Unit : 4

Opto Electronic Devices :

Direct and Indirect Band Gap Semiconductors :

Direct Band Gap Semiconductors :

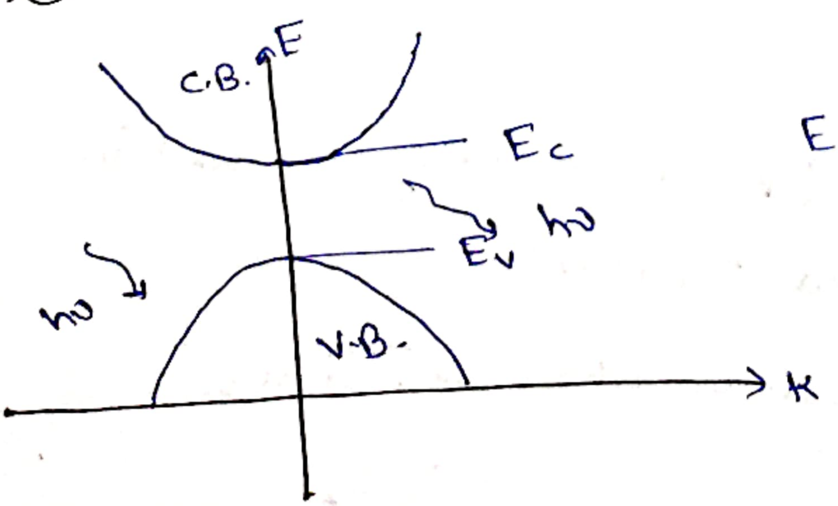
When maximum of valence band and minimum of conduction band occurs at same momentum than the semiconductor is called direct band gap semiconductors.

→ (i) When an e^- in valence band, absorbing energy $h\nu$ goes to conduction band, than after some time e^- jump to valence band and emits a photon of energy $h\nu$ which is equal to $\underline{(E_c - E_v)}$.

→ (ii) This light lies in the visible range.

→ (iii) Direct band gap semiconductors are used in LEDs and Laser diode.

→ (iv) Examples : GaAs (Galerium Arsenide), InP (Indium Phosphide)



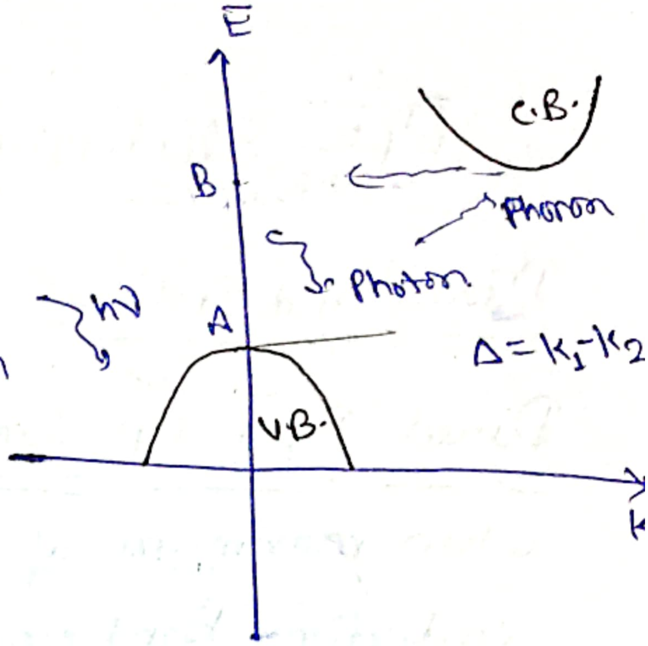
E - k diagram

$$\boxed{E \propto K^2}$$

momentum

Indirect Band Gap Semiconductor:

When maximum of V.B. and minimum of conduction band occurs at two different values ~~know~~ of momentum known as Indirect Band Gap semiconductors.



⇒ When an e^- in V.B. after absorbing energy $h\nu$ goes to conduction than e^- gain some energy from lattice vibration and moves to the bottom of the conduction band.

⇒ After some time, it comeback to point B and emits Phonons. (Stay time ~ 10^{-8} sec) (only read)

⇒ Than e^- come back to valence band and emits photon.

⇒ This photon or light doesnot lie in visible range.

⇒ Indirect band-gap semiconductor are used in amplifiers and Transistors

Eg: Intrinsic semiconductor like Si or Ge.

Electron hole Pair Generation and Recombination:

Generation of e^--hole pair:

⇒ when electrons in valence band get enough energy then they will absorb energy and jump to conduction band.

⇒ This e^- in conduction band called thermally generated free e^-.

⇒ The place where e^- left is called hole

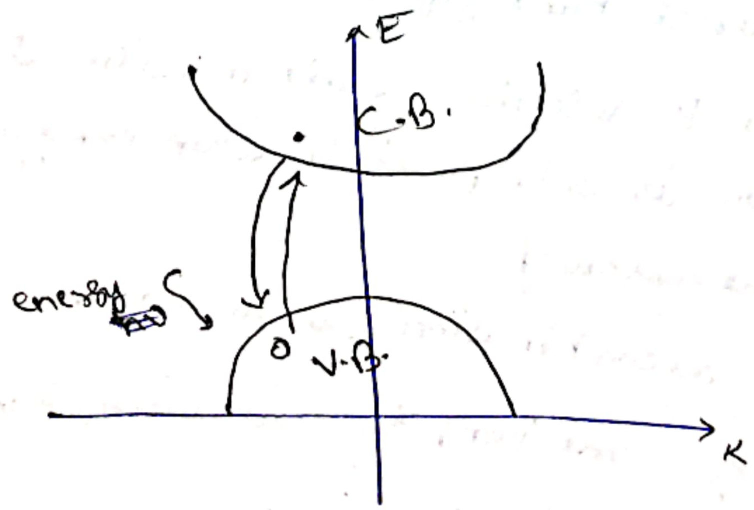
⇒ Electrons and holes always generated in pairs.

⇒ The process in which thermally free e^- and holes are generated in pair is called generation of e^--hole pair.

Recombination of e^--hole pair:

⇒ The process by falling back of thermally generated free e^- to valence band and combine with hole is called e^--hole pair recombination.

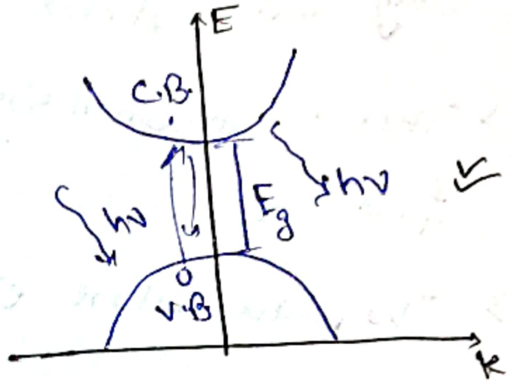
⇒ when e^- recombine with hole, it release energy.



Radiative and Non-Radiative Recombination :

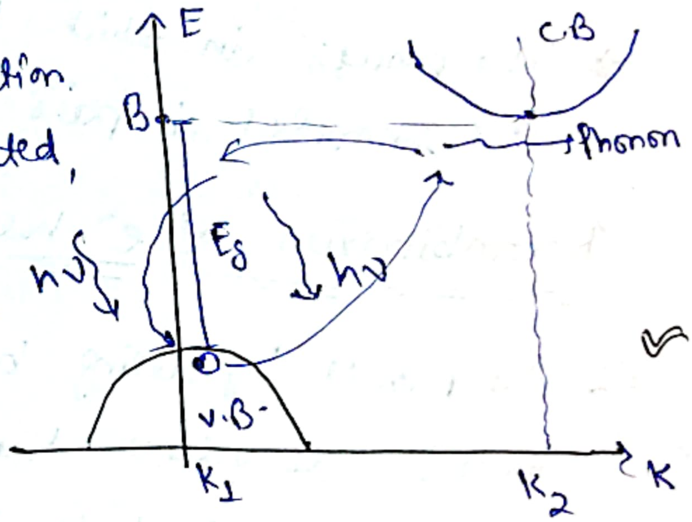
Radiative Recombination: In radiative recombination

google process, the released energy is emitted as electromagnetic radiation.



Non-Radiative Recombination:

google
In a non-radiative recombination process, no radiation is emitted, and the released energy is eventually converted to thermal energy in the form of lattice vibrations.



Radiative Recombination:

class
- ⇒ It occurs in direct band gap semiconductor.
- → It follow the k-selection rule according to which emission is only possible when energy and momentum are conserved
- ⇒ In radiative recombination, when e^- valence band absorb energy and jump to conduction band and leave hole in valence band.

⇒ After some time, this thermally generated free e^- falling back in valence band and recombine with hole.

⇒ In this process it radiate energy in the form of photon.

⇒ This photon lies in the visible range called Radiative Recombination. (figure same)

class Non - Radiative Recombination :-

⇒ It occurs in indirect band gap semiconductor.

⇒ In this process phonons are involved.

⇒ K-selection rule are not obeyed.

⇒ When an e^- in valence band after absorbing some energy goes to conduction band and leave hole in valence band.

⇒ Then e^- quickly moves to the bottom of conduction band by absorbing lattice vibrations called Phonons.

⇒ After some time it emits phonons and come at previous position in conduction band.

⇒ Now electron jump to the valence band and recombine with hole and release energy.

⇒ This energy or photon does not lie in the visible range called non-radiative recombination.

(figure same).

Ques: LED is constructed from Gallenium Arsenide semiconduction material. The energy gap of this LED is 1.9 eV. Calculate the wavelength of light emitted.

Sol:

$$E_g = h\nu = hc/\lambda$$

$$1.9eV = hc/\lambda$$

$$\lambda = \frac{6.62\times10^{-34}\times3\times10^{8}}{1.9\times1.6\times10^{-19}}$$

$$\boxed{\lambda = 6.53\times10^{-7}\ m}$$

Ques: Calculate the energy of a photon in LED having wavelength 6328 Å.

Sol:

$$E = \frac{hc}{\lambda}$$

$$(E)_p = \frac{6.626\times10^{-34}\times3\times10^{8}}{6328\times10^{-10}}$$

$$(E)_{photon} = \frac{6.626\times3}{6328}\times10^{-16}\times\left(\frac{1}{1.6\times10^{-19}}\right) \text{ for in e}$$

$$(E)_{photon} = 1.963\ eV$$

Ques: Calculate the energy band gap of GaAs having photo of wavelength 6934 Å.

Sol:
$$E = \frac{hc}{\lambda} = \frac{6.626\times10^{-34}\times 3\times10^{8}}{6934\times10^{-10}}\times\left(\frac{1}{1.6\times10^{-19}}\right) eV$$

$$E = 1.78\, eV$$

Ques: The energy of CB and VB is 1.9eV and 1.8eV respectively. calculate wavelength.

Sol:
$$\lambda = \frac{6.62\times10^{-34}\times 3\times10^{8}}{0.1\times1.6\times10^{-19}}$$

$\lambda = hc/E.$

$E_g = E_c - E_v$
$= 0.1 ev$

$$\lambda = 124.125\times10^{-7}\, m$$

$$\lambda = 1.24125\times10^{-5}\, m \text{ or } 124125\, \mathring{A}$$

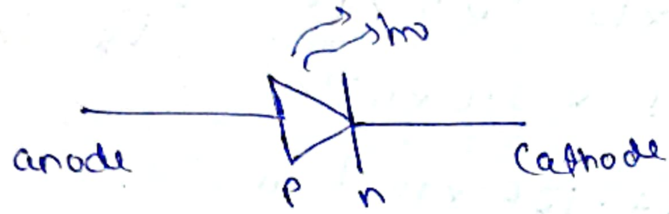
Homo - Junction LED, and Hetro Junction LED's

Homo-Junction LED:	Hetro - Junction LED:
(i) If p-n junction is made up of same type of intrinsic atoms, then the LED is called Homo-Junction LED	(i) If p-n junction is made up of different intrinsic atom then LED is called Hetro Junction LED.
(ii) Layers have similar semiconduc but dopping is different	(ii) Layers have different semi-conductors i.e. having different energy band gap
(iii) It is also called surface emitting LED	(iii) It is also called edge emitting LED.
(iv) It is non-directional light	(iv) It is directional light.
(v) Eg Si and GaAs solar cell, Ge.	(v) Eg: Gallenium Arsenide phosphide

LED's

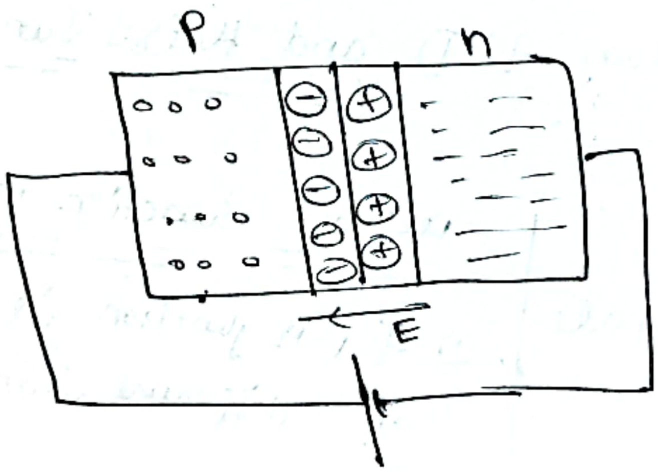
Light emitting diode which is used to emit light.

- It is always used in forward bias.
- It is two terminal device
- It converts electrical energy to light energy.



Structure and Working of LED :-

Structure :-



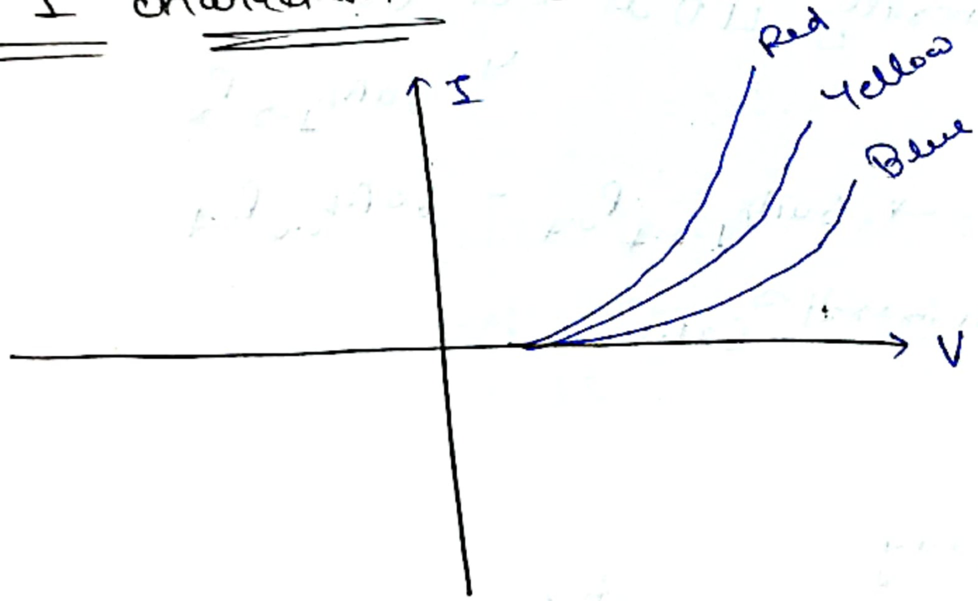
LEDs consist of P-N ~~dt~~ junction diode, which is connected in forward biasing that is P-type semiconductor is connected with +ve terminal of the battery and n-type semiconductor is -ve terminal of the battery.

Working:

- When PN junction is forward bias, free e^- and holes move towards opposite side, as a result free e^- and holes recombine with each others or we can say that free e^- in conduction band combines with holes in valence band.
- As a result, it emits light in the form of photon, this light energy, is in the visible range ($4000\text{Å} - 7000\text{Å}$) and the energy of the light is given by.

$$E_g = h\nu = hc/\lambda$$

V-I characteristics:



$E_g = \frac{hc}{\lambda}$

$\lambda = \frac{hc}{E_g}$

(i) The V-I characteristics of LED is shown in diagram which is similar to normal P-N junction.

(ii) When applied voltage is less than potential barrier, then the current will be zero. If a applied

(iii) voltage is greater than potential barrier then the current increasing by increasing voltage.

* when λ is less, E_g is more.

therefore red is emitted for small voltage and blue is emitted for large voltage.

Advantage of LED :-

* Long life (as no filament)
* ~~fast~~ action
* Low operational voltage.
* Bandwidth is small.
* Cheaper.
* Generally LED is used GaAsP

$GaAs_{1-x}P_x$

Red → $GaAs_{1-0.4}P_{0.4} = GaAs_{0.6}P_{0.4}$

Infrared → GaAs

Uses :-

* Display
* Optical communication
* Surgical lamp (sterilization)
* Navigation light in maritime.

Quantum Efficiency of LED :-

(i) Internal

$$IQE = \frac{\text{No. of photons out from LED}}{\text{No. of electrons injected into LED.}}$$

$$\underbrace{IQE}_{\text{internal quantum efficiency}} = \frac{1}{n(n+1)^2} \quad (n = \text{refractive index of that material})$$

$$\underbrace{EQE}_{\text{external QE}} = IQE \times \text{Extraction coefficient}$$

Ques: A LED has 5×10^{17} electrons injected per sec and it generate 4×10^{17} photons. Calculate IQE.

Sol:

$$IQE = \frac{4 \times 10^{17}}{5 \times 10^{17}} = 0.8$$

$$= 80\%$$

Ques: An LED has IQE of 90% due to optical loss and internal reflections, only 50% of the internally generated photons are able to escape as usual light. Calculate EQE.

Sol:

$$EQE = IQE \times \text{Extraction coefficient}$$

$$= 0.9 \times 0.5$$

$$= 0.45$$

$$\therefore 45\%$$

Hence, external quantum efficiency is 45%

Ques: An LED operate with current of 20mA and emits a photon with an average energy of 2eV the EQE = 40%. calculate optical power output.

Sol: