# Applied Physics

Unit 2: Semiconductor Physics
Dr. G. Patrick

Unit 2: Semiconductor Physics

- Intrinsic and extrinsic semiconductors, Estimation of carrier concentration in intrinsic and extrinsic semiconductors, Dependence of Fermi level on carrier concentration and variation with temperature, Carrier transport: diffusion and drift, p-n junction diode: I-V Characteristics, Zener diode: I-V Characteristics, Hall Effect and its applications.

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Conductors, Semiconductors and Insulators

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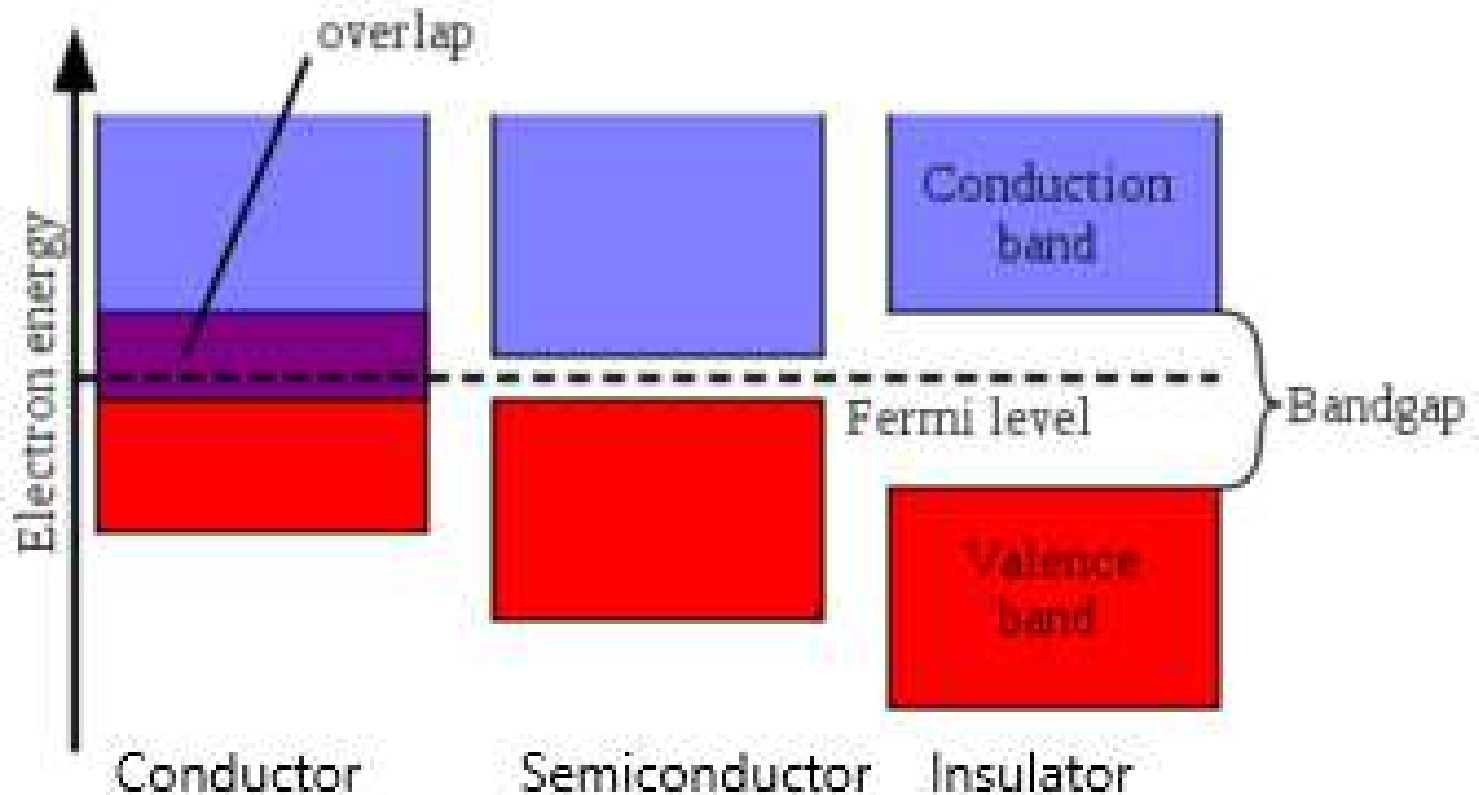
Semiconductors

- Semiconductors are materials having electrical conductivity greater than that of insulators but less than that of conductors.

- Semiconductors may be classified as

  - Intrinsic semiconductor or

  - Extrinsic semiconductor

Intrinsic semiconductor

- Chemically pure semiconductors are called as intrinsic semiconductors.

- Germanium and silicon are intrinsic semiconductors having 4 valence electrons.

- At 0 K all the electrons in the valence band are held by covalent bonding and the material behaves as an insulator at 0 K.

Silicon

Germanium
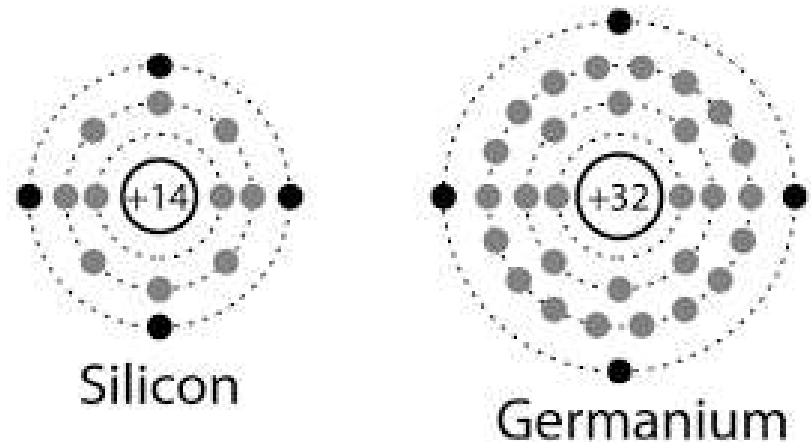
Extrinsic semiconductor

- A semiconductor doped with impurity atoms is called extrinsic semiconductor.

- Extrinsic semiconductors may be n type or p type depending on the dopent.

- n type extrinsic semiconductors are formed when a intrinsic semiconductor is doped with Group V elements like phosphorous, arsenic, antimony etc.

- p type extrinsic semiconductors are formed when a intrinsic semiconductor is doped with Group III elements like aluminium, boron, gallium etc.

Intrinsic vs Extrinsic semiconductor

BASIS OF DIFFERENCE	INTRINSIC SEMICONDUCTOR	EXTRINSIC SEMICONDUCTOR
Doping of impurity	Doping or addition of impurity does not take place in intrinsic semiconductor.	A small amount of impurity is added to a pure semiconductor for preparing extrinsic semiconductor. For n type, Group V elements are added and for p type Group III elements are added.
Density of electrons and holes	The number of free electrons in the conduction band is equal to the number of holes in the valence band.	The number of electrons and holes are not equal. In n type electrons are in majority and in p type holes are in majority.
Electrical conductivity	Electrical conductivity is low.	Electrical conductivity is high
Dependency of electrical conductivity	Electrical conductivity is a function of temperature alone.	Electrical conductivity depends on temperature as well as on the amount of impurity added to the pure semiconductor.
Fermi level	Fermi level is in the middle of forbidden gap.	n type: Fermi level is near conduction band. P type: Fermi level is near valence band.

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Energy level diagram

n type	P type

: Energy band diagram of n-type semiconductor

. Energy band diagram for a p-type semiconductor
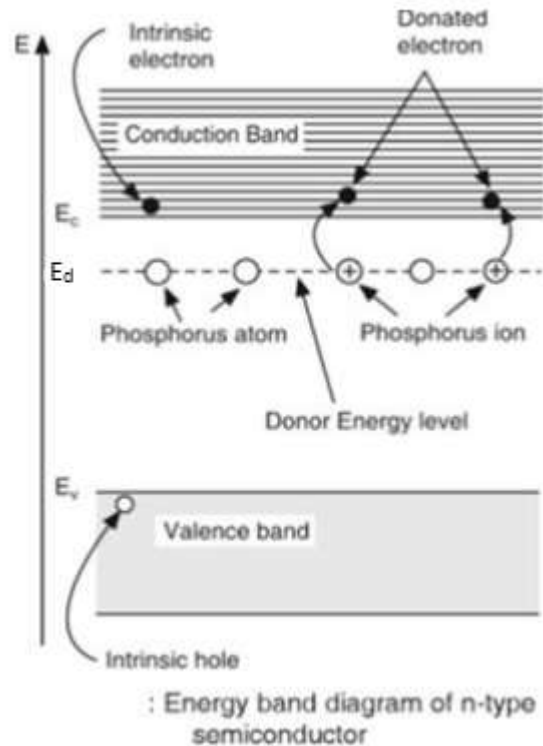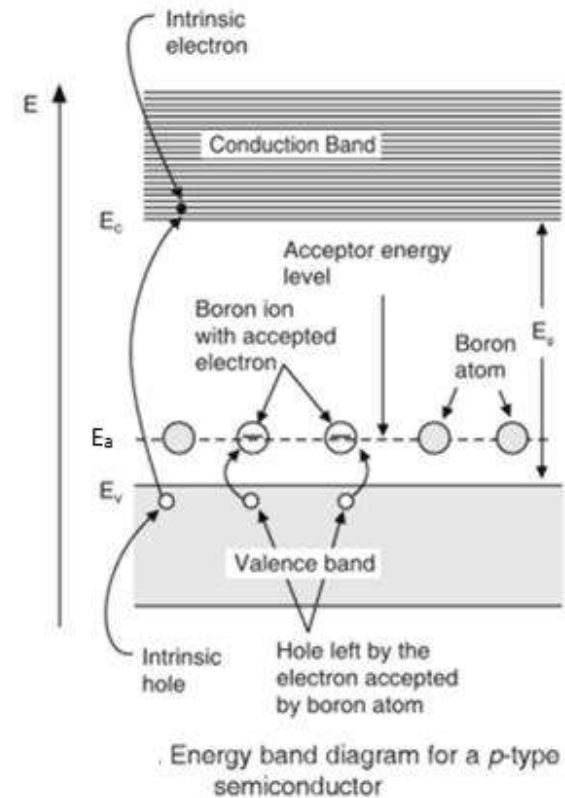
Fermi-Dirac distribution function and Fermi level

- The probability that an electron occupies an energy level E at thermal equilibrium is given by:

$$f(E) = \frac{1}{1+\exp(\frac{E-E_F}{KT})}$$ where E_F is the Fermi level.

- E_F may or may not correspond to an energy level.

- In semiconductors Fermi level is not an allowed energy level. It is a reference energy level according to which we specify the energies of electrons and holes in a semiconductor.

Fermi Level

- Fermi energy is defined as maximum energy that a free electron can have in a conductor at 0 K.

- Fermi energy is the energy of the state at which the probability of electron occupation is half i.e. 0.5 at any temperature above 0 K.

Intrinsic Semiconductor Calculation of electron density

- Let dn be the number of electrons whose energy lies in the energy interval E and E+dE in the conduction band.

- dn = Z(E) f(E) dE, where Z(E) dE is the density of states and f(E) the probability that a state of energy is occupied by an electron.

- The electron density in the conduction band is

$$n = \int_{E_c}^{\infty} Z(E)\, f(E)\, dE \qquad \text{....... (1)}$$

Intrinsic Semiconductor Calculation of electron density

- The density of state in the conduction band is given by

- $Z(E)dE = \frac{4\pi}{h^3}(2m_e^*)^{3/2} E^{1/2}$ dE for E > E_c

- E = E- E_c , the K.E of conduction band electrons.

- $Z(E)dE = \frac{4\pi}{h^3}(2m_e^*)^{3/2} (E - E_c)^{1/2}$ dE ………. (2)

- The probability of an electron occupying an energy level is

f(E) = $\dfrac{1}{1+\exp(\frac{E-E_f}{KT})}$, when the number of particles is very small compared to the available energy levels, the probability of an energy state being occupied by more than one electron is very small.   It implies E- E_f > > KT

Intrinsic Semiconductor Calculation of electron density

- Fermi-Dirac function can be approximated to Boltzmann function. $f(E) = \exp\left[-\dfrac{(E-E_F)}{KT}\right]$ ...(3)

- Using equation (2) and (3) in (1)

- $n = \dfrac{4\pi}{h^3}(2m_e^*)^{3/2}\int_{E_C}^{\infty}(E-E_c)^{\frac{1}{2}}\exp\left[-\dfrac{(E-E_F)}{KT}\right]dE$

- Integrating and rearranging,

- $n = 2\left[\dfrac{2\pi m_e^* KT}{h^2}\right]^{3/2}\exp\left(\dfrac{E_F-E_c}{KT}\right)$ .... (4)

Intrinsic Semiconductor Calculation of hole density

- Let dp be the number of holes whose energy lies in the energy interval E and E+dE in the valence band.

- dp = Z(E) [1- f(E)] dE, where Z(E) dE is the density of states and [1- f(E)] the probability that a state of energy is vacant and not occupied by an electron.

- The hole density in the valence band is

$$p = \int_{-\infty}^{E_v} Z(E) [1-f(E)] \, dE \qquad \text{....... (5)}$$

Intrinsic Semiconductor Calculation of hole density

- The density of state in the valence band is given by

- $Z(E)dE = \frac{4\pi}{h^3}(2m_h^*)^{3/2} E^{1/2} \, dE$

- $E = E_v - E$, the K.E of holes.

- $Z(E)dE = \frac{4\pi}{h^3}(2m_h^*)^{3/2}(E_v - E)^{1/2} \, dE$ ………. (6)

- The probability of an hole occupying an energy level is

$1- f(E) = 1 - \dfrac{1}{1+\exp\left(\frac{E-E_f}{KT}\right)}$ or $1- f(E) = \exp\left[\frac{(E-E_F)}{KT}\right]$ ………(7)

$[E- E_f \ll KT]$

- Using equation (6) and (7) in (5)

- $p = \frac{4\pi}{h^3}(2m_h^*)^{3/2}\int_{-\infty}^{E_v}(E_v - E)^{\frac{1}{2}}\exp[\frac{(E-E_f)}{KT}]dE$

- Integrating and rearranging,

- $p = 2\left[\frac{2\pi m_h^* KT}{h^2}\right]^{3/2}\exp\left(\frac{E_v - E_f}{KT}\right)$ .... (8)

Intrinsic concentration

- When a bond breaks in a pure semiconductor it leads to generation of an electron and hole pair.

- At any temperature T, the number of electrons generated will be equal to the number of holes generated.

- The number of electrons is equal to the number of holes i.e. $n = p = n_i$

- n_i is called as intrinsic density or intrinsic concentration.

Intrinsic concentration

We can write $n_i^2 = np$ where

$$n = 2\left[\frac{2\pi m_e^* KT}{h^2}\right]^{3/2} \exp\left(\frac{E_f - Ec}{KT}\right) \text{ and } p = 2\left[\frac{2\pi m_h^* KT}{h^2}\right]^{3/2} \exp\left(\frac{E_v - E_f}{KT}\right)$$

- $(n_i)^2 = 4\left(\frac{2\pi KT}{h^2}\right)^3 (m_e^* m_h^*)^{3/2} \exp\left(\frac{E_v - E_c}{KT}\right)$

- $(n_i)^2 = 4\left(\frac{2\pi KT}{h^2}\right)^3 (m_e^* m_h^*)^{3/2} \exp\left(\frac{-E_g}{KT}\right)$

- Here $E_c - E_v = E_g$ (forbidden energy gap)

- Hence $n_i = 2\left(\frac{2\pi KT}{h^2}\right)^{3/2} (m_e^* m_h^*)^{3/4} \exp\left(\frac{-E_g}{2KT}\right)$ .... (9)

Intrinsic concentration - dependence on temperature

- $n_i = 2(\frac{2\pi KT}{h^2})^{3/2} (m_e^* m_h^*)^{¾} \exp(\frac{-Eg}{2KT})$

- The intrinsic carrier concentration strongly depends on temperature.

- As the temperature increases more number of covalent bonds break and hence more number of electrons and holes are generated.

Intrinsic concentration – Fermi level

- In an intrinsic semiconductor the number of electrons are equal to the number of holes.

- n = p or

$$2\left[\frac{2\pi m_e^* \mathrm{KT}}{h^2}\right]^{3/2} \exp\left(\frac{E_f - \mathrm{E}_c}{\mathrm{KT}}\right) = 2\left[\frac{2\pi m_h^* \mathrm{KT}}{h^2}\right]^{3/2} \exp\left(\frac{E_v - E_f}{\mathrm{KT}}\right)$$

Assuming the effective mass of electron and hole to be same, i.e. $m_e^* = m_h^*$

$$\exp\left(\frac{E_f - \mathrm{E}_c}{\mathrm{KT}}\right) = \exp\left(\frac{E_v - E_f}{\mathrm{KT}}\right)$$
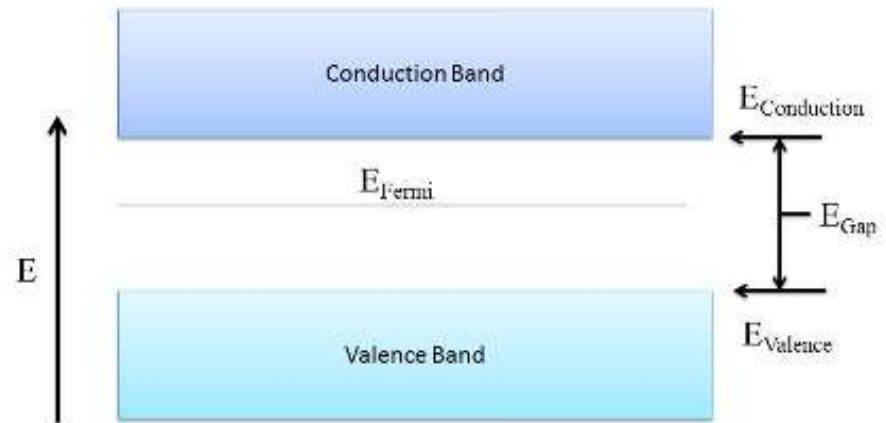
Intrinsic concentration – Fermi level

$$\frac{E_f - E_c}{KT} = \frac{E_v - E_f}{KT}$$

$$2\,E_f = E_v + E_c$$

$$E_f = \frac{E_v + E_c}{2}$$

Thus the Fermi level is located half way between the valance band and conduction band.

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# Variation of Fermi level with temperature in an intrinsic semiconductor

- If $m_h^* = m_e^*$ then the fermi level lies at the centre of the energy gap.

- With an increase in temperature, the fermi level gets displaced upwards if $m_h^* > m_e^*$ or downwards if $m_h^* < m_e^*$
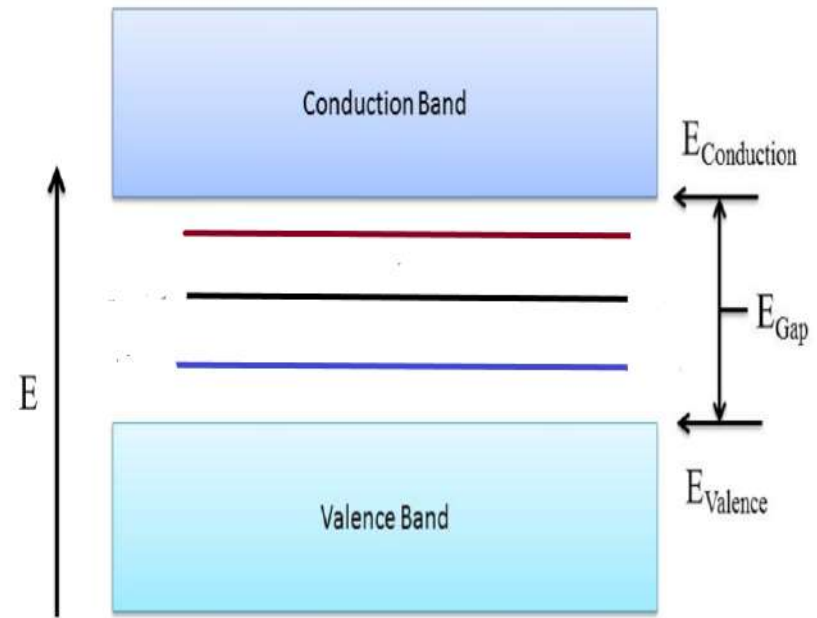
Extrinsic Semiconductor
Carrier concentration in n type semiconductors

- Let N_d be the concentration of donors in the material. At 0 K, the donor atoms are not ionized and are at the level E_d.

- At temperature above 0 K, the donor atoms get ionized and free electrons jump to conduction band.

: Energy band diagram of n-type semiconductor
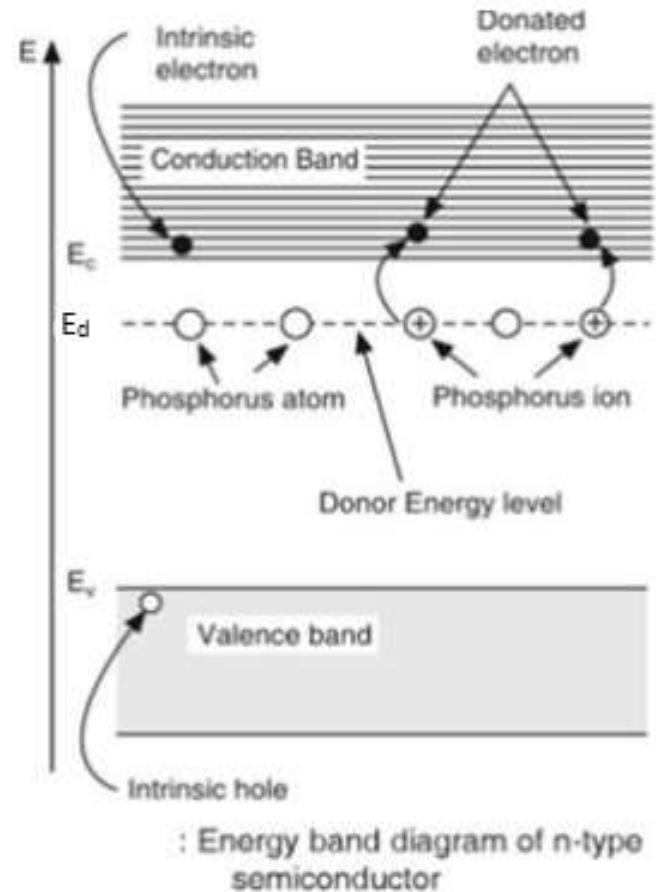
Extrinsic Semiconductor
Carrier concentration in n type semiconductors

- Assume that the electron concentration, n, in the conduction band is equal to the number of donors i.e. $n = N^+_d$ where

- $n = 2\left[\dfrac{2\pi m^*_e KT}{h^2}\right]^{3/2} \exp\left(\dfrac{E_F - Ec}{KT}\right)$ .... (4)

- Let $2\left[\dfrac{2\pi m^*_e KT}{h^2}\right]^{3/2} = N_c$

- Therefore $n = N_c \exp\left(\dfrac{E_F - Ec}{KT}\right)$ also

- $N^+_d = N_d \exp\left(\dfrac{E_d - E_f}{KT}\right)$

- Equate the above equations i.e. $n = N^+_d$

- $N_c \exp\left(\frac{E_F - E_c}{KT}\right) = N_d \exp\left(\frac{E_d - E_F}{KT}\right)$

- Taking logarithm and rearranging

$$\left(\frac{E_d - E_F}{KT}\right) + \left(\frac{E_c - E_F}{KT}\right) = \ln\left(\frac{N_c}{N_d}\right)$$

- $(E_d + E_c) - 2\,E_F = KT \ln\left(\frac{N_c}{N_d}\right)$

-

- $E_F = \left(\dfrac{E_d + E_c}{2}\right) - \left(\dfrac{KT}{2}\right) \ln\left(\dfrac{N_c}{N_d}\right)$

- $E_F = \left(\dfrac{E_d + E_c}{2}\right) + \left(\dfrac{KT}{2}\right) \ln\left(\dfrac{N_d}{N_c}\right)$ .... (10)

- At T = O K, $E_F = \left(\dfrac{E_d + E_c}{2}\right)$

- Substitute the value of E_F from equation (10) in equation (4) and rearrange

- $n = (2\,N_d)^{1/2}\left(\dfrac{2\pi m_e^{*}\text{KT}}{h^2}\right)^{\frac{3}{4}} \exp\left(\dfrac{E_d - \text{Ec}}{2\text{KT}}\right)$ ...... (11)

- Hence the density of the electrons in the conduction band is proportional to the square root of the donor concentration at low temperature. At higher temperature intrinsic behavior predominates and donor concentration becomes insignificant.
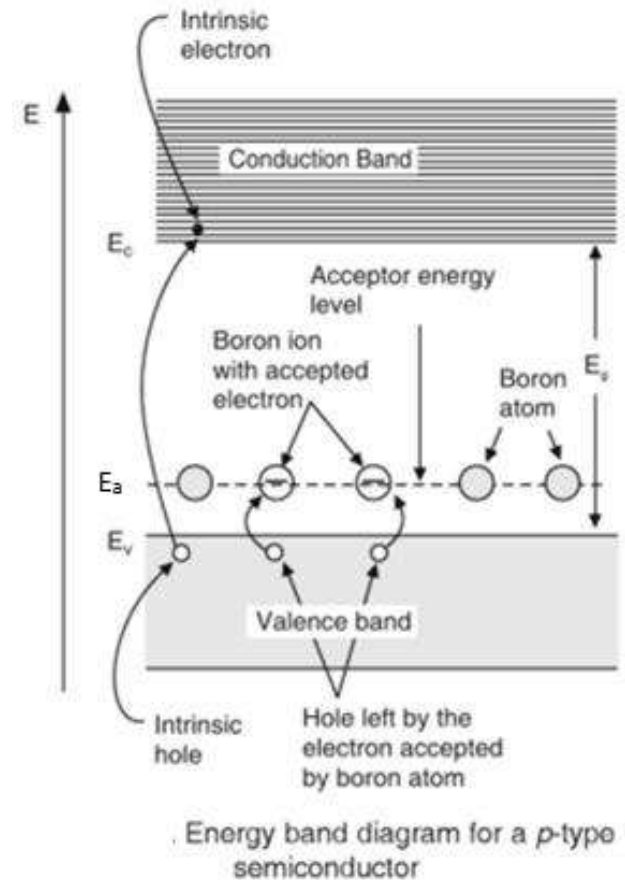
Variation of Fermi level with temperature

- With an increase of temperature E_F increases slightly as per equation (10).

- As the temperature is further increased more number of donor atoms are ionized and at a particular temperature all the donor atoms are ionized.

- Further increase in temperature results in generation of electron – hole pairs due to breaking of covalent bonds and the material tends to behave in intrinsic manner.

Extrinsic Semiconductor
Carrier concentration in p type semiconductors

- Let N_a be the concentration of acceptors in the material. At 0 K, the acceptor atoms are not ionized and are at the level E_a.

- At temperature above 0 K, the acceptor atoms get ionized and holes appear in the valence band.

Energy band diagram for a p-type semiconductor

- Assume that the hole concentration, p, in the valence band is equal to the number of acceptors i.e. $p = N_a^-$ where

- $$p = 2 \left[\frac{2\pi m_h^* KT}{h^2} \right]^{3/2} \exp \left(\frac{E_v - E_f}{KT} \right) \quad \dots\dots\dots (8)$$

- Let $$2 \left[\frac{2\pi m_h^* KT}{h^2} \right]^{3/2} = N_v$$

- Therefore $$p = N_v \exp \left(\frac{E_v - E_f}{KT} \right) \text{ also}$$

- $$N_a^- = N_a \exp \left(\frac{E_F - E_a}{KT} \right)$$

Extrinsic Semiconductor
Carrier concentration in p type semiconductors

- Equate the above equations i.e. $p = N_a^-$

- $N_v \exp\left(\dfrac{E_v - E_F}{KT}\right) = N_a \exp\left(\dfrac{E_F - E_a}{KT}\right)$

- Taking logarithm and rearranging

$$\left(\dfrac{E_F - E_a}{KT}\right) - \left(\dfrac{E_v - E_F}{KT}\right) = \ln\left(\dfrac{N_v}{N_a}\right)$$

- $-(E_v + E_a) + 2E_F = (KT)\ln\left(\dfrac{N_v}{N_a}\right)$

Extrinsic Semiconductor
Carrier concentration in p type semiconductors

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- $E_F = \left(\dfrac{E_v + E_a}{2}\right) + \left(\dfrac{KT}{2}\right) \ln\left(\dfrac{N_v}{N_a}\right)$

- $E_F = \left(\dfrac{E_v + E_a}{2}\right) - \left(\dfrac{KT}{2}\right) \ln\left(\dfrac{N_a}{N_v}\right)$ .... (12)

- At T = O K, $E_F = \left(\dfrac{E_v + E_a}{2}\right)$

Extrinsic Semiconductor
Carrier concentration in p type semiconductors

- Substitute the value of E_F from equation (12) in equation (8) and rearrange

- $p = (2\,N_a)^{1/2} \left(\dfrac{2\pi m_h^{*} KT}{h^2}\right)^{3/4} \exp\left(\dfrac{E_v - E_a}{2KT}\right)$ ...... (13)

- Hence the density of holes in the valence band is proportional to the square root of the acceptor concentration at low temperature. At higher temperature intrinsic behavior predominates and acceptor concentration becomes insignificant.

Variation of Fermi level with temperature

- With an increase of temperature E_F decreases slightly as per equation (12).

- As temperature increases Fermi level decreases since more acceptor atoms are ionized. At a particular temperature all the acceptor atoms are ionized.

- Further increase in temperature results in generation of electron – hole pairs due to breaking of covalent bonds. The material tends to behave in intrinsic manner.

Drift Current

- Under the condition of thermal equilibrium, the electrons and holes are uniformly distributed in a crystal and when no external field is applied current does not flow in the crystal.

- **Drift current**: When an electric field E is applied to a semiconductor, the charge carriers(electrons and holes) start to move and produce drift current.

Drift Current

- The electrons drifting in the conduction band produce a current component J_e given by

- J_e(drift) = $ne\mu_e E$, where μ_e is the mobility of electrons.

- The hole drifting in the valence band cause a current component J_h given by

- J_h(drift) = $pe\mu_h E$, where μ_h is the mobility of holes.

Drift Current

- The total drift current density is,

- J (drift) = J_e(drift) + J_h (drift)

-               = e (nμ_e+ pμ_h) **E**

- Although electrons and holes move in opposite directions, the direction of conventional current flow due to both the carriers is in the same direction.

Diffusion Current

- **Diffusion current**: In semiconductors, current can also flow without the application of external electric field. The charge carriers(electrons and holes) diffuse from regions of high concentration to regions of low concentration until the charge carriers are evenly distributed in the material. This motion of charge carriers produce a current component known as diffusion current.

Diffusion Current

- The current component due to electron diffusion is given by
- J_e(diff) = e D_e $\frac{dn}{dx}$
- The current component due to hole diffusion is given by
- J_h(diff) = - e D_h $\frac{dp}{dx}$
- D_e and D_h are diffusion coefficients for electrons and holes respectively
- The total diffusion current is $J = J_e$(diff) + J_h(diff)
- J = e D_e $\frac{dn}{dx}$ + (- e D_h $\frac{dp}{dx}$)

Drift and Diffusion Current

- The total current density due to drift and diffusion of electrons is

- $J_e = J_e(\text{drift}) + J_e(\text{diffusion})$

- $\quad\quad = e\left(n\mu_e \mathbf{E} + D_e \dfrac{dn}{dx}\right)$

- For holes

- $J_h = J_h(\text{drift}) + J_h(\text{diffusion})$

- $\quad\quad = e\left(p\mu_h \mathbf{E} - D_h \dfrac{dp}{dx}\right)$

pn Junction

- A p-n junction is formed when a p- type and n- type semiconductor are joined through the process of crystal growth. Within the semiconductor the region where there is a transition from p- type to n- type is called a junction.

- In p-type material holes are majority charge carriers and electrons are minority charge carriers.

- In n-type material electrons are majority charge carriers and holes are minority charge carriers.

pn Junction
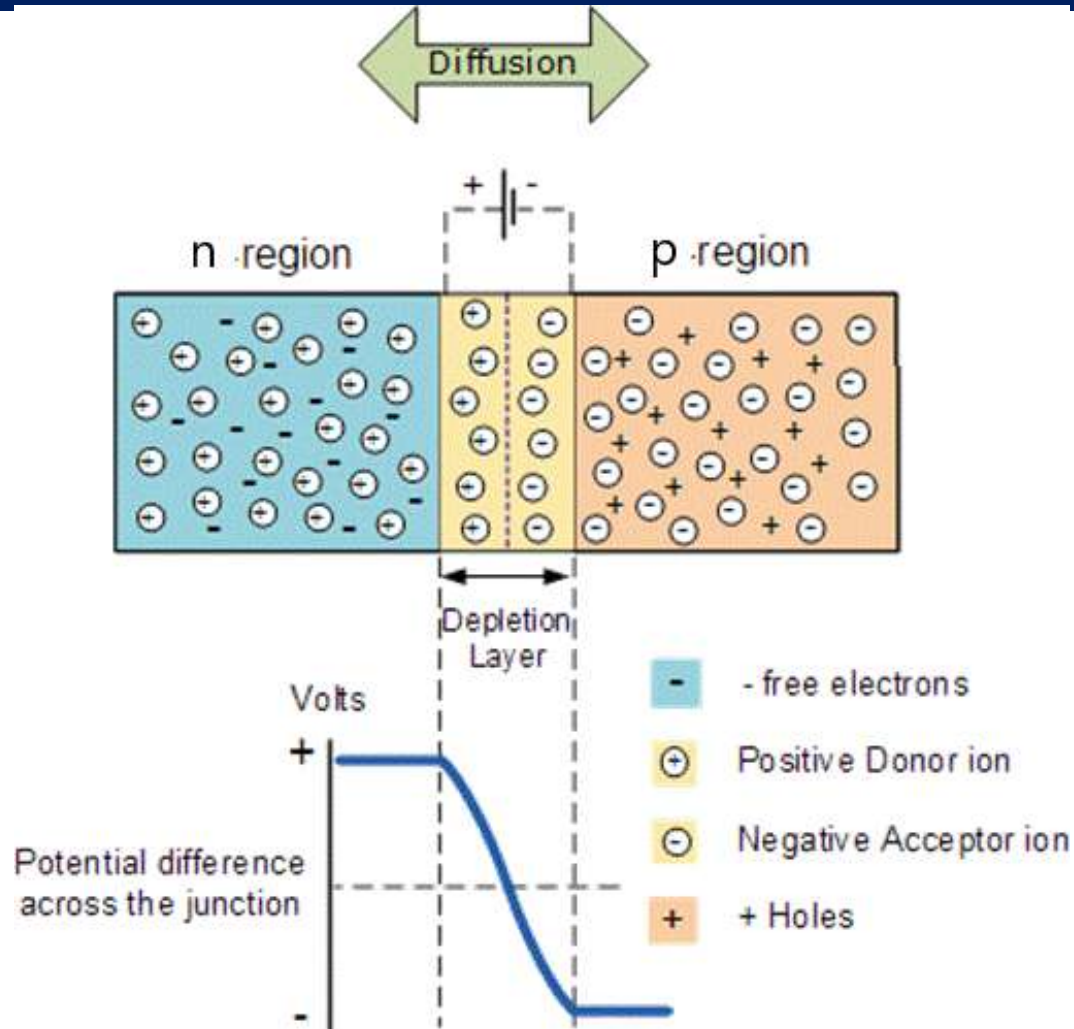
pn Junction

- At the junction, holes diffuse from p region to n region and likewise electrons diffuse from n region to p region. The electrons and holes recombine and disappear at the junction region.
- Around the junction region, free electrons and holes recombine and only immobile ions are present. This region is called space charge region. This region is also called depletion region.
- The fixed ions in the depletion region produce electric field, **E**. This electric field opposes the further diffusion of electrons and holes from n-type region to p-type region. The electric field gives rise to a potential called potential barrier.
- Further diffusion of electrons and holes across the potential barrier can only take place when they overcome the potential barrier.

Energy level diagram
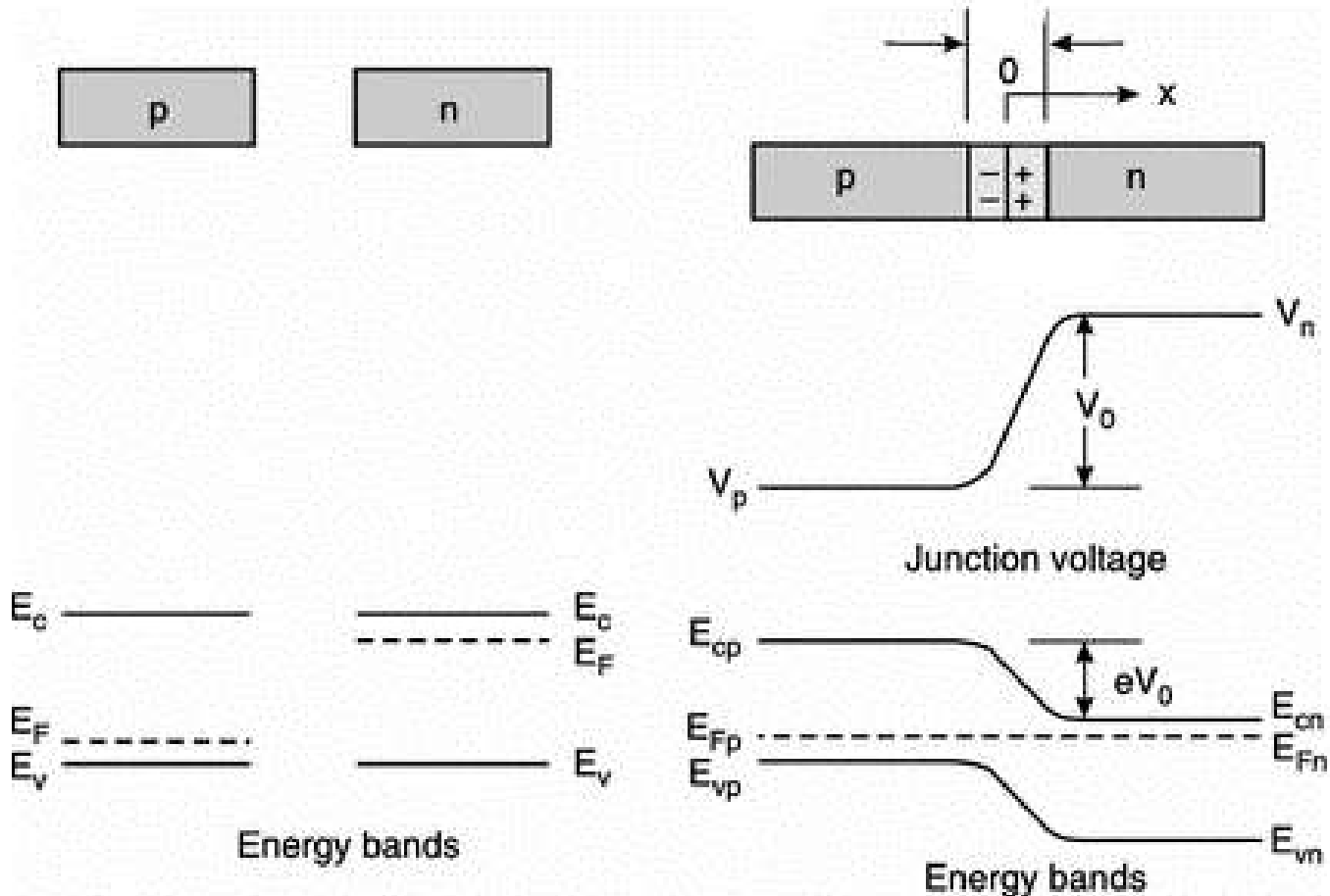
Energy level diagram

- $v_{o=}v_n - v_p$, where v_o is the contact potential or the barrier voltage.

- V_n is the potential of depletion region on n side.

- V_p is the potential of depletion region on p side.

- Under unbiased condition no net current flows and fermi level is common on n side and p side.

- The electric field is given by

- $E = E_{vp} - E_{vn} = E_{cp} - E_{cn} = e V_o$

Circuit symbol of p-n junction diode

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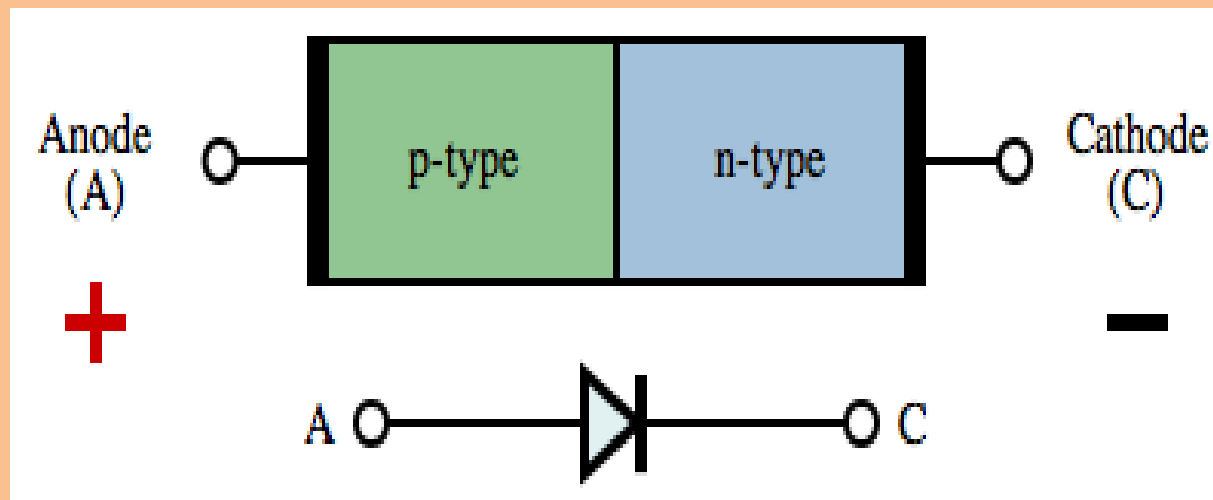
pn junction: I-V Characteristics

Equilibrium, forward bias, reverse bias
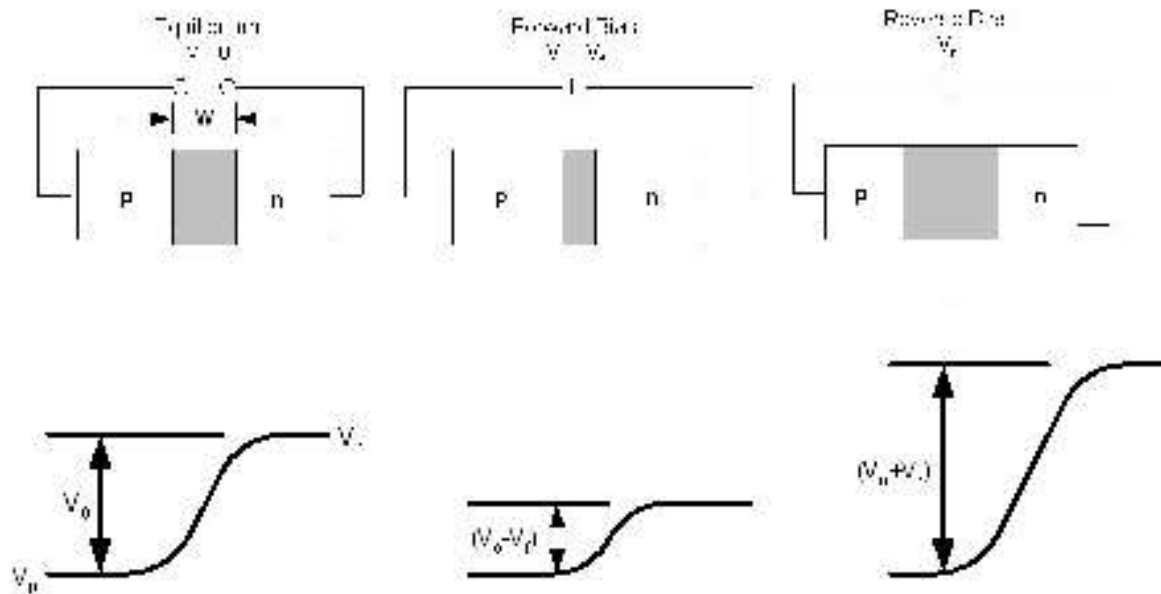
pn junction: I-V Characteristics

- **Unbiased circuit:**

  When the junction is not connected to any voltage source, it is said to be unbiased. Due to the presence of barrier potential across the junction, there is no flow of charge carriers and hence there is no current flow through the junction.

- **Forward biased circuit:**

  When the positive terminal of the source (battery) is connected to p region and negative terminal to n region, the junction is said to be forward biased.

- **Reverse biased circuit:**

  When the positive terminal of the source (battery) is connected to n region and negative terminal to p region, the junction is said to be reverse biased.

Pn Junction: Forward bias

- When a dc voltage, V_F is connected to the diode in such a way that the positive terminal of the source is connected to the p-region and the negative terminal to the n-region, then the junction is forward biased.

- The voltage across the junction decreases by an amount, V_O - V_F, where V_O is the barrier voltage.

- The majority charge carriers move across the junction and hence the width of the depletion region decreases.

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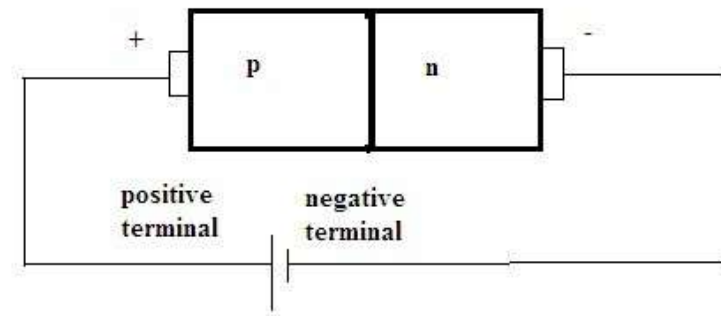
Pn Junction: Reverse bias

- When a dc voltage, V_R, is connected to the diode in such a way that the positive terminal of the source is connected to the n-region and the negative terminal to the p-region, then the junction is reverse biased.

- The voltage across the junction increases and is equal to, $V_O + V_R$, where V_O is the barrier voltage.

- The majority charge carriers are pushed away from the junction and hence the width of the depletion region increases.

- Minority charge carriers drift across the barrier and give rise to current.

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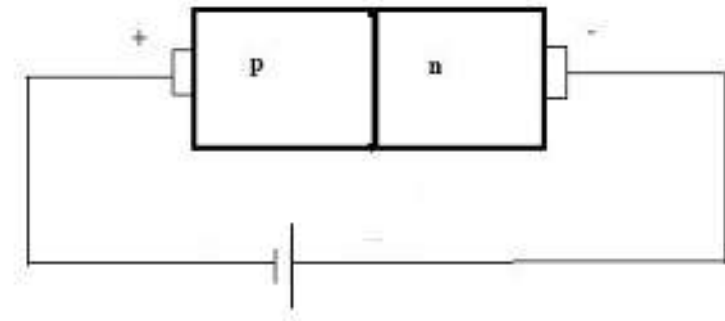
pn junction: I-V Characteristics

- A graph that shows the variation in current in a device with variation of voltage applied across it is called I-V Characteristics.

- The I-V Characteristics of a pn junction is non linear.

- The pn junction acts as a closed switch in forward bias condition allowing large current to flow through it, and acts as an open switch in reverse bias condition causing a very small amount of current to flow through it.

pn junction: I-V Characteristics
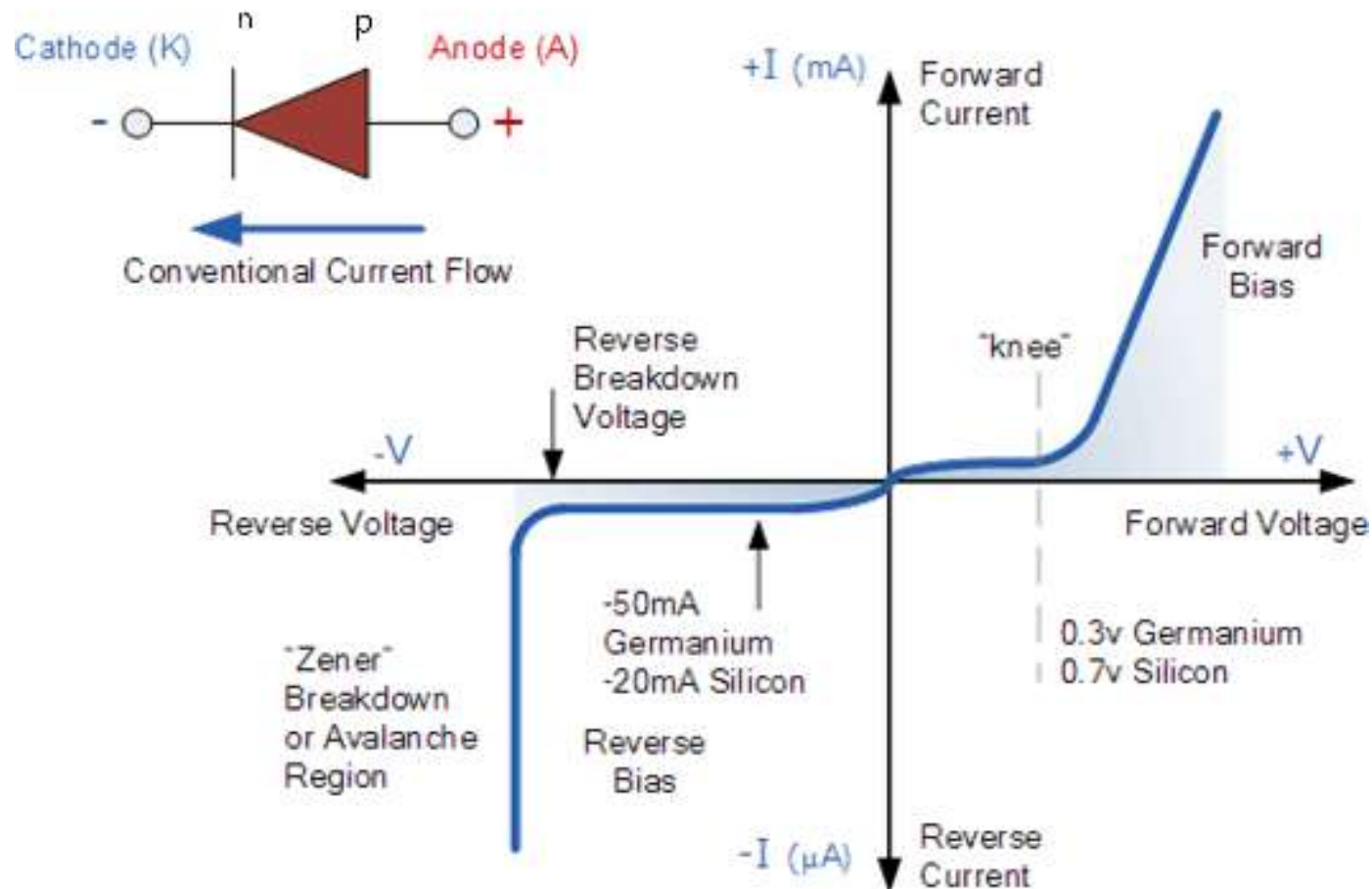
pn junction: I-V Characteristics

Forward bias:

- As long as the forward bias voltage is less than the voltage across the potential barrier, the current through the junction is negligibly small.

- The voltage at which the current increases sharply is called cut - in voltage or knee voltage.

- As the forward voltage increases beyond the potential barrier voltage, there is an exponential increase in forward current. The current is in mA.

- The knee voltage for germanium is 0.3 V and for silicon it is 0.7 V.

pn junction: I-V Characteristics
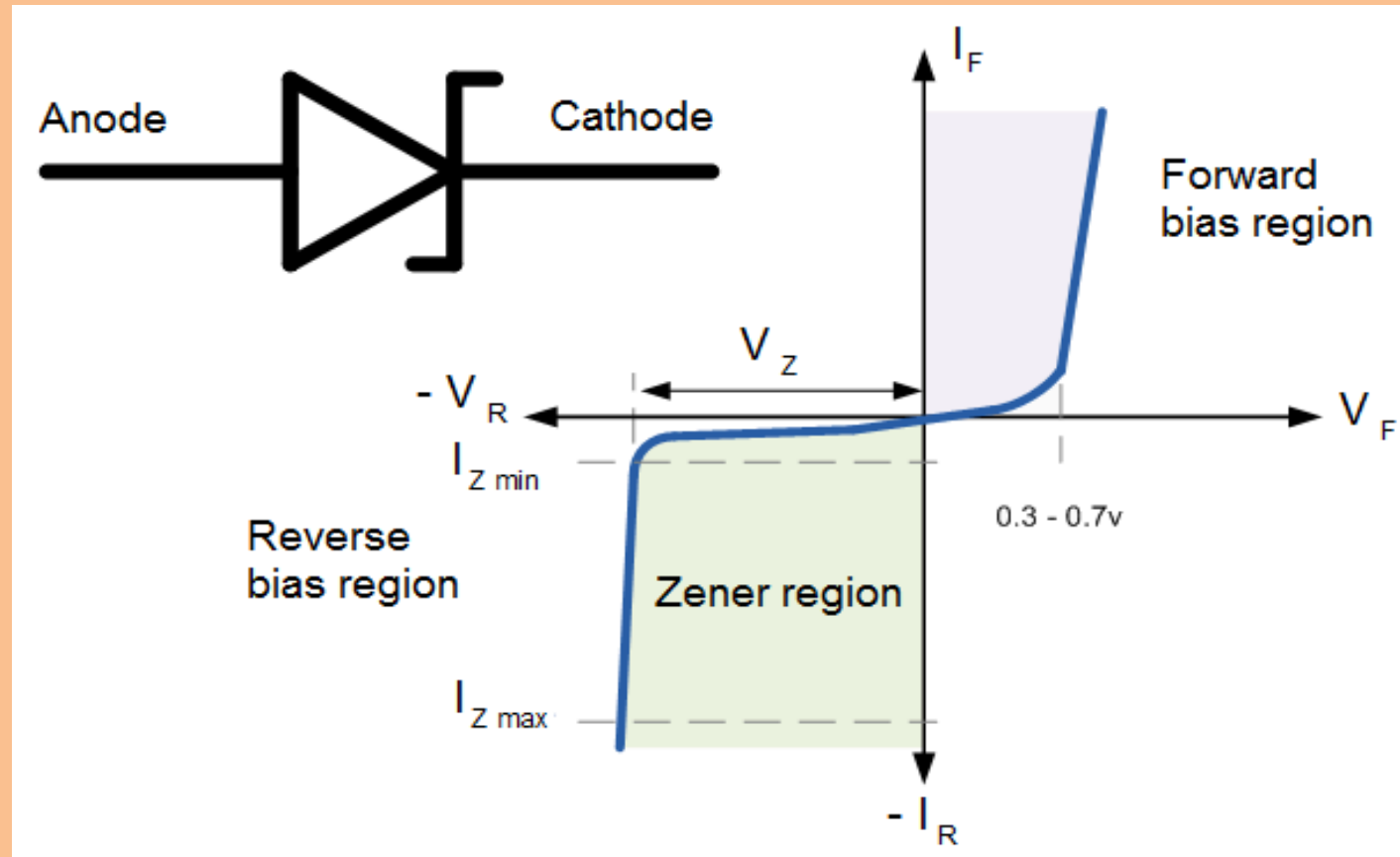
Reverse bias:

- Under reverse bias condition a small reverse current (in μ A) flows across the junction due to minority charge carriers.
- When the applied reverse voltage is high, it breaks the covalent bonds of the crystal and a large number of charge carriers are produced. Thus the current rises suddenly in the reverse direction. The reverse voltage at which the diode breaks down is called breakdown voltage or Zener voltage.
- The diode break down may be due to Avalanche break down or due to Zener break down.
- Avalanche break down occurs in diodes which are lightly doped.
- Zener break down occurs in diodes which are thin and heavily doped.

Zener diode: I-V Characteristics

- Zener diode is a semiconductor diode specially designed to operate in the breakdown region of the reverse bias. Zener diodes are always operated in the reverse bias condition. The breakdown phenomenon is reversible and harmless.

Anode ——▷|— Cathode

Zener diode: I-V Characteristics

Zener diode: I-V Characteristics

- Zener diode acts similar to a ordinary diode under forward bias condition.
- In reverse bias condition, as the reverse voltage is increased a small amount of current called leakage current flows. Leakage current is due to minority charge carriers.
- At a particular value of reverse voltage, the current increases suddenly. This voltage is called breakdown voltage or Zener voltage, V_z.
- In ordinary diodes the breakdown voltage is high and if reverse current is allowed to flow, then the diode will be damaged.
- Zener diodes are designed so that their Zener voltage is much lower, about 2.4 volts.

Zener diode: I-V Characteristics

- When a reverse voltage above the Zener voltage is applied to a Zener diode, there is a controlled breakdown which does not damage the diode.

- In the Zener region the voltage across the Zener diode remains constant but the current changes depending on the supply voltage.

- The location of Zener region can be controlled by varying doping levels. An increase in doping will decrease the Zener potential.
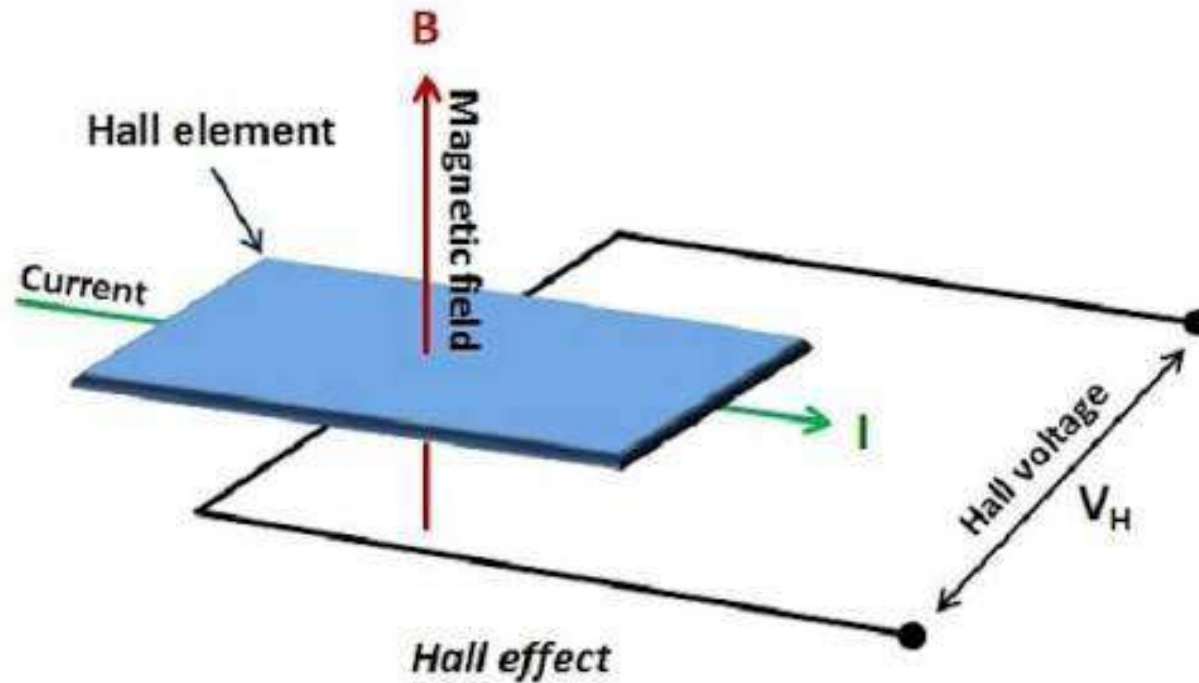
Hall Effect

- When a piece of conductor (metal or semiconductor) carrying current is placed in a transverse (perpendicular) magnetic field, an electric field is produced inside the conductor in a direction normal to both the current and the magnetic field. This phenomenon is known as Hall Effect and the generated voltage is known as Hall voltage.

Hall Effect

- If the material is a p type semiconductor, when electric and magnetic field is applied at right angle to each other, holes experience a force and are accumulated on one face of the material. This causes a potential difference and a voltage is developed called Hall voltage.

- If the material is a n type semiconductor, when electric and magnetic field are applied at right angle to each other, electrons experience a force and are accumulated on one face of the material. This causes a potential difference and a voltage is developed called Hall voltage.

Hall Effect

Hall effect

Hall Effect

- Consider a n type semiconductor in which electrons have a velocity "v" due to current flow. Let "B" be the applied magnetic field. The electrons experience a force of "Bev" due to the magnetic field.

- This causes the electron current to be deflected causing a negative charge to accumulate on one face of the semiconductor.

- A potential difference is established across the two faces of the material causing a field "E_H". This field gives rise to a force "e E_H" on the electrons.

Hall Effect

- At equilibrium
- $e\,E_H = Bev$
- $E_H = Bv$ …..(1)
- If J is the current density, then $J = nev$ where n is the number of charge carriers.
- $v = \dfrac{J}{ne}$ …….(2)
- Substitute the value of v from (2) in (1)
- $E_H = B\,\dfrac{J}{ne}$

Hall Effect

- The Hall effect is described by means of Hall coefficient, R_H

- $R_H = \dfrac{1}{ne}$

- $E_H = B\,\dfrac{J}{ne}$ or $E_H = B\,J\,R_H$

- $R_H = \dfrac{1}{ne} = \dfrac{E_H}{BJ}$

Hall Effect- Applications

- **Determination of the type of Semi-conductors:**

  The Hall coefficient R_H is negative for an n-type semiconductor and positive for p-type semiconductor. Thus the sign of Hall coefficient can be used to determine whether a given Semi-conductor is n-type or p-type.

- **Calculation of carrier concentration:**

$$R_H = -\frac{1}{ne} \quad \text{or} \quad n = \frac{1}{eR_H}(\text{number of electrons})$$

Hall Effect - Applications

- **Determination of Mobility:**

  If the conduction is due to electrons, then the conductivity is

  $$\sigma = ne\mu$$

  $$\mu = \frac{\sigma}{ne} = \sigma R_H$$

  $\mu = \sigma R_H$ where μ is the mobility of charge carriers.

- **Measurement of Magnetic Flux Density:**

  Hall Voltage is proportional to the magnetic flux density B for a given current I. so, Hall Effect can be used to measure magnetic flux density in metal.