(A) It states that Postulates C.F.E.T.

* Metals → Molecules → atoms → nucleus → particles

* electrons have 2 types

  (i) core electron - very close to nucleus

  (ii) valance e^- - far from nucleus

* valance electrons are free e^-, They are compared with freely moving gas molecules.

* Free moving electrons collide with each other called elastic collision. This happens in absence of electric field.

* In the pressence of electric field the e^- take up electric field & move towards +ve potential with Drift velocity.

* Average distance taken by free e^- between two successive collisions is "Mean free path" (λ_D)

* COLLISION TIME (τ_c):

  Average time taken by free e^- via two successive collision.

* RELAXATION TIME (τ_R):

  Time taken by free e^- to move from equlibrium state to disturbed state.

Q Write the success of classical free electron theory?

(A)

(A) * It verifies ohm's law

* It explains electrical conductivity of metals
* It explains thermal conductivity of metals
* It derives wideman - franz law.

Q Write 3 failures of CFET?

(A) ~~It failed to~~

(A) * It failed to explain the electric specific heat and the specific heat capacity of metals.

* It fails to explain superconducting properties of metals
* It fails to explain phenomena like photo electric effect, compton effect, Black body radiation etc.

Postulates of quantum free electron theory

Ⓐ * All the assumptions obeys quantum theory of solids
* electrons have uniform potential
* electron exhibits the wave nature [DC-Broglie]
* All energy levels are quantised.
* All electrons are restricted inside crystal.
* electrons obeys paulis exclusive principle
[NO two e⁻ can have same set of quantum numbers].
* It Obeys Fermi dirac statistics.

Ⓠ Success of Quantum free electron theory

Ⓐ * It explains the phenomena like photo electric, black body radiation & specific heat of metals
* It explains electrical & thermal conductivity of metals
* It explains Thermionic phenomenon.
* It also explains magnetic susceptibility of metals.

Q. write a short note on Band theory of solids

Write a short note on Band theory of solids

(A) The Band theory discusses about Three most important energy bands

(i) Valence band: The energy band that consists of valence electrons energy levels, is known as the valence band. The valence band is present below the Conduction band & the electrons of this band are loosely bound to the nucleus of the atom.

(ii) CONDUCTION Band: The energy band that consists of the free electrons energy levels is known as conduction band.

(iii) FORBIDDEN band: The energy gap between the valence & conduction band. The electrical conductivity of a solid is determined from the forbidden gap only. & hence classified as conductors, semi conductors & insulators

Q) Explain 3 types of E-K diagram?

Explain 3 types of E-K diagram

A) There are 3 types of EK diagrams

① Periodic zone:-

The periodic zone repetition of allowed energy values corresponding to each allowed band, which is obtained by the periodic repetition of the region of $\frac{\pi}{a} < x < \frac{\pi}{a}$ through whole K-space

② Extended zone:-

-> In this sheme, different bands are drawn in different zones on K-space.

-> A discontinuous is obtained at $K = \pm \frac{n\pi}{a}$ where $n = \pm 1, \pm 2 \ldots$

for $K = -\frac{\pi}{a}$ to $\frac{\pi}{a}$ in first zone.

$K = -\frac{\pi}{a}$ to $\frac{2\pi}{a}$ & $\frac{\pi}{a}$ to $\frac{2\pi}{a}$ second zone

③ Reduced zone :-

-> In this scheme the first Brillouin zone is shown since the E-K diagram is periodic. It is sufficient to restrict to first zone in reduced scheme.

-> If we know the energy values of first zone with respect to K then we known every where because energy eigen values are periodic

Q) What is meant by Brillouin zone? Explain?

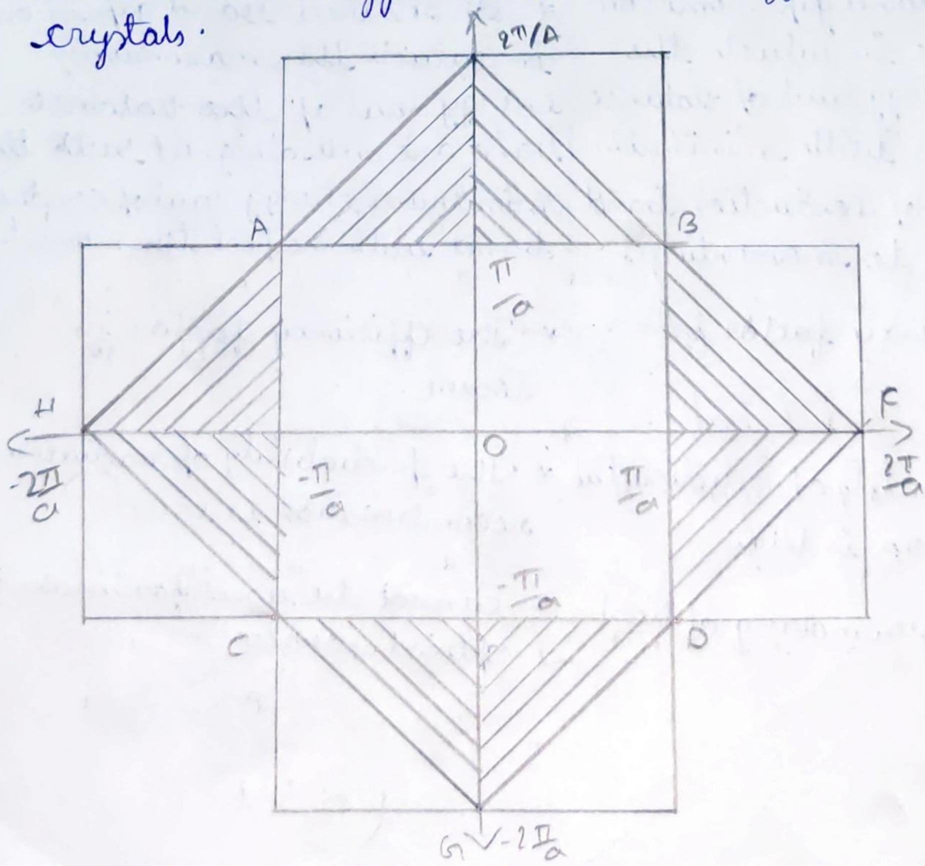
Brillouin zone

A) A Brillouin zone is defined as a wigner-seitz primitive cell in the reciprocal lattice.

* The different Brillouin zones corresponds to primitive cells of a different type that come up in the theory of electronic levels in a periodic potential.

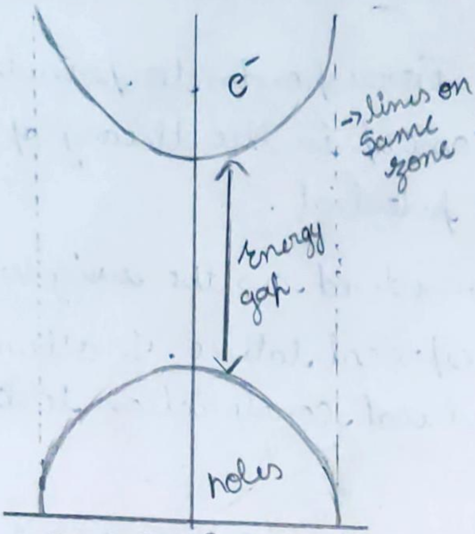
* The first Brillouin zone is considered as the wigner-seitz primitive cell in the reciprocal lattice. In other words, the first zone is a geometrical construction to the WS primitive cell in K-space.

* These Brillouin zones are used to describe and analyze the electron energy in the band energy structure of crystals.

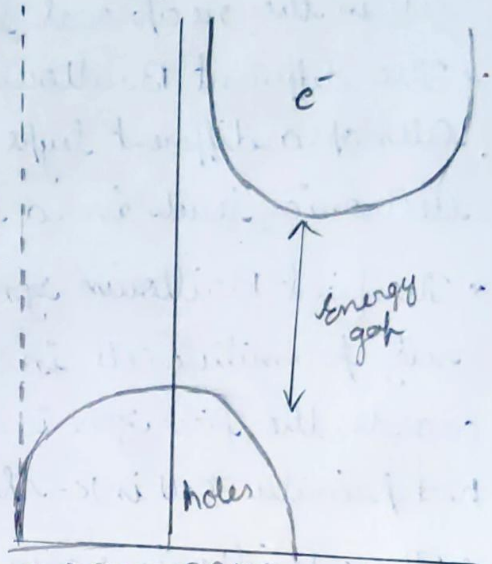


Q) Write any 3 differences b/T direct & indirect bandgap semiconductor.

Write any 3 differences between direct and indirect band gap semiconductor



DIRECT BAND GAP



INDIRECT BANG GAP

* A direct band gap semi con-ductor is one in which the maximum energy level of valance band allings with minimum energy level of conduction band with respect to momentum.	* An Indirect band gap is one in which the maximum energy level of the valance band are misalligned with the minimum energy level of conductio band with respect to momentum
* The efficiency factor is higher	* The efficiency factor is lower.
* The probability of radioactive recombination is high	* The probability of radioactive recombination is low
* preffered for making optical sources	* cannot be used for making optical sources.

Ⓠ Write a short note on phonons?

Write a short note on phonons

Ⓐ * A phonon is a definite discrete unit (or) quantum of vibrational mechanical energy, just as a photon is a quantum of electromagnetic (or) light energy.

* It is the smallest unit of light similarly for sound, the smallest unit is called phonon.

* Atoms were considered as rigid, with atoms stuck in their lattice. In reality, atoms can be considered as simple harmonic oscillation. The oscillation has a grand state energy and an associated vibrational mode at 0°K.

* It is named phonon because at high energy levels long wavelength phonons give rise to sound. According to quantum mechanics; similar particle nature so, phonon is also treated as a quasi particle.

* Important application of phonons is in the field of super conductivity, where the electrical resistance of material becomes zero.

Q what is effective mass? Obtain expression for effective mass of electrons?

What is effective mass? Obtain expression for effective mass of electrons

A The effective mass of the electron is defined as the mass of the electron, when it is accelerated by applying electric field.

The energy of electron $E = \frac{p^2}{2m}$ — ①   where p is momentum

$p = \hbar K$ $\hbar = \frac{h}{2\pi}$

$p^2 = \hbar^2 k^2$ — ② $k = \frac{2\pi}{\lambda}$

Sub ② in ① $E = \frac{\hbar^2 K^2}{2m} \rightarrow$ ③

Diffn Eq ③ w.r.t 'k'.

$\frac{1}{\hbar^2}\left(\frac{d^2E}{dk^2}\right) = \frac{1}{m}$ — ④

as force $F = -eE = m^*a$

$E - E_c = C_1 k^2$ — ⑤

Diff w.r.t. ⑤ 'k'. $\frac{dE}{dk} - 0 = C_1 2k$

differentiated again $\frac{d^2E}{dk^2} = C_1 k$.

Multiply by $\frac{1}{\hbar^2}$ on both sides

$\frac{1}{\hbar^2}\left(\frac{d^2E}{dk^2}\right) = \frac{C_1 k}{\hbar^2}$ — ⑥

comparing ④ & ⑤

$\frac{1}{\hbar^2}\left(\frac{d^2E}{dk^2}\right) = \frac{C_1 k}{\hbar^2} = \frac{1}{m^*} \Rightarrow m^* = \frac{1}{\frac{1}{\hbar^2}\left(\frac{d^2E}{dk^2}\right)}$

Q) Explain probability of occupation in a given energy level using fermi-Dirac distribution

Explain probability of occupation in a given energy level using fermi dirac distribution

A) The distribution of e^- among levels is described by function $f(E)$, probability of an e^- occupying an energy level 'E'.

(i) when $E < E_F$ for energy levels lying below E_F, $(E - E_F)$ is a negative quantity & hence

$$F(E) = \frac{1}{1+e^{-\infty}} = \frac{1}{1+0} = 1$$

That means all the levels below E_F are occupied by e^-s.

(ii) when $E > E_F$ for energy levels lying above E_F $(E - E_F)$ is a positive quantity.

$$F(E) = \frac{1}{1+e^{\infty}} = \frac{1}{1+\infty} = 0.$$

* This equation indicates all the levels above E_F are vacant

(iii) where $E = E_F$

$$F(E) = \frac{1}{1+e^0} = \frac{1}{1+1} = \frac{1}{2} \text{ at all temperatures}$$

The probability of finding an e^- with energy equal to fermi energy in a metal is 1/2 at any Temp.

* At $T = 0K$ all the energy levels upto E_F are occupied & all energy levels are empty.

* $T > 0K$, some levels above E_F are partially filled while some levels below E_F are partially empty.

Q) write any three differences b/T N-Type & P type semi conductor.

Write any 3 differences between N type and P type semi conductor

A)

PTYPE	N-TYPE
* Ptype semi conductor is formed due to the dopping of III group elements.	* Ntype semi conductors are formed due to dopping of nitrogen, Arsenic, Bismoth...
* There are also known as Trivalent semi conductors	* There are also known as pentavalent semi conductor.
* This is +ve type semi conductor it means it deficiency of 1 e^- is required.	* This is -ve type semi conductor it means excess of 1 e^- is required.
* Here majority charge carriers are holes & minority are electrons	* Here majority charge carriers are electrons & minority are holes.

Q) write the classification of electronic materials on the basis of band theory.

Write the classification of electronic materials on the basis of band theory

A) A band theory explains energy band & mechanism of semi conductors.

* An energy band which separates the conduction band & valence band is called Band gap.

* Based on energy gap, the materials are classified as 3 categories

1. conductors: In a conductor, there is a large no. of free electrons at room temperature, so energy gap does not exist. The valence band & conduction band over lap with each other.
Ex: silver, iron ...

2. Insulator: In insulators, the energy gap is very high 7ev. So at very high temperature (or) voltage, electrons can not move from valence band to conduction band, so this material cannot conduct at all.
ex: wood, paper..

3. Semi conductor: In semi conductor, at absolute 0° temp, the conduction band is empty & it behaves like insulator. At normal temp some e move to C.B. Hence it can conduct partially at normal (or) room temperature.
As temp increases energy gap decreases.
ex:- silicon, germanium.

Write a note on reverse bias P-N juntion

A) when the P-type is connected to the negative terminal of the battery and the n-type is connected to the positive side then the P-n junction is said to be reverse biased. In this case, the built-in electric field and the applied electric field are in the same direction when the two fields are added, the resultant electric field is in the same direction as the built-in electric field creating a more resistive, thicker depletion region. becomes more resistive and thicker if the applied voltage becomes larger.

write note on forward bias P-n junction

Write a note on forward bias P-N junction

A) Forward Biased PN Junction A PN junction is Said to be forward-biased when the P-type region of a junction is connected to the positive terminal of a voltage source and the n-type region is connected to the voltage source's negative terminal In this forward-biased condition, due to the attraction of the positive terminal of the source, electrons that participated in covalent band creation in the P-type material will be attracted towards the terminal. As a result the Number of covalent bonds is broken and electrons are shifted towards the positive terminal. This results in the electrons' concentration in the crystal closer to the ~~terminal~~ terminal to increase, and these electrons recombine with holes here.

Explain concepts of P-n junction.

A) A P N junction diode is one of the simplest semiconductor devices around, and which has the characteristic of passing current in only one direction only. However, unlike a resistor, a diode does not behave linearly with respect to the applied voltage as the diode has an exponential current-voltage (I-V) relationship and therefore we can not described its operation by simply using an equation such as ohm's law. By ~~[illegible]~~ applying a negative voltage (Reverse bias) results in the free charges being pulled away from the junction resulting in the depletion layer width being increased. This has the effect of increasing or decreasing the effective resistance of the junction itself allowing or blocking the flow of current through the diodes p.n-junction.

Explain concepts of P-N junction

Discuss about drift current

A) In condensed matter physics and electrochemistry, drift current is the electric current is the electric current, or movement of charge carriers which is due to the applied electric field, often stated as the electromotive force over a given distance. When an electric field is applied across a semiconductor material, a current is produced due to the flow of charge carriers. The drift velocity is the average velocity of the charge carriers in the drift current. The drift velocity, and resulting current, is characterized by the mobility, for details, see electron mobility (for solids) or electrical mobility (for a more general discussion.

Discuss about drift current

Discuss about diffusion current?

A) Diffusion current is a current in a semiconductor caused by the diffusion of charge carriers (holes and or electrons. This is the current which is due to the transport of charges occurring because of non-uniform concentration of charged particles in a semiconductor. The drift current, by contrast, is due to the motion of charge carriers due to the force exerted on them by an electric field. Diffusion current can be in the same or opposite direction of a drift current. The diffusion current and drfit current together are described by the drift-diffusion equation.

Discuss about diffusion current

1) What is intrinsic semiconductor?

What is intrinsic semiconductor

A) An intrinsic semiconductor is a pure semiconductor without any significant dopant species present also called an undoped semiconductor or i-type semiconductor. The number of charge carriers is therefore determined by the properties of the material itself instead of the amount of impurities. in intrinsic semiconductors the number of excited electrons and the number of holes are equal: n=p. This may be the case even after doping the semiconductor, through only if it is doped with both donors and acceptors equally in this case, n=p still holds, and the semiconductor remains intrinsic though doped.

What is extrinsic semiconductor

A) An extrinsic semiconductor is a semiconductor doped by a specific impurity which is able to deeply modify its electrical properties, making it suitable for electronic. applications (diodes, transistors, etc.) or optoelectronic applications (light emitters and detectors).

There are two types of extrinsic semiconductors:-

P-type semiconductor:- P for positive a hole has been added through doping with a group-III element)

N-type semiconductor:- N for Negative an extra electron has been added through doping with a group-V element.

where the Fermi energy level does lies in intrin>:
Semiconductor How does it varies with respect to
temperature.

A) Fermi level in intrinsic semiconductor

The probability of occupation of energy levels in valance band and conduction band is called Fermi level. At absolute zero temperature intrinsic semiconducto-'c acts as perfect insulator. However as the temperature increases free electrons and holes gets generated.

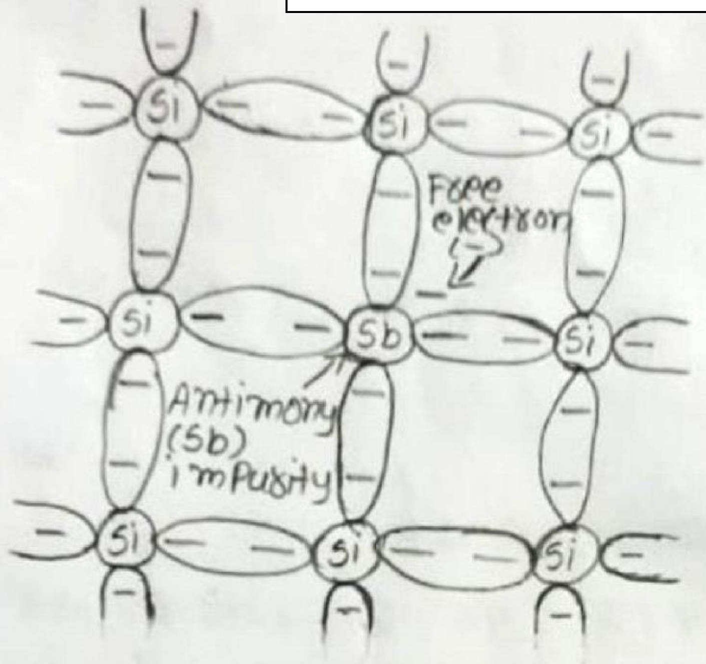
In intrinsic or pure semiconductor, the number of holes in valence band is equal to the number of electrons in the conduction band. Hence, the probability of occupation of energy levels in conduction band and valence band are equal. Therefore, the Fermi level for the intrinsic c semiconductor lies in the middle of forbidden band.

Where the fermi energy level does lies in intrinsic semiconductor? How does it varies with respect to temperature

Explain N-type semiconductor with diagram?

A)

Explain N-type semiconductor with diagram



N-type semiconductor

A N-type semi conductor is created by doping this pure silicon crystal lattice with a pentavalent impurity element like Antimony (Sb). In an N-type semi conductor the atom of pentavalent impurity elemenent Antimong (Sb) is in between silicon atoms. Thesilicon atoms have four electrons in the valance shell. Each of the silicon atom creates a covalent bond with an electron of the prevalent impurity atom.

Explain about carrier generation?

A) Carrier generation describes processes by which electrons gain energy and move from the valance band to the conduction band, producing two mobile carriers; while recombination describes processes by which a conduction band electron loses energy and re-occupies the energy state of an electron hole in the valence band.

Explain about carrier generation

Describe the difference between p-type and N-type se

Describe the difference between p type and n type semiconductor material

A)

P-TYPE Semiconductor	N-TYPE Semiconductor
1) In P-Type semiconductor III group element is added as doping element	1) In N-TYPE semiconductor V group element is added as doping element.
2) Impurity added creates vacancy of electrons (holes) called as Acceptor Atom.	2) Impurity added provides extra electrons and is known as Donor Atom.
3) Trivalent impurity like Al, Ge in etc. are added	3) Pentavalent impurity like P, As, Sb, Bi etc. are added
4) Holes are majority charge carriers and Electrons are minority charge carriers	4) Electrons are majority charge carriers and Holes are minority charge carriers
5) The hole density is much greater than the electron density. $n_h >> n_e$	5) The electron density is much greater than the hole density. $n_e >> n_h$

where the Fermi energy level does lies in N-type semi conductor. How does it varies with respect to temperature.

A) IN n-type semi conductor
- At 0K the fermi level E_{Fn} [Fn] lies between the conductio band and the donor level
- As temperature increases more and more electrons shift to the conduction band leaving behind equal number of holes in the valence band. These electron hole pairs are intrinsic carriers.
- with the increase in temperature the intrinsic carriers dominate the donors.
- To maintain the balance of the carrier density on both sides the fermi level E_{Fn} gradually shifts downwards.
- Finally at high temperature when the donor density is almost negligible E_{Fn} is very close to E_{Fi}.

Where the fermi energy level doss lies in the N-type semiconductor . How does it varies with respect to temperature?

Explain about recombination?.

A) Carrier recombination:-

Explain about recombination

-> Radiative Recombination - Photon is release
-> Non-radiative recombination - Phonon is release
-> Auger Recombination - kinetic energy is release (given off to another electron).

1) Band to Band:- An e^- moves from its conduction band state into the empty valence band state associated with the hole (mechanism of Radiative recombination).

2) Trap-Assisted:- An e^- falls into a "trap", an energy level within the band gap caused by the presence of a foreign atom or a structural defect (Shockley - Hall - Read)

3) Auger recombination:- An electron and a hole recombine in a band-to band transition, but now the resulting energy is given off to another e^- or hole.

where the Fermi energy level does lies in P-type Semi conductor How does its varies with respect to temperature

A) • At ok then fermi level E_{FP} in a p-type semiconductor lies between the acceptor level and the valence band.

- with the increase in temperature more and more holes are created in the valance band as equal Number of electrons move to the conduction band.

- As temperature increases the intrinsic holes dominate the acceptor holes

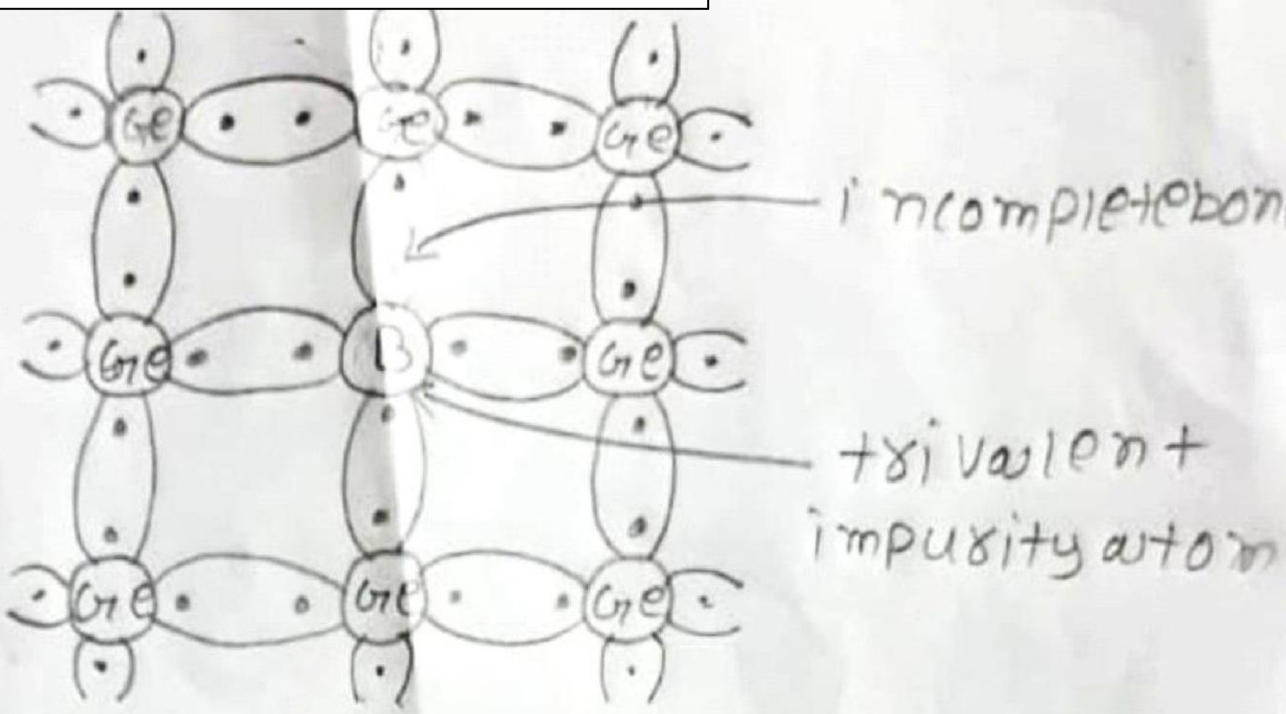
- Hence the Number of intrinsic carriers in the conduction band and in the valance band become early equal to high temperature

- The fermi level E_{FP} gradually shifts upwards to maintain the balance of carrier density above and below it.

Where the fermi energy does lies in P type semiconductor? How does it varies with respect to temperature

Explain p-type semiconductor with diagram

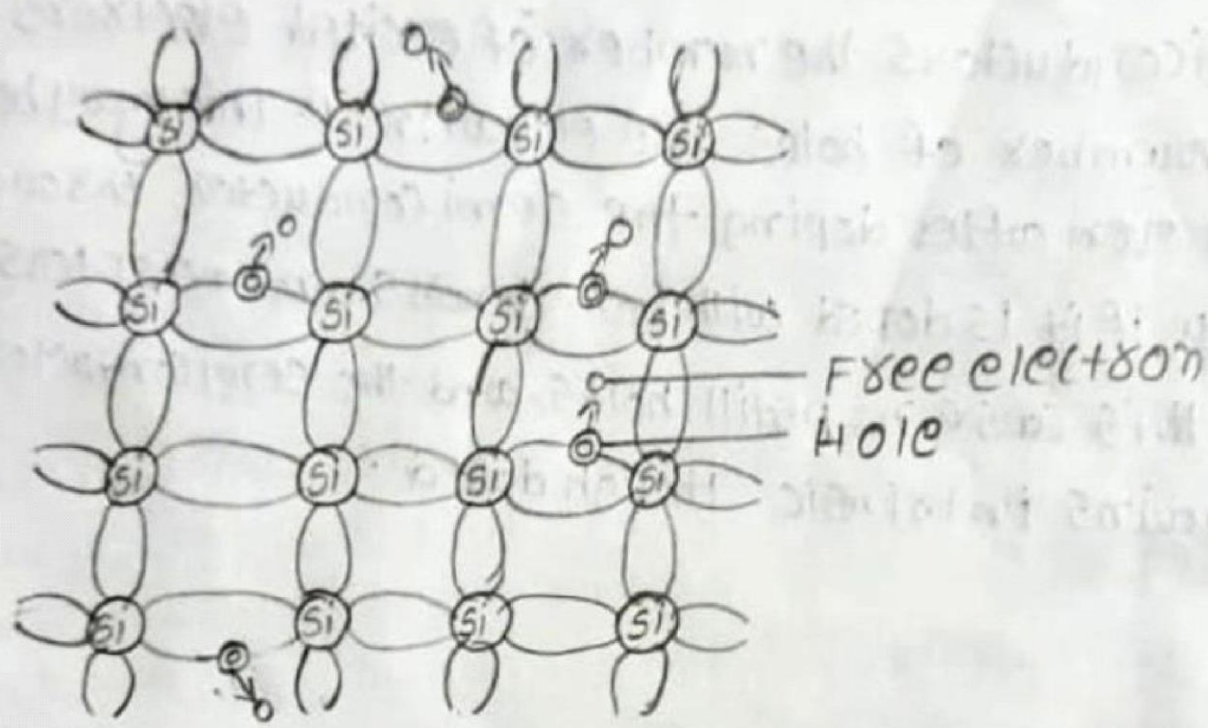
Explain p-type semiconductor with diagram



The extrinsic p-type semiconductor is formed when a trivalent impurity is added to pure semiconductor in a small amount, and as a result, a large number of holes are created in it. A large Number of holes are provided in the semiconductor material by the addition of trivalent impurities like Gallium and Indium such types of impurities which produce p-type semi-conductor are known as an Acceptor Impurities because each atom of them create one hole which can accept one electron.

2) Explain atomic structure and energy level diagram of intrinsic semiconductor?

A) An intrinsic semiconductor is an undoped semiconductor. This means that holes in the valence band and vacancies created by electrons that have been thermally excited to the conduction band, as opposed to doped semiconductors where holes or electrons are supplied by a "foreign" atom acting as an impurity



The intrinsic semiconductor examples are Si & Ge

in the above energy band diagram, the conduction band is filled totally. once the temperature is increased, some heat energy can be supplied to it. so the electrons from the valence band are supplied toward the conduction band by leaving the valence band.

Explain atomic structure and energy level diagram of intrinsic semiconductor

Write the applications of OLED?

Write the applications of OLED

Ans) An OLED has many application, few of them are listed below:-

*) OLEDs are used to create digital displays in devices such as television screen, smart phones, etc.

*) white OLED devices are used in solid-state lighting applications.

*) Polymer OLEDs are used in inkjet printing for flexible display.

*) Transparent organic OLED's are used for opaque substance such as metal and require a transparent cathode.

Write the demerits of OLED?

Write demerits of OLED

Ans) An OLED has some demerits. Few of them given below.

*) White, Red El Green OLEDs offer life time of about 5 to 25 years where as blue OLED offers about 1.6 years.

*) OLEDs ~~expensi~~ is too expensive when compared to other display types.

*) OLEDs are susceptible to water and hence it can be easily damaged by water.

*) OLED Screens are even worse when compared to other display types in case they expose to sunlight

*) The overall luminance of OLEDs are degraded.

Write the merits of OLED?

Write merits of oled

Ans) An OLED has many merits. Few of them are given below.

*) The life span of OLEDs are more. So that it lasts ~~of~~ for long life.

*) OLEDs are energy efficient i.e., OLEDs ~~com~~ consume less power.

*) OLEDs consume less power so that they can operate effectively on less voltage electrical system. They are much safer if something goes wrong.

*) OLEDs are physically small. But even though, it produces a wide sprectrum.

* OLEDs have great colour rendering index (CRI)

write the working of OLED?

Write the working of oled

Ans) <u>working of OLED:</u>

OLED's work in a similar way to conventional diodes and LEDs, but instead of using layers of n-type and p-type semiconductors, they use organic molecules to produce their electrons and holes. A simple OLED is made up of six different types. On the top and bottom there are layers of protective glass or plastic. The top layer is called seal and bottom layer is called substrate. In between those layers, there's a negative terminal and positive terminal. Finally in b/n cathode and anode, there are two layers made from organic molecules called the emissive layer and a conductive layer.

write the construction of OLED?

Write the construction of OLED

Ans) Construction of OLED:

An OLED device consists of a ~~plu~~ plurality of functional organic layers including a hole transport layer, a light-emitting layer, and an electron transport layer, and all of these layers are situated between an anode and cathode. In an OLED device, the light-emitting layer is excited by the recombination energy of electrons from the cathode and holes from the anode, and then the light-emitting layer emits light when returning to the ground state. one of the electrodes consists of transparent material in order to extract light from the light emitting layer.

Explain the working of LED

Explain the working of led

Ans) LED (Light Emiting Diode):

→ PN Junction diode, which emits light when forward biased, this phenomenan is called electroluminisense.

→ In all semiconductors, some amount of energy is radiated in the form of heat.

→ In silicon and Germanium, greather percentage of energy is emitted as heat.

→ In gallium phosphide (GaP) or gallium Arsenide phosphide (GaAsP), the energy is radiated in form of light in visible spectrum.

Working of LED:

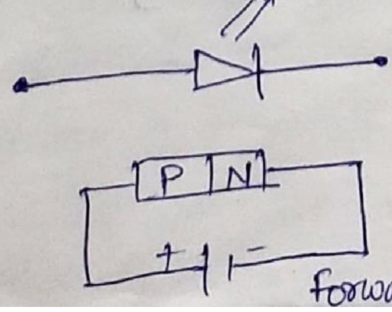
(i) when LED is forward biased, the electrons and holes move towards the junction and recombination takes place.

(ii) As a result, the electrons lying in conduction bands of N-region falls into holes lying in the valence band of P-region.

(iii) The difference of ~~b/m~~ energy b/n conduction Band and ~~for~~ valence band is radiated in form of light.

(iv) Thus each recombination causes light emission.

(v) The brightness of the emitted light is directly proportional to the forward bias current.



Forward Biased LED

Define LED and write it's principle ?

Define led and write it's principle

Ans) LED : A light - emitting diode (LED) is a semicond. light source that emits light when current flows through it. Electrons in the semiconductor recombines with electron holes, releasing energy in the form of photons.

working principle of LED :

A light - emitting diode is a two - lead semiconductor light source. It is a p-n junction diode that emits light when activated. when a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons.

What are the applications of LED?

Application of LED

Ans) There are many applications of LED and some of them are explained below.

*) LED is used as a bulb in the homes and industries.

*) The LEDs are used in motorcycles and cars as head lights.

*) These are used in mobile phones to display the message.

*) At the traffic light signals LEDs are used.

Write the demerits of LED.

Demerits of LED

Ans) *) LEDs are expensive. So that the cost of them are High.

*) The performance standardization has not yet been streamlined for LEDs.

*) More over, if these LEDs are overheated, their lamp life would be reduced.

*) Also, the transformer compatibility effect on LED alot.

*) LEDs must be supplied with the voltage above the threshold and a current below the rating. This can involve series resistor or current - regulated power supplies.

Write the merits of LED.

Merits of LED

Ans) ~~L~~ LED's are durable and they can be extended ~~for~~ to last for long life.

*) LED's are capable of turning about 70% of their energy into light. So that they are energy efficient.

*) LED's are capable of emitting an extremly high level of brightness.

*) LED's are offered in wide range of colours.

*) In LED, low radiated heat is emitted out.

*) LEDs operate at full brightness from the moment we flip the switch. So that instantanous illumination take place.

Write the construction of LED?

Construction of LED

Ans) In the construction of LED, the recombination of the charge carrier occurs in the p-type material, and hence P-material is the surface of the LED. For the maximum emission of light, the anode is deposited at the edge of the P-type material. The cathode is made of gold film, and it is usually placed at the bottom of N-region. This gold layer of cathode helps in reflecting the light to the surface. The gallium arsenide phosphide is used for the manufactering of LED which emits red or yellow light for emission. The LED are also available in green, yellow amber and red in colour.

Write a note on Organic LED?

Note on organic LED

Ans) An Organic light-Emitting diode (OLED) is a solid state light device that makes use of flat light emitting technology with the help of two conductors between which a series of organic thin films are kept. Unlike other display modes, an OLED does not require backlighting. Because of its low power consumption and great brightness, OLED is used as a backlight source in LCD displays, electronic equipment, signaling as well as in general lighting moreover, OLED-based screens can be significantly thinner, resulting in lighter weight. Also, OLED has better contrast and allows a higher refresh rate. And the power consumption for this OLED's is also low.

Write a note on photocurrent in P-n junction?

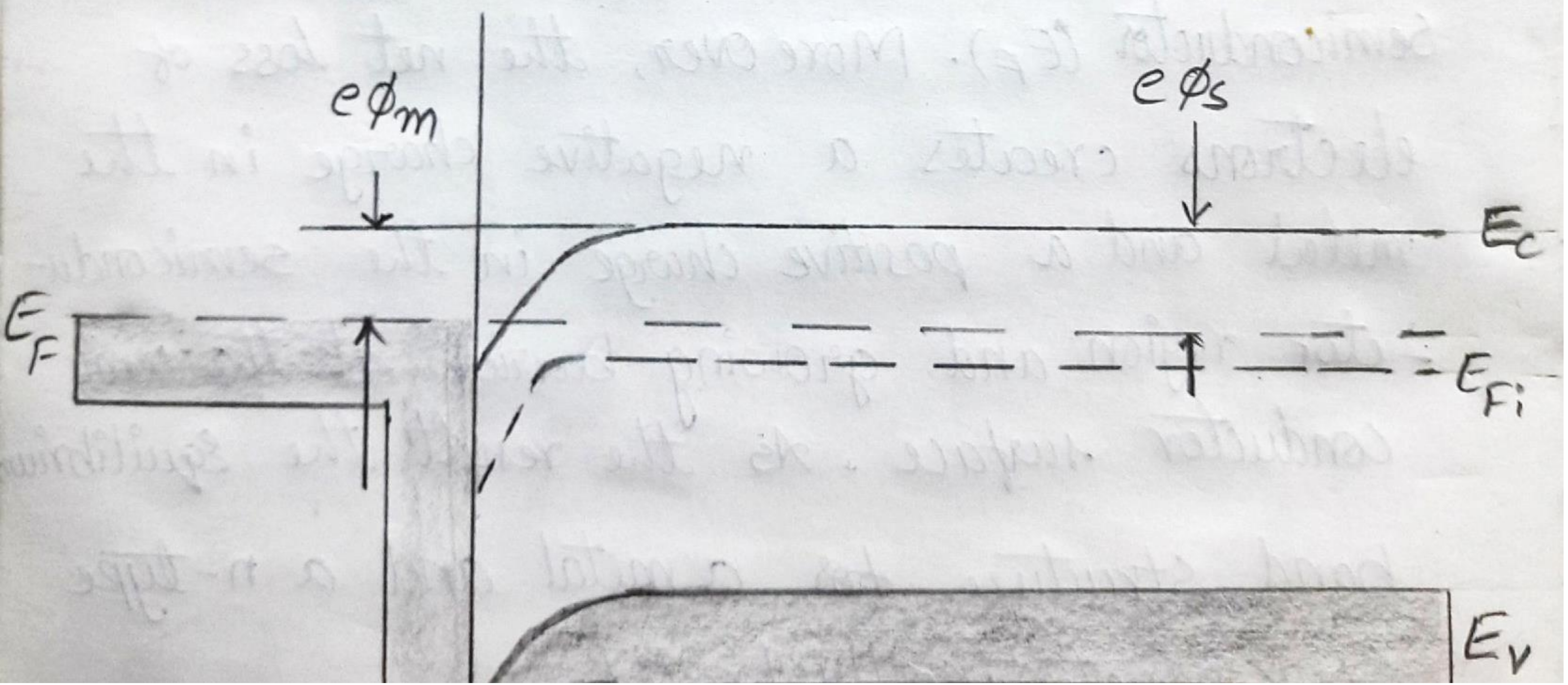
Write a note on photocurrent in P-N juntion

Ans) A photocurrent is an electric current through a photosensitive device, such as a photo diode, as the result of exposure to radient power. The photocurrent may occurs as a result of the photo electric, photo-voltaic or photoemissive effect. More over this photo-diode is a semiconductor p-n junction device that converts light into an electric current. The current is generated when photons are absorbed in the photodiode. They may contain optical filters, buit-in lenses, and may have large or small surface areas. At sufficiently high optical intensities, as can be reached with ultrashort pulses of light, the photocurrent can be obtained through two-photon absorption. Here the photocurrent is proportional to the square of the incident power.

What is rectifying contact ? Explain with diagram.

What is rectifying contact? Explain with diagram

Ans) A rectifying contact is a similar to a pn junction. As it allows a large current in one voltage polarity and a much smaller current in the other. Here, the contact is said to be ohmic so that a non-rectifying one. More over the most commonly used rectifying contact is the schottky barriers diode (SBD).



What happens to a band when we make contact b/n metals and semiconductors?

What happens to a band when we make contact between metals and semiconductor

Ans) When a metal and a semiconductor material are brought together, an instant ideal MS contact is formed. If there is no electron movement during the ~~const process~~ contacting process, the band diagram will be mismatch with fermi ~~level~~ energy in the metal and the fermi energy in the Semiconductor (E_F). Moreover, the net loss of electrons creates a negative charge in the metal and a positive charge in the semiconductor region and growing barrier at the semiconductor surface. As the result the Equilibrium band structure for a metal and a n-type Semiconductor is illustrated.

Module 3

What do you mean by Band to band and impurity to band transition in semiconductors?

Photon Interactions in Bulk Semiconductors.

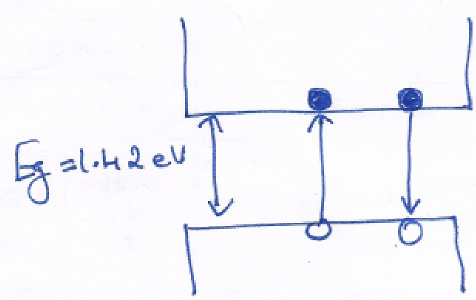
(a) Band to Band (Inter band) Transitions:

→ An absorbed photon can result in an electron in the valence band making an upward transition to the conduction band

→ This results in a electron-hole pair.

→ The electron-hole recombination can result in the emission of a photon.

→ Band to band transitions many be assisted by one or more phonons.



Band-to-band transitions in GaAs, can result in absorption or emission of photons of wavelength $\lambda_o < \lambda = \frac{hc_o}{E_g} = 0.87\,\mu m$

(b) Impurity to Band Transitions:

→ An absorbed photon can result in a transition between a donor (or acceptor) level and a band in a doped semiconductor.

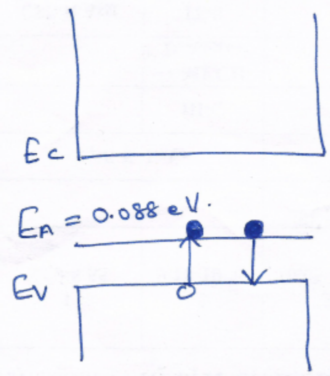
→ In a p-type material, a low-energy photon can lift an electron from the valence band to acceptor level, where it becomes trapped by a Acceptor atom.

→ A hole is created in the valence band and the acceptor atom is ionized.

→ Or a hole may be trapped by an ionized acceptor atom

→ The result may be the electron decays from its acceptor level to recombine with hole.

→ The energy may be released radiatively (in the form of an emitted photon) or non-radiatively (in the form of phonons).



The absorption of a photon of wavelength $\lambda_A = hc_o/E_A = 14\,\mu m$ results in a valence band to acceptor level transition in Hg-doped Ge (Ge:Hg).

2. Define optical absorption process in semiconductor with diagram.

Absorption

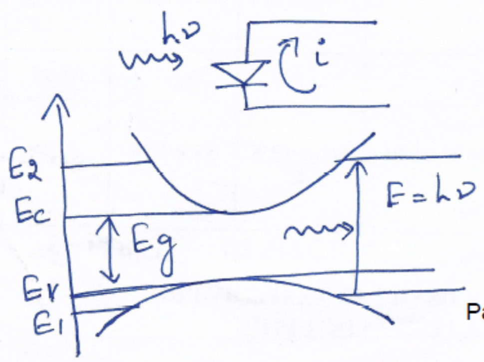
→ Electron excitation from the valence to the Conduction band may be ~~introduced by~~ induced by the absorption of a photon of appropriate energy ($h\nu > E_g$ or $\lambda < \lambda_g$)

→ An electron-hole pair is generated.

→ This adds to the Concentration of mobile charge carriers and increases the Conductivity of the material.

→ The material behaves as a photoconductor with a Conductivity proportional to photon flux.

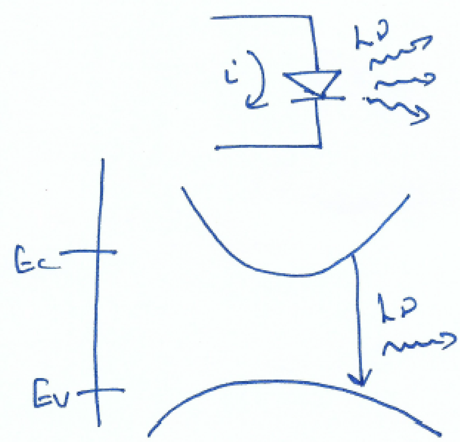
→ This effect is used to detect light.



The absorption of a photon results in the generation of an electron-hole pair.

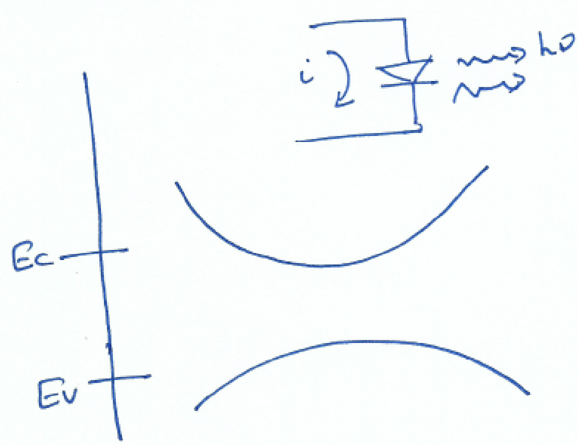
3. Define the types of optical emission process with diagram.

→ Spontaneous emission is the underlying phenomenon on which the light-emitting diode is based



The recombination of an electron hole pair results in Spontaneous emission of a photon. LED operate on this basis.

→ Stimulated emission is responsible for the operation of Semiconductor optical amplifiers and laser diodes.



Electron-hole pair recombination can be induced by a photon. This results in the stimulated emission of the identical photon.

Spontaneous Emission

→ The Spotaneouss emission does not require any external energy.

→ The atom goes back to its ground state after its lifetime in the excited state.

→ Then, the number of atoms making Spontaneous emission per unit volume per unit time can be expressed as.

$$N_{sp} = A_{21} N_2$$

where, A_{21} → the proportionality constant

N_2 → number of atoms in ~~N_2~~ E_2.

Stimulated Emission:

→ The atoms in the excited state is given an external energy and is forced to go the ground state.

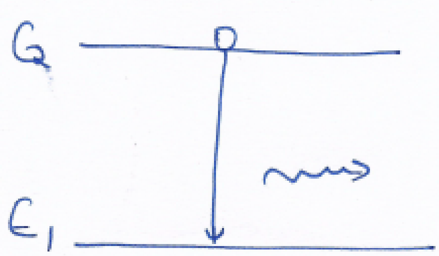
→ The atom in the excited state is not allowed to stay for its lifetime.

→ Then, the number of transitions per unit volume per unit time is given by.

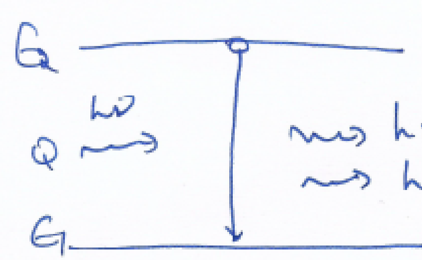
$$N_{st} = B_{21} N_2 Q$$

where, B_{21} → the ~~pr~~ proportionality constant

N_2 → number of atoms at E_2.



Spotatancous Emission



Stimulated Emission

4. What is Optical recombination process? Write three optical properties in which optical recombination process is observed.

(1)

Re Combination Process.

→ The operation of all optoelectronic devices is based on Creation ~~of~~ or annihilation of electron-hole pairs.

→ Pair formation essentially involves raising an electron in energy from the valence band to conduction band, leaving a hole behind in valence band.

→ Simplest way to achieve this phenomenon is to ~~irradiate~~ irradiate the Semiconductor.

→ Photons with sufficient energy are absorbed, and these impart their energy to the valence band electrons and raise them to the Conduction band. This process is Called absorption.

→ Recombination: the reverse process of electron hole pair annihilation, where energy is released is Called recombination

→ Recombination may be radiative or non-radiative.

→ Non-radiative transition: is the process where the excess energy due to recombination is usually imparted to ~~photons~~ phonons and dissipated as heat.

→ Radiative Transition: is the process where the excess energy due to recombination is dissipated as photons, with energy usually equal to bandgap

→ ~~Luniscence~~ Luminescence: The luminescent process is in which the electron-hole pairs are created and recombined radiatively.

→ Photoluminescence: ~~inst~~ involves the radiative recombination of electron-hole pairs created by injection of photons.

→ Cathodoluminescence: is the process of radiative recombination of electron-hole pairs created by electron bombardment.

→ Electroluminescence: is the process of radiative recombination following injection with p-n junction or similar device.

5. Using the relation $N_1 Q B_{12} = N_2 A_{21} + N_2 Q B_{21}$, derive the expression for ratio between spontaneous and stimulated coefficient. (Einstein's coefficient)

In thermal equilibrium at temperature T, with radiation frequency n and energy density u(v). Let N_1 and N_2 be the number
rise to absorption per unit time

For equilibrium $P_{12} = P_{21}$

$N_1 B_{12} u(v) = N_2 [A_{21} + B_{21} u(v)]$

$$u(\nu) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}}$$

$$u(\nu) = \frac{A_{21}}{B_{21}} \frac{N_2}{\frac{N_1}{N_2}\left(\frac{B_{12}}{B_{21}}\right) - 1} \qquad \text{.........(5.5)}$$

According to Boltzmann distribution law number of atoms N_1 and N_2 in energy states E_1 and E_2 in thermal equilibrium at te

$$\frac{N_1}{N_2} = \frac{e^{\frac{-E_1}{KT}}}{e^{\frac{-E_2}{KT}}}$$

$$\frac{N_1}{N_2} = e^{\frac{-(E_1-E_2)}{KT}} = e^{\frac{h\nu}{KT}} \qquad \text{.........(5.6)}$$

Substituting N_1/N_2 in Eq (5.5), we get

$$u(\nu) = \frac{A_{21}}{B_{21}} \frac{N_2}{e^{\frac{h\nu}{KT}}\left(\frac{B_{12}}{B_{21}}\right) - 1}$$

Comparing it with Plank's Radiation law

$$u(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{\frac{h\nu}{KT}} - 1}$$

We get

(i) $\frac{B_{12}}{B_{21}} = 1$ **;B_{12} = B_{21}**, The probability of spontaneous emission is same as that of induced absorptic
two-level system.

(ii) $\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$ The ratio of spontaneous emission and stimulated emission is proportional to ν^3. This implies t
between the two states increases.

→ At thermal equilibrium,

$$B_{12} N_1 Q = A_{21} N_2 + B_{21} N_2 Q$$

$$Q = \frac{A_{21}}{\frac{N_1}{N_2} B_{12} - B_{21}}$$

→ From Boltzmann's distribution law, at a given temperature T, the ratio of the population of two levels is given by,

$$\frac{N_1}{N_2} = e^{(E_2 - E_1)/kT} = e^{h\nu/kT}$$

→ Also, According to Planck's black body radiation theory,

$$Q = \frac{8\pi hc}{\lambda^5} \frac{1}{e^{h\nu/kT} \; 1} \longrightarrow (1)$$

→ Then, $Q = \dfrac{A_{21}}{B_{12} e^{h\nu/kT} - B_{21}} = \dfrac{A_{21}}{B_{21} (e^{h\nu/kT} - 1)}$ → (2)

for $B_{21} = B_{12}$

→ Comparing (1) & (2)

$$\frac{A_{21}}{B_{21}} = \frac{8\pi hc}{\lambda^5}$$

Here, A & B are called as Einstein's Coefficients. which gives the value of ratio of Spotaneous to Stimulated emission.

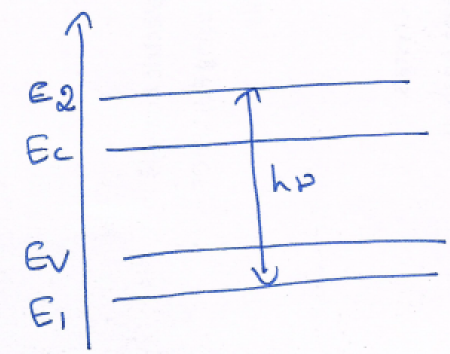
6. What is optical joint density of states? Write the expression for finding optical joint density of states and state how it is relates with energy band gap of materials.

Optical Joint Density of States.

There are Conditions under which the transitions leading to absorption and emission of radiation take place.

Conservation of Energy:

→ The absorption or emission of a photon of energy $h\nu$ requires that the energies of the two states involved in the interaction be separated by $h\nu$.



→ The Conservation of energy is followed ~~vote~~ for a photon emission to occur by electron-hole recombination, when an electron occupying an energy level E_2 interacts with a hole occupying an Energy level E_1.

$$E_2 - E_1 = h\nu$$

Conservation of Momentum:

→ Momentum must also be Conserved in the process of photon emission/absorption,

$$p_2 - p_1 = h\nu/c = h/\lambda$$

$$k_2 - k_1 = 2\pi/\lambda$$

→ The photon/momentum magnitude h/λ is very small in comparison with range of momentum values that electrons and holes can assume.

→ Hence, the momenta of the electron and hole participating in the interaction must therefore be approximately equal.

→ This condition, $k_2 \approx k_1$, is called the k- selection rule.

→ Transitions obeying this rule are represented in E-k diagram by vertical lines, indicating that the change in k is negligible on the scale of the diagram.

2

Energies and Momenta of the Electron and Hole with which a photon interacts.

→ Conservation of energy and momentum require that a photon of frequency ν interact with electrons and holes of specific energies and momenta determined by semiconductor E-k relation.

→ For a direct bandgap semiconductor,

$$E_c - E_v = E_g.$$

$$E_2 - E_1 = \frac{\hbar^2 k^2}{2m_v} + E_g + \frac{\hbar^2 k^2}{2m_c} = h\nu.$$

where, $k^2 = \frac{2m_r}{\hbar^2}(h\nu - E_g)$

$$\frac{1}{m_r} = \frac{1}{m_v} + \frac{1}{m_c}$$

→ Then,

$$E_2 = E_c + \frac{m_r}{m_c}(h\nu - E_g).$$

$$E_1 = E_v - \frac{m_r}{m_v}(h\nu - E_g) = E_2 - h\nu$$

→ If $m_c = m_v$.

$$E_2 = E_c + \frac{1}{2}(h\nu - E_g).$$

Optical Joint Density of States.

→ The density of states $\rho(\nu)$ with which a photon of energy $h\nu$ interacts under conditions of energy and momentum conservation in a direct-bandgap semiconductor.

→ This quantity incorporates the density of states in both the conduction and valence bands is called the optical joint density of states.

Density of states of conduction band, $\rho_c(E_2)$

$$\rho(\nu)\, d\nu = \rho_c(E_2)\, dE_2$$

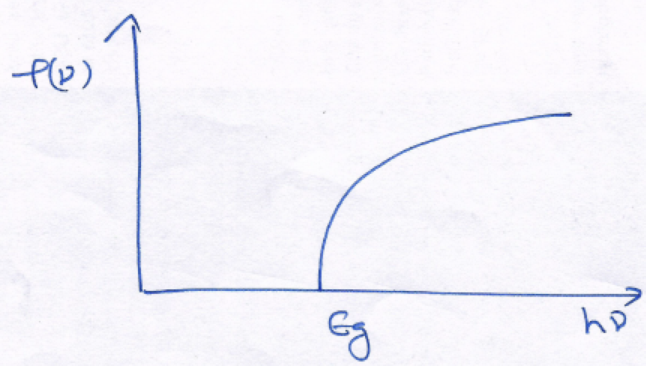
$$\rho(\nu) = \frac{dE_2}{d\nu} \rho_c(E_2).$$

$$\rho(\nu) = \frac{h m_r}{m_c} \rho_c(E_2)$$

→ The number of states per unit volume per unit frequency

$$\rho(\nu) = \frac{(2m_r)^{3/2}}{\pi \hbar^2} \sqrt{h\nu - E_g}, \quad h\nu \geq E_g$$

[Optical Joint Density of States]



The DOS with which a photon of energy $h\nu$ interacts increases with $h\nu - E_g$ in accordance with a square-root law

7. What is Density of states for photons? Write the expression to find density of state for photons in -terms of energy and frequency.

Density of States for Photons. ①

→ To define the density of states for the photon field, the periodic boundary condition is used that the wave function should be periodic in x, y, z directions with a period L.

→ Therefore,

$$k_x = l\frac{2\pi}{L}, \quad k_y = m\frac{2\pi}{L}, \quad k_z = n\frac{2\pi}{L}$$

→ The volume of a state in k-space is therefore $(2\pi/L)^3$

→ The volume of a state in k-space is therefore $(2\pi/L)^3$

→ Using the dispersion relation for the photon.

$$\omega_k = \frac{kc}{n_r}.$$

when c/n_r is the speed of light in the medium with a refractive index n_r,

→ By changing the sum over $\vec{k}$ to an integral,

$$\frac{d^3k}{(2\pi/L)^3} = \frac{k^2\, dk\, d\Omega}{(2\pi/L)^3}$$

where, $(2\pi/L)^3 \to$ differential volume in k-space.
$d\Omega \to$ differential solid angle

→ Then, $N(E_{21}) = \frac{2}{V}\sum_{k} \delta(E_2 - E_1 - E_k)$

$\rightarrow$ Then, $N(E_{21}) = \frac{2}{V}\sum_{K} \delta(E_2 - E_1 - E_K)$

$$= 2\int \frac{K^2 dK\, d\Omega}{(2\pi)^3}\, \delta[E_2 - E_1 - E_K]$$

where V is the volume of space.

$E_K = \hbar\omega_K = \frac{\hbar K c}{n_r}$ is the photon energy

Here, the integration over solid angle is 4π.

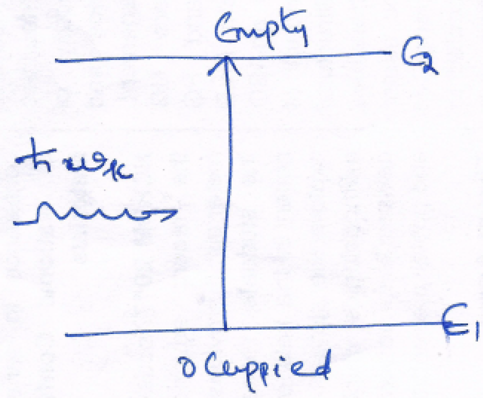
(2)

$\rightarrow$ Then, $N[E_{21}) = \frac{8\pi n_r^3 E_{21}^2}{h^3 c^3} = \frac{n_r^3 E_{21}^2}{\pi^2 \hbar^3 c^3}$

which is the number of states with photon energy E_{21} per unit volume per energy interval, $cm^{-3}(eV)^{-1}$

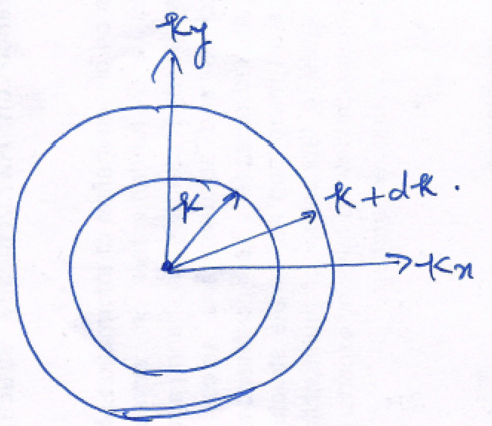
& $E_{21} = E_2 - E_1$ is the energy spacing between the two levels.

(a)



A photon incident on a discrete two-level System where Level 1 is occupied and level 2 is empty.

(b)



The k-Space diagram for the density of photon States.

$$k_x = l\frac{2\pi}{L},\quad k_y = m\frac{2\pi}{L},\quad k_z = n\frac{2\pi}{L}.$$

8. Define the concept of Fermi Golden rule. Write the equation to find transition rate per unit volume of a system.

Optical Transitions Using Fermi's Golden Rule

→ Consider a Semiconductor illuminated by light.

→ The interaction between the photons and the electrons in the Semiconductor can be described by the Hamiltonian

$$\vec{H} = \frac{1}{2m_0}(\vec{p} - e\vec{A})^2 + \vec{V}(r)$$

where, m_0 is the free electron mass.

$e = -|e|$ for electrons.

$\vec{A}$ is the vector potential accounting for the presence of electromagnetic field.

$V(r)$ ~~is~~ is the periodic potential.

→ The electron-photon interaction Hamiltonian can be derived by ~~exap~~ expanding the Hamiltonian,

$$\vec{H} = \frac{p^2}{2m_0} + \vec{V}(r) - \frac{e}{2m_0}(\vec{p}\cdot\vec{A} + A\cdot\vec{p}) + \frac{e^2A^2}{2m_0}$$

$$\simeq H_0 + H'$$

where, $H_0 \rightarrow$ Unperturbed Hamiltonian.

$H' \rightarrow$ Perturbation due to light Hamiltonian

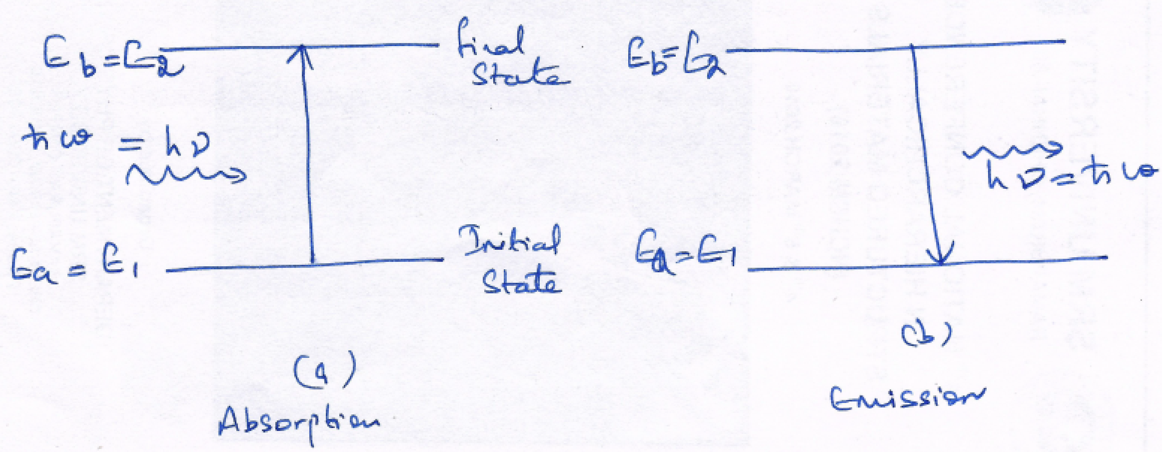
$$H_0 = \frac{p^2}{2m_0} + \vec{V}(r)$$

Also, the Coloumb gauge $\nabla \cdot \vec{A} = 0$

since, $\vec{p} = (\hbar / i)\, \nabla$

(2)

→ Transition rate due to Electron - Photon interaction.



→ Using Time-dependent perturbation theory, the transition rate for the absorption of a photon can be derived, assuming an electron is initially at state E_1, is given by Fermi's Golden rule.

→ $$W_{abs} = \frac{2\pi}{\hbar} |\langle b|H'(r)|a\rangle|^2 \delta(E_b - E_a - \hbar\omega)$$

Where, $E_b > E_a$ is assumed.

→ The total upward transition rate per unit volume ($s^{-1}cm^{-3}$) in the crystal taking into account the probability that state E_a is occupied and state b is empty is.

$$R_{a \to b} = \frac{2}{V} \sum_{k_a} \sum_{k_b} \frac{2\pi}{\hbar} |H'_{ab}|^2 \delta(E_b - E_a - \hbar\omega) f_a (1 - f_b)$$

Σ denotes the sum over initial and final states

f_a → Fermi-Dirac distribution that E_a is occupied

$(1 - f_b)$ → Fermi-Dirac distribution that E_b is empty

→ The prefactor 2 takes into account the sum over spins.

3

→ The Matrix element H'_{ba} is given by.

$$H'_{ba} = \langle b|H'(r)|a\rangle = \int \psi_b^*(r)\, H'(r)\, \psi_a(r)\, d^3r$$

→ Similarly, the transition rate for the emission of a photon if an electron is initially at state E_b is.

$$W_{ems} = \frac{2\pi}{\hbar} |\langle a|H'^{+}(r)|b\rangle|^2 \, \delta(E_a - E_b + \hbar\omega)$$

→ The downward transition rate per unit volume ($s^{-1} cm^{-3}$) is

$$R_{b\to a} = \frac{2}{V} \sum_{k_a} \sum_{k_b} \frac{2\pi}{\hbar} |H'^{+}_{ab}|^2 \, \delta(E_a - E_b + \hbar\omega) \, f_b(1 - f_a)$$

→ Using even property of δ (delta function)

$$\delta(-x) = \delta(x)$$

$$|H'_{ba}| = |H'^{+}_{ab}|$$

→ The net upward transition rate per unit volume can be given as

$$R = R_{a\to b} - R_{b\to a}$$

$$= \frac{2}{V} \sum_{k_a} \sum_{k_b} \frac{2\pi}{\hbar} |H'_{ba}|^2 \, \delta(E_b - E_a - \hbar\omega) \, (f_a - f_b)$$

→ Optical Absorption Coefficient.

The absorption Coefficient α (1/cm) in the Crystal is the fraction of photons absorbed per unit distance

$$\alpha = \frac{\text{Number of photons absorbed per second per unit volume}}{\text{Number of injected photons per second per unit area.}}$$

(4)

→ The injected number of photons per second per unit area is the optical intensity $P(W/cm^2)$ divided by the energy of a photon $\hbar\omega$.

→ Therefore,

$$\alpha(\hbar\omega) = \frac{R}{P/\hbar\omega} = \frac{\hbar\omega}{\left(\frac{n_r c \varepsilon_0 \omega^2 A_0^2}{2}\right)} R$$

where, $R \rightarrow$ net upward transition rate per unit volume

$\omega \rightarrow 2\pi/\lambda$, wave number/angular velocity

$c \rightarrow$ Velocity of light

$n_r \rightarrow$ refractive index of the medium.

$A \rightarrow$ Vector potential for electromagnetic field.

$\varepsilon_0 \rightarrow$ permittivity of free space

9.What is optical Amplification and feedback?

Optical Amplification and feedback.

Laser Amplification

→ Light amplification is achieved by stimulated emission from an atomic or molecular system with a transition whose population is inverted.

→ Population inversion: The upper energy level is more ~~at~~ populated than the lower.

→ The laser amplifier is a distributed-gain device characterized by its gain coefficient (gain per unit length) $\gamma(\nu)$, which governs the rate ~~of~~ at which the photon-flux density, ϕ increases

→ When the photon-flux density ϕ is small, the gain coefficient

$$\gamma_0(\nu) = N_0\sigma(\nu) = N_0 \frac{\lambda^2}{8\pi t_{sp}} g(\nu)$$

Where,

N_0 = equilibrium population density difference, N_0 increases with increasing pumping rate

$\sigma(\nu) = \frac{\lambda^2}{8\pi t_{sp}} g(\nu)$ = transition cross section

$8\pi t_{sp}$

t_{sp} = Spontaneous lifetime

$g(\nu)$ = transition lineshape.

$\lambda = \frac{\lambda_0}{n}$ = wavelength in the medium with refractive index n

(2)

Losses inside amplification system.

→ The intensity of a light beam in a amplifier system, gradually diminishes owing to various losses such as absorption, radiation through the side surface, etc.

→ The intensity diminishes by an exponential law

$$I(z) = I_0 \exp(-\alpha z)$$

where, α is the loss factor.

→ The energy in the beam diminishes exponentially according to the equation,

$$W(t) = W_0 \exp(-t/\tau_c)$$

Where, the energy falls to its W/e Value in time τ_c

→ The distance covered by the light flux in time τ_c is

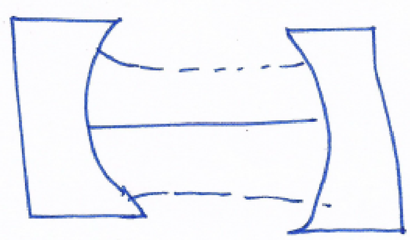
$$z = c\tau_c$$

$$I(z) = I_0/e$$

where, $\alpha z = \alpha c \tau_c = 1 \Rightarrow \alpha = 1/c\tau_c$

→ If the losses are of different types, the association of α_i lossfactor with each of loss is possible and further, if they are independent of each other, then

$$\alpha = \sum \alpha_i$$



(a) A ~~Conc~~ Confocal Resonator.

9. What is photovoltaic effect? Draw the diagram to show p-n junction under illumination.

Photovoltaic Effect

→ Sunlight can be converted to electricity due to the photovoltaic effect discovered by Edmund Becquerel, a french scientist in 1839.

→ Sunlight is composed of photons, or packets of energy. These photons contain various amount of energy corresponding to the different wavelengths of light.

→ when photons strike a solar cell, a semiconductor P-N Junction device, they may be reflected or absorbed, or they may pass through the cell.

→ Absorption of a photon in a solar cell results in the generation of electron-hole pair (EHP)

→ This EHP, when separated from each other across the P-N Junction, results in the generation of a voltage across the junction.

→ This voltage can drive a current in an external circuit, which is called as photocurrent

→ The device is called as Photovoltaic Cell or device.

Photo voltaic Effect – p-n Junction under illumination.

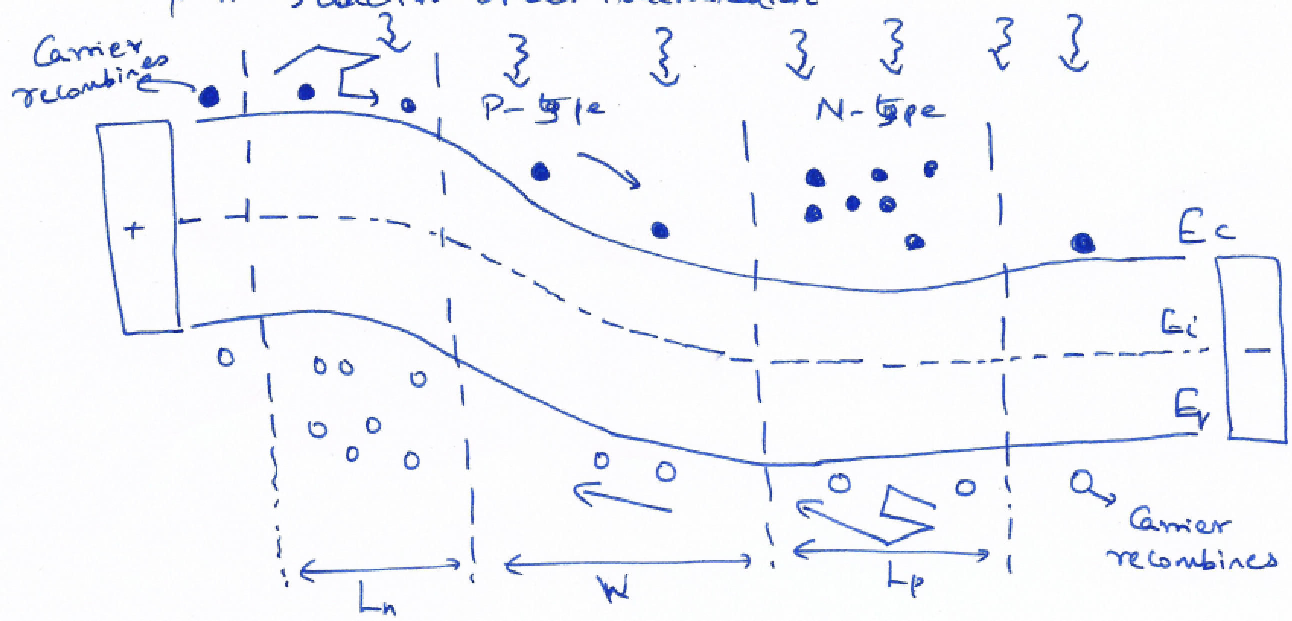
→ When there is no light falling on the diode (p-n junction) no electron-hole pair is generated for photocurrent.

→ But p-n junction is illuminated, it absorbs solar radiation and electron-hole pairs are generated.

→ It can be safely assumed that the generation rate of electron-hole pairs will be uniform in the p-n junction area, extended to the entire [illegible] area.

p-n Junction Under illumination

(2)



→ Under the uniform illumination Condition, generation of Carrier will occur in the Space-Charge region as well as quasi-neutral region.

→ The Carriers that are generated in the Space-Charge region will be immediately be Swept away due to the electric field (electrons towards N-side and holes towards p-side).

→ Due to the electric field, chances of recombination of these electrons pairs are quite less.

→ The electron-hole pairs which are generated in the quasi-neutral region will move around in a random manner.

→ In their random motion, Some of the generated minority Carriers will Come near to the Space-charge region edge, where they will experience a force due to electric field and will be pulled at the other Side.

→ Only the minority Charge Carriers will Cross the junction.

③

→ Minority electrons from P-side will Come to N-side (leaving behind their positively Charged partner, hole)

(leaving behind their positively charged ...)

→ Minority holes will come from N-side to p side (leaving behind their negatively charged partner, an electron).

→ There is a net increase in the positive charges at P-side and a net increase in negative charge at N-side.

→ This build up of a positive and negative charge causes a potential difference to appear across the P-N junction due to light falling on it.

→ This generation of photovoltage is called Photovoltaic effect

→ The contribution to the photovoltage is coming only from the carriers that are generated within the width ($L_n + W + L_p$)

Light Generated Current

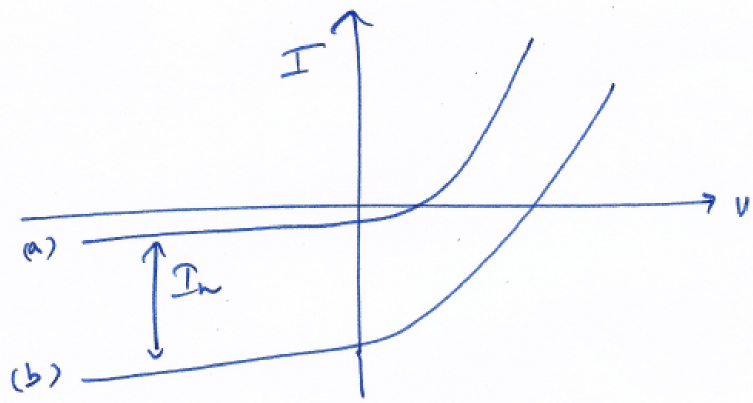
→ In a P-N junction diode, four current components are present in equilibrium condition: electron drift, electron diffusion hole current and hole diffusion.

→ In equilibrium condition, net current is zero which requires the drift and diffusion currents of carriers to be equal and opposite.

→ When pn-junction is illuminated, a net large drift current due to minority electrons and holes, which flows from N-side to p-side.

→ Since, this current flow is generated by light, it is known as light-generated current or photocurrent, I_L.

→ Hence, the power can be generated by the device.



(a) Dark I-V Curve.

(b) when light shines on a p-N Junction diode,
IV Curve of illuminated p-n Junction

→ The overall effect of light shining is to shift the I-V Curve of the diode downwards in the current-voltage axis.

Solar cell-Applications of photovoltaic effect

Application of Photovoltaic Effect - Solar Cell.

- → When light shines on a Solar Cell, photovoltage is generated.
- → The generated voltage across the Solar Cell can drive the current in external circuit and therefore can deliver power.
- → In order to collect the energy of a photon in the form of of electrical energy, through Solar Cells, the following actions must take place:
  - (a) increase in the potential energy of Carriers (generation of electron-hole pairs).
  - (b) Separation of Carriers.
- → I-V equation for the Solar Cell can be derived in the same manner as that for a P-N junction diode.
- → Here, the generation term G will not be zero, as it is taking place in the space charge region and recombination is zero.
- → The Total Current through the junction is given by,

$$I_{total} = qA\left(\frac{D_n}{L_n} n_{p0} + \frac{D_p}{L_p} p_{n0}\right)\left(e^{qV/\eta kT} - 1\right) - qAG\left(L_n + L_p + W\right)$$

$$I_{total} = I_0\left(e^{qV/\eta kT} - 1\right) - I_L.$$

$$I_{total} = I_o\left(e^{qV/nkT} - 1\right) - I_L.$$

where $I_L = qAG(L_n + L_p + W)$ is the light generated current.

→ This indicates that the carriers generated within the volume of cross-sectional area A and length $(L_n + L_p + W)$ contribute to I_L.

10. Define the given terms used to find efficiency of solar cell: (i) Short circuit current,

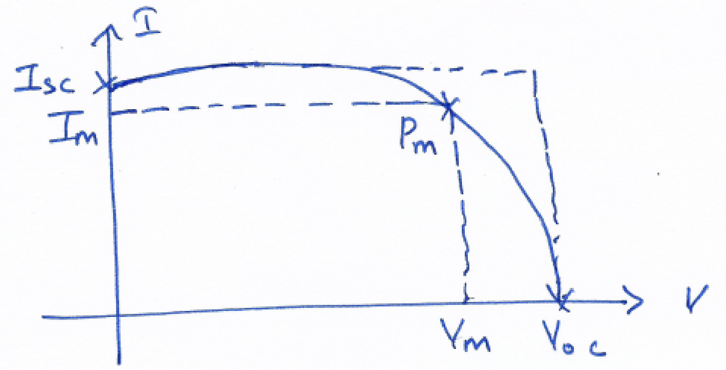
Determination of Efficiency of a Solar Cell.

→ Solar Cells are characterized and compared with each other with four parameters:

1 Short Circuit Current, I_{sc}: (mA/cm^2)

→ This is the maximum current ~~that~~ flows in a Solar Cell when its terminals at p-side and N-side are shorted with each other, i.e, $V = 0$

→ $I_{sc} = -I_L$, where Shortcircuit Current is nothing but the light-generated current.



Typical plot of a solar cell I-V curve and its parameters.

(ii) Open circuit voltage and

2 Open Circuit Voltage V_{oc}: (mV or V)

→ It is the maximum voltage generated across the terminals of a Solar Cell when they are kept open, i.e, $I = 0$.

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{I_L}{I_o} + 1\right)$$

(iii) Fill factor.

③ Fill factor FF: (%)

→ It is the ratio of the maximum power $P_m = V_m \times I_m$ that can be extracted from a solar cell to the ideal power $P_o = V_{oc} \times I_{sc}$.

$$FF = \frac{P_m}{P_o} = \frac{V_m I_m}{V_{oc} I_{sc}}$$

②

→ FF represents the squareness of the solar I-V curve.

(iv)Efficiency

(4) Efficiency η : (mW/cm^2 or W/m^2)

→ The ratio of the power output to power input.

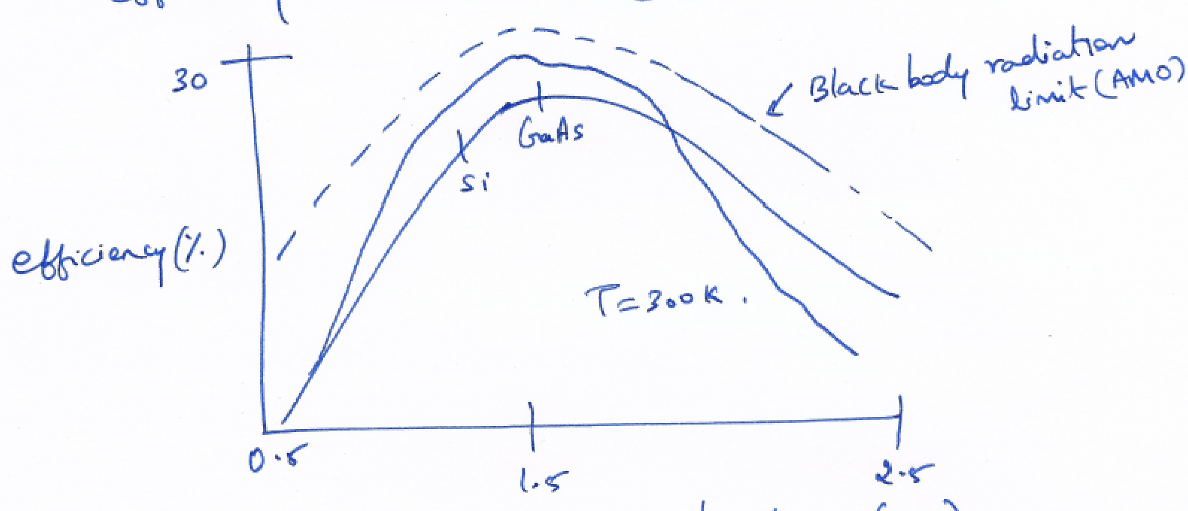
→ The power output is the maximum power point P_m of a solar cell.

→ Input power is the power of Solar radiation P_{rad}.

$$\eta = \frac{P_m}{P_{rad}}.$$

$$\eta = \frac{V_m I_m}{P_{rad}} = \frac{V_{oc} I_{sc} FF}{P_{rad}}.$$

Efficiency in terms of Bandgap.



Maximum Possible Solar Cell efficiencies as a function of

Maximum possible Solar

energy band gap of SemiConductor Materials.

→ There is an optimum bandgap for which efficiency of a Solar Cell would be maximum.

→ The open circuit voltage of a Solar Cell increases with increase in bandgap.

11. Determine the Open-Circuit Voltage V_{oc} of the solar cell, if Saturation Current (I_s) = 0.75×10^{-10} A, Light Generated Current (I_L) = 0.65 A, Ideality Factor (n) = 0.9, and Temperature (T) = 310K. (Answer: V_{oc}= 0.55V)

12. Determine the Conversion Efficiency of the solar cell, if Short-Circuit Current (I_{sc}) = 3.5A, Open-Circuit Voltage (V_{oc})= 0.6V, Fill Factor (FF) = 0.7 and Input Power (P_{in}) = 10W. (Answer: Conversion Efficiency =14.7%)

$I_{sc} = 3.5\,A$ $\quad \eta = ?$

$V_{oc} = 0.6\,V$

$FF = 0.7$

$P_{in} = 10\,W$

$$\eta = \frac{P_m}{P_{rad}} = \frac{P_{out}}{P_{in}} = \frac{V_m I_m}{10} = \frac{V_{oc} \times I_{sc} \times FF}{10}$$

$$= \frac{V_{oc} \times 3.5 \times 0.7}{10}$$

$$FF = \frac{V_m \times I_m}{V_{oc} \times I_{sc}}$$

$$= \frac{0.6 \times 3.5 \times 0.7}{10}$$

$$= \frac{0.42 \times 3.5}{10}$$

$$= 0.147$$

or

14.7%

13. Define the efficiency of solar cell. Write the expression and a plot to show variation of efficiency with band gap of materials

④ Efficiency η : (mW/cm² or W/m²)

→ The ratio of the power output to power input.

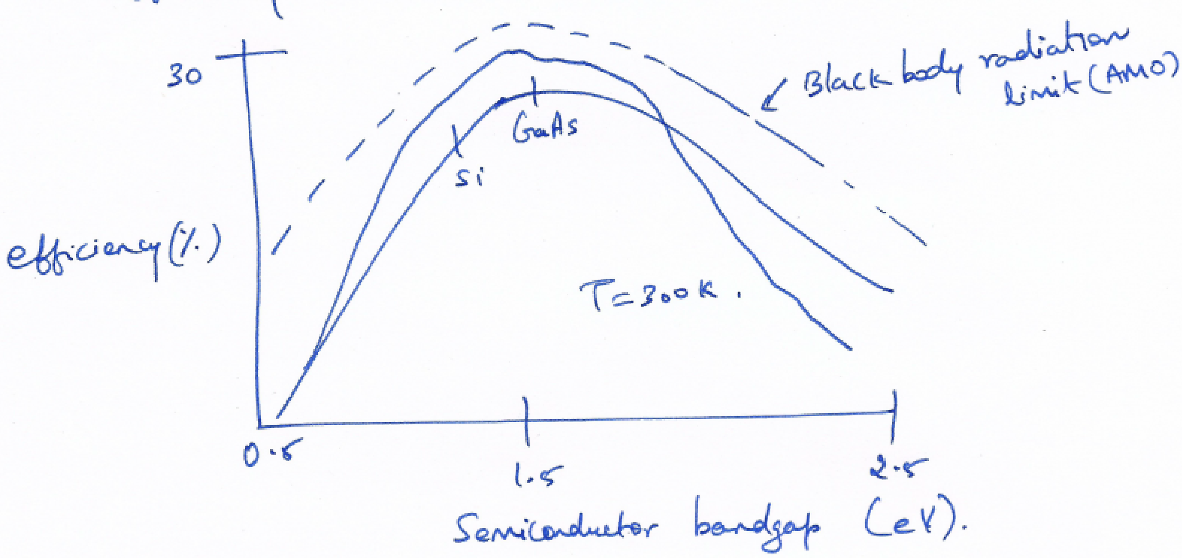
→ The power output is the maximum power point P_m of a solar cell.

→ Input power is the power of solar radiation P_{rad}.

$$\eta = \frac{P_m}{P_{rad}}.$$

$$\eta = \frac{V_m I_m}{P_{rad}} = \frac{V_{oc} I_{sc} FF}{P_{rad}}.$$

Efficiency in terms of Bandgap.



Maximum Possible Solar Cell efficiencies as a function of

Maximum possible solar cell ... energy band gap of semiconductor materials.

→ There is an optimum band gap for which efficiency of a solar cell would be maximum.

→ The open circuit voltage of a solar cell increases with increase in bandgap.

14. Define any three losses which decreases the efficiency of solar cell.

Losses in Solar Cells determining efficiency.

① Loss of low energy photons:

→ Photons of energy value less than that of the bandgap values donot get absorbed in the material.

② Loss due to excess energy of photons:

→ when the photon energy E is higher than the bandgap energy E_g, the excess energy $= E - E_g$ is given off as a heat to the material.

③ Voltage Loss:

→ The voltage corresponding to the bandgap of a material is obtained by dividing the bandgap by charge, E_g/q. This is referred to as bandgap voltage.

④ Fill factor loss:

→ The ff factor is around 0.89.

→ This type of loss arises due to the parasitic resistance (series and shunt resistance) of the cell.

⑤ Loss by reflection.

→ A part of incident photons is reflected from the cell surface

⑥ Loss due to incomplete absorption.

→ The loss of photons which have enough energy to get absorbed in the solar cell, but do not get absorbed in the cell due to limited solar cell thickness.

⑦ Loss due to metal coverage:
→ Shadows due to metal contacts, reduce illumination area

⑧ Recombination Losses:
→ Not all the generated electron-hole pairs contribute to the Solar Cell Current and Voltage due to recombination losses.

15. Make a short note on postulates of Drude model for electrical conductivity of material. Define the term
(i) Drift Velocity, (ii) Relaxation time of electron.

Drude - Lorentz Theory.

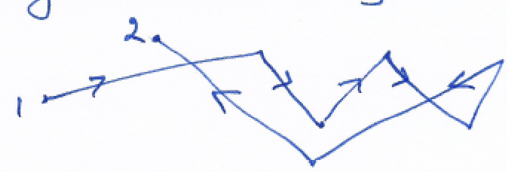
→ The first theory, namely, classical free electron theory, was developed by Drude and Lorentz in 1900.

→ According to this theory, metal contains free electrons which are responsible for the electrical conductivity and metals obey the laws of classical mechanics.

→ The classical free electron theory reveals that the free electrons are fully responsible for electrical conduction.

Postulates of classical free Electron Theory.

→ The free electrons or electron gas, available in a metal move freely here and there during the absence of an electric field similar to the gas molecules moving in a vessel.

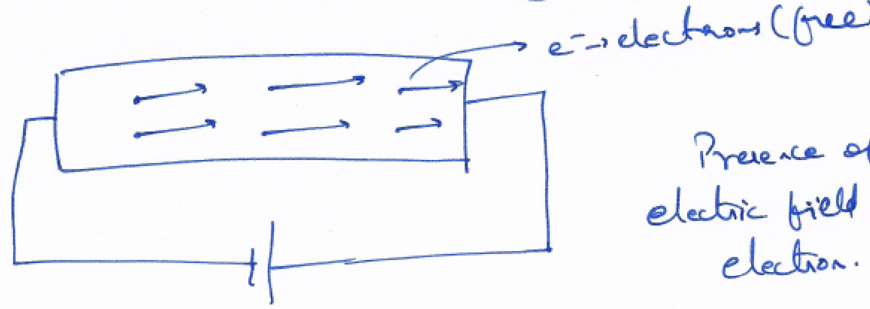


Absence of electric field, free electron.

→ These free electrons collide with other free electrons or positive ion cores and the walls of the container. Collisions of this type are known as elastic collisions.

→ The total energy of an electron is assumed to be purely kinetic energy.

→ Suppose an electric field is applied to the material through an external source, the free electrons gain some energy and are directed to move towards a higher potential.



Presence of electric field - free electron.

→ These electrons acquire a constant velocity known as drift velocity, which obey the Maxwell - Boltzmann distribution studies.

→ Drift velocity: It is defined as the average velocity acquired by the free electrons in a particular direction during the presence of an electric field.

→ Relaxation Time: The relaxation time is defined as the time taken by a free electron to reach its equilibrium position from its disturbed position, during the presence of an applied field.

$$\tau = \frac{l}{\langle v \rangle}$$

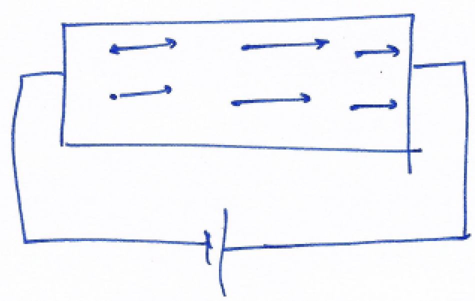
where l is the distance traveled by the electrons.

16. Write the expression to find electrical conductivity using Drude model.

Expression for Electrical Conductivity.

→ Consider a Conductor which is Subjected to an electric field of strength E.

→ Consider that "n" is the Concentration of free electrons with mass "m" and charge "e".

→ 

Metal- Conduction.

→ According to Newton's Second law of motion, the force f acquired by the electrons is equal to the force exerted by the field ~~of~~ on the electrons.

→ The equation of motion, $ma = -eE \Rightarrow a = \frac{-eE}{m}$

→ Acceleration, $a = \frac{-eE}{m}$

→ velocity, $v = -\frac{eE}{m} t + c$ (by integrating $ma = eE$)

where, C = integrating Constant

→ when there is no electric field, the average velocity of electron is zero

→ Then, $t = 0$, $\langle v \rangle = 0$ leading to $C = 0$

→ Hence velocity of an electron, $v = -\frac{eE}{m} t$

→ According to ohm's law, the current density in a Conductor,

$$J = \frac{I}{A}$$

→ The charge dq flowing through this area A in time dt is given by.

$$dq = -enAv\,dt$$

$$\frac{dq}{dt} = I = -enAv$$

(A)

where I is the current flowing through the Conductor with an

Cross Section A.

→ $J = -nev = \frac{ne^2 E}{m} t$

$$\boxed{J = \frac{ne^2 E}{m} t}$$

→ The current density is directly proportional to the applied field E.

→ When the field increases, the current density also increases and its remains infinity when the field is applied for a long time.

→ Actually, J never becomes infinity.

→ It remains constant beyond a certain field strength.

→ This is due to the presence of collision of free electrons which is not taken into account for the derivation of conductivity.

17. Determine the Conductivity ( ) of the Intrinsic Semiconductor. The given parameters are: μ_e = 0.145 m^2/V-s; μ_h= 0.055 m^2 /V-s; n_i= $1.5625\times10^{16}/m^3$; q = 1.602×10^{-19} C. (Answer: 5 x 10^{-4} mhos/m).

7. $\sigma = ?$

$\mu_e = 0.145$ ~~[illegible]~~

$\mu_h = 0.055$

$n_i = 1.5625 \times 10^{16}$

$q = 1.6 \times 10^{-19}$ c

$$\sigma = n_i q (\mu_e + \mu_h)$$

$$= 1.5625 \times 10^{16} \times 1.6 \times 10^{-19} (0.145 + 0.055)$$

$$= 0.5 \times 10^{-3} \text{ mhos/m}$$

14. Bands of alternating light and dark lines that are formed by inelastic scattering interactions that are related to atomic spacings in the specimen are called ____.
(A) Auger bands (B) Bragg bands (C) Lorentz bands (D) **Kakuchi bands**

15. Nanotechnology deals with ___ of nanostructures into useful nanoscale devices such as electronic circuits and mechanical devices at the molecular level
(A) the design (B) manufacturing (C) applications (D) **engineering**

1.What do you mean by Density of states?
• The density of states function describes the number of energy states that are available in a system and is essential for determine the carrier concentrations and energy distributions of carriers within a semiconductor.
• In semiconductors, the free motion of carriers is limited to two, one and zero spatial dimensions. When applying semiconductor statistics to systems of these dimensions, the density of states in quantum well (2D), quantum wires (1D) and quantum dots (0D) must be known.
2. What are low dimensional systems?
•A low-dimensional system, also called confined system, is any way quantum system in which the carriers are free to move in two, one, or zero dimensions in these systems, the spatial dimensions are of the order of De Broglie wavelength of the carriers and therefore the carrier energy states and density of states become quantized. As a result, the electronic, electrical, and optical behaviour of the carriers are governed by quantum mechanical principles or mechanisms
• A low-dimensional system is one where the motion of microscopic degrees-of-freedom, such as electrons, phonons or photons, is restricted from exploring the full three dimensions of the present world.
• In the low dimensional quantum systems such as Quantum well, Quantum wire and Quantum dot, the charge carriers are free to move in two, one and zero dimensions respectively.
• The main advantages of these low dimensional semiconductor systems are in the realizations of important devices, like the double heterostructure lasers with low threshold at room temperature, high effective LEDs, bipolar transistors, p-n-p-n switching devices, high electron mobility transistors (HEMT) and many other optoelectronic devices.
3. Brief the DOS in low dimensional systems?
• A low-dimensional system is one where the motion of microscopic degrees-of-freedom, such as electrons, phonons or photons, is restricted from exploring the full three dimensions of the present world.
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4. Compare the DOS in OD,1D and 2D systems. ************
in zero-dimensional (0D) nanomaterials all the dimensions are measured within the nanoscale (no dimensions are larger than 100 nm). Most commonly, 0D nanomaterials are nanoparticles.
In one-dimensional nanomaterials (1D), one dimension is outside the nanoscale. This class includes nanotubes, nanorods, and nanowires.

In two-dimensional nanomaterials (2D), two dimensions are outside the nanoscale. This class exhibits plate-like shapes and includes graphene, nanofilms, nanolayers, and nano coatings.

5. Discuss about quantum well, quantum wire and quantum dot.

Quantum well: -

•If one dimension is reduced to the nano-range while the other dimensions remain large, then we obtain a structure known as quantum well. In these systems the particles are confined in one direction and are free to move in two directions.

•The conduction electrons are confined in a narrow dimension and such a configuration is referred as quantum well.

Quantum wire: -

•If two dimensions are reduced the nano-range and one remain large, the resulting structure is referred to as a quantum wire. In these systems the particles are confined in two directions and are free to move in one direction

•A quantum wire is a structure such as a copper wire that is long in one dimension, but has a nano-meter size as its diameter. In this case, the electrons move freely along the wire but are confined in the transverse directions.

Quantum dot: -

•The extreme case of this process of size reduction in which all three dimensions reach the low nano-meter range is called a quantum dot. In these systems the particles are confined in all three directions and can not move freely in any spatial direction.

•The quantum dot may have the shape of a tiny cube, a short cylinder or a sphere with low nanometre dimensions.

6. What are the different allotropes of carbon?

•Diamond, graphite and fullerenes (substances that include nanotubes and 'buckyballs', such as buckminsterfullerene) are three allotropes of pure carbon.

7. Write the properties of CNT.

CNT exhibits extraordinary mechanical properties:

•The Young's modulus is over 1 Tera Pascal. It is stiff as diamond.

•The estimated tensile strength is 200 GPa. These properties are ideal for reinforced composites, Nano electromechanical systems (NEMS)

•Apart from remarkable tensile strength, CNT nanotubes exhibit varying electrical properties (depending on the way the graphite structure spirals around the tube, and other factors, such as doping), and can be superconducting, insulating, semiconducting or conducting (metallic)

•CNT Nanotubes can be either electrically conductive or semi conductive, depending on their helicity (shape), leading to nanoscale wires and electrical components.

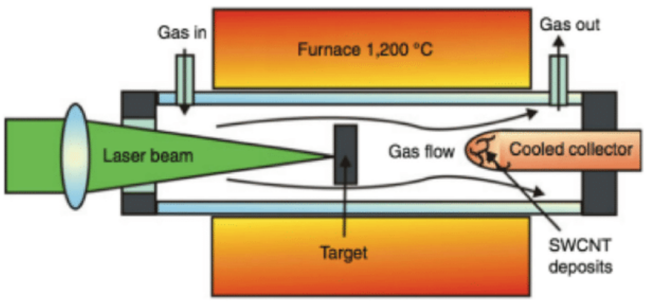
Chemical reactivity:

•The chemical reactivity of a CNT is very high as compared with a graphene sheet because of its curved surface.

•A Nanotube with smaller diameter results in increased reactivity.

8. How will you synthesize CNT by Laser ablation?

Process: -



<u>Process: -</u>

•Vaporizes graphite at 1200 0C with Helium or argon gas
• A hot vapor plume forms and expands and cools rapidly
• Carbon molecules condense to form large clusters
• Yield of up to 70%

9. Give any 3 Applications of CNT.

•Carbon Nanotube can be used as a conducting channel in Field emission Transistor
•Because of their flexibility, Nanotubes can also be used in scanning probe instruments.
•High Strength Composites
•Conductive Composites
•Medical Applications

10. Brief on the working of CVD

<u>A basic CVD process consists of the following steps: -</u>

•A predefined mix of reactant gases and diluent inert gases are introduced at a specified flow rate into the reaction chamber;
•The gas species move to the substrate;
•The reactants get adsorbed on the surface of the substrate;
•The reactants undergo chemical reactions with the substrate to form the film; and
•The gaseous by-products of the reactions are desorbed and evacuated from the reaction chamber.

11. Differentiate heterogenous and homogenous reactions in CVD

s.no	Homogeneous reactions	Heterogeneous reactions
1	Reactions that take place in the gas phase are known as homogeneous reactions	Reactions that take place at the substrate surface are known as heterogeneous reactions
2	selectively occur on the heated surface of the wafer where they create good-quality films.	Homogeneous reactions form gas phase aggregates of the depositing material, which adhere to the surface poorly and at the same time form low-density films with lots of defects.

•heterogeneous reactions are much more desirable than homogeneous reactions during chemical vapor deposition.

12. Differentiate Hot wall reactor and cold wall reactor in CVD

s.no	Hot wall reactor	cold wall reactor
1	a reactor is said to be 'hot-wall' if it uses a heating system that heats up not only the wafer	In cold wall reactors, the substrate itself is heated
2	In hot-wall reactors, films are deposited on the walls in much the same way as they are deposited on wafers.	'Cold-wall' reactors use heating systems that minimize the heating up of the reactor walls while the wafer is being heated up
3	Example: - radiant heating from resistance-heated coils.	Example: - of which is heating via IR lamps inside the reactor.

13. Classify CVD based on the operating pressure
•These are classified into 3 types based it on the range of their operating pressure.
1) Atmospheric pressure CVD
•Reactors operate at atmospheric pressure, and are therefore the simplest in design.
2) Low-pressure CVD
•reactors operate at medium vacuum (30-250 Pa) and higher temperature than APCVD reactors.
3) Plasma Enhanced CVD
•reactors also operate under low pressure, but do not depend completely on thermal energy to accelerate the reaction processes.

14. Brief on the working of PVD.
• Physical vapour deposition (PVD) is fundamentally a vaporisation coating technique, involving transfer of material on an atomic level. It is an alternative process to electroplating
• The process is similar to chemical vapour deposition (CVD) except that the raw materials/precursors, i.e. the material that is going to be deposited starts out in solid form, whereas in CVD, the precursors are introduced to the reaction chamber in the gaseous state.

15. What are the four 4 processes in PVD?
• PVD processes are carried out under vacuum conditions. The process involved four steps:
1.Evaporation
2.Transportation
3.Reaction
4.Deposition

Evaporation
During this stage, a target, consisting of the material to be deposited is bombarded by a high energy source such as a beam of electrons or ions. This dislodges atoms from the surface of the target, 'vaporising' them.

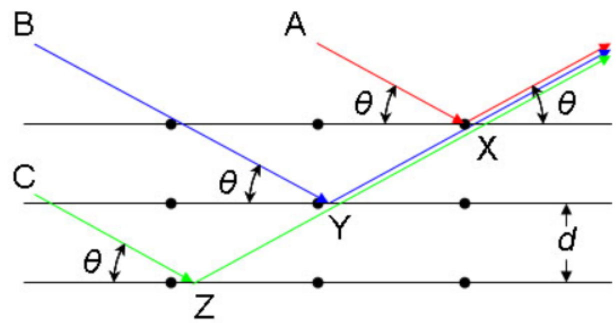
Transport
This process simply consists of the movement of 'vaporised' atoms from the target to the substrate to be coated and will generally be a straight-line affair.

Reaction
The atoms of metal will then react with the appropriate gas during the transport stage.

Deposition
This is the process of coating build up on the substrate surface. Depending on the actual process, some reactions between target materials and the reactive gases may also take place at the substrate surface simultaneously with the deposition process.

16. State Bragg's law?

Bragg's law: - The law states that when the x-ray is incident onto a **crystal** surface, its angle of incidence 'θ', will reflect back with a same angle of scattering 'θ'. And, when the path difference, d is equal to a whole number, n, of wavelength, a constructive interference will occur.



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

where:

- λ is the wavelength of the x-ray,
- d is the spacing of the crystal layers (path difference),
- θ is the incident angle (the angle between incident ray and the scatter plane), and
- n is an integer

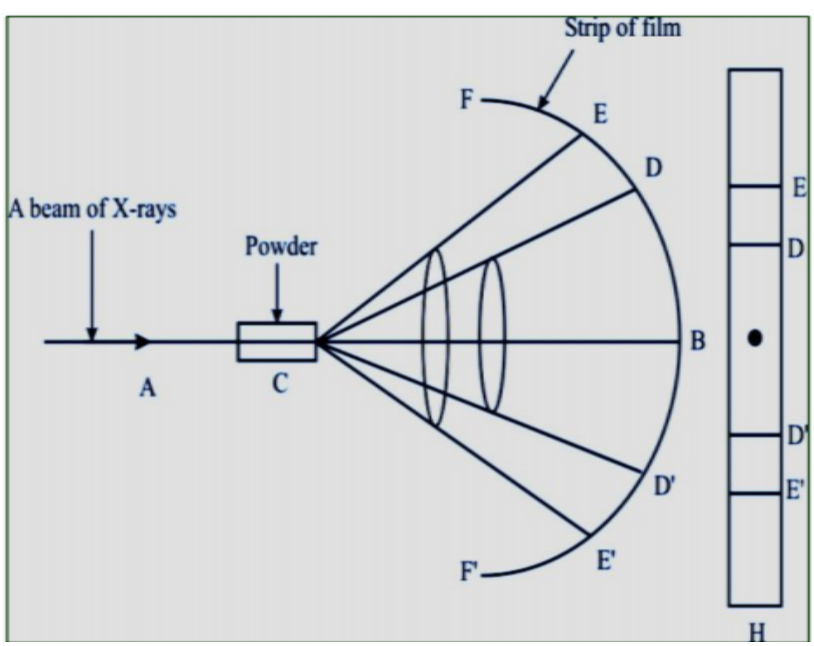
17. What is the method of Powder XRD?

The powder method:

•A narrow beam of monochromatic X-rays fall on the finely powdered specimen to be examined, and the diffracted rays are passed on to a strip of film which almost completely surrounds the specimen.

•The random orientation of crystals produces diffraction rings. This method is commonly used for identification purposes by comparing the data with the standard files available.

•For a cubic crystal the identification of lines in the powder photograph is simple compared to other types.



18. What is the principle of SEM?

• Scanning electron microscopes (SEMs) use an electron beam to image samples with a resolution down to the nano-meter scale. The electrons are emitted from a filament and collimated into a beam in the electron source. The beam is then focused on the sample surface by a set of lenses in the electron column.

• "Scanning Electron Microscopy", or SEM analysis, provides high-resolution imaging useful for evaluating various materials for surface fractures, flaws, contaminants or corrosion

19. How are backscattered, secondary and Auger electrons utilised in SEM?

Backscattered Electrons: -

•The production of backscattered electrons varies directly with the specimen's atomic number.

•This differing production rates causes higher atomic number elements to appear brighter than lower atomic number elements.

•This interaction is utilized to differentiate parts of the specimen that have different average atomic number.

Secondary Electrons: -

• Production of secondary electrons is very topography related.

• Due to their low energy, 5eV, only secondaries that are very near the surface (<10nm,) can exit the sample and be examined.

• Any changes in topography in the sample that are larger than this sampling depth will change the yield of secondaries due to collection efficiencies.

• Collection of these electrons is aided by using a "collector" in conjunction with the secondary electron detector.

Auger Electrons: -

• Auger Electrons have a characteristic energy, unique to each element from which it was emitted from.

• These electrons are collected and sorted according to energy to give compositional information about the specimen

20. What is the principle of TEM?

•TEM Principle: -The TEM operates on the same basic principles as the light microscope but uses electros instead of light. ... Because the wavelength of electrons is much smaller than that of light, the optimal resolution attainable for TEM images is many orders of magnitude better than that from a light microscope

21. How does unshattered, elastically scattered and inelastically scattered electrons provide information in TEM?

•When a specimen is a crystal, elastically scattered electrons become diffracted waves that travel in specific directions given by the Bragg condition. ... As a specimen is thinner, the intensity of a TEM image or a diffraction pattern is explained by elastically scattered electrons.

22. What is the principle of AFM?

•AFM Principle: -

•Surface Sensing: -

an AFM uses a cantilever with a very sharp tip to scan over a sample surface. As the tip approaches the surface, the close-range, attractive force between the surface and the tip cause the cantilever to deflect towards the surface. However, as the cantilever is brought even closer to the surface, such that the tip makes contact with it, increasingly repulsive force takes over and causes the cantilever to deflect away from the surface.

• Detection Method: -

A laser beam is used to detect cantilever deflections towards or away from the surface. By reflecting an incident beam off the flat top of the cantilever, any cantilever deflection will cause slight changes in the direction of the reflected beam. A position-sensitive photo diode (PSPD) can be used to track these changes. Thus, if an AFM tip passes over a raised surface feature, the resulting cantilever deflection (and the subsequent change in direction of reflected beam) is recorded by the PSPD.

•Imaging: -

An AFM images the topography of a sample surface by scanning the cantilever over a region of interest. The raised and lowered features on the sample surface influence the deflection of the cantilever, which is monitored by the PSPD. By using a feedback loop to control the height of the tip above the surface—thus maintaining constant laser position—the AFM can generate an accurate topographic map of the surface features.

23. Comment on the working concept of AFM.

•The Atomic Force Microscope works on the principle measuring intermolecular forces and sees atoms by using probed surfaces of the specimen in nanoscale. ... The Atomic Force Microscope (AFM) takes the image of the surface topography of the sample by force by scanning the cantilever over a section of interest.

24. Define Diffusion.

•Diffusion is the process of movement of molecules under a concentration gradient. It is an important process occurring in all living beings. Diffusion helps in the movement of substances in and out of the cells. The molecules move from a region of higher concentration to a region of lower concentration until the concentration becomes equal throughout.

25. Define ion implantation.

•Ion implantation is a low-temperature process by which ions of one element are accelerated into a solid target, thereby changing the physical, chemical, or electrical properties of the target. Ion implantation is used in semiconductor device fabrication and in metal finishing, as well as in materials science research. The ions can alter the elemental composition of the target (if the ions differ in composition from the target) if they stop and remain in the target. Ion implantation also causes chemical and physical changes when the ions impinge on the target at high energy. The crystal structure of the target can be damaged or even destroyed by the energetic collision cascades, and ions of sufficiently high energy (10s of MeV) can cause nuclear transmutation.

26. Define epitaxial growth

•Epitaxial growth is broadly defined as the condensation of gas precursors to form a film on a substrate. Liquid precursors are also used, although the vapor phase from molecular beams is more in use.

27. Shortly discuss the band diagrams of dissimilar single layer p-n junction.

28. Shortly discuss the band diagrams of dissimilar double layer p-n junction.

Module-IV

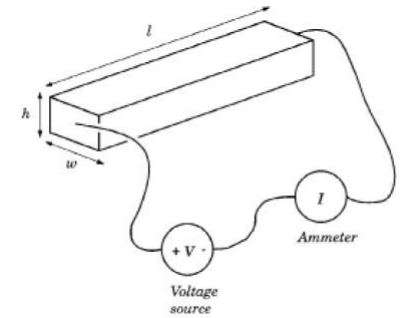
1. Explain resistivity of a given material determined using two probe method.

ANS:

Two-probe method:

Let us consider a rectangular bar of length l, height h and width w as shown in figure. copper wire are attached both ends of the bar.

The resistivity of the bar can be measured by measuring voltage drop across the wire due to passage of known current supplied by the battery *E* through the probes 1 and 2. The potential difference *(V)* between the two contacts at the ends of the bar can be measured by a voltmeter. Therefore, the resistivity of the wire is, i.e.,



$$\rho \equiv \frac{Rwh}{l}$$

2. Mention any three advantages of Four Point Probe over two point probe method.

ANS:

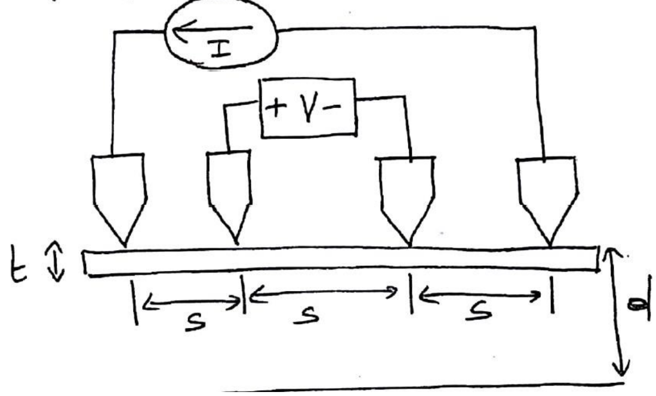
Advantage of four probe method over two probe method

Four point probe is preferred than two-point probe as the contact and spreading resistances in two point probe are large and the true resistivity cannot be actually separated from measured resistivity. In the four probe method, contact and spreading resistances are very low with voltage probes and hence accuracy in measurement is usually very high. To measure very low resistance values, four probe method is used. The resistance of probe will be not be added to that of sample being tested. It uses two wires to inject current in the resistance and another two wires to measure the drop against the resistance.

3. Explain how the sample is connected to the probes in Four Point Probe method.

ANS:

→ The four-point probe method, has four equally spaced in-line probes with probe tip diameters small compared to the probe spacing, "s".



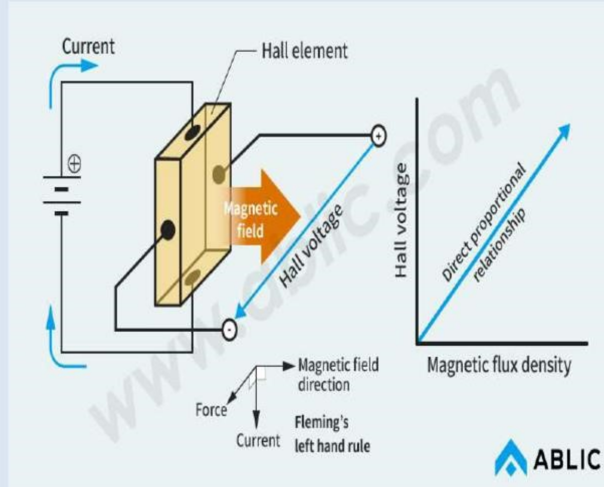
In-line four-point probe measurement of a conductive film of thickness t, uses a known current source, high-impedance voltmeter, spring loaded sharp probes.

4. State Hall Effect with diagram.

ANS:

Definition

When a piece of conductor (metal or Semiconductor) carrying current is placed in a transverse 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 the Hall Effect and the generated voltage is called the Hall voltage.



5. Derive the expression for the Hall coefficient of n type semiconductor

ANS;

At equilibrium , $eE_H = Bev$ (or) $E_H = Bv$ (1)

If J is the current density, then , $J = -nev$ (2)

Where 'n ' is the concentration of current carriers,

From equ. (2)

$v = J/-ne$ (3)

Substituting the value of v in equ. (1) we get,

$E_H = BJ/-ne$ (4) .

- The Hall Effect is described by means of the Hall coefficient 'R_H ' in terms of current density ' J' by the relation,

$$E_H = R_H BJ$$

$$\text{(or) } R_H = E_H / BJ \qquad (5)$$

By substituting the value of E_H from equ. (4) we get,

$$R_H = BJ/ -neBJ = -1/ne \qquad (6)$$

- Since all the three quantities E_H, J and B are measurable , the Hall coefficient R_H and hence the carrier density 'n' can be found out.

6. Write any three applications of Hall Effect.

ANS:

Applications of Hall effect:

(1) Determination of type of semiconductor

For a N-type semiconductor, the Hall coefficient is negative whereas for a P-type semiconductor, it is positive. Thus from the direction of the Hall voltage developed, one can find out the type of semiconductor.

(2) Calculation of carrier concentration

Once Hall coefficient R_H is measured, the carrier concentration can be obtained from,

$n = 1/eR_H$ or $p = 1/eR_H$

(3). Determination of mobility

We know that, conductivity, $\sigma_n = ne\mu_e$ (or) $\mu_e = \sigma_n / ne = - \sigma_n R_H$

Also $\sigma_p = pe\mu_h$ or $\mu_h = \sigma_p / pe = \sigma_p R_H$. Thus by measuring σ and R_H, μ can be calculated.

(4) Measurement of magnetic flux density:

Using a semiconductor sample of known 'R_H' the magnetic flux density can be deduced from $R_H = V_H t / BI$ or $B = V_H t / R_H I$

7. A silicon plate of thickness 1 mm, breath 10mm and length 10mm is placed in a magnetic field of 0.5 Wb/m^2 acting perpendicular to its thickness. If 1×10^{-3}A current flows along its length, calculate the Hall voltage developed if the Hall coefficient is 3.66×10^{-4} m^3/C.

ANS:

4. A silicon plate of thickness 1 mm, breath 10mm and length 100mm is placed in a magnetic field of 0.5 Wb/m^2 acting perpendicular to its thickness. If 10^{-2} A current flows along its length, calculate the Hall voltage developed if the Hall coefficient is $3.66 \times 10^{-4}\ m^3$ / coulomb.

Given Data:

t= 1mm; w= 10mm ; L = 100 mm ; B = 0.5 Wb/m^2 ; I = 10^{-2} A ; $R_H = 3.66 \times 10^{-4}\ m^3$ / coulomb.

Solution:

Hall coefficient $R = V_H t / IB$

$V_H = R_H IB/t$

$= 3.66 \times 10^{-4} \times 10^{-2} \times 0.5 / 1 \times 10^{-3}$

$= 1.83 \times 10^{-3}$ V = 1.83 mV

8. An n-type semiconductor has Hall coefficient = $4.16 \times 10^{-4}\ m^3C^{-1}$. The conductivity is 10^8 $ohm^{-1}m^{-1}$. Calculate its charge carrier density and electron mobility at room temperature.

ANS:

i) Carrier density(n) $= \frac{1}{R_H q}\ cm^{-3}$

R_H = Hall coefficient
q = Charge of the e^- or hole (c)

$= \frac{1}{4.16 \times 10^{-4} \times 1.6 \times 10^{-19}}$

Carrier density(n) $= 1.502 \times 10^{22}\ m^{-3}$, $\mu_d = 4.16 \times 10^{4}\ m$

ii) Carrier mobility (μ) $= R_H\, \sigma\ cm^2 V^{-1} s^{-1}$

R_H = Hall coefficient
σ = conductivity ($C V^{-1} s^{-1} cm^{-1}$)

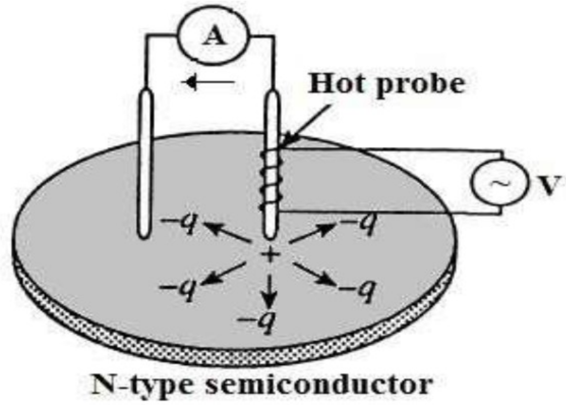
$= 4.16 \times 10^{-4} \times 10^{8}$
$= 4.16 \times 10^{4}\ m^2 V^{-1} s^{-1}$

9. Explain the working principle of hot point probe method.

ANS:

Principle:

•A conventional Hot-Probe experiment enables a simple and efficient way to distinguish between n-type and p-type semiconductors using a hot probe and a standard multi- meter.



While applying the cold and hot probes to an n-type semiconductor, positive voltage readout is obtained in the meter, whereas for a p- type semiconductor, negative voltage is obtained.

10. Explain the principle of capacitance-voltage measurement method.

ANS:

Principle:

- The capacitance at an p-n or metal –semiconductor junctions depends on the properties of the charge- depletion layer formed at the junction
- The depletion regions is the vicinity of the PN junction and is " depleted" of free carriers due to the drift field required to maintain charge neutrality.

Capacitance-Voltage measurements

- Hillibrand and Gold (1960) first described the use of capacitance –voltage (C-V) methods to determine the majority carrier concentration in semiconductors.
- C-V measurements are capable of yielding quantitative information about the diffusion potential and doping concentration in semiconductor materials.
- The technique employs PN-junctions, metal- semiconductor junctions (Schottky barriers), electrolyte –semiconductor junction MIS field effect semiconductors.
- C-V measurements yield accurate information about the doping concentrations of majority carriers as a function of distance (depth) from the junction.

11. How does the capacitance of p-n junction diode vary in forward bias and reverse bias.

ANS:

Deep-level transient spectroscopy(DLTS)

DLTS Principle:

- Emission of trapped charge carriers change the depletion capacitance of a PN-junction or Schottky diode. The transient measurement provides information on the defect levels in the band gap.

- Deep-level transient spectroscopy is a method of determining the concentration and thermal emission rate of semiconductor deep levels by measuring capacitance transients as a function of temperature.

- A Schottky or p-n diode is first forward biased to fill the traps, then the capacitance transient caused by carrier emission from filled traps in the depletion region is measured at the quiescent reverse bias.

- A DLTS peak is generated when the thermal emission rate of the trap is the same as that of the rate window. Because of the strong temperature dependence of the trap emission rates, it is possible to resolve the emission from different traps using an appropriate emission rate window.

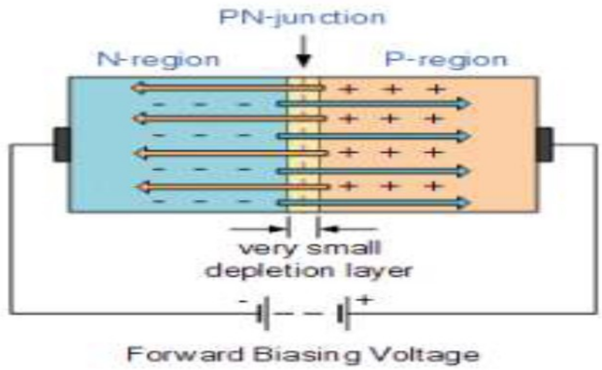
- When voltage across a p-n junction is changed, there is a corresponding change in the depletion region width. This change in width causes a change in the number of free charge carriers on both sides of the junction, resulting in a change in the capacitance.

- This change has two contributions; a) the contribution due to change in depletion width known as the junction capacitance and b) the contribution due to change in minority carrier concentration called the diffusion capacitance.

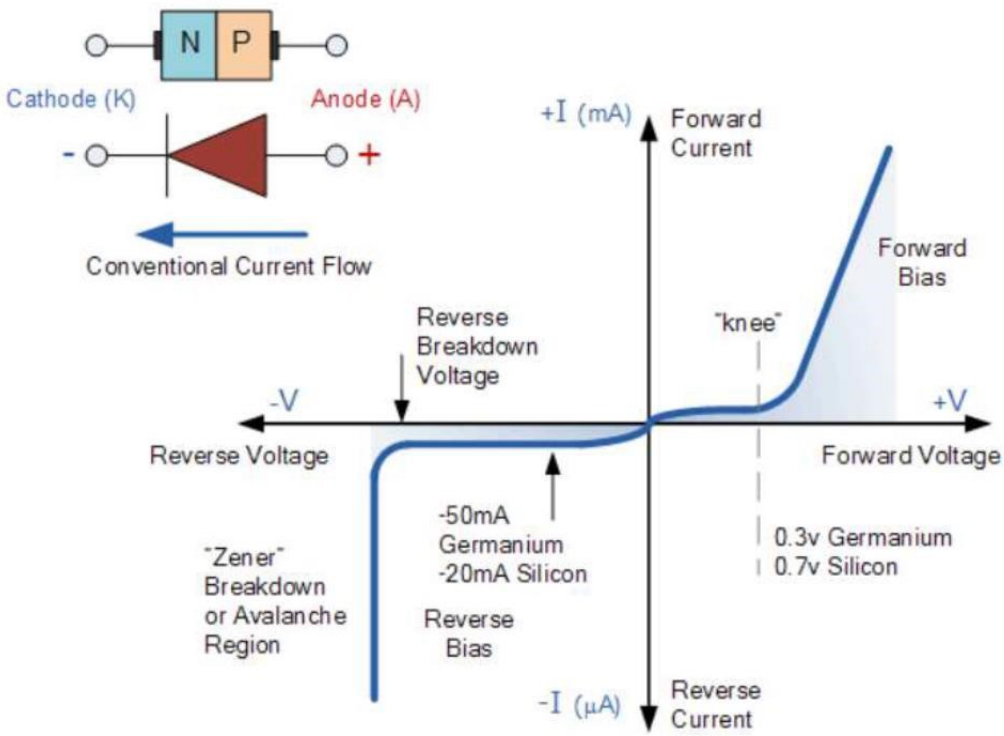
- Junction capacitance is dominant under reverse biased conditions while diffusion capacitance is dominant under forward biased conditions.

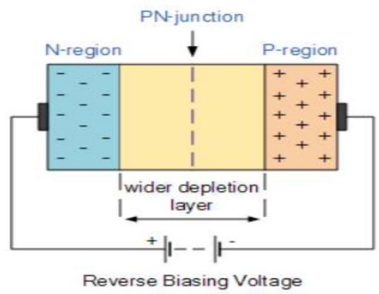
12. Explain forward biasing and reverse biasing of p-n junction diode.

ANS;



➢When a diode is connected in a **Forward Bias** condition, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material. If this external voltage becomes greater than the value of the potential barrier, approx. 0.7 volts for silicon and 0.3 volts for germanium, the potential barriers opposition will be overcome and current will start to flow.





- When a diode is connected in a **Reverse Bias** condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material.

- The net result is that the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path, almost an insulator. The result is that a high potential barrier is created thus preventing current from flowing through the semiconductor material.

- This condition represents a high resistance value to the PN junction and practically zero current flows through the junction diode with an increase in bias voltage. However, a very small **leakage current** does flow through the junction which can be measured in micro-amperes, (μA).

13. Write a short note on I-V characteristics of p-n junction diode in reverse bias.

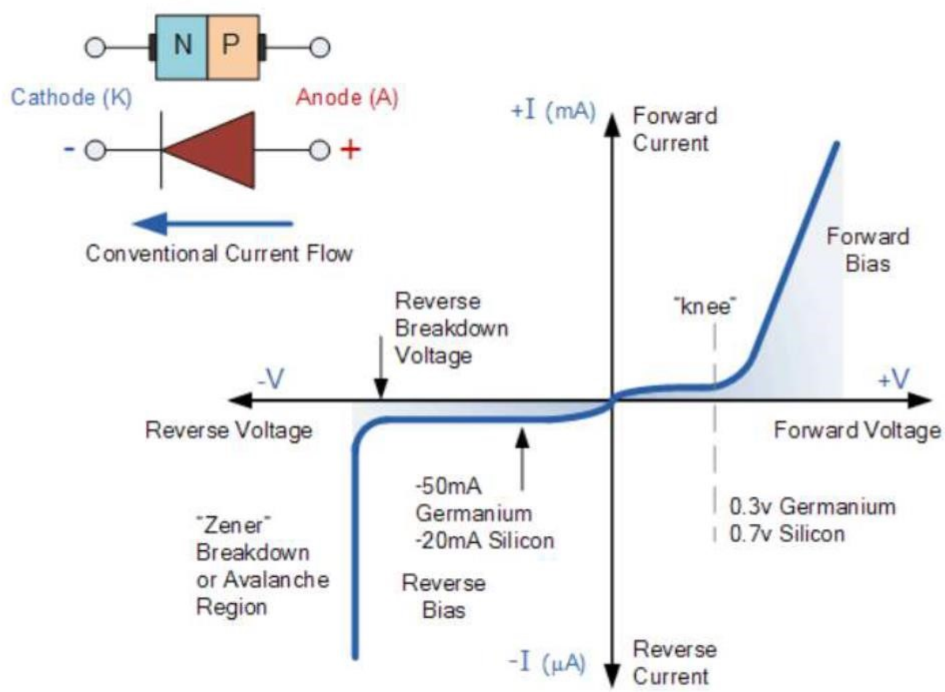
ANS:

I-V Characteristics in a Diode

- A *PN Junction Diode* is one of the simplest semiconductor devices around, and which has the characteristic of passing current in only one direction only. However, unlike a resistor, a diode does not behave linearly with respect to the applied voltage as the diode has an exponential current-voltage (I-V) relationship and therefore we can not described its operation by simply using an equation such as Ohm's law.

- If a suitable positive voltage (forward bias) is applied between the two ends of the PN junction, it can supply free electrons and holes with the extra energy they require to cross the junction as the width of the depletion layer around the PN junction is decreased.

- By applying a negative voltage (reverse bias) results in the free charges being pulled away from the junction resulting in the depletion layer width being increased. This has the effect of increasing or decreasing the effective resistance of the junction itself allowing or blocking current flow through the diode.



14. What are Shallow Level Traps and Deep Level Traps?

ANS;

Introduce energy level in the band structure

•Shallow level

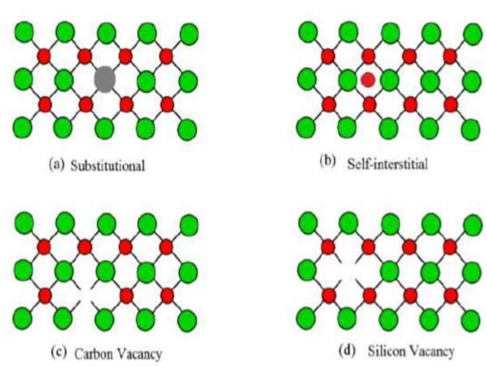
–Close to the edges of the bandgap

–Use mainly as a dopant

•Deep level

–Close to the middle of the bandgap

–Act as generation/recombination or trap center.



15. State combined Beer Lambert Law.

ANS;

The **Beer-Lambert law** is the linear relationship between **absorbance** and concentration of an **absorbing** species. The **Beer-Lambert law** implies that both the type and the concentration of the molecules are important in the process of radiation **absorption**.

- When the light beams are passed through a dilute sample, the absorption will be less since there is only less number of absorbing particles presented.
- The light beam was passed through a concentrated sample.
- The intensity of the transmitted beam was considerably low, which leads to violation of Beer Lambert's law.
- The law thus states that for a dilute solution, A = Kcl

  Where,

  A – absorbance
  K – molar absorbance coefficient
  c– molar concentration
  l - Path length

16. Write any three applications of U-V spectroscopic technique.

ANS:

Applications of UV Spectroscopy

- UV absorption spectroscopy can characterize those types of compounds which absorbs UV radiation thus used in qualitative determination of compounds. Identification is done by comparing the absorption spectrum with the spectra of known compounds.
- This technique is used to detect the presence or absence of functional group in the compound. Absence of a band at particular wavelength regarded as an evidence for absence of particular group.
- Kinetics of reaction can also be studied using UV spectroscopy. The UV radiation is passed through the reaction cell and the absorbance changes can be observed.

17. What is Photoluminescence? And how it is classified in to?

ANS:

• Luminescence is an electromagnetic (EM) radiation phenomenon due to excessive thermal radiation or incandescence in physical system.

• With regard to luminescent semiconductors, when energy of incident photon is equal or beyond the energy band gap, it will excite the electron of valence band into conduction band through band gap.

Luminescence of semiconductors can divide two types:

(1) Radiative transition

When an electron drops to lower energy state from higher energy state, it will probably occur radiative transition regardless of intrinsic state or energy state formed by impurities. Therefore, the system is not a balanceable condition and we assume that excited phenomena will generate electron-hole pairs in semiconductors. Firstly, we consider some basic transitions:

(a)Band-to-band transition:

Band-to-band transition is the relationship of free-electrons and holes. Those transitions usually occur in direct band gap materials such as Ⅲ-Ⅴ compounds where the electron-hole pairs will generate radiation recombination effectively between conduction band and valence band.

(b)Free exciton transition

If the material is very pure, an electron and a hole will attract each other to form exciton. Then, they will recombine to generate a very narrow spectrum. In Ⅲ-Ⅴ compounds, free exciton energy state usually describes Wannier-Mott approximation. The energy of free exciton can be expressed as Equation 1.

$$E_n = 2\pi^2 m^* e^4 / h^2 \varepsilon^2 n^2 \tag{1}$$

In this equation, m* is effective mass, h is Planck constant, ε is dielectric constant, and n is quantum number.
However, there are probably several mechanisms to result in non-radiative transition. Those transitions will compete with radiative transition to result in lower luminescence.

(c)Free-to-bound transition

The transition is free-to-bound transition between energy bands of materials and impurity energy level. This transition is between the impurity and one of energy bands such as from conduction band to acceptor or from donor to valence band. The energy of radiative photon is E_g-E_b and E_b is bound energy of shallow impurity energy level.

(d)Donor-acceptor pair recombination

The transition is between donor and acceptor. After optical pumping, the electrons and holes will be bounded at D+ and A- locations to generate neutral D_0 and A_0 centers. Some neutral donor electrons will recombine with neutral acceptor holes radiatively.

Non-radiative transition

Some opportunities which cause non-radiative transition will compete with radiative recombination transition and influence luminescent efficiency negatively. They can describe as below:

a) Because of thermal oscillation to generate phonons;

a) Recombination on the surface state includes two dimensional dislocation, and agglomerative boundary et al. through step-wise transition which causes loss energy. It also calls cascade process;

a) Impurity locations are often not radiative recombination centers;

a) Loss energy of trapped carriers will excite other carriers in the lattice and emit non-radiative loss energy by Auger process.

UNIT 4

PART A-ONE MARK QUESTIONS

QUESTION NO.	QUESTIONS
1	In a …………, the electrons are ejected from photosensitive surface and are amplified within the cell. (A) Photodiode (B) Bolometer (C) Electrode (D) **photomultiplier tube**
2	Alkali metals and their oxides are best ……….. materials. **(A) Photo emissive** **(B)** Conducting **(C)** Insulating **(D)** Semiconducting