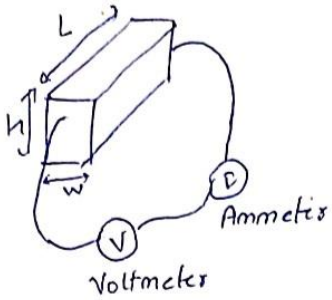
Module-IV

Two Probe

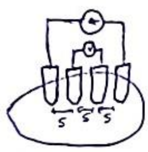


$$\left(\rho = \frac{RW}{L}\right)$$

Potential of bar can be found by measuring pottential difference across wire.

Four Probe

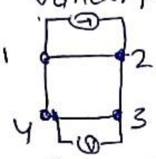
fourpoint
- Bulk
- ThinSheet

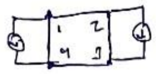


Bulk → $(2\pi s)(V/I) = \rho$

Thin = $\rho = \left(\frac{\pi t}{\ln 2}\right)\left(\frac{V}{I}\right)$

Vanderpaw





$$\rho_A = \frac{\pi}{\ln 2} t_s \left(\frac{V_1 - V_2 + V_3 - V_4}{4I}\right) f_a$$

$$\rho_B = \frac{\pi}{\ln 2} t_s \left(\frac{V_5 - V_6 + V_7 - V_8}{4I}\right) f_b$$

$f_A = f_B = 1$

$$\rho = \frac{\rho_A + \rho_B}{2}$$

→ current source used to supply current outer probe & potential is developed across inner probes.

Hall Effect → When current carrying conductor placed in magnetic field, Electric field is produced inside conductor given by flemming left hand rule.

for n type = $\mathcal{E}_H = BJ/-ne$ $\quad V = J/-ne$ $\quad$ & $\mathcal{E}_H = BeV$ $\quad \sigma_n = ne\mu_e$

$R_H = -1/ne$ $\quad \mathcal{E}_H = BV$ $\quad \mu_e = \sigma_n/ne = -\sigma_n R_H$

for P type $\quad \mathcal{E}_H = V_H/W$ $\quad R_H = \frac{V_H}{WBJ}$ $\quad \sigma_p = pe\mu_e$ $\quad \mu_p = \frac{\sigma_p}{pe} = -\sigma_p \cdot R_H$

$R_H = +1/pe$

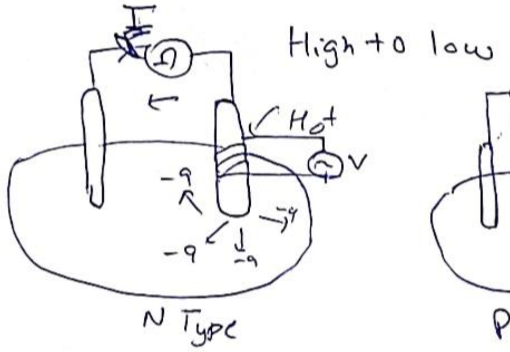
Hot probe

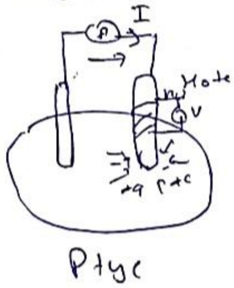
→ Hot probe connected to positive terminal; Cold probe to negative, thermally excited charge carriers move from Hot probe to cold, so majority Charge carriers define electrical potential sign of current

$$\nabla \mathcal{E} = \frac{Q}{\varepsilon_0 \varepsilon_r}$$

→ n type → Positive

→ P type → Negative

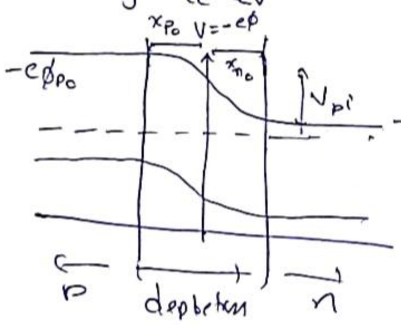


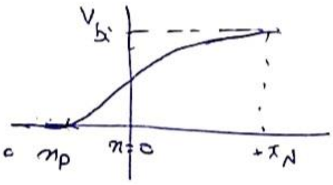


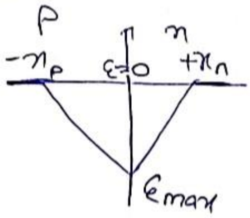
Capacitance-Voltage Measurement

→ Capacitance at P-N junction depend upon properties of charge depletion layer

→ $\mathcal{E}_g = \mathcal{E}_C - \mathcal{E}_V$







$$\frac{\partial^2 V}{\partial x^2} = \frac{\partial \mathcal{E}}{\partial x} = \frac{P(x)}{\varepsilon} = \frac{e}{\varepsilon}\left[P^+(x) - N^-(x) + N_D^+(x) - N_A^-(x)\right]$$

P type $\dfrac{\partial^2 V}{\partial x^2} \simeq \dfrac{e}{\varepsilon} N_D^+$ N type $\dfrac{\partial^2 V}{\partial x^2} \simeq \dfrac{e}{\varepsilon} N_A^-$

C-V measurement

$$V(x) = V_{bi}\left[2\left(\frac{x}{w}\right) - \left(\frac{x}{w}\right)^2\right]$$

$$V_{bi} = \frac{KT}{e} \ln\left(\frac{N_d N_a}{n_i^2}\right)$$

DLTS

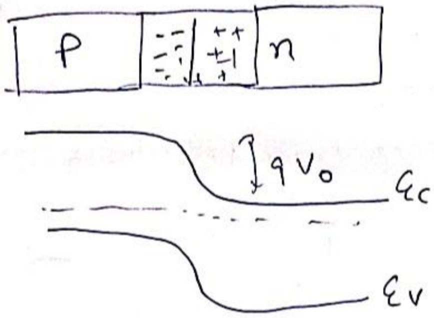
→ its method of determining concentration & thermal emission rate of semiconductor deep levels by measuring capacitance transients and function of temperature.

$$C(t) = C_{rb} - \Delta C_0 e^{(-e_n t)}$$

$$\underbrace{e_p n_T}_{\text{filled traps}} = (e_n + e_p) N_T \rightarrow \text{Total density}$$

→ Under reverse bias → Junction Capacitance (depletion width.

→ Under forward bias → Diffusion Capacitance (minority carrier conc)



$$C = \frac{\varepsilon A}{W}$$

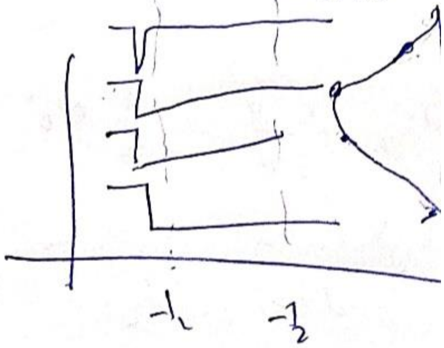
forward → $q(V_0 - V_f)$ Revers $q(V_0 + V_R)$

Point defect

Substitution	Vacancy	Interstitial Impurity	Self interstitial
Extra impurity in onsin	missing atom	extra impurity interstitial	extra atom in interstitial

→ Trap Carrier conc $n_{(t)}(t) = N_T e^{-e_n t}$

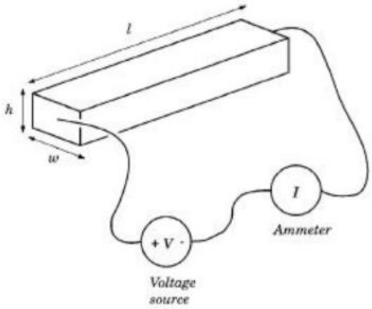
$$\Delta C_0 = \frac{N_T}{2 N_d} C_{rb}$$



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

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.,

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

In general, we use a multimeter for measuring the resistance of the materials. The typical range of resistance measured using the multimeter is 1 Ω to 2 MΩ, but varies with the models and company.

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

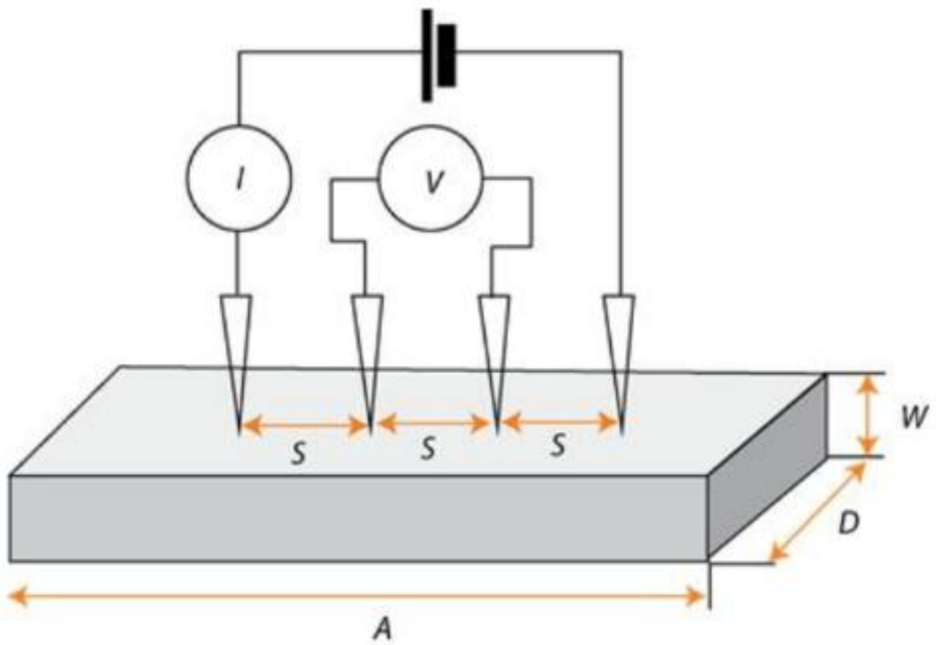
Advantage of four probe method over two probe method

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.

Material with random shapes can now be measured with the help of 4 probe method.
It does not inject impunity to the material which is being tested/sample.

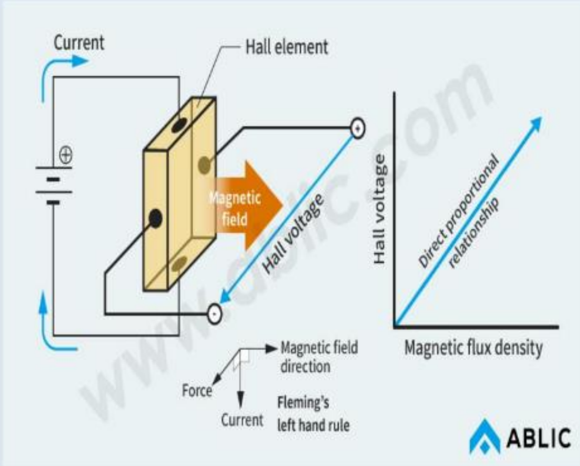
3.Explain how the sample is connected to the probes in the Four Point Probe method. State Hall Effect with diagram.

A high impedance current source is used to supply current through the outer two probes, which sets up an electric field in the sample. The potential difference developed across the inner probes, which draw no current due to the high input impedance voltmeter in the circuit, is measured through two inner probes.



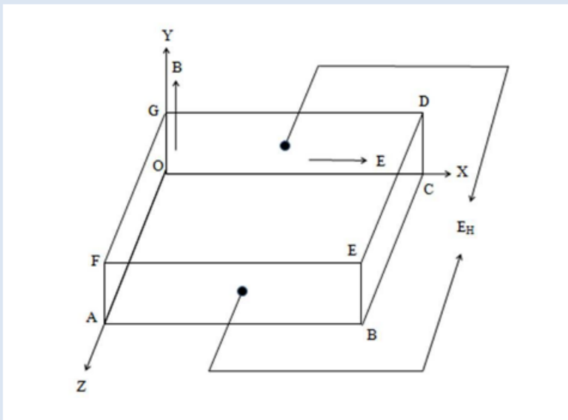
Definition

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.



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

Consider a conventional current flow through the strip along OX and a magnetic field if induction B is applied along axis OY.



Case – I If the Material is N-type Semi- Conductor (or) Metal

- If the strip is made up of metal or N-type semiconductor, the charge carriers in the strip will be electrons.
- As conventional current flows along OX, the electrons must be moving along XO. If the velocity of the electrons is ‘v’ and charge of the electrons is ‘-e’, the force on the electrons due to the magnetic field is,
- $F = -Bev$, which acts along OZ. This causes the electrons to be deflected and so the electrons accumulate at the face ABEF.

- Thus, face ABEF will become negative and the face OCDG becomes positive. A potential difference is therefore established across faces ABEF and OCDG., causing a field E_H.
- This field gives rise to a force of ' $-eE_H$' on the electrons in the opposite direction (i.e, in the negative Z direction).

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.

5.Write any three applications of Hall Effect.

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 $B = V_H t / R_H I$

6.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 1x10 -3 A current flows along its length, calculate the Hall voltage developed if the Hall the coefficient is 3.66x 10 -4 m 3 /C.

6) $t = 1mm = 10^{-3} m$

$B = 10mm$

$l = 10mm$

$B = 0.5 Wb/m$

$I = 1\times10^{-3} A$

$R_H = 3.66\times10^{-4} m^3/C$

$$R_H = \frac{V_H t}{IB}$$

$$V_H = \frac{R_H I B}{t}$$

$$= \frac{3.66\times10^{-4} \times 10^{-3} \times \cancel{3.66\times10^{-4}}\ 0.5}{10^{-3}}$$

$$\Rightarrow 1.83 \times 10^{-4}$$

7.An n-type semiconductor has Hall coefficient = 4.16 x10 -4 m 3 C -1 . The conductivity is 10 8 ohm -1 m -1 . Calculate its charge carrier density and electron
mobility at room temperature. Ne(density)=-3*pie/8(Rh*e) |||| concentration=-1/Rh*e

Date :

Q7) $R_H = 4.16 \times 10^{-4}\ m^3/C$

$\sigma = 10^8$ ohm/m

$R_H = -1/ne$

$n = \frac{-1}{R_H e} \Rightarrow$

$$\boxed{n_e = \frac{3\pi}{8}\ \frac{+1}{R_H e}}$$

$$\Rightarrow \frac{3\pi}{8} \times \frac{1}{1.6 \times 10^{-19} \times 4.16 \times 10^{-4}}$$

$\Rightarrow 0.177 \times 10^{23}$

$\Rightarrow 1.77 \times 10^{22}\ m^{-3}$ m^{-3}

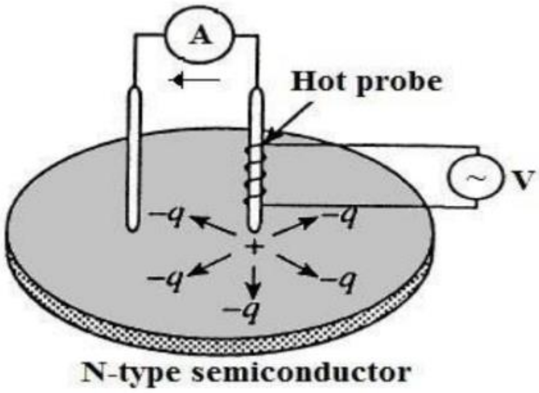
$$\mu_e = \frac{\sigma_e}{n_e e} \Rightarrow \frac{10^8}{1.77 \times 10^{22} \times 1.6 \times 10^{-19}}$$

$\Rightarrow 0.35 \times 10^{-5}\ m^2 V^{-1} s^{-1}$

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

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.

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

Principle:

- The capacitance at a 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.

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

Capacitance of P-N Junction Diode:

Any variation of the charge within a p-n diode with an applied voltage variation yields a capacitance which must be added to the circuit model of a p-n diode. The capacitance associated with the charge variation in the depletion layer is called the junction capacitance, while the capacitance associated with the excess carriers in the quasi-neutral region is called the diffusion capacitance.

Expressions for the capacitances are obtained by calculating the change in charge for a change in applied voltage, or:

$$C = \frac{dQ}{dV}$$

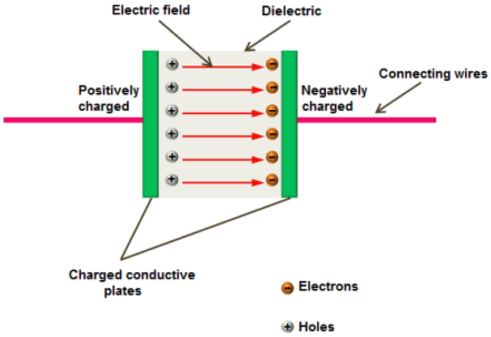
Types of Capacitance of P-N Junction Diode:

In a p-n junction diode, two types of capacitance take place. They are,

- Transition capacitance (C_T)
- Diffusion capacitance (C_D)

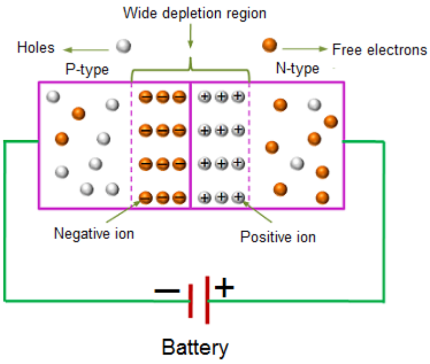
Transition capacitance (C_T):

The conducting plates or electrodes of the capacitor are good conductors of electricity. Therefore, they easily allow electric current through them. On the other hand, dielectric material or medium is poor conductor of electricity. Therefore, it does not allow electric current through it. However, it efficiently allows electric field.



When voltage is applied to the capacitor, charge carriers starts flowing through the conducting wire. When these charge carriers reach the electrodes of the capacitor, they experience a strong opposition from the dielectric or insulating material. As a result, a large number of charge carriers are trapped at the electrodes of the capacitor. These charge carriers cannot move between the plates. However, they exerts electric field between the plates. The charge carriers which are trapped near the dielectric material will stores electric charge. The ability of the material to store electric charge is called capacitance.

In a reverse biased p-n junction diode, the p-type and n-type regions have low resistance. Hence, p-type and n-type regions act like the electrodes or conducting plates of the capacitor. The depletion region of the p-n junction diode has high resistance. Hence, the depletion region acts like the dielectric or insulating material. Thus, p-n junction diode can be considered as a parallel plate capacitor.



Reverse bias

The amount of capacitance changed with increase in voltage is called transition capacitance. The transition capacitance is also known as depletion region capacitance, junction capacitance or barrier capacitance. Transition capacitance is denoted as C_T.

The change of capacitance at the depletion region can be defined as the change in electric charge per change in voltage.

CT = dQ / dV

Where,

CT = Transition capacitance

dQ = Change in electric charge

dV = Change in voltage

The transition capacitance can be mathematically written as,

$C_T = \varepsilon A / W$

Where,

ε = Permittivity of the semiconductor

A = Area of plates or p-type and n-type regions

W = Width of depletion region

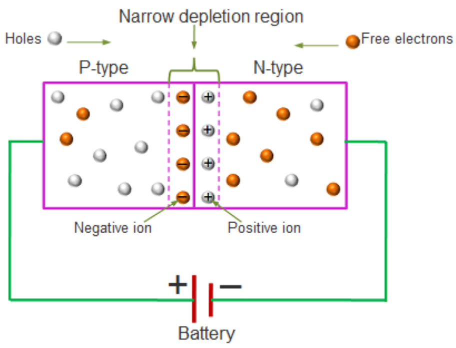
Diffusion capacitance (C_D):

Diffusion capacitance occurs in a forward biased p-n junction diode. Diffusion capacitance is also sometimes referred as storage capacitance. It is denoted as C_D.

In a forward biased diode, diffusion capacitance is much larger than the transition capacitance. Hence, diffusion capacitance is considered in forward biased diode.

When forward bias voltage is applied to the p-n junction diode, electrons (majority carriers) in the n-region will move into the p-region and recombines with the holes. In the similar way, holes in the p-region will move into the n-region and recombines with electrons. As a result, the width of depletion region decreases.

The electrons (majority carriers) which cross the depletion region and enter into the p-region will become minority carriers of the p-region similarly; the holes (majority carriers) which cross the depletion region and enter into the n-region will become minority carriers of the n-region.



Forward bias

When the width of depletion region decreases, the diffusion capacitance increases. The diffusion capacitance value will be in the range of nano farads (nF) to micro farads (μF).

The formula for diffusion capacitance is

$C_D = dQ / dV$

Where,

C_D = Diffusion capacitance

dQ = Change in number of minority carriers stored outside the depletion region

dV = Change in voltage applied across diode

11.Explain forward biasing and reverse biasing of p-n junction diodes.

- 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.

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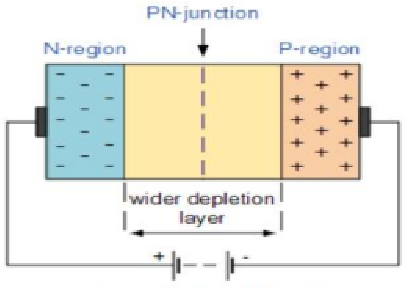

- When a diode is connected in a **Reverse Bias** condition, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material.

- 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.

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

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

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.

14.State combined Beer Lambert Law.

- Basic principle of spectroscopy is the Beer-Lambert’s law (also known as beer’s law) that relates the attenuation of light to the properties of the material through which the light is travelling.
- Lambert's law stated that absorbance of a material is directly proportional to its thickness (path length).
- Much later, August Beer discovered another attenuation relation in 1852. Beer's law stated that absorbance is proportional to the concentrations of the material sample.
- The modern derivation of the Beer–Lambert law combines the two laws and correlates the absorbance to both the concentrations and the thickness of the material.
- Absorption spectra of chemical samples are generated when a beam of electromagnetic radiation is passed through a sample, and the chemical sample absorbs a portion of the photons of electromagnetic energy passing through the sample.

4

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

Applications of UV Spectroscopy

Detection of Impurities

- Best methods for determination of impurities in organic molecules.
- Additional peaks can be observed due to impurities in the sample and it can be compared with that of standard raw material.
- By also measuring the absorbance at specific wavelength, the impurities can be detected.

Structure elucidation of organic compounds

- It is useful in the structure elucidation of organic molecules, such as in detecting the presence or absence of unsaturation, the presence of hetero atoms.
- UV absorption spectroscopy can be used for the **quantitative determination of compounds** that absorb UV radiation.
- 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.

16.What is Photo-luminescence? And how it is classified in to?

Concept of Photoluminescence

• 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.

• Semiconductors generate recombination radiation from excited state to ground state.

• Absorption will also happen when an electron is excited to higher energy level from neutral acceptor energy level and it can also transit to ionization donor energy level from valence band or transit to conduction band from ionization acceptor energy level. Those phenomena can explain the energy band or impurities in the semiconductor successfully.

• Photoluminescence which inspects optical property of luminescent semiconductor materials is a strong and nondestructive technology.

• According to analytic data of photoluminescence, we can know the kind of impurities, band gap, and impurity activation energy etcetera from the spectra.

• We can estimate the composition of the compound from the peak intensity of PL spectra.

• Using photoluminescence can investigate the internal interface of hetero-structure that general physical or electronic measurements can not measure.

Fluorescent solutions under UV-light. Absorbed photons are rapidly re-emitted under longer electromagnetic wavelengths.

Concept of Photoluminescence

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.

$$E_n = 2\pi^2 m^* e^4 / h^2 \varepsilon^2 n^2 \qquad (1)$$

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.

Motivation to study:

Hindi:

https://youtu.be/lSOAR9QBGtA?t=5

Telugu:

https://youtu.be/0GEcisJumQs?t=97