BAPATLA ENGINEERING COLLEGE (AUTONOMOUS) BAPATLA

DEPARTMENT OF PHYSICS

22-23 August (Reg) Scheme (CSE,IT,EEE)

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I/IV B.Tech (Regular\Supplementary) DEGREE EXAMINATION

August, 2023 **Common to CS/EE/EI & IT Branches**

Second Semester **Semiconductor Physics &Nano materials**

Time: Three Hours **Maximum:** 70 Marks

Answer question 1 compulsory. **(14X1 = 14Marks)**
Answer one question from each unit. **(4X14=56 Marks)**

			CO	BL	1M
1	a)	Fermi energy is the energy of the highest filled state at -------------temperature.	CO1	L4	1M
	b)	Write any two failures of free electron theory.	CO1	L1	1M
	c)	What do you mean by hole?	CO1	L1	1M
	d)	The mobile charge carriers in a semiconductor are ---------------------.	CO2	L1	1M
	e)	In an intrinsic semiconductor, the number of electrons in conduction band and holes in valance band are equal. True/false	CO2	L4	1M
	f)	Write the expression for continuity equation.	CO2	L1	1M
	g)	Mention any two applications of photo diode.	CO3	L3	1M
	h)	LED emits light under -------------- bias condition.	CO3	L1	1M
	i)	Define Faraday effect.	CO3	L1	1M
	j)	In nanomaterials, with decrease of particle size the number of atoms at the surface ----------------.	CO4	L4	1M
	k)	Mention any two applications of carbon nanotubes.	CO4	L3	1M
	l)	What are nanomaterials?	CO4	L1	1M
	m)	What do you mean by dark current in APD.	CO3	L2	1M
	n)	State Bragg’s law.	CO4	L1	1M
		<u>Unit-I</u>			
2	a)	Distinguish between direct and indirect band gap materials.	CO1	L1	4M
	b)	Explain energy bands in solids by using kronig-penny model and classify the types of electronic materials based on band theory of solids.	CO1	L2	10M
		(OR)			
3	a)	What is density of states? Obtain an expression for density of states.	CO1	L1	7M
	b)	What do you mean by effective mass of an electron? Obtain an expression for effective mass of an electron.	CO1	L2	7M
		<u>Unit-II</u>			
4	a)	What are semiconductors? Distinguish between n-type and p-type semiconductors.	CO2	L1	7M
	b)	Obtain an expression for concentration of electrons in an intrinsic semiconductor.	CO2	L3	7M
		(OR)			
5	a)	Discuss the p-n junction diode in detail.	CO2	L2	8M
	b)	State and obtain the expressions for drift and diffusion currents.	CO2	L1	6M
		<u>Unit-III</u>			
6	a)	Distinguish between LED and LCD.	CO3	L1	6M
	b)	Explain the principle, construction and working of solar cell.	CO3	L1	8M
		(OR)1			
7	a)	Explain the principle, construction and working of PIN diode.	CO3	L2	8M

	b)	Calculate the wavelength of radiation emitted by an LED made up of a semiconducting material with a band gap energy 2.8 eV. Identify the colour of the light emitted from LED.	CO3	L3	6M
		Unit-IV			
8	a)	Discuss about quantum confinement effect and surface area to volume ratio in nanomaterials. Write the important properties of nanomaterials.	CO4	L2	6M
	b)	Explain in detail the synthesis of nanomaterials by Sol-Gel method.	CO4	L4	8M
		(OR)			
9	a)	Illustrate the important applications of nanomaterials in different fields of science and technology.	CO4	L1	7M
	b)	Describe the construction and working of scanning electron microscope (SEM).	CO4	L3	7M

I. a) Fermi energy is the energy of the highest filled state at **0K** temperature.

b) Write any two failures of free electron theory.
Two failures from classical or quantum theories

c) What do you mean by hole?

Absence or vacancy created by electron in valance band.

d) The mobile charge carriers in a semiconductor are **electrons and holes**.

e) In an intrinsic semiconductor, the number of electrons in

conduction band and holes in valance band are equal. True/false – **True**

f) Write the expression for continuity equation.

$$\boxed{\frac{\partial(\Delta n)}{\partial t} = -\frac{\Delta n}{\tau_n} + D_n\frac{\partial^2(\Delta n)}{\partial x^2} - \mu_n E\left[\frac{\partial(\Delta n)}{\partial x}\right]}$$

g) Mention any two applications of photo diode.

Any **two applications**

h) LED emits light under **Forward bias** condition.

i) Define Faraday effect.

Optically inactive substances acquire the ability of rotating the plane of polarisation of light when they are subjected to a magnetic field, parallel to propagation direction.

j) In nanomaterials, with decrease of particle size the number of atoms at the surface **Increases**

k) Mention any two applications of carbon nanotubes.

Any **two applications**

l) What are nanomaterials?

The solid materials whose physical size is in the range of 1 to 100nm.

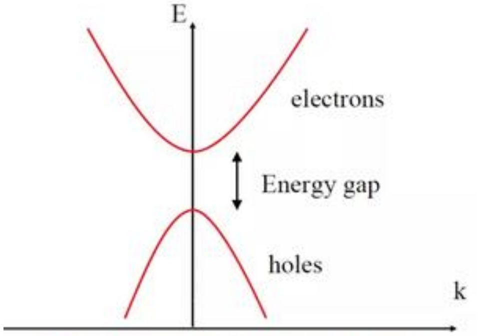
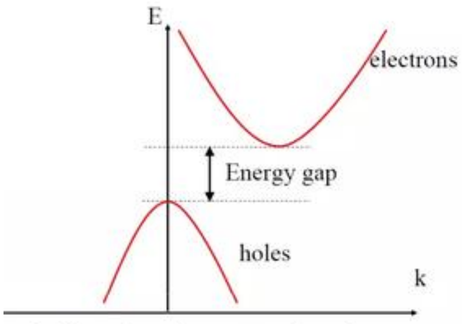
m) What do you mean by dark current in APD.

Current generated in a reverse biased p-n junction in the absence of light

n) State Bragg's law.

$n\lambda = 2d \sin\theta$

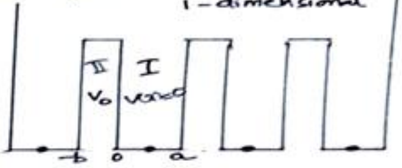
2. a. Distinguish between direct and indirect band gap materials - 4m
Any 4 differences

Direct bandgap materials	Indirect bandgap materials
 Direct bandgap semiconductors	 Indirect bandgap semiconductors
The materials for which maximum of valence band and minimum of conduction band lie at same value of k are called direct band gap materials.	The materials for which maximum of valence band and minimum of conduction band does not occur at same value of k are called indirect band gap materials.
Here there will be direct transitions	Here there will be Indirect transitions
By recombination we get light energy	By recombination we get heat energy
These are used to make opto-electronic devices like LED, laser diode etc.	These are used for making diodes, transistors etc.
Ex: GaAs,InP,GaInP	Si,Ge

b) Explain energy bands in solids by using kronig-penny model and classify the types of electronic materials based on band theory of solids – 10m
kronig-penny model (9m = explanation-5m, diagram-1m, two cases-3m) + 1 difference based on energy band diagram for three materials-1m

KRÖNIG-PENNY MODEL:-

The solution of Schrödinger wave equation for a varying periodic potential (Sinusoidal) is not easily obtained. To overcome this problem, instead of assuming a sinusoidal potential, it is assumed that the electron moves in a rectangular potential. This model was given by Kronig-Penny. The variation of potential of electron while it is moving through ion core is as shown in figure.



This modal contains only two regions I & II.

For region I, $V(x) = 0$ $(0<x<a)$

For region II, $V(x) = V_0$ $(-b<x<0)$ Where $V(x)$ is potential.

The time independent Schrödinger wave equations for the two regions is given as

$$\frac{d^2\psi}{dx^2} + \frac{8\pi^2 m}{h^2} E\,\psi = 0 \text{ ------------------------(1) for } 0<x<a$$

& $$\frac{d^2\psi}{dx^2} + \frac{8\pi^2 m}{h^2} (E - V_0)\,\psi = 0 \text{ --------------------(2) for } -b<x<0$$

By assuming total energy, E is less than potential energy V_0, define two quantities $\alpha^2 and\ \beta^2$ such that

$$\alpha^2 = \frac{8\pi^2 mE}{h^2} \rightarrow E = \frac{\alpha^2 h^2}{8\pi^2 m} \text{ --------------- (3)}$$

$$\beta^2 = \frac{8\pi^2 m(V_0 - E)}{h^2} \text{ --------------- (4)}$$

Sub. (3) & (4) in (1) & (2)

$$\rightarrow \quad \frac{d^2\psi}{dx^2} + \alpha^2\psi = 0 \text{ --------------- (5)}$$

$$\rightarrow \quad \frac{d^2\psi}{dx^2} - \beta^2\psi = 0 \text{ --------------- (6)}$$

Using Bloch theorem, the solution of above two equations is given by

$$\psi(x) = U_k(x)e^{ikx}, \text{ where } U_k(x) = U_k(x+a). \text{ ---------------- (7)}$$

By differentiating equation (7) twice and by substituting the values of $\frac{d^2\psi}{dx^2}$ and ψ in (5) & (6), two independent second order linear differential equations are obtained. By applying boundary conditions to the solutions of two equations, we will get four linear equations in A, B, C, D. The solution for these equations can be obtained only when the determinant of the coefficients of A, B, C, D Vanishes.

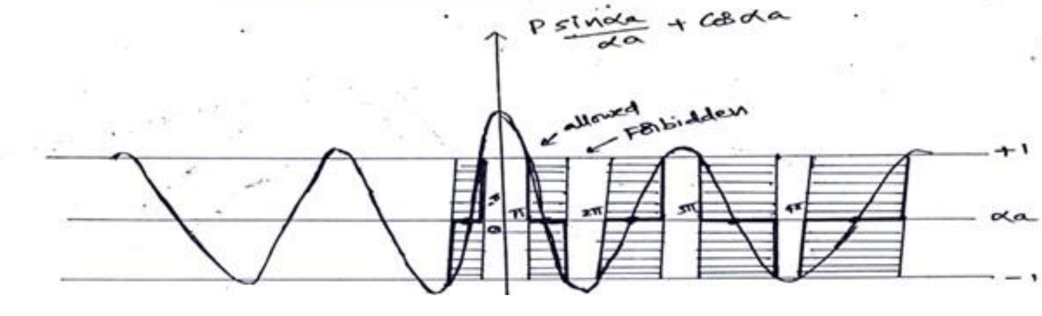
On solving the determinant, we will get a condition

$$\frac{P\sin\alpha a}{\alpha a} + \cos\alpha a = \cos ka \text{ ------------------(8)}$$

Where $P = \frac{mV_0 ab}{h^2}$ is known as scattering power of potential barrier. With increase in potential, V_0, scattering power 'P' also increases.

'V_0 b' is known as barrier strength. And $K = \frac{2\pi}{\lambda}$ is propagation constant.

From equation (8) it is clear that L.H.S values are limited by the R.H.S values. Since cos ka is bounded between ± 1, hence only certain ranges of values of α are allowed. If we plot the left hand side of this equation against α a, it will be possible to determine those allowed values. The remaining energy values which are not allowed are known as forbidden energy values. The plot is as shown in fig.



From the above fig. the following conclusions may be drawn.

(1). The motion of electrons in a periodic lattice is characterized by the bands of allowed energy and forbidden energy.

(2). As the value of α a (energy) increases, the width of allowed energy bands increases and width of forbidden bands decreases.

(3). With increasing P, i.e., with increase in potential barrier the width of an allowed band decreases. As $P \rightarrow \alpha$, the allowed energy band becomes narrow and the energy spectrum is a line spectrum.

If $P \rightarrow \infty \Rightarrow \sin \alpha a = 0$ [from (8)]

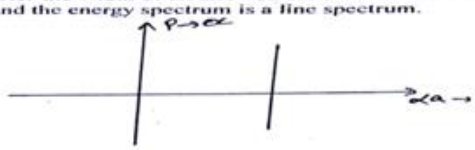
$$\Rightarrow \alpha a = \pm n\pi$$

$$\Rightarrow \alpha^2 = \frac{n^2\pi^2}{a^2}$$

But $\alpha^2 = \frac{8\pi^2 mE}{h^2}$ [from (3)]

$$\therefore \frac{n^2\pi^2}{a^2} = \frac{8\pi^2 mE}{h^2}$$

$$\Rightarrow E = \frac{n^2h^2}{8ma^2} \quad \text{------------ (9)}$$



The line spectrum is shown in figure. This equation (9) shows that energy levels are discrete and are separated by forbidden regions.

(4). When $P \rightarrow 0$, then $\cos \alpha a = \cos ka$

$$\Rightarrow \alpha = k$$

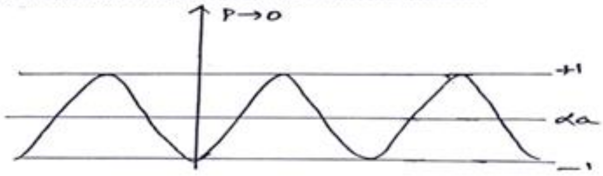
$$\Rightarrow \alpha^2 = k^2$$

$$\Rightarrow \text{But } \alpha^2 = \frac{8\pi^2 mE}{h^2} \text{ and } k^2 = \left(\frac{2\pi}{\lambda}\right)$$

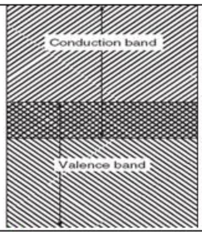
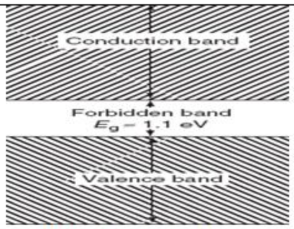
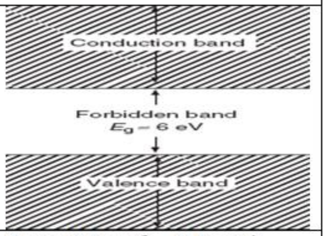
$$\Rightarrow \frac{8\pi^2 mE}{h^2} = \left(\frac{2\pi}{\lambda}\right)^2$$

$$\Rightarrow E = \left(\frac{h^2}{2m}\right)\left(\frac{m^2v^2}{h^2}\right) \qquad \left[\because \lambda = \frac{h}{mv}\right]$$

$$E = \tfrac{1}{2} mv^2$$



Hence we get only K.E, which means that the electrons are completely free. From the energy spectrum diagram it is clear that all energy levels are allowed and no forbidden energy levels exist. This concerns for the case of metals.

characteristic Property	**Metal**	**semiconductor**	**Insulator**
1. Band			
2. Forbidden energy gap	No FEG	small FEG of ~1 eV	Large FEG of ~ 6eV and more

3.a. What is density of states? Obtain an expression for density of states – 7m

Definition -1, diagram-1, explanation-5

Density of Energy States

The *density of states* is given by the number of available electron states per unit volume per unit energy range at a certain energy level, *E*.

$$\therefore \qquad Z(E)dE = \frac{N(E)\,dE}{L^3} = \frac{4\pi}{h^3}(2m)^{3/2} E^{1/2} dE$$

Z(*E*) is called the **density of states function**.

Number of Energy States : Let us consider a specimen of a metal. For the sake of simplicity, we consider it to have the shape of a cube with the side *a*. We assume that the free electrons travel absolutely freely within the volume of the specimen.

The quantized value of energy is given by $E = \frac{h^2(n_x^2+n_y^2+n_z^2)}{8ma^2}$

the energy of an electron is determined by the sum of the squares of the quantum numbers n_x^2, n_y^2, n_z^2. We get the same value for energy for several different combinations of these three quantum numbers.

Corresponding to each set we can find a specific energy state (or energy level) E. Quantum number space is an imaginary space where the values of quantum numbers are denoted along the three axes respectively.

In this space, a radius vector n may be drawn from the origin of the coordinate system to a point (nx, ny, nz) where $n^2 = n_x^2 + n_y^2 + n_z^2$

It is easy to see that all points on the surface of a sphere of radius n will correspond to the same energy. All points within the sphere represent quantum states with energies smaller than E.

Number of energy states within a sphere of radius n = Volume of the sphere $= \frac{4\pi}{3} n^3$

Since the quantum numbers can have only positive integer values, the n-values can only be defined in the positive octant of the sphere.

Therefore, the number of quantum states with energy equal to or smaller than E is proportional to the first octant of the sphere.

Number of energy states within one octant of the sphere of radius $n = \frac{1}{8} X \frac{4\pi}{3} n^3$

Similarly, the number of energy states within one octant of a sphere of radius $(n + dn)$ corresponding to energy $(E + dE) = \frac{1}{8} X \frac{4\pi}{3} (n + dn)^3$

The number of energy states having energy values between E and $(E + dE)$ is given by

$N(E)\, dE = \frac{1}{8} X \frac{4\pi}{3} (n + dn)^3 - \frac{1}{8} X \frac{4\pi}{3} n^3$

Terms corresponding to higher powers of dn are negligibly small and are hence neglected.

$N(E) dE = \frac{\pi}{2} n^2\, dn$

By substituting n and involving pouli's exclusion principle, we finally get

Number of energy states $N(E)dE = \frac{4\pi}{h^3} \left(2m^{\frac{3}{2}}\right) a^3 E^{\frac{1}{2}}\, dE$

And density of states $Z(E)dE = N(E)dE/a^3 = \frac{4\pi}{h^3} \left(2m^{\frac{3}{2}}\right) E^{\frac{1}{2}}\, dE$

3.b. What do you mean by effective mass of an electron? Obtain an expression for effective mass of an electron.

Definition-1m, diagram -1m, derivation-5m

Effective mass of an electron:-

"When an electron in a periodic of lattice is accelerated by an electric field or magnetic field, then the mass of the electron is called effective mass, m^*"

According to quantum theory, an electron moving with a velocity, 'v' can be treated as a wave packet moving with the group velocity, v_g

$$v = v_g = \frac{d\omega}{dk} \qquad \text{-------- (!)}$$

where 'ω' is angular frequency = $2\pi\nu$, 'k' is propagation vector $= \frac{2\pi}{\lambda}$

We have energy of an electron, $E = h\nu = \hbar\omega$ -------- (2)

where $\hbar = h/2\pi$ and $\omega = 2\pi\nu$

$$\text{From (2)} \quad \frac{dE}{dk} = \hbar \frac{d\omega}{dk} \Rightarrow \frac{d\omega}{dk} = \frac{1}{\hbar}\frac{dE}{dk} \qquad \text{-------- (3)}$$

$$\text{From (1) \& (3)} \quad v_g = \frac{1}{\hbar}\frac{dE}{dk} \qquad \text{-------- (4)}$$

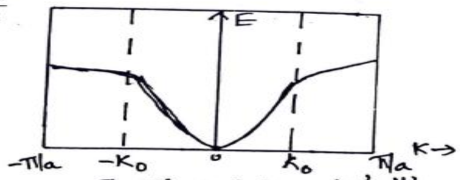
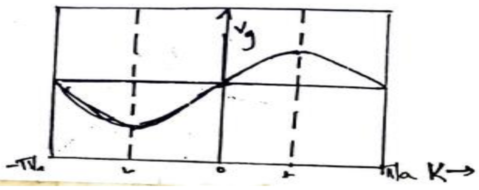


Fig (a) Variation of 'E' Vs 'K'



From E-K relations, the variation of E versus K for the region $-\pi/a$ to π/a is shown in fig.(a). Using this plot we can predict that 'E' varies directly with 'k' up to point of inflection 'K_0' and after that E does not vary with K directly and energy becomes constant. Form (4) we can calculate velocity using E-K variation graph.

The variation of 'v' with K shows that for K = 0, v = 0. As K increases v increases upto inflection point, K_0 and beyond K_0, v decreases and v = 0 at π/a

the negative values of 'K' exhibit same nature.

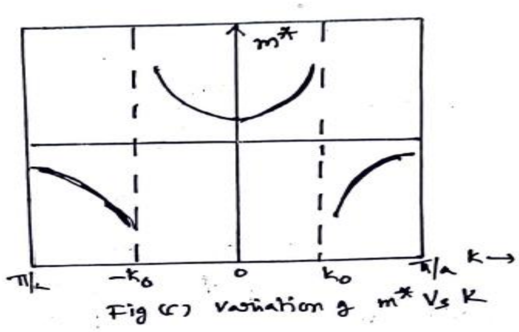


Fig (c) Variation of m^* Vs K

Variation of m* with K:-

From (4) acceleration, $a = \frac{d}{dt} V_g$

$$= \frac{d}{dt}\left(\frac{1}{\hbar}\frac{dE}{dK}\right)$$

$$= \frac{d}{dt}\left(\frac{1}{\hbar}\frac{dE}{dK}\cdot\frac{dK}{dK}\right)$$

$$a = \frac{1}{\hbar}\left(\frac{d^2E}{dK^2}\cdot\frac{dK}{dt}\right) \text{------------(5)}$$

we have momentum, $p = \hbar k$ with $\hbar = \frac{h}{2\pi}$ & $K = \frac{2\pi}{\lambda}$

$$\frac{dP}{dt} = \hbar\frac{dk}{dt} \qquad \left[\because \frac{dP}{dt} = \frac{d(mv)}{dt} = ma = F\right]$$

$$\frac{dk}{dt} = \frac{F}{\hbar} \text{------------(6)}$$

$$\therefore \text{From (5) \& (6) } a = \frac{1}{\hbar}\left(\frac{d^2E}{dK^2}\cdot\frac{F}{\hbar}\right)$$

$$\Rightarrow F = \left[\frac{\hbar^2}{d^2E/dk^2}\right].a \text{------------(7)}$$

But force, F = effective mass(m^*) × acceleration (a)

$$\therefore \text{From (7) } m^* = \left[\frac{\hbar^2}{(d^2E/dk^2)}\right]$$

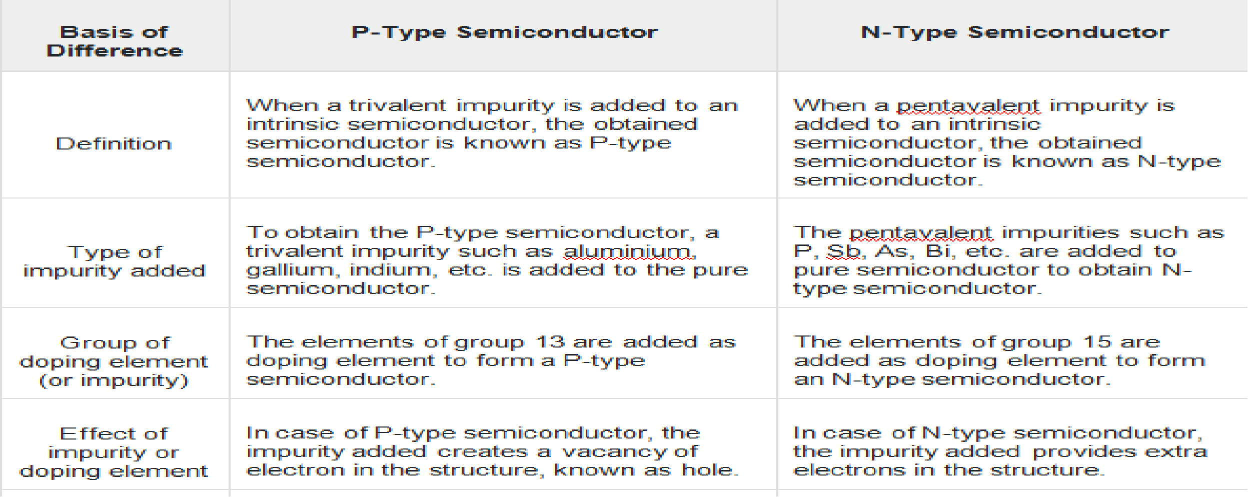
Fig.(c) shows the variation of m^* with k. near k = 0, the effective mass approaches m. as the value of 'k' increases m^* increases up to inflection point above the point of inflection m^* is negative with respect to k. As k tends to $\frac{\pi}{a}$, m^* decreases to a small negative value.

4.a. What are semiconductors? Distinguish between n-type and p-type semiconductors.-7m

Definition-1m, any five differences-6m

Semiconductors are defined as substances whose conductivity lies between that of an insulator and a conductor.

example- Si,Ge,GaAS



Basis of Difference	P-Type Semiconductor	N-Type Semiconductor
Definition	When a trivalent impurity is added to an intrinsic semiconductor, the obtained semiconductor is known as P-type semiconductor.	When a pentavalent impurity is added to an intrinsic semiconductor, the obtained semiconductor is known as N-type semiconductor.
Type of impurity added	To obtain the P-type semiconductor, a trivalent impurity such as aluminium, gallium, indium, etc. is added to the pure semiconductor.	The pentavalent impurities such as P, Sb, As, Bi, etc. are added to pure semiconductor to obtain N-type semiconductor.
Group of doping element (or impurity)	The elements of group 13 are added as doping element to form a P-type semiconductor.	The elements of group 15 are added as doping element to form an N-type semiconductor.
Effect of impurity or doping element	In case of P-type semiconductor, the impurity added creates a vacancy of electron in the structure, known as hole.	In case of N-type semiconductor, the impurity added provides extra electrons in the structure.

Energy levels	P-type semiconductor has acceptor energy levels very close to the valance band and away from the conduction band.	N-type semiconductor has donor energy levels very close to the conduction band and away from the valance band.
Effect of temperature rise	When the temperature of P-type semiconductor is increased, it can easily accept an electron from valance band to acceptor energy level.	When the temperature of N-type semiconductor is increased, it can easily donate an electron from donor energy level to the conduction band.
Conductivity	In P-type semiconductors, the conductivity is due to the presence of holes.	The conductivity in the N-type semiconductor is due to the presence of electrons.
Fermi level	In a P-type semiconductor, the fermi level lies between the acceptor energy level and the valance band.	In an N-type semiconductor, the fermi level lies between the donor energy level and the conduction band.

4.b. Obtain an expression for concentration of electrons in an intrinsic semiconductor.-7m

Calculation of density of electrons

Let dn be the number of electrons available between energy interval Ë and E + dE in the conduction band.

dn = Z(E) F(E) dE

where $Z(E)\,dE$ is the density of states in the energy interval E and $E + dE$ and $F(E)$ is the electron occupancy probability i.e. the probability that a state of energy E is occupied by an electron. If E_c is the energy corresponding to the bottom of the conduction band, to calculate the number of electrons in the conduction band the above equation (9.1) has to be integrated from E_c to the energy corresponding to the top of the conduction band,

$$\text{i.e,} \qquad n = \int_{E_c}^{\infty} Z(E)\, F(E)\, dE$$

We know that the density of states i.e., the number of energy states per unit volume within the energy interval E and $E + dE$ is given by

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

Since the electron is moving in periodic potential, and E starts from bottom of conduction band E_c the above equation becomes

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

Probability of an electron occupying an energy state E is given by

$$F(E) = \frac{1}{1 + \exp\left(\frac{E-E_F}{kT}\right)}$$

$$F(E) = \left[1 + \exp\left(\frac{E - E_F}{kT}\right)\right]^{-1}$$

For all possible temperatures

$$E - E_F \gg kT$$

Hence $F(E) = \exp -\left(\frac{E - E_F}{kT}\right) = \exp\left(\frac{E_F - E}{kT}\right)$

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

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

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

To solve this integral, let us put

$E - E_c = x$

$\therefore \quad E = E_c + x$

$dE = dx$

$$\therefore \quad n = \frac{4\pi}{h^3}(2m_e^*)^{3/2}\exp\left(\frac{E_F}{kT}\right)\int_0^{\infty}x^{1/2}\exp -\frac{(E_c + x)}{kT}dx$$

Using gamma function it can be shown that

$$\int_0^{\infty}x^{1/2}\exp\left(\frac{-x}{kT}\right)\,dx = (kT)^{3/2}\frac{\pi^{1/2}}{2}$$

Hence

$$n = \frac{4\pi}{h^3}(2m_e^*)^{3/2}\left(\exp\frac{E_F - E_c}{kT}\right)(kT)^{3/2}\frac{\pi^{1/2}}{2}$$

i.e., The number of electrons per unit volume of the material is given by,

$$n = 2\left(\frac{2\pi m_e^* kT}{h^2}\right)^{3/2}\exp\left(\frac{E_F - E_c}{kT}\right)$$

5.a. Discuss the p-n junction diode in detail.-8m

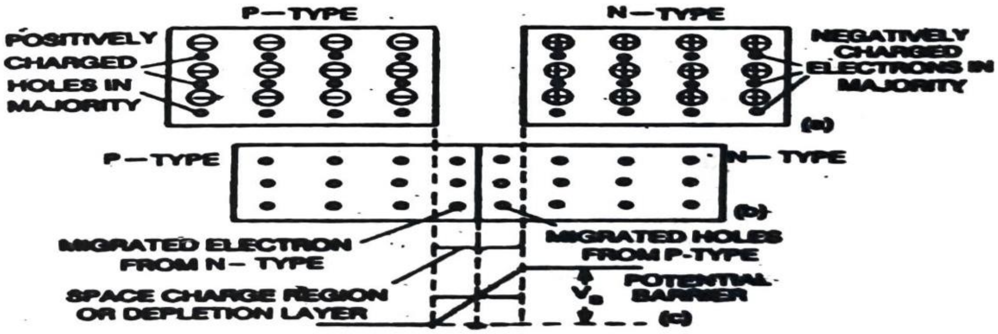
Construction – 2m, Forward and reverse bias with graph – 6m

P-N JUNCTION DIODE

This is a two terminal device consisting of a *P-N* junction formed either in Ge or Si crystal.

a *P-N* junction is formed from a piece of semi-conductor (say germanium) by diffusing *P*-type material to one half side and *N*-type material to other half side.

P-type semi-conductor has negative acceptor ions (shown by encircled minus sign) and positively charged free holes which move about on *P* side. Similarly, *N*-type semi -conductor has positively donor ions (shown by encircled positive sign) and negatively charged free electrons which move about *N*-side.



(a) P-type and N-type semiconductor (not joined)
(b) P-N junction (after joining). (c) potential barrier
Fig. (12).

Now let us consider that the two pieces are joined together as shown in fig. (12b). As *P*-type material has high concentration of holes and *N*-type material has high concentration of free electrons and hence there is a tendency of holes to diffuse over to *N*-side and electrons to *P*-side. The process is known as diffusion. So due to diffusion, some of the holes from *P*-side cross over to *N*-side where they combine with electrons and become neutral. Similarly, some of the electrons from *N*-side cross over to *P*-side where they combine with holes and become

(1) **Forward bias.** *When an external voltage is applied to P-N junction in such a direction that it cancels the potential barrier and permits the current flow is called as forward bias.* To apply a forward bias, the positive terminal of a battery is connected to *P*-type semi-conductor while the negative terminal is connected to *N*-type semi-conductor

(i) **Forward bias.** For the forward bias of a *P-N* junction, *P*-type is connected to the positive terminal while the *N*-type is connected to the negative terminal of a battery. The potential at *P-N* junction can be varied with the help of potential divider. At some forward voltage (0·3 V for Ge and 0·7 V for Si) the potential barrier is altogether eliminated and current starts flowing. This voltage is known as threshold voltage (V_{th}) or cut-in voltage or knee voltage. It is practically same as barrier voltage V_B. For $V < V_{th}$, the current flow is negligible. As the forward applied voltage increases beyond threshold voltage, the forward current rises exponentially as shown in fig. (18). It should be remembered that if the forward voltage is increased beyond a certain safe value, it produces an extremely large current which may destroy the junction due to overheating.

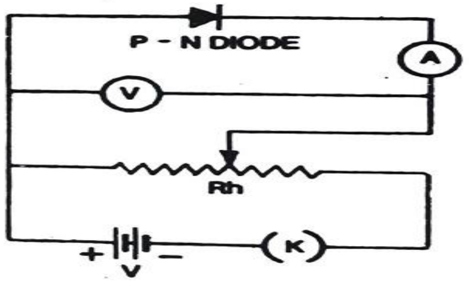


Fig. (17). Circuit arrangement.

(2) **Reverse bias.** *When an external voltage is applied to P-N junction in such a direction that it increases the potential barrier then it is called as reverse bias.* For reverse bias, the positive terminal of the battery is connected to *N*-type semi-conductor and negative terminal to *P*-type

(ii) **Reverse bias.** For the reverse bias of *P-N* junction *P*-type is connected to the negative terminal while *N*-type is connected to the positive terminal of a battery. The reverse potential at *P-N* junction can be varied with the help of potential divider. In this case the junction resistance becomes very high and practically no current flows through the circuit. However, in practice, a small current of the order μ A flows in the circuit due to minority carriers. This is known as reverse current. The reverse current is shown in fig. . As the reverse voltage is increased

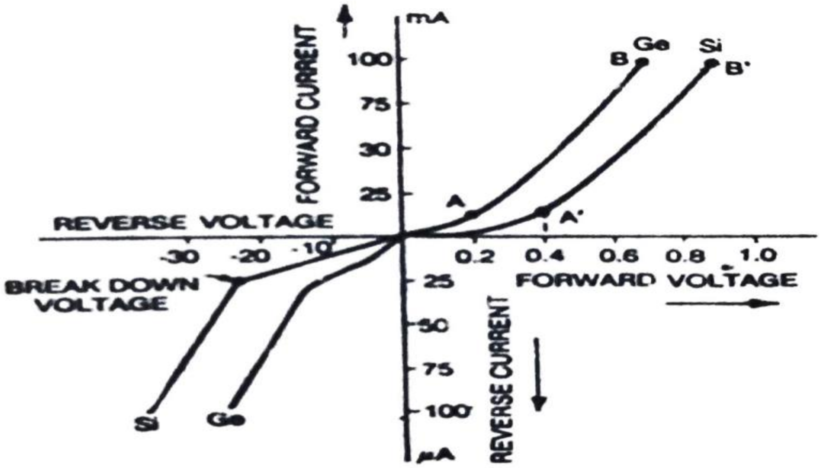


Fig. (18). Volt-Ampere characteristics of *P-N* junction.

from zero, the reverse current quickly rises to its maximum or saturation reverse voltage is further increased, the kinetic energy of electrons (Minority carriers) become so high that they knock out electrons from the semiconductor atoms. At this stage *breakdown of junction* occurs and their is a sudden rise of reverse current. Now the junction is destoryed permanently.

5.b. State and obtain the expressions for drift and diffusion currents.-6m

Drift and Diffusion currents-3+3=6M

State and obtain the expressions for drift and diffusion currents. CO2

Drift and Diffusion currents-3+3=6M

Drift:

In a material (metal or semiconductor), in the absence of electric field, the random motion of electrons results in net charge to be zero. This is because charge movement in one direction is balanced by charge movement in other direction. But when an external field is applied, each charge carrier experiences a force such that all the charge carriers move in one direction. This net movement of charge carriers is known as drift. Therefore the electric current density is given by

$$J = (ne)v_d \text{ -------------------(1)}$$

Where 'ne' is the total charge and v_d is drift velocity

We have Ohm's law in terms of conductivity σ and current density J is given by $J = \sigma E$ -----------------(2)

We have mobility $\mu = \frac{v_d}{E} \rightarrow v_d = \mu E$ ------------------------------(3)

From (1) & (3) we can write $J = ne\mu E$ --------------------------(4)

From (2) & (4) we can write $\sigma = ne\mu$ -------------------------(5)

In case of a semiconducting material, the current flow is due to electrons and holes. Therefore current densities due to electrons and holes is given by $J_n(drift) = n\mu_n eE$

$$J_p(drift) = p\mu_p eE$$

And the total drift current is the sum of above two equations ⇒

$$J\,(drift) = n\mu_n eE + p\mu_p eE$$

And total conductivity is given by $\sigma = ne\mu_n + pe\mu_p$

Diffusion:

In addition to the drift motion, the carriers in a semiconductor may move by diffusion. Diffusion occurs whenever there is a non-uniform concentration of charge carriers. Excess carriers are introduced locallly in a semiconductor, either by heating or radiation incidence. Then the excess carriers move from the region of higher concentration to region of lower concentration tending to produce a uniform distribution. This phenominon is called diffusion.

Let us suppose that the concentration '*Δn*' of electrons varies with distance x in the semiconductor, then the concentration gradient will be $\frac{\partial(\Delta n)}{\partial x}$

According to Fick's law, the rate of carrier diffusion is proportional to concentration gradient and the movement is in the direction of negative gradient. Hence rate of flow is proportional to $-\frac{\partial(\Delta n)}{\partial x}$.

This implies that rate of flow $= -\boldsymbol{D_n}\frac{\partial(\Delta n)}{\partial x}$; where D_n is known as diffusion coefficient. This flow constitutes an electron diffusion current density given by

$$J_n(diffusion) = -(e)(rate\ of\ flow\ across\ unit\ area)$$

$$= -(\boldsymbol{e})\left(-\boldsymbol{D_n}\frac{\partial(\Delta n)}{\partial x}\right) = \boldsymbol{eD_n}\frac{\partial(\Delta n)}{\partial x}\text{------------(6)}$$

Similarly for an excess hole concentration, diffusion current density is given by

$$J_p(diffusion) = (e)(rate\ of\ flow\ of\ holes\ across\ unit\ area)$$

$$= (\boldsymbol{e})\left(-\boldsymbol{D_p}\frac{\partial(\Delta p)}{\partial x}\right) = -\boldsymbol{eD_p}\frac{\partial(\Delta p)}{\partial x}\text{--------------(7)}$$

6.a. Distinguish between LED and LCD.-6m- Any three differences

LED	LCD
LED stands for Light Emitting Diode	LCD stands for Liquid Crystal Display

High power consumption (mW)	① low power consumption (μW)
Not suitable for large area display	② Suitable for large area display
more cost	③ less cost
Angle of viewing is not limited	④ Angle of viewing is limited.
They can be operated over a wide range of temperature	⑤ Their operation is limited to a temperature range of about 0°c to 60°c

6.b. Explain the principle, construction and working of solar cell. – 8m

Principle-1m, Constuction-3m, Working-4m

Solar cell

Principle :- The electromagnetic energy radiated from the sun is called solar energy.

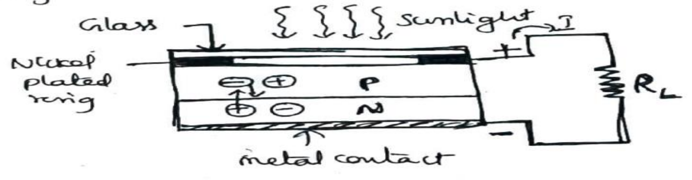
→ A solar cell is a simple P-N junction diode which converts solar energy into electrical energy and it works on the principle of photovoltaic effect. ie conversion of light energy into electrical energy.

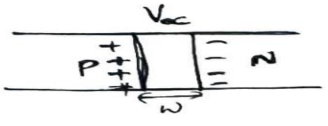
→ It is also known as self generated device. ie a voltage is generated as light strikes the device without any external bias.

Construction :- A solar cell consists of a P-N junction diode usually made of Si. It can be also constructed with many other semiconducting materials like Gallium Arsenide (GaAs), Indium Arsenide (InAs), cadium Arsenide (CdAs), and cadium Telluride (CdTe). (Their energy gap matches with the visible range of sunlight)

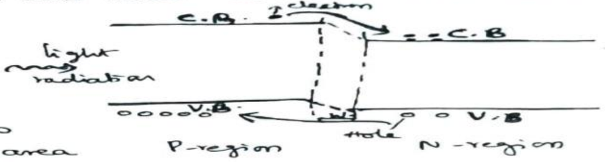
The P-N Junction diode so formed is packed in a can with a glass window on the top so that light may fall upon P and N-type materials. The thickness of P-region is kept very small so that electrons generated in this region can diffuse to the junction before recombination takes place. IIIly Thickness of N-region is also kept small to allow holes generated near the surface to diffuse to the junction before they recombine.

A heavy doping of P and N-regions is recommended to obtain a large photovoltage. A Nickel plated ring is provided around the P-layer which acts as a positive terminal. A metal contact at the bottom serves as the negative output terminal





Working:- when light is allowed to incident on a P-N junction diode, Photons collide with valence electrons and impart them sufficient energy enabling them to leave their parent atoms. Thus electron-hole pairs are generated on both P and N sides of the junction as shown in fig. These electrons and holes reach the depletion region 'W' by diffusion and are then separated by the strong barrier field existing there. However, the minority carriers ie electrons in the P-side slide down the barrier potential to reach the N-sides and holes in the N-side move to the P-side.



→ Their flow constitutes the minority current which is directly proportional to the illumination and also depends on the surface area being exposed to light.

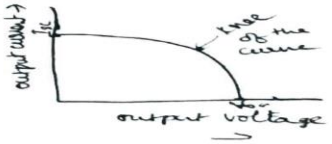
→ The accumulation of electrons and holes on the two sides of the junction give rise to an open circuit voltage V_{oc} which is a function of illumination.

→ If a load 'R_L' is connected to the cell, then carriers move in the circuit creating current.

→ when the value of the load is minimum, the current will be maximum and is known as short-circuit current, I_{sc}.

<u>characteristics</u>

V-I characteristics of a solarcell is as shown in fig.



Max. power output is obtained when the cell is operated at the knee of the curve

Energy Conversion Efficiency:-

A solarcell's energy conversion efficiency (η) is the percentage of power converted (from absorbed light to electrical energy) and collected.

$$\text{Solarcell conversion efficiency}(\eta) = \frac{\text{Power output}}{\text{Power input}}$$

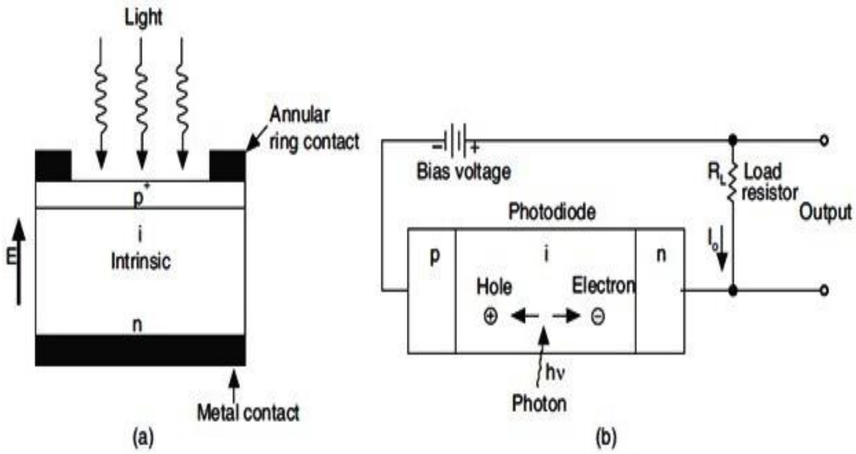
$$= \frac{\text{Electrical output} \times 100}{\text{Total radiation input} \times \text{Active Area}}$$

7.a. Explain the principle, construction and working of PIN diode. -8m

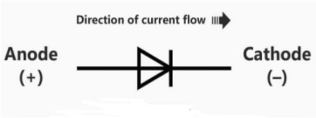
Principle-1m, construction-3m,working-4m

e p-i-n Photodiode

It is a reverse biased p-n junction which produces photo current(photoelectric effect) with a large intrinsic gion sandwiched between p and n-regions.The structure of a *p-i-n* photodiode is shown in Fig. It is a device that nsists of *p* and *n* regions separated by a very lightly doped intrinsic region (*i*). The first and most important feature of -*n* photodiode is that its depletion region extends well into the intrinsic region, as it is lightly doped. Under ficiently large reverse bias, the depletion region could extend through the intrinsic region, where by the entire rinsic region could be made free of charge carriers. The intrinsic layer in effect widens the depletion region and erefore increases area available for capturing light. Thus, the *p-i-n* structure of the photodiode enables us to increase e width of the depletion region to a value far greater than a simple *pn*-junction.



p-i-n photodiode (a) a side view of the structure (b) circuit diagram



The *p-i-n* diode has a wide intrinsic semiconductor layer between *p-* and *n-*regions. The intrinsic layer has no e charges, so its resistance is high and most of the bias voltage drops across it. When an incident photon has energy ater than or equal to the band gap energy of the semiconductor material, the photon can give up its energy and :ite an electron from the valence band to the conduction band. This process generates free *electron-hole* pairs. These rriers are mainly generated in the depletion (depleted intrinsic) region where most of the incident light is absorbed. e high electric field present in the depletion region causes the free carriers to separate and be collected across the 'erse biased junction. This gives rise to a current flow in the external circuit. As the intrinsic layer is wide enough, ıst of the photons are absorbed and larger photocurrent is produced. Therefore, *p-i-n* photodiode is more sensitive ın *pn*-photodiode.

vantages of p-i-n-photodiode

he depletion region is very wide and extends throughout the intrinsic region and hence the reverse bias need not be ied to widen the depletion region.

he reverse bias applied is small, of the order of 5V.

ls the depletion area is wider, most of the incident photons are absorbed in this region and hence the efficiency of s device is high.

he dark current in this device is smaller.

7.b. Calculate the wavelength of radiation emitted by an LED made up of a semiconducting material with a band gap energy 2.8 eV. Identify the colour of the light emitted from LED.

formula-1m, calculation-3m, colour identification-2m

We have $E_g = h\vartheta = hc/\lambda$

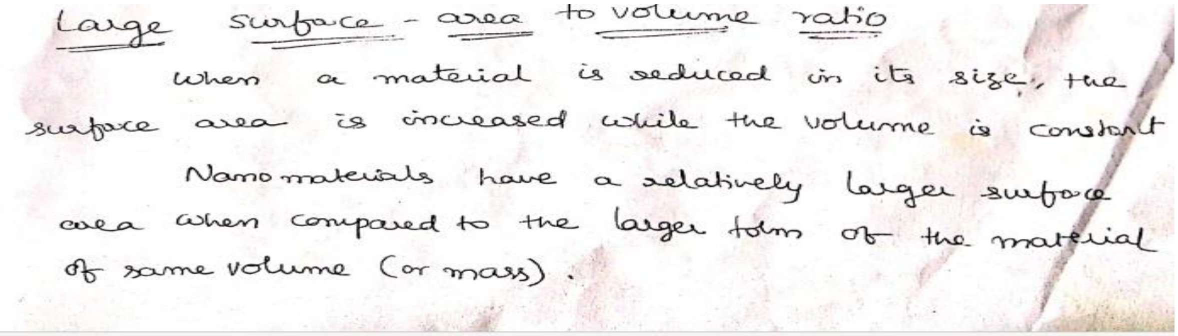
For $E_g = 2.8\text{eV}$ with $h=6.625\text{X}10^{-34}$ and $c = 3\text{X}10^{8}$

We get $\lambda = \frac{6.625\text{X}10^{-34}\text{X}3\text{X}10^{8}}{2.8\text{X}1.6\text{X}10^{-19}}\text{J} = 4.436\text{X}10^{-7}\text{m}$ (aprox.) $=4436\text{X}10^{-10}\text{m}=4436$ A°

The colour of light will be blue

8.a. Discuss about quantum confinement effect and surface area to volume ratio in nanomaterials. Write the important properties of nanomaterials. -6m

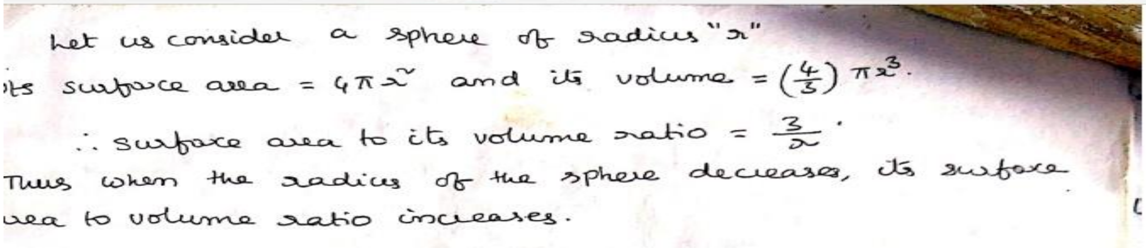
Quantum confinement-2m, surface area to volume ratio-2m, any two properties-2m



Large surface - area to volume ratio

When a material is reduced in its size, the surface area is increased while the volume is constant

Nano materials have a relatively larger surface area when compared to the larger form of the material of same volume (or mass).

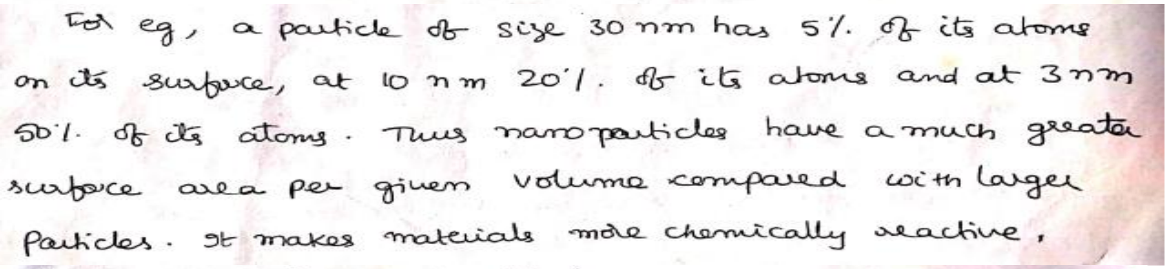


Let us consider a sphere of radius "r"

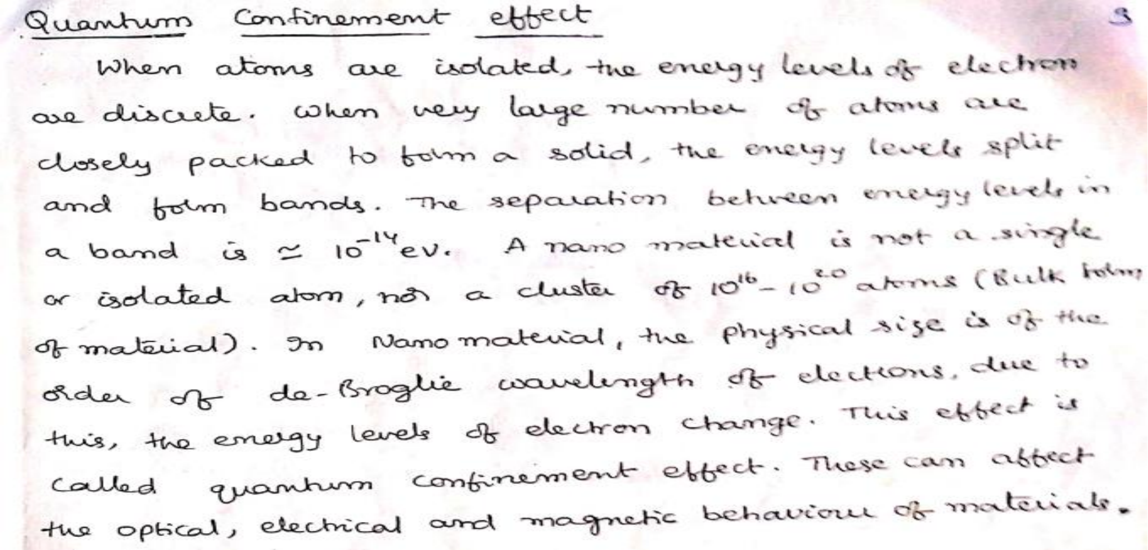
its surface area = $4\pi r^2$ and its volume = $\left(\frac{4}{3}\right)\pi r^3$.

$\therefore$ surface area to its volume ratio = $\frac{3}{r}$.

Thus when the radius of the sphere decreases, its surface rea to volume ratio increases.



For eg, a particle of size 30 nm has 5% of its atoms on its surface, at 10 nm 20% of its atoms and at 3 nm 50% of its atoms. Thus nanoparticles have a much greater surface area per given volume compared with larger particles. It makes materials more chemically reactive,



Quantum Confinement effect

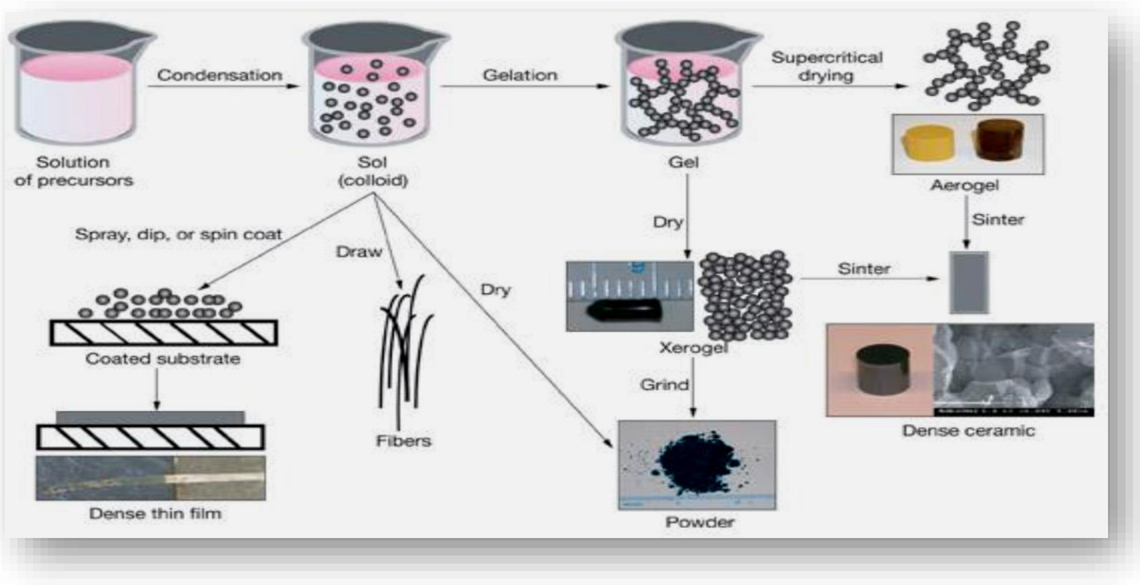
When atoms are isolated, the energy levels of electron are discrete. When very large number of atoms are closely packed to form a solid, the energy levels split and form bands. The separation between energy levels in a band is $\simeq 10^{-14}$ eV. A nano material is not a single or isolated atom, nor a cluster of $10^{16}-10^{20}$ atoms (Bulk form of material). In Nano material, the physical size is of the order of de-Broglie wavelength of electrons. due to this, the energy levels of electron change. This effect is called quantum confinement effect. These can affect the optical, electrical and magnetic behaviour of materials.

8.b. Explain in detail the synthesis of nanomaterials by Sol-Gel method.-8m

Diagram-2m, explanation-6m

Sol-gel method:

The sol-gel process is a wet chemical process to make ceramic and glass materials. This synthesis technique involves the conversion of a system from a colloidal liquid, named **sol**, into a semi-solid **gel** phase. The sol-gel technology can be used to prepare ceramic or glass materials in a wide variety of forms: ultra-fine or spherical shaped powders, thin film coatings, ceramic fibres etc. An overview of the sol-gel process is illustrated in Fig.



Mechanism of Sol-gel process

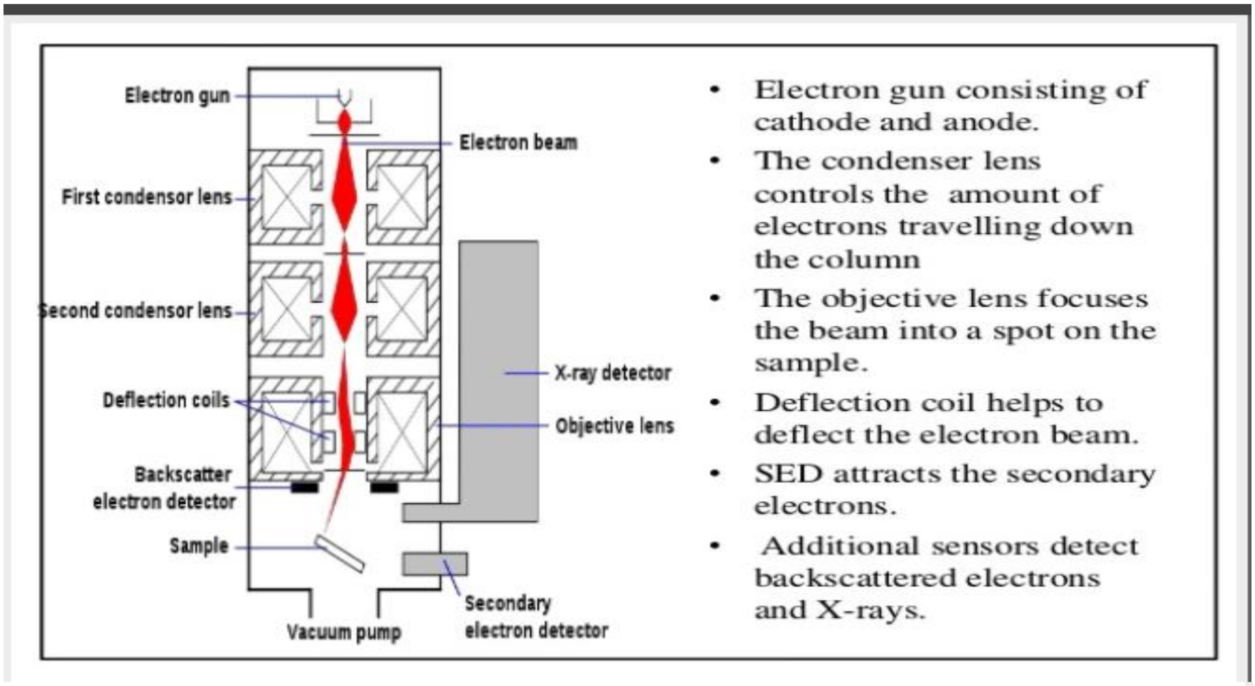
Material $\xrightarrow[\text{Aqueous solution}]{\text{Dissolved in}}$ **Solution** $\xrightarrow[\text{hydrolysis}]{\text{Series of}}$ **colloidal Solution** $\xrightarrow[\text{Addition of Gelling agent}]{\text{Condensation/ Polymerization}}$ **Gel** $\xrightarrow[\text{techniques}]{\text{Different}}$ **Different Materials (Aero gels, Xerogels, Dense ceramics etc.,)**

The starting materials used in the preparation of the sol are usually inorganic metal salts or metal organic compounds, which are dissolved in aqueous solution or alcohol. This solution, by hydrolysis and polycondensation reactions forms the sol. Further processing of the sol enables one to make ceramic materials in different forms. Thin films can be produced from sol by spin-coating or dip-coating. By adjusting viscosity of a sol in a suitable viscosity range, ceramic fibers can be drawn from the sol. Sol can be dried so that the trapped water and alcohol are removed, the network shrinks and the condensation process moves further. By adding a gelling agent, sol is brought into gel form through polymerization process. By drying and heat-treatment, the gel is converted into dense ceramic or glass materials. If the liquid in a wet gel is removed under a supercritical condition, a highly porous and extremely low density aerogel material is obtained. Ultra-fine and uniform ceramic powders are formed by precipitation, spray pyrolysis etc. The size and shape of nano material depends on

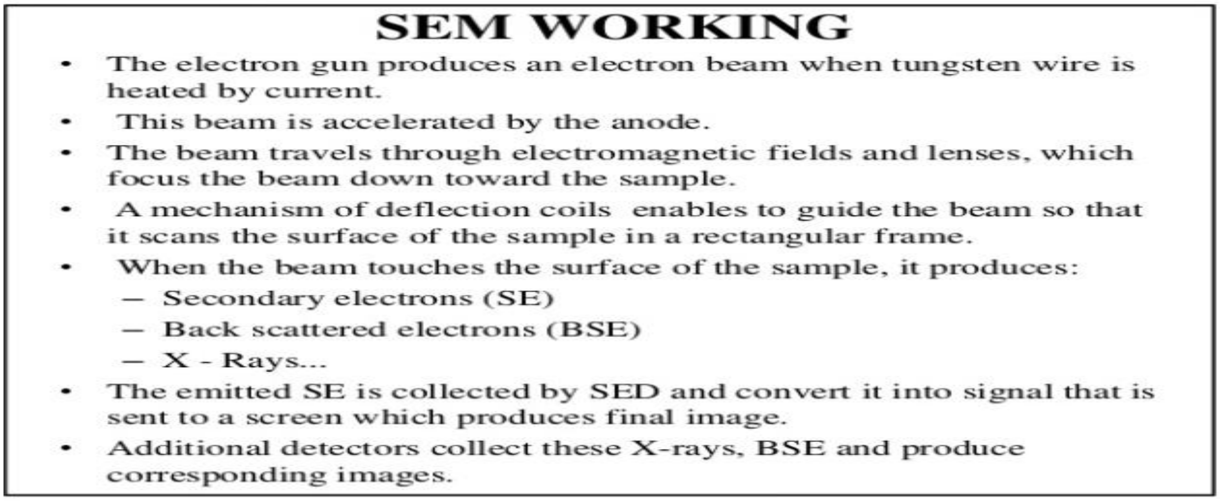
1. Reagent concentrations 2. P^H of solution 3. Temperature and time of reaction

4. Nature and concentration of catalyst 5. Drying

9.a. Illustrate the important applications of nanomaterials in different fields of science and technology.-7m
Any seven applications-7m
9.b. Describe the construction and working of scanning electron microscope (SEM).
Construction-3m, working – 4m

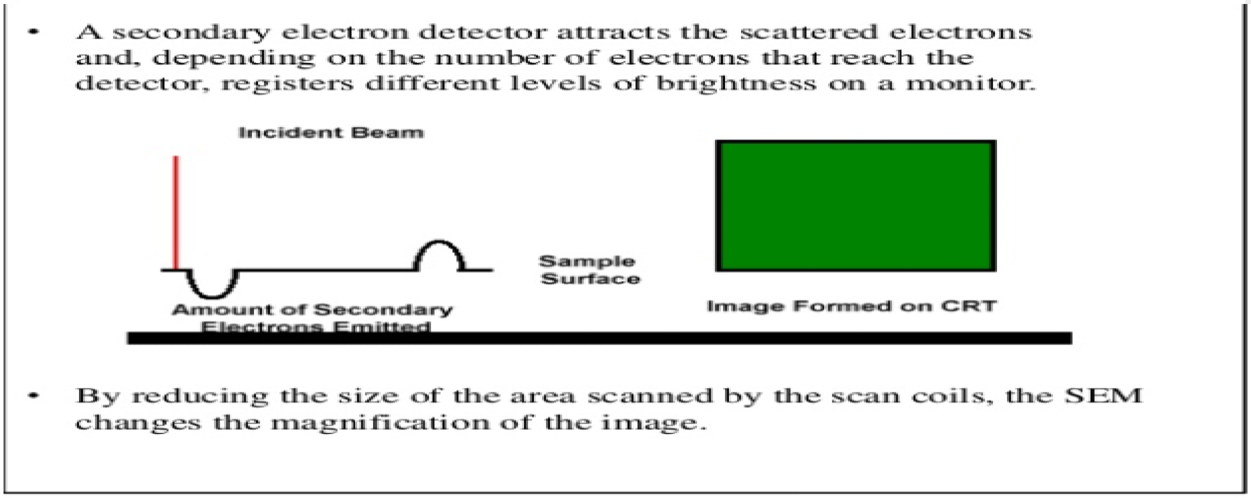


- Electron gun consisting of cathode and anode.
- The condenser lens controls the amount of electrons travelling down the column
- The objective lens focuses the beam into a spot on the sample.
- Deflection coil helps to deflect the electron beam.
- SED attracts the secondary electrons.
- Additional sensors detect backscattered electrons and X-rays.



SEM WORKING

- The electron gun produces an electron beam when tungsten wire is heated by current.
- This beam is accelerated by the anode.
- The beam travels through electromagnetic fields and lenses, which focus the beam down toward the sample.
- A mechanism of deflection coils enables to guide the beam so that it scans the surface of the sample in a rectangular frame.
- When the beam touches the surface of the sample, it produces:
  - Secondary electrons (SE)
  - Back scattered electrons (BSE)
  - X - Rays...
- The emitted SE is collected by SED and convert it into signal that is sent to a screen which produces final image.
- Additional detectors collect these X-rays, BSE and produce corresponding images.



- A secondary electron detector attracts the scattered electrons and, depending on the number of electrons that reach the detector, registers different levels of brightness on a monitor.

- By reducing the size of the area scanned by the scan coils, the SEM changes the magnification of the image.