage drop is due to barrier potential & internal resistance.

Mechanism of current flow (Forward bias)



- When the diode is reverse biased , holes in the p- region are attracted towards the negative terminal of the supply and electrons on the n- side are attracted towards the +ve terminal of the supply.
- **Widening of depletion region** : Due to movement of majority carriers away from the junction , width of depletion layer increases .
- The minority electrons on p-side are attracted by +ve end of dc supply. Hence these electrons will cross the junction and constitute the reverse current I_S of the diode.
- The reverse current flows due to minority carriers is also called as the "Reverse Saturation current" , doubles its value for every 10^0C rise in temperature.

Q.7. What are Zener diodes ? Explain its operation & characteristics. How a Zener diode can be used as a Voltage regulator ?

<u>**Related Short Answer Question**</u>

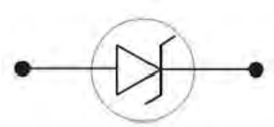
(i) What is zener diode ? Plot & explain its characteristics curve.

(ii) What is Zener diode ? How is Zener diode used as a voltage regulator in a power supply ? Explain.

(iii) What is a breakdown diode (Zener diode). Discuss the origin of breakdown of a junction.

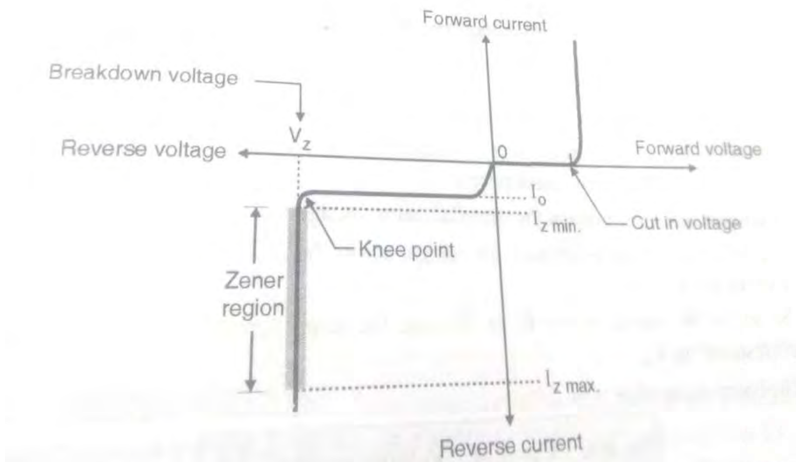
Zener Diode

Zener diode is a special type of p-n junction semiconductor diode that are designed to operate in the breakdown region



The V-I characteristics of Zener diode is a graph of voltage across the diode versus the current flowing through it .This characteristic is divided into two parts

1. Forward Characteristics 2. Reverse Characteristics



Forward Characteristics

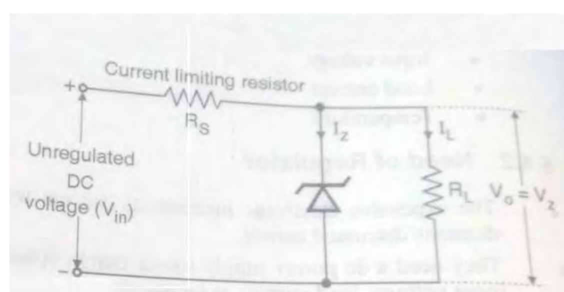
The Forward Characteristics of Zener diode is almost identical to forwar Characteristics of a p-n junction diode.

Reverse Characteristics

- The Reverse Characteristics of Zener diode is substantially different from that of the p-n junction diode.
- As we increase the reverse voltage , initially a small reverse saturation current "I_0" flows. This current flows due to thermally generated minority carriers.
- At a certain value of reverse voltage, the reverse current will increase suddenly and sharply. This is an indication that breakdown has occurred This breakdown is called as zener breakdown voltage or zener voltage denoted by V_Z.
- After breakdown , the voltage across the zener diode remains constant equal to V_Z
- The value of V_Z can be controlled by controlling the doping levels of p and n regions.

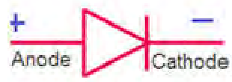
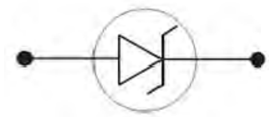
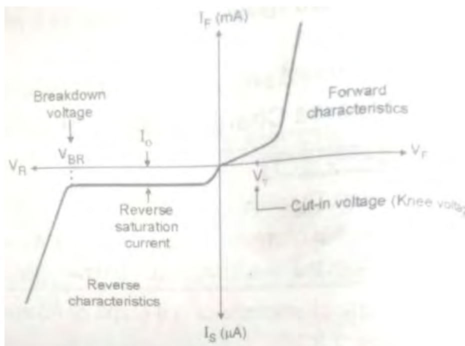
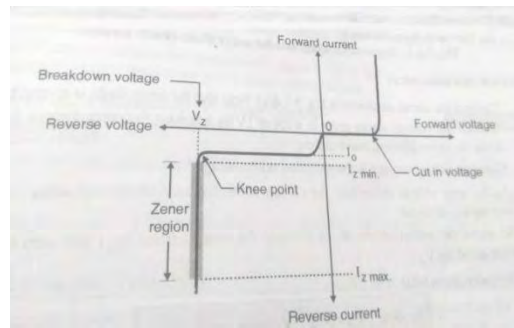
The Zener Voltage Regulator

The voltage across the zener diode remains constant equal to V_Z when it is operated in the "Zener region", this fact is utilized in Zener voltage regulator.



- If the unregulated input DC voltage is able to breakdown zener diode, a constant voltage is maintained across the load i.e. not effected by unregulated supply.
- If $V_{in}\uparrow$ then $I\uparrow$, but I_L is constant as $I_L = \frac{V_Z}{R_Z}$
- Hence $I_Z\uparrow$ as $I_Z = I - I_L$
- If $V_{in}\downarrow$ then $I\downarrow$, but I_L is constant
- Hence $I_Z\downarrow$ as $I_Z = I - I_L$

Q.8. Compare pn junction diode & Zener diode

S.No.	pn junction diode	Zener diode
1.	This is operated in the forward biased condition	Zener diode is normally operated in reverse bias condition.
2.		
3.		
4.	Applications: rectifiers, clipper, clamper, voltage multipliers etc	Applications: Voltage regulators, Voltage limiters etc.

Q.9. What do you understand by Zener & Avalanche breakdown? Distinguish between the two.

S.No.	Zener breakdown	Avalanche breakdown
1.	This is observed in zener diodes having V_Z between 4 to 6 volts	This is observed in zener diodes having V_Z above 6 volts.
2.	The valence electrons are pulled into conduction band due to intense electric field appearing across the narrow depletion region.	The valence electrons are pushed into conduction band due to the energy imparted by colliding accelerated minority carriers.
3.	The V-I Characteristics of Zener breakdown is vary sharp	The V-I Characteristics of Avelanche breakdown increases gradually . it is not as sharp as tzener breakdown.
4.	The breakdown voltage decreases with the increase in temperature.	The breakdown voltage increases with the increase in temperature.

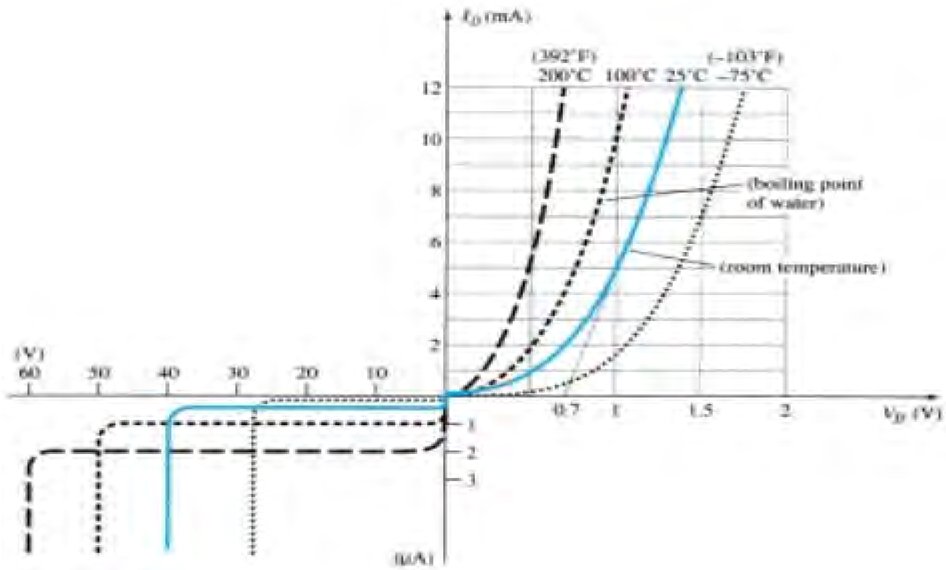
Q.10. What is Knee voltage of a diode? Give its value for germanium and silicon diodes.

Ref. to Q.2

Q.11 Explain the effect of temperature on the temperature on the reverse saturation current in junction diode .

The diode characteristics is expressed by **Schockley equation** , I= $I_0[\exp(\frac{eV_T}{K_B T})-1]$

The parameters I_0 & V_T are temp. dependent



The forward characteristic of a si diode shifts to the left at a rate of 2.5mV per ^{0}C increase in temp.

In the reverse bias region , the reverse saturation current of a silicon diode doubles for every 10^{0}C rise in temperature.

The reverse breakdown voltage will increase or decrease depending on zener potential.

Q.12. What is a tunnel diode ? Explain its operation and working. Draw the characteristics of a tunnel diode and give its main use.

Or

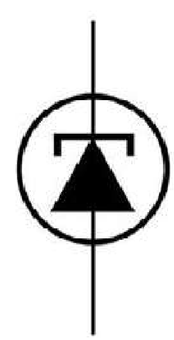
What is a tunnel diode? Draw the volt-ampere characteristic curves of a such a diode. Explain the occurrence of a negative differential resistance in the characteristic. Mention some of its uses.

Or

Describe the construction and working of a tunnel diode. Sketch its V-I characteristics and explain. Mention its application.

Tunnel Diode

When the impurity is very high(≈$10^{25}/m^3$) in both P and N-region of a P-N Junction diode , then the diode is known as tunnel diode. Since the barrier width of a diode is becomes very thin (≈10^{-6}cm) then, on applying forward bias voltage many carriers can tunnel through the depletion region known as tunneling. Hence the diode is known as tunnel diode.



No bias condition

Due to heavily doped, the fermi level lies within the bands of semiconductor at $T=0^0K$. Under no bias condition , the fermi level in the p side is at the same energy as the fermi level in N-side(fig. 1)AS the fermi level is the highest occupied energy level, so no current flows through the junction.

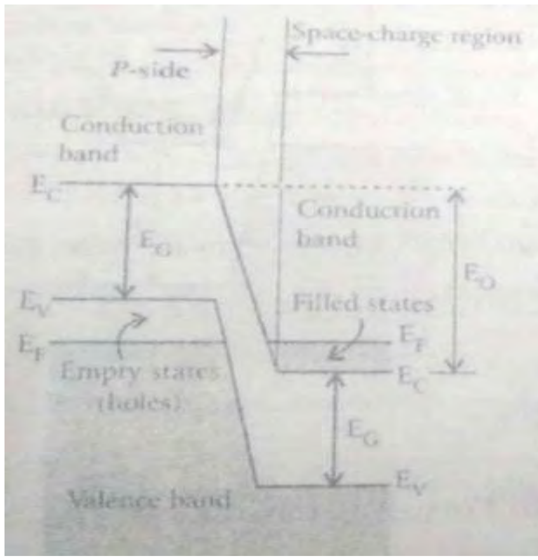


Fig. 1

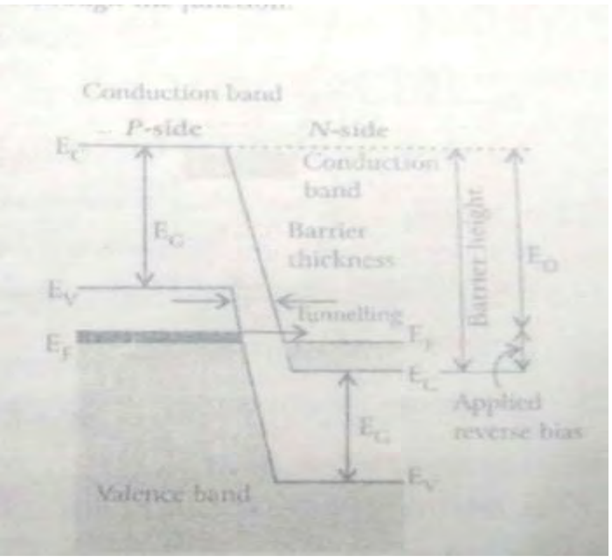


Fig. 2

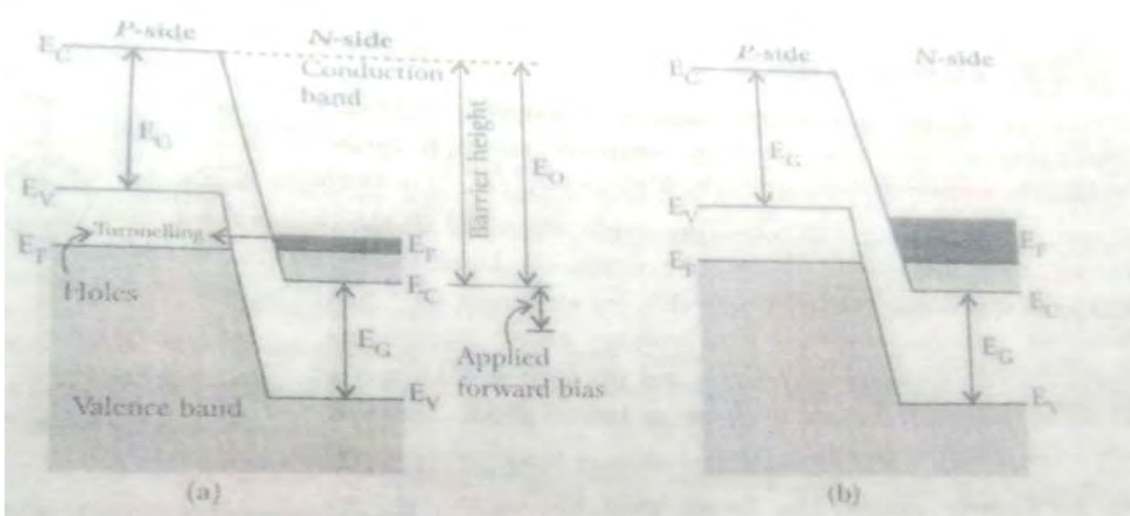
Reverse bias condition

On applying the reverse bias, the height of potential barrier is increased and the fermi level in the p- side goes up relative to that in N side(fig.2). The electrons in the valence band of p-side faces available unoccupied states at the same energy in the conduction band of N-side, across the barrier. Hence the electrons can tunnel from valence band of p-side to conduction band of N-side giving rise to reverse diode current.

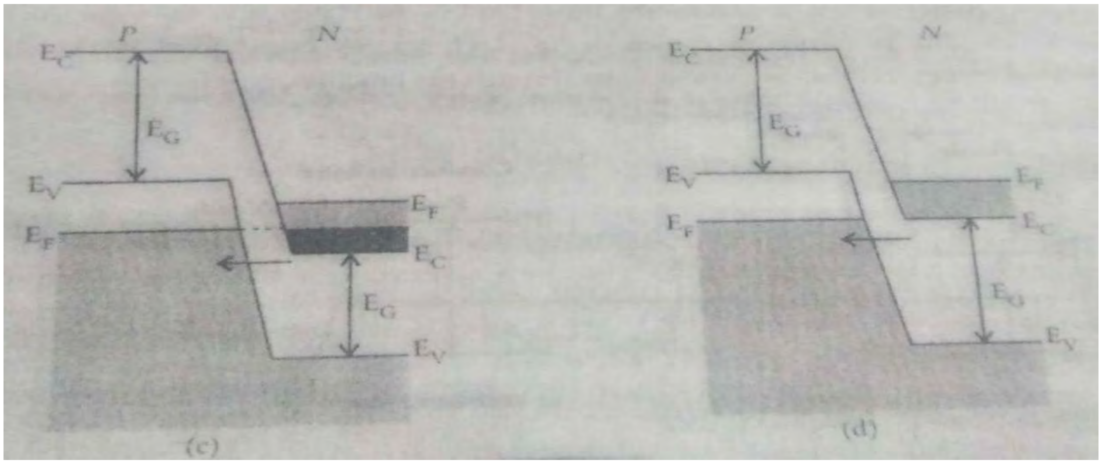
More the reverse bias, larger no. of electrons find available unoccupied sates on other side of thin barrier, as a result tunnel current increases with the reverse bias.

Forward bias condition

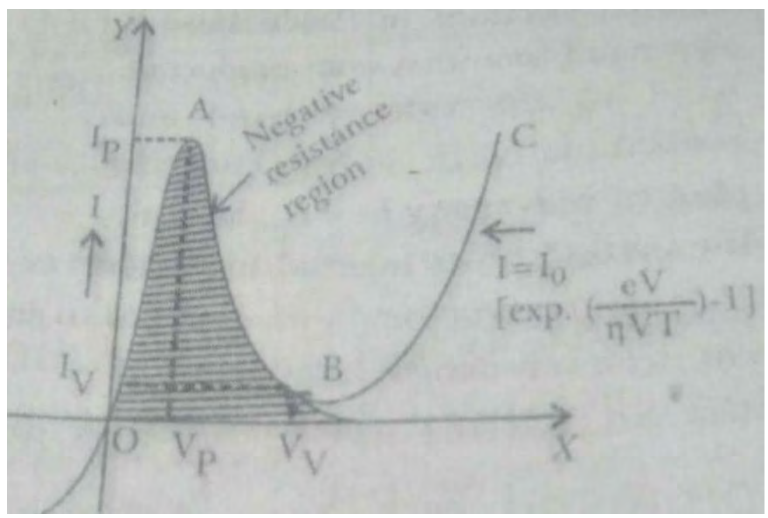
On applying forward bias , the height of potential barrier is decreased and the fermi level in the N-side moves up relative to that of p-side.[fig.(a)]. The electrons in the conduction band of N-side finds allowed empty energy states (holes) in valence band of p-side(at the same energy), across the barrier, Hence the electrons tunnel from N-side to p-side giving rise to large forward current.



On increasing the forward bias, maximum no. of electrons leave the occupied states in N-side & tunnel through the barrier to empty states in p-side, causing a peak current I_P to flow [fig.(b)]. On increasing the forward bias further, tunneling current decreases because available unoccupied states in p-side decreases[fig.(c)]. This corresponds to –ve resistance region AB of the V-I characteristics of tunnel diode. Finally for even larger forward bias, the energy band diagram is obtained as shown in [fig.(d)]



V-I Characteristics of Tunnel diode



The V-I characteristics of tunnel diode as shown in fig. The Portion OA of the characteristics is due to tunneling phenomenon.
If the forward voltage increases beyond V_P, current decreases and reaches to the minimum value I_V known as the valley current.
The forward bias voltage corresponding to valley current is known as valley voltage(V_V).
The tunnel diode posses –ve resistance b/w region AB. Above valley voltage , the tunnel diode behaves like an ordinary diode and the current increases exponentially with forward bias voltage.

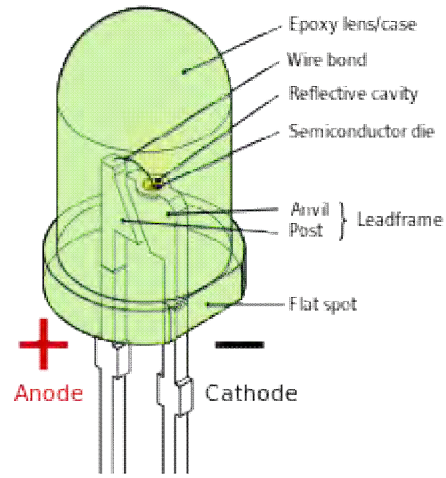
Q.13. Write short notes on :

(i) Solar cell. **(ii) L.E.D.**

Solar cell: A solar cell or photovoltaic cell, is an electrical device that converts the light energy into electrical energy by the photovoltaic effect, which is a physical and chemical phenomenon . Solar cells are the building blocks of solar panels.

They are used as a photo detector in optical communication.
The operation of a photovoltaic (PV) cell requires three basic attributes:

- The absorption of light, generating either electron-hole pairs or excitons.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.



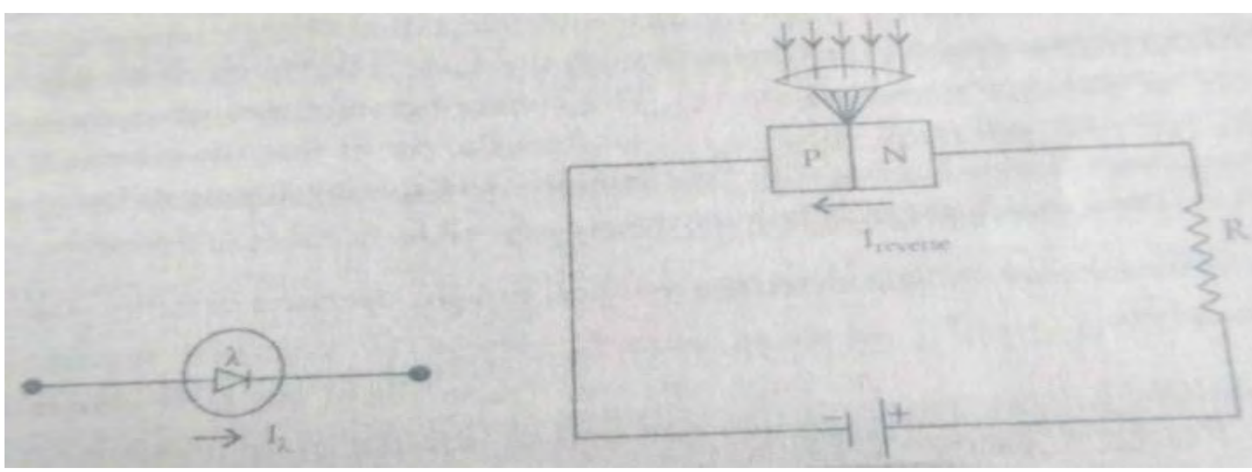
L.E.D.: L.E.D. i.e. light emitting diode is a p–n junction diode, which emits light when activated. When a suitable voltage is applied across the diode, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and the color of the light (corresponding to the energy of the photon) is determined by the energy band gap of the semiconductor.
LEDs are now used in applications as diverse as aviation lighting, automotive headlamps, advertising, general lighting, traffic signals, camera flashes, and lighted wallpaper.

Q.14. Explain the working of photo diodes.

Or

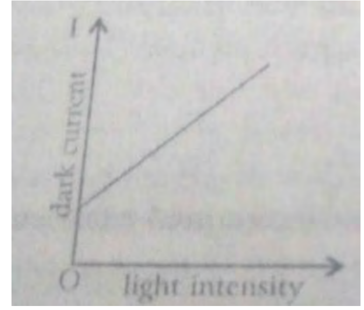
Describe the construction and working of a photo diode. Give its characteristics.

Photo diode is a reverse baised P-N junction whose operation depends on the intensity of light fall on it . The symbol of photo diode is shown in fig.



In reverse biased P-N junction, a small reverse saturation current flows due to thermally generated holes & electrons (minority charge carriers) being swept across the junction, when there is no illumination.

Since there is no illumination or incident light , this reverse saturation current is known as **dark current,** In photodiode, the light energy dislodge valence electrons from their orbit as thermal energy dislodge valence electrons orbit as thermal energy dislodge valence electrons from their orbit on increasing the junction temperature and generating more electron- hole pairs, this increase the reverse current flowing through the diode.



Further increase in the light intensity increase the reverse current. It means light intensity and reverse current are linearly related as shown in fig.(a)

Fig. a

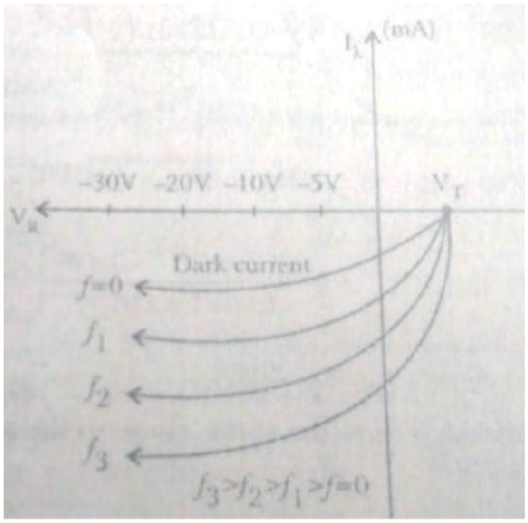


Fig. b

VI Characteristics

- The VI Characteristics shown in fig.(b) . It is a plot b/w current & reverse voltage for different illumination or light intensity (f). In the absence of illumination , the current through the diode is due to the thermally generated minority carriers, known as dark current.

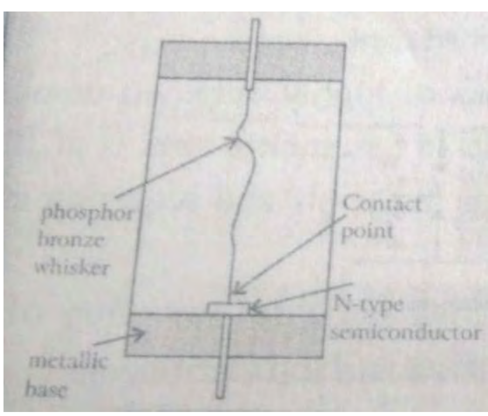
Dark current becomes zero when the applied voltage is positive and equal to V_T.

- From curve it is clear that the current through the diode varies almost linearly with light intensity and the spacing among different curve is equal for same increment in light intensity i.e. $f_2 = 2\, f_1,\ f_3 = 2f_2$ and so on.
- Photo diodes are used in light detection systems in light operated switches, tape, film, sound tracks etc.

Q.16. What is point contact diode? Discuss its working & uses at high frequencies. [Kanpur 2014]

Or

Explain the construction and working of point contact diode. Mention its application at high frequencies. [Kanpur 2016]



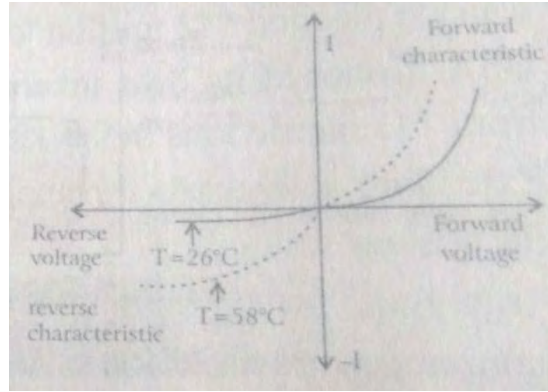
Point Contact diode is a small wafer of a semiconductor crystal having an area of few square millimeters and a thickness of a fraction of mm. The crystal is soldered to a metallic base so that an external ohmic contact can be made.

The point contact is made by pressing phosphorous bronze wire (called cat wisker) against the exposed surface of semiconductor crystal. In case of N-type semiconductor , the forward current flows from the phosphor bronze wire to the semiconductor.

The operation of the diode depends on the pressure of contact between a point and a semiconductor crystal.

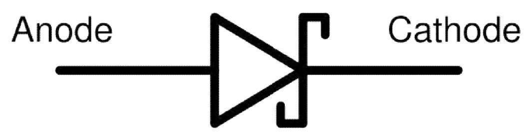
The **V-I characteristics** curve of the point contact diode for two different temperature T=26^{0}C & 58^{0}C is shown in fig.

Point contact diode is very useful for the operation at high frequencies (≈10KHz) and in pulse circuits in contrast to normal diode.



Q.17. What is Schottky diode ? Why Schottky diode is known as hot carrier diode? How it differs in construction from a normal P- N junction ? Give its working , characteristics and applications.

As frequency increases , the action of normal diodes begins to deteriorate as a rectifier. They are no longer able to switch off fast enough to produce a well-defined rectified signal. The solution for this problem is the schottky diode.



The symbol shown in figure, the cathode side looks like a rectangular S, which stands for schottky diode.

Differ from normal diode

It is a semiconductor diode formed by the junction of a semiconductor with a metal. This diode uses a metal such as gold, silver, or platinum on one side of the junction and doped silicon (typically n-type) on the other side.

Diode Biasing

When the schottky diode is unbiased, free electrons on the n-side are in smaller orbits then the free electrons on the metal side. This difference in orbit size is called the **Schottky barrier**, approximately 0.25V.

When the diode is forward bias, free electrons on the n side can gain enough energy to travel in larger orbits, because of this electrons cross the junction and enter the metal , producing a large forward current. Since the metal has no holes, there is no charge storage and no reverse recovery time.

Hot carrier diode

Schottky diode is called as a hot carrier diode , this name came as follows . Forward bias increases the energy of the electrons on the n-side to a higher level then that of electron on the metal side of the junction. This increase in energy inspired the name hot carrier for the n-side electrons.

As soon as these high- energy electrons cross the junction , they fall into the metal, which has a lower-energy conduction band.

High- Speed Turnoff

Due to lack of charge storage schottky diode can be turned off faster than the normal diode. Because this property , the diode is used to rectify frequencies above 300MHz.

Applications

- Used in RF mixer and Detector diode
- Used in high power rectifier.
- Used in Solar cell applications
- Schottky barrier diodes may also be used as a clamp diode in a transistor circuit to speed the operation when used as a switch.

Q.18. What is thermistors? Give its construction, working and applications. [Important]

A thermistor is a type of resistor whose resistance strongly depends on temperature. The word thermistor is a combination of words "thermal" and "resistor". Thermistors are available in various shapes like disc, rod, washer, bead etc as shown in fig.(a).

A thermistor is a temperature-sensing element composed of sintered semiconductor material and sometimes mixture of metallic oxides such as Mn, Ni, Co, Cu and Fe, which exhibits a large change in resistance proportional to a small change in temperature.

Pure metals have positive temperature coefficient of resistance, alloys have ≈ zero temperature coefficient of resistance and semi conductors have negative temperature coefficient of resistance.

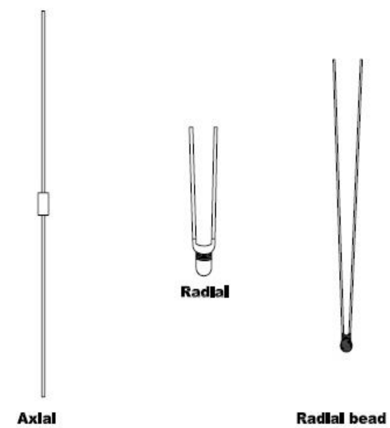


Fig. a

Thermistors can be classified into two types:

- Positive temperature coefficient (PTC) thermistor:-resistance increase with increase in temperature.
- Negative temperature coefficient (NTC) thermistor:- resistance decrease with increase in temperature.

The thermistor exhibits a highly non-linear characteristic of resistance vs. temperature.

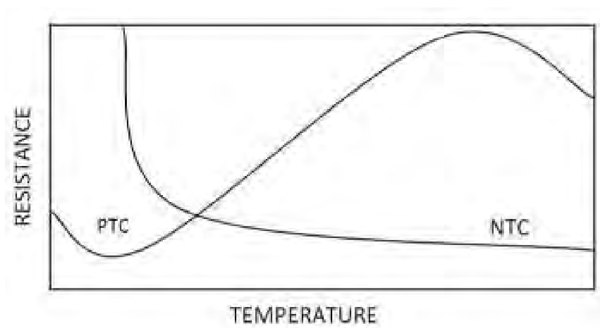


Fig. b

PTC thermistors can be used as heating elements in small temperature controlled ovens. NTC thermistors can be used as inrush current limiting devices in power supply circuits. Inrush current refers to maximum, instantaneous input current drawn by an electrical device when first turned on.

Applications

- PTC thermistors were used as timers in the degaussing coil circuit of most CRT displays. A degaussing circuit using a PTC thermistor is simple, reliable (for its simplicity), and inexpensive.
- PTC thermistors are used as heater in automotive industry to provide additional heat inside cabin with diesel engine or to heat diesel in cold climatic conditions before engine injection.
- PTC thermistors is used as current-limiting devices for circuit protection, as replacements for fuses.
- NTC thermistors is used to monitor the temperature of an incubator.

- Thermistors are also commonly used in modern digital thermostats and to monitor the temperature of battery packs while charging.
- We regularly use NTC thermistors in automotive applications.
- NTC thermistors are used in the Food Handling and Processing industry, especially for food storage systems and food preparation. Maintaining the correct temperature is critical to prevent food borne illness.
- NTC thermistors are used throughout the Consumer Appliance industry for measuring temperature. Toasters, coffee makers, refrigerators, freezers, hair dryers, etc. all rely on thermistors for proper temperature control.
- We can regularly use the Thermistors in the hot ends of 3D printers; they monitor the heat produced and allow the printer's control circuitry to keep a constant temperature for melting the plastic filament.
- NTC thermistors are used as resistance thermometers in low-temperature measurements of the order of 10 K.
- NTC thermistors can be used as inrush-current limiting devices in power supply circuits.

Numerical

Q.1. When a silicon diode having a doping concentration of $N_A = 9 \times 10^{16}$ cm^{-3} on p-side and $N_D = 1 \times 10^{16}$ cm^{-3} on n-side is reverse biased, the total depletion width is found to be 3 µm. Given that the permittivity of silicon is 1.04×10^{-12} F/cm, find the depletion width on the p-side and the maximum electric field in the depletion region.

Exp: Given $N_A = 9 \times 10^{16} / cm^3$; $N_D = 1\times10^{16} / cm^3$

Total depletion width, $x= x_n+x_p=3$ µm.

$$\in = 1.04 \times 10^{-12} \text{ F / cm}$$

Since $\frac{X_n}{X_p} = \frac{N_A}{N_D} = = (9 \times 10^{16)}/(1 \times 10^{16})$

$X_n = 9X_p$

$\because x= x_n+x_p=3$ µm.

$9 x_p + x_p = 3$ µm.

$\therefore x_p = 0.3$ µm

Max. Electric field, $E= qN_AN_D / \in = (1.6*10^{-19} *9 \times 10^{16} * 1\times10^{16}) / (1.04 \times 10^{-12})$

$= 4.15 \times 10^5$ V / cm Ans

Q.2. A diode has a power rating of 5W. if the diode voltage is 1.2 V and the diode current is 17.5 A, what is the power dissipation ? will the diode be destroyed ?

Exp: $\because P_D = V_D I_D$

$\therefore P_D= (1.2V)(1.75A)=2.1W$

$\because P_D < 5W$ so the diode will not destroyed.

Q.3. Find the dynamic resistance of a P-N junction diode at a forward current of 2mA. Assume kT/q= 25mV.

Exp: Given , forward current = 2mA= 0.002A

Volt equivalent of temp. , V_T= **kT/q= 25mV**

$\because$ Dyamic resistance (r) = $\eta V_T/I$ $(\eta=1)$

$\therefore r = 0.025/0.002= 12.5\ \Omega$.

Q.4. Assuming the barrier potential of 0.7V at an ambient temperature of 25^0C , What is the barrier potential of a silicon diode whwn the junction temperature is 100^0C ? At 0^0C ?

Exp: When the Junction temp. is 100^0C , the change in barrier potential is

ΔV= (-2.5mV/^{0}C) ΔT = (-2.5mV/^{0}C)(**100^0C - 25^0C**)= -187.5mV

∴ The barrier potential will decrese by 187.5mV

i.e. V_B= 0.7V – 0.18V = 0.52 V Ans

When the Junction temp. is 0^0C , the change in barrier potential is

ΔV= (-2.5mV/^{0}C) ΔT = (-2.5mV/^{0}C)(**0^0C - 25^0C**)= 62.5mV

∴ The barrier potential will increase by 62.5mV

i.e. V_B= 0.7V = 0.0625 = 0.7625 V Ans

Q.5. A Silicon diode has a saturaration current of 5nA at 25^0C. What is the saturation current at 100^0C ?

Exp: The change in temp

∴ΔT = 100^0C - 25^0C= 75 ^{0}C

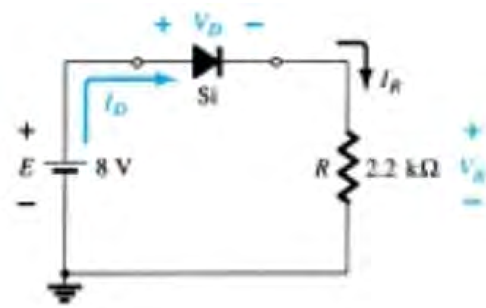
∵ there is seven doubling between 25^0C to 95 ^{0}C

∴ I_S = (2^7)(5nA)= 640nA

∵ there is 5 ^{0}C rise in temp from 95^0C to 100 ^{0}C

∴ I_S = (1.07^5)(640nA)= 898nA Ans

Q.6. For the series diode configuration determine V_D, V_R and I_D.



Exp: ∵ Diode is of silicon type therefore V_D= 0.7V

V_R= (8-0.7)V/2.2KΩ

= 7.3V/2.2KΩ

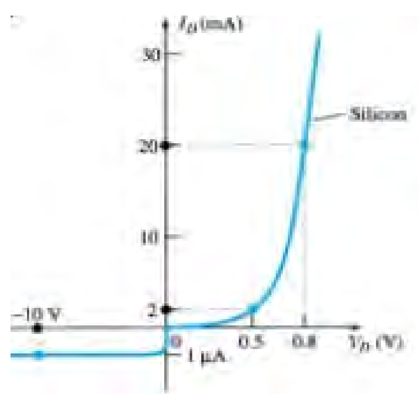
= 3.32mA Ans

Q.7. Determine the dc reistance levels for the diode shown in fig. at

(a) $I_D = 2mA$

(b) $I_D = 20mA$

(c) $V_D = -10V$



Exp: (a) At $I_D = 2mA, V_D = 0.5\ v$(from the curve)

∴ R_D=V_D/I_D =0.5v/2mA= 250 Ω Ans

(b) At $I_D = 20mA, V_D = 0.8\ v$(from the curve)

∴ R_D=V_D/I_D =0.8v/20mA = 40 Ω Ans

(c) At $V_D = -10V, I_D = -1\mu A$ (from the curve)

∴ R_D=V_D/I_D =-10v/- 1μA = 10 MΩ Ans

Q.8. The current through p-n junction is 50mA at a forward bias voltage of 3.0volt. At temp. 27^0C , find the static and dynamic resistance of the diode.

Exp: Given V=3V, I=50mA

Static resistance is given as R_{dc}=V/I

∴ R_{dc} = 3/50mA

= 60 Ω Ans

Dynamic resistance is given as $r_{ac} = \frac{dV}{dI}$

$\because$ $I = I_0[\exp(\frac{eV}{\eta K_B T}) - 1]$ $= I_0[\exp(\frac{V}{\eta V_T}) - 1]$

Here V_T= 0.026V=26mV, I= 50mA

for silicon η= 1 ,r_{ac}= ηV_T/ I = 26mV/50mA= 0.52 Ω Ans

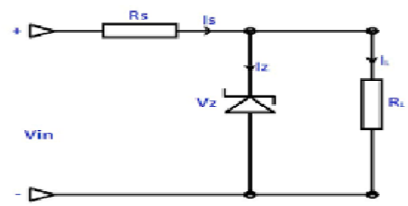
Q.9. Calculate the value of

(i) Voltage difference across series resistance.

(ii) Electric current in zener diode.

Given V_{in}= 100V , V_Z= 60V , R_S = 5KΩ , R_L= 10KΩ

Exp: Given V_{in}= 100V , V_Z=60V, R_S = 5KΩ , R_L= 10KΩ



(i) Then V_S(voltage across R_S) = (100-60) V= 40V Ans

(ii) I_S= 40V/ 5KΩ = 8mA

I_L= V_Z/ R_L = 60V/10 K Ω= 6mA

$\because$ $I_S = I_Z + I_L$

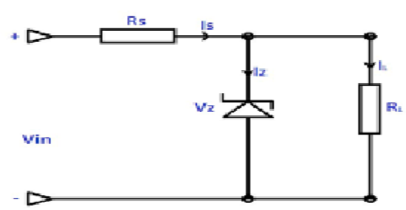
$\therefore$ I_Z = (8-6)mA= 2mA Ans.

Q.10. For the following circuit find:

(i) Output voltage (ii) Voltage drop across R_S (iii) Current through the zener diode

Given V_{in}= 120 V , V_Z= 50V , R_S = 5KΩ , R_L= 10KΩ

Exp: Given V_{in}= 120V , V_Z=50V, R_S = 5KΩ , R_L= 10KΩ



(i) Since zener diodes breakdown takes place

$\therefore$ Output Voltage = V_Z= 50V Ans.

(ii) V_S(voltage across R_S) = (120-50) V= 70V Ans

(iii) I_S= 70V/ 5KΩ = 14mA

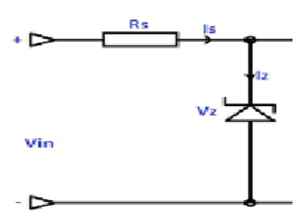
I_L= V_Z/ R_L = 50V/10 K Ω= 5mA

$\because$ $I_S = I_Z + I_L$

$\therefore$ I_Z = (14-5)mA= 9mA Ans.

Q.11. Maximum 20mA current can flow through a zener diode . If Zener voltage is 6volt, how much resistance will have to be applied in series with the zener diode for 9 volt supply? Calculate load current & zener current if load resistance is of 1 KΩ.

Part –I Exp: Given V_{in}= 9V , V_Z=6V, I_Z= 20mA, R_S = ?



$\because$ I_Z= 20mA, & the zener diode is in series of R_S

It means 20mA current will also flow through R_S

Here V_S= (9-6)V= 3V

I_S= 20mA

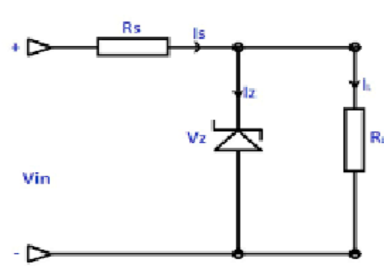
$\therefore$ R_S = 3V/20mA= 150 Ω Ans

Part –II

Exp: Given V_{in}= 9V , V_Z=6V, V_S= 3V ,

R_S = 150 Ω,

R_L= 1K Ω , I_Z= ?, I_L=?



$\because V_S = 3V$

$\therefore I_S = 3V/150\,\Omega = 20mA$

$\therefore I_L = 6V/1K\,\Omega = 6mA$

$\because I_S = I_Z + I_L$

$\therefore I_Z = (20-6)mA = 14mA$ Ans

Q.12. A zener regulator has Vz=15V. The input voltage may vary from 22 to 40volt and load current from 20 to 100mA. To hold load voltage constant under all conditions, what should be the value of series resistance?

Exp: Given $V_{in} = 15V$,

$\delta V_i = (40-22)V = 18V$

$\delta I_L = (100-20)mA = 80mA$

$\because \delta V_i = R\,\delta I_L$

$\therefore R = 18/(8x\,10^{-2}) = 225\,\Omega$ Ans

Q.13. A LED is made of gallium phosphide for which the band gap energy E_g= 2.26eV, at room temperature. Find the wavelength of light emitted by it when it is forward biased.

Exp: Given $E_g = 2.26eV = 2.26\ x 1.6x10^{-19}$ Joule

$h = 6.62\ x\ 10^{-34}$, $c = 3x10^8 m/s$

$\because$ The wavelength of the emitted light is given as $\lambda = h_c/E_g$

$\therefore \lambda = 6.62\ x\ 10^{-34}/3x10^8 = 5.49x\ 10^{-7}$

$= 5490\ \dot{A}$ Ans