BUDDHA SERIES

(Unit Wise Solved Question & Answers)

Course – B. Tech (ECE)

College – Buddha Institute of Technology

(AKTU CODE-525)

Department: Electronics and Communication Engineering

Subject: Optical Communication (BEC-057)

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Unit – 3

Q1. What types of materials are used in optical sources? [AKTU: 2020-21]

ANS:

Materials used in optical Sources (LED & LASER) - LASER diodes and LED almost use direct gap semiconductors. Most direct-gap semiconductors are compound materials formed by combining elements from group III in periodic table (Aluminum (Al), Gallium (Ga), Indium (In) and group V (Nitrogen (N), Phosphorous (P), Arsenic (As), Antimony (Sb).

The main semiconductor compound materials used to manufacture LED are -

(1) Indium gallium nitride (InGaN): blue, green and ultraviolet high brightness LEDs.

(2) Aluminum gallium indium phosphide (AlGaInP): Yellow, orange and red high-brightness LEDs.

(3) Aluminum gallium arsenide (AlGaAs): Red, and infrared LEDs.

Q2. What are the advantages & disadvantages of LED light? [AKTU:2022-23]

LED has the following advantages-

(1) Simpler fabrication
(2) Low cost
(3) High Reliability
(4) Less temperature dependence
(5) Simpler drive circuitry
(6) Linearity

LED has following drawbacks.

(1) Generally Low optical power coupled into fiber.
(2) Lower modulation bandwidth
(3) Harmonic distortion.

Q3. Explain heterojunction structure of LED. The radiative and non-radiative recombination lifetime of the minority carriers in the active region of a double heterostructure LED are 60 ns and 100 ns respectively. Evaluate the bulk recombination or total carrier recombination lifetime and

power generated internally in the device when the peak wavelength is 0.87 µm at a drive current of 40mA.

[AKTU:2023-24]

ANS:

Total carrier recombination Life time

$$\tau = \frac{\tau_r \tau_{nr}}{\tau_r + \tau_{nr}}$$

$\tau_r = 60\ ns = 60 \times 10^{-9}$ Sec.

$\tau_{nr} = 100 ns = 100 \times 10^{-9}$ sec

$$\tau = \frac{60 \times 10^{-9} \times 100 \times 10^{-9}}{60 \times 10^{-9} + 100 \times 10^{-9}} = 37.5 \times 10^{-9}\ s.$$

Internal quantum efficiency of the device,

$$\eta_{int} = \frac{\tau}{\tau_r} = \frac{37.5 \times 10^{-9}}{60 \times 10^{-9}} = 0.625$$

$\lambda = 0.87\ \mu m$. $h = 6.626 \times 10^{-34}$, $c = 2.998 \times 10^{8}$ m/s.

Power internally generated within the device,

$$P_{int} = \eta_{int} \frac{hci}{e\lambda}$$

$$= \frac{0.625 \times 6.626 \times 10^{-34} \times 2.99 \times 10^{8} \times 40 \times 10^{-3}}{1.6 \times 10^{-19} \times 0.87 \times 10^{-6}}$$

$= 35.6$ mw

Q4. Explain the following:

(a) Internal quantum efficiency

(b) External quantum efficiency

ANS:

Internal Quantum efficiency –

The LED internal quantum essiciency η_{int} is defined as the ratio of the radiative recombination rate to the total recombination rate.

$$\eta_{int} = \frac{r_r}{r_t} = \frac{r_r}{r_r + r_{nr}} = \frac{R_r}{R_t}$$

where R_r = Total number of recombination per second

r_t = Total recombination rate per unit volume

r_r = Radiative recombination rate per unit volume

r_{nr} = Non-radiative recombination rate per unit volume.

External Quantum Efficiency – (EQE)

The external quantum efficiency of LED is defined as the number of injected electrons per unit time that are converted to the number of 'emitted photons' per unit time (outside the LED device)

$$\text{EQE of LED} = \frac{\text{Emitted photons outside LED / sec}}{\text{Injected electrons / sec}}$$

* The external power efficiency η_{ep} is defined as the ratio of the optical power emitted externally P_e to the electric power provided to the device P.

$$\eta_{ep} = \frac{P_e}{P} \times 100$$

The optical power emitted Pe into a medium of low refractive index n from the face of a planar LED fabricated from a material of refractive index nx is given by

$$P_e = \frac{P_{int} F n^2}{4 n_x^2}$$

P_{int} = Power generated internally
F = Transmission factor of the semiconductor - external interface.

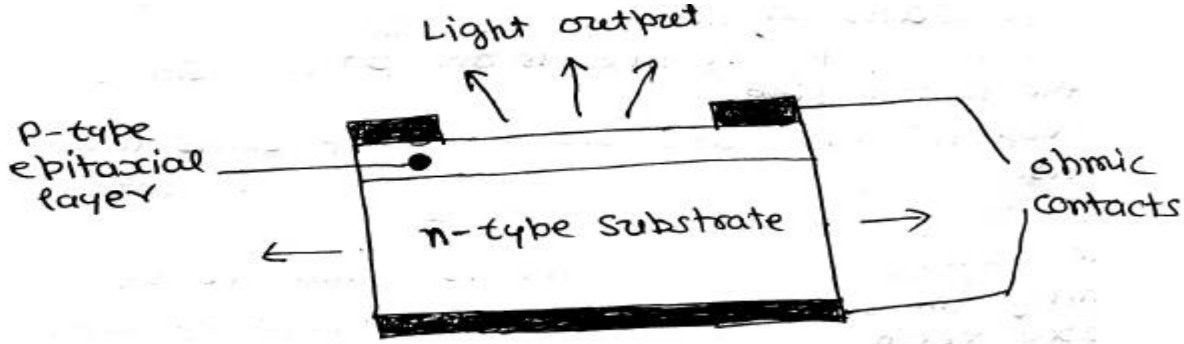
Q5. Describe various type of LED structure with their diagram. [AKTU:2022-23]

ANS:

LED structure - There are six major types of LED structures-

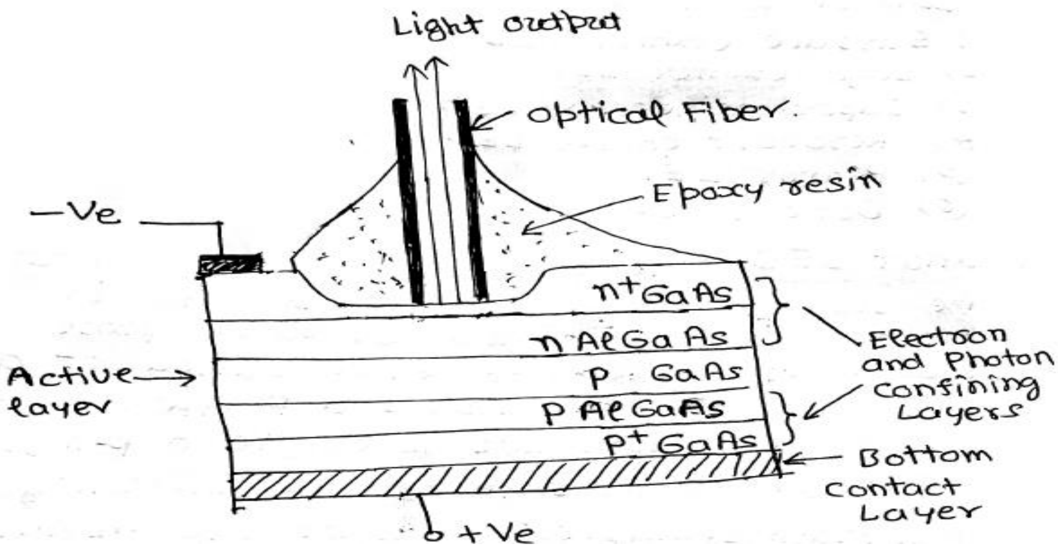
(1) Surface emitter LED
(2) Edge emitter LED
(3) Superluminescent LED
(4) Resonant cavity LED
(5) Planar LED
(6) Dome LED.

Planar LED - The planar LED is the simplest of the structures that are available and is fabricated by either liquid - or vapor - phase epitaxial process over the whole surface of a GaAs substrate. This involves a p-type diffusion into the n-type substrate to create a p-n junction. Forward current flows through the junction gives Lambertain spontaneous emission and the device emits light from all surfaces. However, only a limited amount of light escapes the structure due to total internal reflection.



The structure of a planar LED showing the emission of light from all surfaces

Surface Emitter LEDs - (S-LED) -



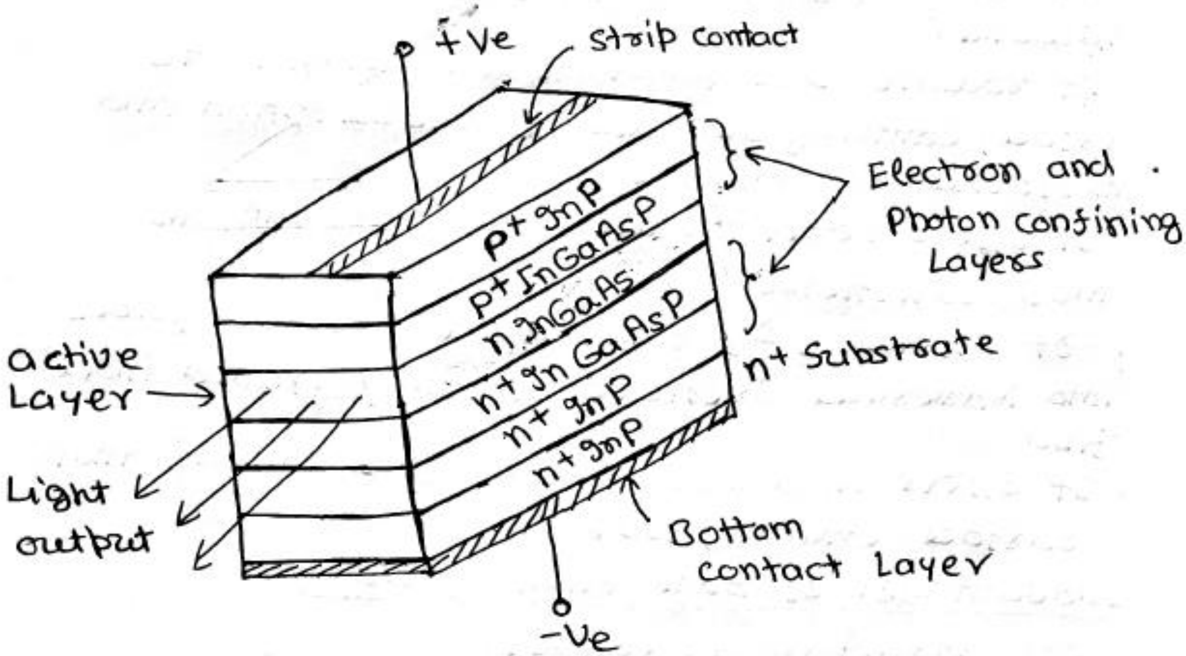
The Surface emitter LED structure consists of thin central active layer of P type GaAs. This central layer is bounded by n-type AlGaAs and n^+ type GaAs at the top side. This central layer is bounded by P type AlGaAs and p^+ type GaAs at the bottom side.

* The top n^+ type GaAs and bottom p^+GaAs layers are used to provide low resistive ohmic contacts only.
* The external optical fiber is connected by etching the top layers and by shielding with epoxy resin.

* when refractive indices of both P-type and n-type materials are same, light is free to come out from all sides of semiconductor device due to no confinement. However only active region near the surface will emit the significant amount of light while absorbing from the other parts. Hence it is called a surface emitting LED. Output radiation is originated from the central thin layer p-type GaAs layer.

Edge Emitting LED - (E-LED) -

E-LED is used for long wavelength optical communication approx between 1.33 to 1.55 um.



Edge Emitting Layer

* Central active layer is made using n InGaAs having narrow bandgap. It is bounded by wide bandgap layers such as p^+ InGaAsP and n^+ InP cladding layers.
* These two cladding layers help in confining injected electrons and holes into the middle layer. It also helps emitted photons to travel along LED axis as per optical properties.
* Due to above, light is emitted from the edge of the LED. Hence it is known as edge emitting LED.

Q6. Compare surface emitting and edge emitting LEDs. **[AKTU: 2020-21]**

Comparision of S-LED and E-LED –

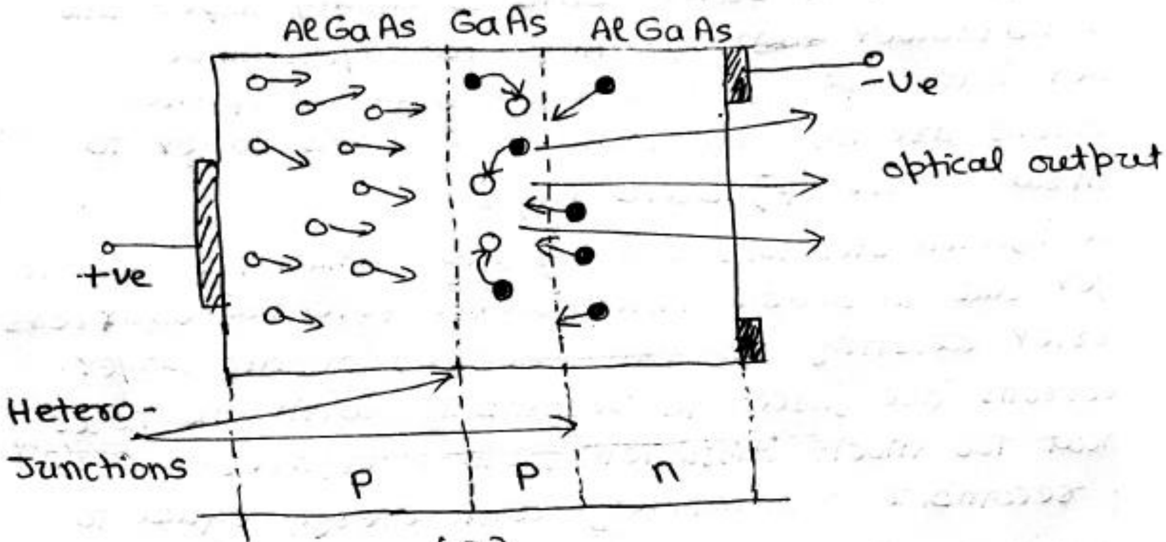
SLED Surface Emitting LED	ELED Edge emitting LED
1. Easy to fabricate	1. Difficult to fabricate
2. Light is emitted from the surface of active Layer	2. Light is emitted from the edge of active layer
3. wide spectral width	3. narrow spectral width
4 maximum internal quantum efficiency is up to 60 %.	4. maximum internal quantum efficiency is in the range of 60 % to 80 %.

5. Less Reliable	5. Highly reliable
6. Less modulation bandwidth	6. Better modulation bandwidth of the order of MHz
7. Couple Less optical power into low NA fiber.	7. Couple more optical power into Low NA fiber
8. Easy to mount and handle	8. Difficult to mount and handle
9. Low system performance	9. High system performance

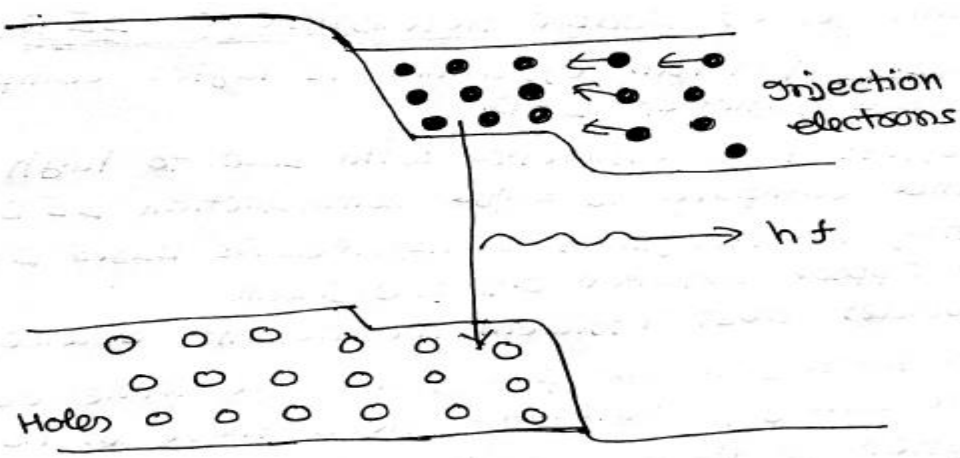
Q7. What do you mean by double hetero-junction ? What are the advantages of double Hetero structure? [AKTU: 2020-21]

ANS:

In order to achieve efficient confinement of emitted radiation double hetero-junctions are used in LED structures. A heterojuction is a junction formed by dissimilar semiconductors. Double heterojunction is formed by two different semiconductors on each side of active region. The two materials have different bandgap energies and different refractive indices. The changes in bandgap energies create potential barrier for both holes and electrons. The free charges can recombine only in narrow well defined active layer side.



(a)



(b)

(a) Layer structure of double heterojunction LED
(b) Energy band diagram of double heterojunction LED

Fig: Principle of operation of double heterojunction LED

As shown thin layer of GaAs is sandwiched between two layers of Al Ga As. GaAs is lightly doped and has narrower bandgap. Al Ga As layers have wider bandgap. when forward bias is applied, electrons are injected from (n) Al GaAs layer to central active (P) GaAs layer.

* The injected electrons are trapped within the middle layer due to double heterojunction potential barrier existing on both sides of middle Layer.
* Electrons are forced to recombine with the holes without too much diffusion from interfaces. They recombine radiatively with energy equal to the bandgap of GaAs.

Advantages of Double Heterojunction LED:-

1. Internal quantum efficiency is higher compared to single junction LED.
2. It offers high efficiency with Low to high radiance compared to single homojunction LED.
3. Emitting wavelength of GaAs/AlGa As based DH LED appear between 0.8 to 0.9 μm.
4. provides most efficient incoherent sources
5. Both n-region and p regions are made out of wide bandgap materials. Hence there is no absorption in these regions. They form optical windows.
6. n and p region can be highly doped.
7. Radiative recombination rate is high.

Disadvantages- (1) These LEDs are useful at Low temperature.

(2) complexity involves during growth process.

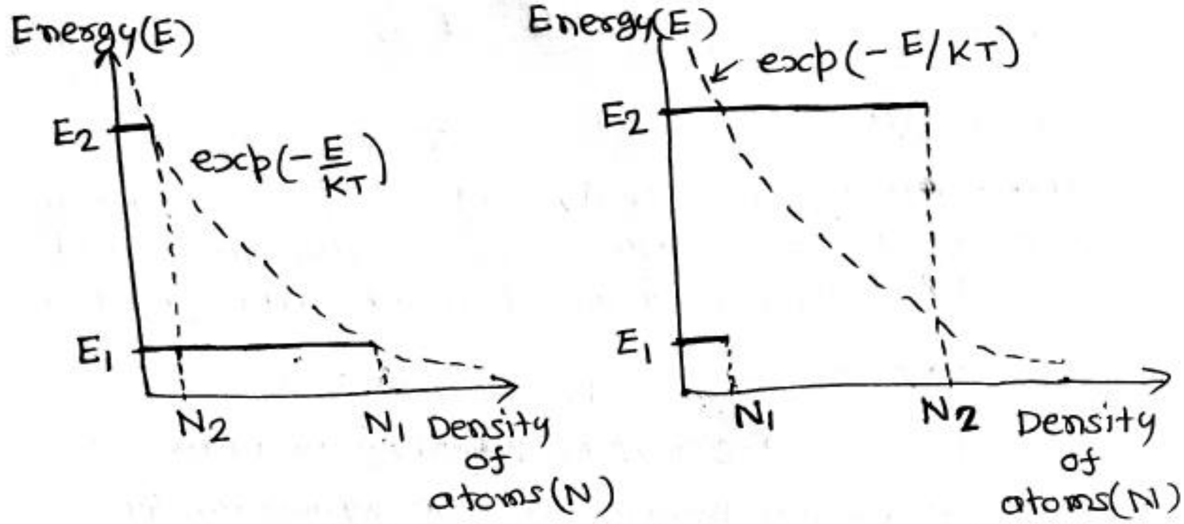
Q8. What are the features required in fiber optical sources?
ANS: Features Required in Fiber Optical Sources:

1. Ideally, the light output should be highly directional.
2. The source should be linear.
3. Should emit light at wavelength where the fiber has low losses and low dispersion and where the detectors are efficient.
4. Should be capable for simple signal modulation over a wide bandwidth.
5. Must couple sufficient optical power in the fiber.
6. Should have very narrow spectral bandwidth (linewidth) in order to minimize dispersion in the fiber.
7. Must be capable of maintaining a stable output which is largely unaffected by change in ambient conditions. (e.g. temperature)
8. Source should be comparatively cheap and highly reliable.

Q9. Explain the term 'Population Inversion' used in optical communication.
ANS:

Population Inversion - or Pumping -

Under the conditions of thermal equilibrium, the lower energy level E_1 of the two-level atomic system contains more atoms than upper energy level E_2. However, to achieve optical amplification it is necessary to create a nonequilibrium distribution of atoms such that the population of upper energy level is greater than that of lower energy level. (i.e $N_2 > N_1$). This condition is known as population inversion.



(a) Boltzman distribution for a system in thermal equilibrium

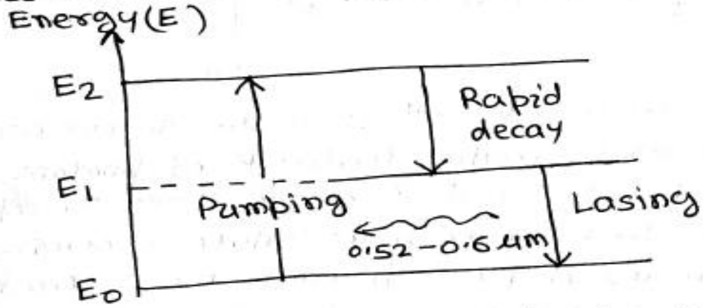
(b) a nonequilibrium distribution showing population inversion

Populations in a two- energy level system.

* In order to achieve population inversion it is necessary to excite atoms into uper energy level E_2 and hence obtain a nonequilibrium distribution. This process is achieved using an external energy source and is known as pumping. Pumping is normaly done by the application of intense radiation.

* In three level system, the energy levels are ground level E_0, a metastable level E_1 and a third level above the metastable level E_2. with suitable pumping the electrons in some of the atoms may be excited from the ground state into higher level E_2. Since E_2 is a normal level the electrons will rapidly decay by nonradiative process to either E_1 or directly to E_0

Hence empty states will always in E_2. The metastable level E_1 exhibits a much longer life time than E_2 which allow a large number of atoms to accumulate at E_1. hence density of atoms in metastable state E_1 increases above the ground state and a population inversion is obtained between these two levels.



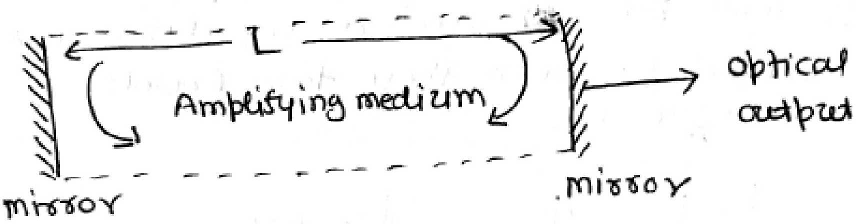
Population inversion and Lasing for three-level system – ruby (crystal) lesser.

Q10. Describe the optical feedback and laser oscillation in optical waveguide. [AKTU:2022-23]
ANS:

Optical Feedback and Laser Oscillation –

Optical feedback is a phenomenon in a laser in which a part of the coherent emission light returns to the laser cavity. Light amplification in the laser occurs when a photon colliding with an atom in the excited energy state causes the stimulated emission of a second photon and then both of these photons release two more. Continuation of this process effictively creates avalanche multiplication, and when the electromagnetic waves associated with these photons are in phase, amplified coherent emission is obtained.

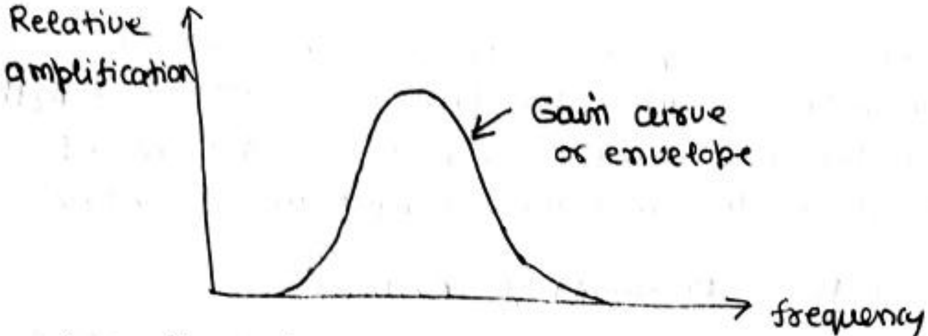
To achieve this laser action it is necessary to contain photons within the laser medium and maintain the conditions for coherence. This is achieved by using mirrors at the end of amplifing medium as shown in fig.



The optical cavity formed is similar to an oscillator because it provides positive feedback of photons by reflection at either end of cavity. Hence the optical signal is fed back many times while receiving amplication as it pass through the medium. The structure therefore acts as a Fabry - Perot resonator.

* A stable output is obtained at saturation when optical gain is exactly matched by the losses in the amplifying medium. The major loss in amplying medium is due to absorption, scattering and diffraction at the mirrors.
* Oscillations occur in laser cavity over a small range of frequencies where the cavity gain is sufficient to overcome the above losses. Hence the device is not a perfectly monochromatic source but emits over a narrow spectral band other oscillation frequencies within the spectral band result from frequency variations due to the thermal motion of atoms within the amplifying medium.

Resonant Frequencies–



when the optical spacing between the mirrors is L, the resonance condition along the axis of cavity is given by,

$$L = \frac{\lambda q}{2n} = \frac{c q}{f 2n}$$

λ = Emission wavelength
n = Refractive index of amplifying medium
q = an integer

Discrete Emission frequencies f are given by

$$f = \frac{qc}{2nL}$$

The different frequencies of oscillation within the laser cavity are determined by various integer values of q and each constitutes a resonance or mode. These modes are seperated by a frequency interval δf, where

$$\delta f = \frac{c}{2nL}$$

The mode seperation in terms of free space wavelength is given by

$$\delta \lambda = \frac{\lambda^2}{c} \delta f$$

$$\delta \lambda = \frac{\lambda^2}{2nL}$$

Q11. Derive the threshold condition for laser oscillations to sustain. [AKTU: 2021-22]

Threshold Condition for Laser Oscillation-

The steady state conditions for laser oscillation are achieved when the gain in amplifying medium exactly balances the total losses. Hence, although population inversion between the energy levels providing the laser transition is necessary for oscillation to be established, it is not alone sufficient for lasing to occur. In addition a minimum or threshold gain within the amplifying medium must be attained such that laser oscillations are initiated and sustained. This threshold gain may be determined by considering the change in energy of a light beam as it passes through the amplifying medium.

* In laser cavity, the fractional round trip loss incurred by light beam is-

$$\text{Fractional loss} = r_1 r_2 \exp(-2\bar{\alpha} L) \quad —(1)$$

where, L = Length between the two end mirrors

r_1 and r_2 = Reflectivities of mirrors

$\bar{\alpha}$ = Loss coefficient per unit length due to absorption, scattering, diffraction at the mirrors.

* The fractional round trip gain is given by

$$\text{Fractional Gain} = \exp(2\bar{g} L) \quad —— (2)$$

where $\bar{g}$ = Gain Coefficient per Unit Length produced by stimulated emission

Hence, $\exp(2\bar{g}L) \times r_1 r_2 \exp(-2\bar{\alpha}L) = 1$

or $r_1 r_2 \exp[2(\bar{g}-\bar{\alpha}] = 1$ —— (3)

or $\exp[2(\bar{g}-\bar{\alpha})L] = \frac{1}{r_1 r_2}$

or $\ln \exp[2(\bar{g}-\bar{\alpha})L = \ln \frac{1}{r_1 r_2}$

or $2(\bar{g}-\bar{\alpha})L = \ln \frac{1}{r_1 r_2}$

$$\bar{g}-\bar{\alpha} = \frac{1}{2L} \ln \frac{1}{r_1 r_2}$$

$$\bar{g} = \bar{\alpha} + \frac{1}{2L} \ln \frac{1}{r_1 r_2}$$

Hence Threshold gain per unit length

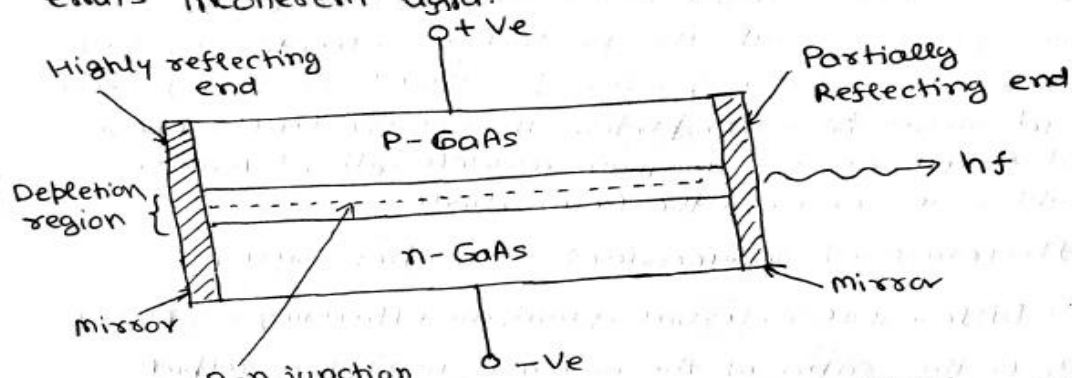
$$\boxed{\bar{g}_{th} = \bar{\alpha} + \frac{1}{2L} \ln \frac{1}{r_1 r_2}} \quad \text{—— (4)}$$

Q12. Explain the principle, construction and working of semiconductor injection laser. Also define total efficiency and external power efficiency of a semiconductor injection laser.

[AKTU: 2023-24]

ANS:

The Semiconductor Injection Laser or Injection Laser Diode (ILD) - A Laser diode or injection Laser diode is a device in which the p-n junction of a diode is used as a lasing medium. The energy is supplied in the form biasing of diode. The Laser diode normally emits coherent light, while LED emits incoherent light.



Ga-As injection Laser with Fabry-Perot cavity

A p-n junction is formed by two layers of doped Gallium Arsenide (GaAs). There is a highly reflect surface at one end of p-n junction and a partial reflective surface at the other end, forming a resonant cavity for photons. The Laser diode is forward biased by an external voltage source. Due to forward bias, electrons move from n region to p region and recombination of electrons and holes takes place at the junction Due to radiative recombination photons are released. As the forward current increases, more electrons enter the depletion region and more photons are emitted.

Some of the photons that are randomly drifting within the depletion region strikes the reflected surfaces (mirrors) perpendicularly. These reflected photons move along the depletion region, striking atoms and releasing additional photons. This back and forth movement of photons increases the generation of photons and a very intense beam of laser light is formed by the photons that pass through the partially reflective end of p-n junction. Each photon produced in this process is identical to other photons in energy level, phase and frequency. So a single wavelength of intense light emerges from the laser diode.

Differential external quantum efficiency of Laser –

It is the ratio of the increase in photon output rate to the given increase in number of injected electrons. It is also known as slope quantum efficiency.

$$\eta_D = \frac{dP_e / hf}{dI / e} \simeq \frac{dP_e}{dI(E_g)}$$

where P_e = optical emitted power

I = current

hf = Photon energy

e = charge on electron.

E_g = band gap energy expressed in eV.

Total Efficiency (External quantum efficiency)

It is defined as,

$$\eta_T = \frac{\text{Total number of output photons}}{\text{Total number of injected electrons}}$$

$$= \frac{P_e / hf}{I / e} \simeq \frac{P_e}{I E_g}$$

$$\eta_T = \eta_D \left(1 - \frac{I_{th}}{I}\right)$$

I_{th} = Threshold current.

External Power Efficiency – It is the ratio optical emitted power to the electrical input power.

$$\eta_{ep} = \frac{P_e}{P} \times 100\ \%$$

$$\eta_{ep} = \eta_T \left(\frac{E_g}{V}\right) \times 100\ \%$$