
KTU
NOTES

MODULE 1 (CHAPTER 1)
LASER

1)**What are the characteristics or properties of laser beam**.
a)High Directionality)Monochromatic)Coherence)Intense brightness

2) Distinguish between spontaneous emission and stimulated emission.

Spontaneous Emission	Stimulated Emission
1)The process of emission of radiation when an atom drops from an excited state to a lower energy state without the help of any external agency is termed as Spontaneous emission.	1)The process of emission of radiation when an atom drops from an excited state to a lower energy state with the help of an external stimulus or photon having same energy as that of the excited atom is termed as stimulated emission
2)Polychromatic radiation(light)	2) Monochromatic radiation
3)Less directionality	3)High directionality
4) Incoherent radiation	4) Coherent radiation
5)Less intensity	5)High intensity

3) Explain metastable state and population inversion.
Ans:**Metastable state** is an excited state of an atom or molecule with a longer lifetime(10^{-3}s) than the other excited states(10^{-8}s).
Population Inversion The condition in which the population(no: of atoms) in the excited state is more than that of ground state is called population inversion.
$\frac{N_2}{N_1} = e^{-\frac{(E2-E1)}{kT}}$ (where N1-no: of atoms in ground state,N2-no of atoms in excited state.,E1-ground state energy,E2-excited state energy.,k=Boltzmann constant, T-Temperature)

4) What are Einstein coefficients.
Ans: **Einstein coefficients** are mathematical quantities (constants) which gives the measure of the probability of absorption or emission of light by an atom or molecule.

Einstein's coefficients are :

a) A_{21} = "Einstein's coefficient of spontaneous emission" = the probability per unit time that an atom in energy state 2 will spontaneously emit a photon and undergo a transition to energy state 1,

b) B_{12} = "Einstein's coefficient of absorption" = the probability per unit time per unit mean intensity at frequency ν_0 that an atom in energy state 1 will absorb a photon of frequency ν_0 and jump to energy state 2,

b) B_{21} = "Einstein's coefficient of stimulated emissions" = the probability per unit time per unit mean intensity at frequency ν_0 that an atom in energy state 2 will emit a photon of frequency ν_0 and jump to energy state 1

5) Explain absorption, spontaneous emission and stimulated emission.

a)**Absorption**: Consider a system of two energy level E1(ground state)and E2(excited state),with energy difference E2-E1=hυ.
If a photon of energy E= hυ, incident on the system then atom in the ground state receive this energy and jumps to excited state E2.This process of excitation of atoms to higher energy levels after receiving energy is called absorption

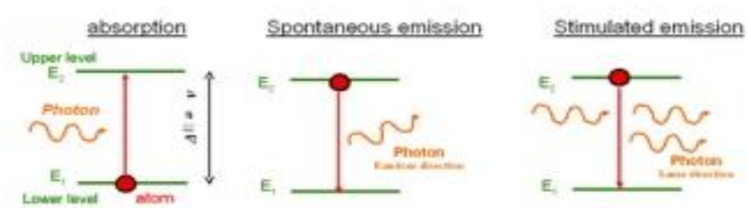
Rate of absorption = $B_{12}N_1U(\upsilon)$, (where B_{12}-Einstein's coefficient of absorption, N_1-number of atoms in ground state, $U(\upsilon)$- energy density of incident radiation (at unit frequency range about υ).

b) Spontaneous emission: The process of emission of radiation when an atom drops from an excited state to a lower energy state without the help of any external agency is termed as Spontaneous emission.

Rate of spontaneous emission = $A_{21}N_2$, (where A_{21} -Einstein's coefficient of spontaneous emission, N_2 - number of atoms in excited state.

c) Stimulated emission: The process of emission of radiation when an atom drops from an excited state to a lower energy with the help of an external photon having same energy as that of the excited atom is called **Stimulated emission**: . Here the emitted photon and the incident photon moves in same direction and have a constant phase relationship. In other words the emergent beam from stimulated emission will be coherent.

Rate of stimulated emission = $B_{21}N_2U(\upsilon)$, (whereB_{21} -Einstein's coefficient for stimulated emissions,N_2-number of atoms in excited state,$U(\upsilon)$- energy density of incident radiation (at unit frequency range about υ).



6) Explain pumping mechanism.

Ans : Pumping mechanism –It is the process of transferring atoms from ground state to excited state by giving external energy.

Eg-Optical pumping- Electrons are excited using light

Electrical pumping –Electrons are excited using electrical discharge.

Direct pumping-Electrons are excited using forward bias

7) What is resonant cavity of a laser.

Ans : Resonant cavity consists of two mirrors one is fully reflecting and other is partially reflecting. It compensates the optical losses by provides optical feedback and helps in achieving amplification of light beam in a laser.

8) Explain the principle of laser.

Ans :Principle of laser relies on the production of coherent laser beam from stimulated emission by achieving population inversion in active medium with the help of pumping mechanism and resonant cavity.

9**) Write 4 application of laser**.

a)**Industrial application:** Cutting ,drilling, welding , 3-D printing of various automobile and aircraft structures and spare parts etc

b) **Medical application:** Cancer treatment, cataract surgery, tattoo removal , tooth decay removal,gum reshaping etc

c) **Defense application:** Death rays to destroy enemy planes ,missilesetc, laser also used for target designator and range finders.

d)**Communication and IT :** Optical fibre communication ,printers, barcode scanners etc

e)**Scientific and research applications :** Spectroscopy, Plasma analysis, laser induced breakdown spectroscopy.

10) Explain Active medium.

Ans : Active medium is the heart of a laser system and is responsible for producing gain and subsequent generation of laser. It consists of a metastable state in order to achieve population inversion for establishing laser action by stimulated emission. Meta-stable states are excited states which have more lifetime(10^{-3}s) than normal excited state(10^{-8}s)

11)**What are the advantages and disadvantages o of semiconductor laser.**

Advantages :

1) Very small in size,
2) Requires only low power to operate and can be operated continuously,
3) High efficiency(30-50%,
4) Can be easily integrated with optical fibres for communication,
5) Output of semiconductor laser can be modulated by very high frequency(in gigahertz range),hence it is very useful in optical fibre communication.

Disadvantages : Output is generally wide beam and also less monochromatic due to crystalline defects and thermal distortions.

12)**What are the advantages and disadvantages of gas laser.**

Ans: Advantages :

1)Highly monochromatic and pure spectrum due to lack of crystalline defects and thermal distortions
2) Can be operated continuously,
3) Easily portable and cheap

Disadvantages : Low efficiency(0.1%)

13) What are the advantages and disadvantages of ruby laser

Ans: Advantages :

1)Long storage time of the population inversion is well suited for production of high power laser pulses

Disadvantages : Low efficiency, output is not continuous, excess heat is produced during operation, Requires high power for operation

14) **What are the components of a laser?**

Ans: The three main components of a laser are

1) **Pumping mechanism** –It is the process of transferring atoms from ground state to excited state by giving external energy
2) **Active medium** -is the heart of a laser system and is responsible for producing gain and subsequent generation of laser. It consists of a metastable state in order to achieve population inversion for establishing laser action by stimulated emission
3) **Resonant cavity** : It consists of two mirrors one is fully reflecting and other is partially reflecting. It compensates the optical losses by provides optical feedback and helps in achieving amplification of light beam in a laser.

15) **Explain the working of a laser**

Ans: When we achieve population inversion condition in an active medium using suitable pumping mechanism ,a spontaneously emitted photon can initiate stimulated emission and cause amplification of light by oscillating back and forth between the resonant cavity containing a fully reflecting mirror and partially reflecting mirror. Finally the highly coherent light beam from the stimulated emission emerges out through partially reflecting mirror and we get laser output beam.

16) Explain the term critical inversion.

Ans: Amplification of light in resonant cavity only takes place when population inversion reaches a particular value called critical inversion.
At steady state of lasing threshold the energy losses are compensated by the energy obtained by light beam from active medium by stimulated emission. Using resonant cavity

17) Explain briefly the characteristics of laser beam.

Ans: **a)Directionality :** Laser light has high directionality, it is emitted in a specific direction, with a very low divergence. The laser beam is narrow and can be concentrated on a small area, this property is due to optical resonance cavity action ,as only light waves which propagate along axis of resonant cavity are sustained and amplified

b)Monochromaticity : Laser light is emitted at a single wavelength, unlike sunlight, which spans multiple wavelengths**.**

c)Coherence : Light waves emitting from a laser are coherent in nature this means that these light waves have same frequency ,same wavelength and they maintain a constant phase difference with each other.

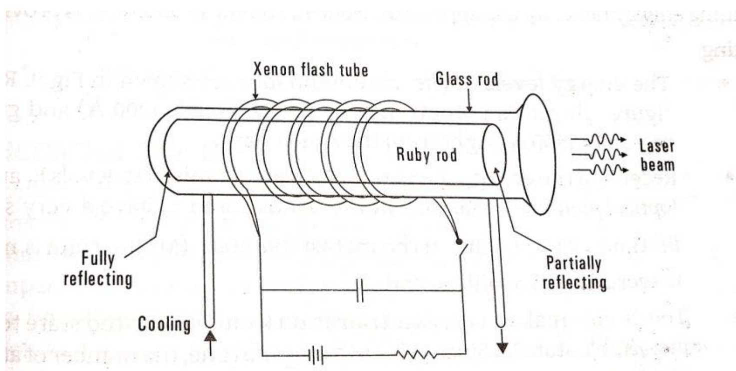
d)Intensity : Laser light is more intense than ordinary light because all the energy is concentrated on a narrow region. A laser of moderate power has a brightness which is several orders of magnitude higher than the brightness of the strongest conventional light source, this is due to high directional and coherence property of laser beam

ESSAY QUESTIONS

1) **Outline the principle and working of Ruby laser.Write 5 applications of Ruby laser.**

RUBY LASER

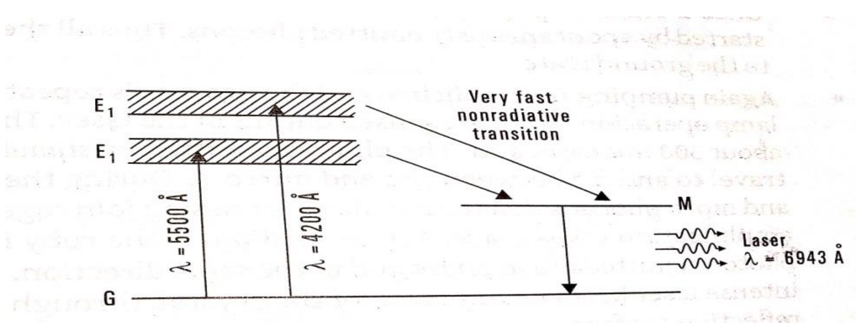
Ans: In a ruby laser, a single crystal of ruby (Al_2O_3 doped with Cr_2O_3) in cylindrical shape acts as a laser medium or active medium. The ruby rod(2cm in diameter and 25cm in length) is made by doping (Al_2O_3) (sapphire) with small amounts of chromium ions (Cr^{3+}).With 0.05% of Cr^{3+} ion ruby appear pink in colour and with 0.1% of Cr^{3+}ionit will appear red in colour



Pumping Mechanism : Optical pumping provided by Xenon flash lamp (helical shaped Quartz tube filled with Xenon gas).It produces flashes of white light having few megawatt energy ,which lasts for several milliseconds.

Active medium : Ruby rod (active centre:Cr^{3+} ion)
Resonant cavity: Ends of the ruby rod is polished flat, one end is fully polished whereas,other end is partially polished.

Energy levels of Cr^{3+} ion are shown in the fig



Working:

When Xenon flash lamp produces flashes of white light,Cr^{3+} ion absorbs blue(4200A) and green(5500A) coloured light from it and jumps to excited energy levels E1and E2,since these levels have very short life time(10^{-9}s) they quickly jumps to metastable state M,which has a longer life time($3.5*10^{-3}$s) as a result number of atoms in these states keeps increasing finally leads to population inversion between state metastable state M and ground state G.At this condition a spontaneously emitted photon from metastable state can initiate stimulated emission and we get laser output having a wavelength of 6943A(red colour).

The flashed lamp operation leads to a pulsed output lasting 300microseconds of power about 10 to 40kw.

Only a small portion of the optical energy provided by Xenon flash lamp is used for pumping Cr^{3+} ion and rest of the energy heats up the apparatus. Hence a cooling mechanism is provided for removing heat from the system.

Applications : 1)Holography 2)Removal of tattoos and skin lesions 3)Measuring properties of plasma.

2) **Outline the principle and working of CO_2 laser.Write 5 applications of CO_2 laser.**

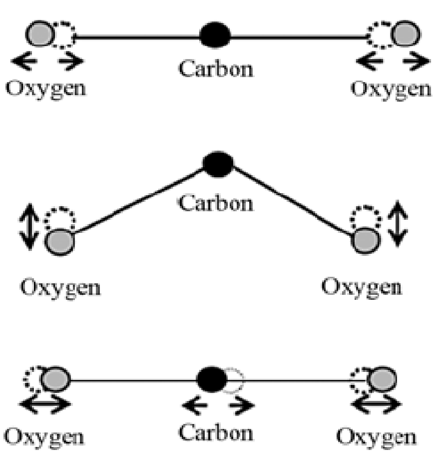
CARBON DIOXIDE (CO_2) LASER

Ans:

The CO_2, gas laser is the first molecular gas laser , developed by **Indian born American Scientist Prof. C.K.N. Patel.**

It is a four-level molecular gas laser. In this laser, transition takes place between vibrational energy states of carbon dioxide molecules.

<u>Vibrational modes(Energy states) of CO_2 molecules</u>



A carbon dioxide molecule has a carbon atom at the centre with two oxygen atoms attached, one at each sides. Such a molecule when excited by absorbing sufficient energy vibrates in **three independent modes**. They are

(a) Symmetrical stretching mode or Symmetric stretching mode

(b) Bending mode

(c) Asymmetrical stretching mode or Asymmetric stretching mode

(a) Symmetric stretching mode

In this mode of vibration, carbon atom is at rest. Both oxygen atoms vibrate such that they are moving away or approaching the fixed carbon simultaneously along the axis of the molecule.

(b) Bending mode

In this mode of vibration, both oxygen atoms and carbon atom vibrate perpendicular to molecular axis

(c) Asymmetric stretching mode

In this mode of vibration, both oxygen atoms and carbon atom vibrate asymmetrically, i.e., oxygen atoms move in one direction while carbon atom moves in the opposite direction.

These vibrational modes represent different vibrational excited energy levels of CO_2 molecule and each of these mode can only have discrete energy values (integer multiple of some fundamental value). Energy states of the molecule can be represented by three integers(i j k),for example (020)means the molecule is in a state with zero energy for symmetric mode, two quanta of energy for bending mode and zero energy for asymmetric mode

CONSTRUCTION AND WORKING OF CO_2 LASER

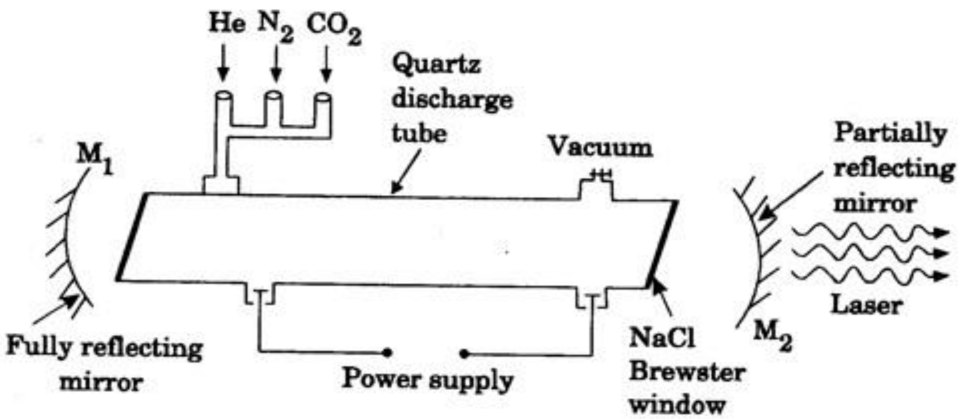


Fig. 5.22 CO_2 laser

CO_2 laser consists of a quartz discharge tube 5 m long and 2.5 cm in diameter (Fig. 5.22). This discharge tube is filled with the gas mixture of CO_2, nitrogen and helium in the ratio 1:2:3.

The terminals of the discharge tube are connected to D.C. power supply. The ends of this tube are fitted with Brewster windows so that the laser light generated is plane polarised.

Pumping Mechanism :Electric discharge pumping method

Active medium :Mixture of CO_2,N_2,He gas in the ratio1:2:3

Resonant cavity (optical resonator): Two concave mirrors one is fully reflecting M_1 and other is partially reflecting M_2

Working: When the power supply is switched on, the fast moving electron from the electric discharge collides with the N_2 molecule and excites it to the energy level F2 from F1.

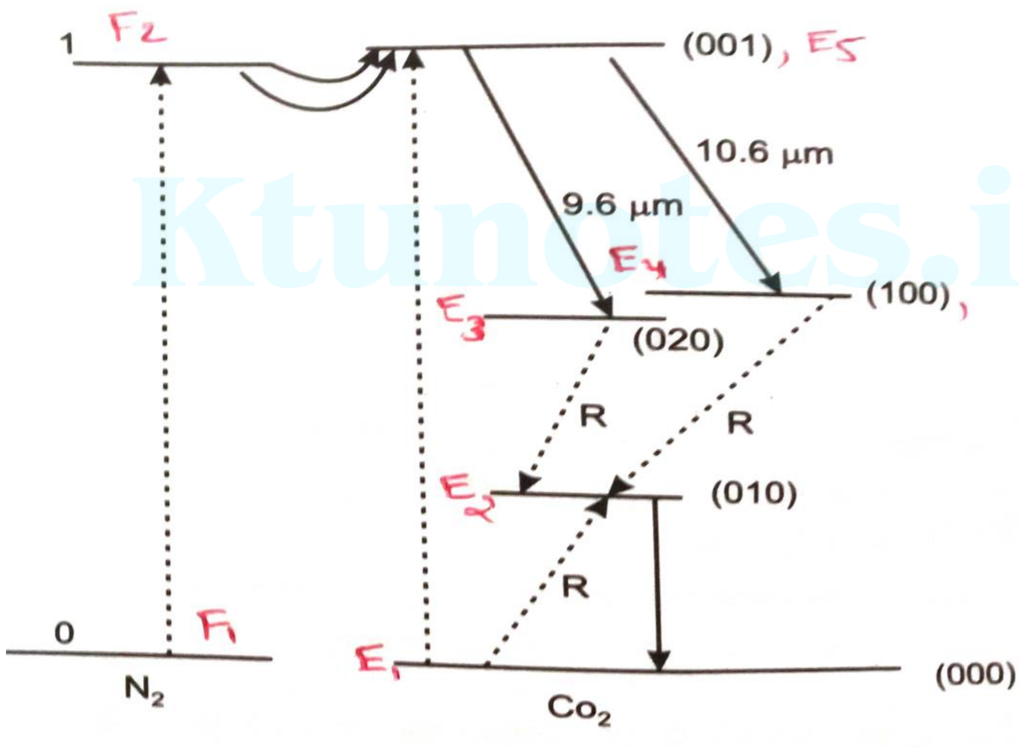
$N_2 + e^* \rightarrow N_2^* + e$

The excited energy level F_2 of of N_2 molecule has approximately same energy as that of excited energy levels E_5 of CO_2 molecule , thus when excited N_2 molecule in energy level F_2 collide with the CO_2 molecule in the ground state E_1, resonance energy transfer takes place and the CO_2 molecule excites to the energy levels E_5 and also N_2 molecule gets de-excites to the ground level F_1.Therefore the purpose of N_2 molecule is to help in achieving a population inversion in the CO_2 molecule .(CO_2 molecule can also excite o energy level E_5 by the collision with fast moving electron from electric discharge)

$$\boxed{N_2^* + CO_2 \rightarrow CO_2^* + N_2}$$

After sufficient collision of CO_2 molecule with N_2 molecule , the state of population inversion can be achieved between the levels E_5 and E_4 and also with the energy levels E_5 and E_3.

Now a spontaneously emitted photon can initiate stimulated emission and thereby create amplification of light with the help of resonant cavity.



The following two transitions will take place

(i) Transition E_5 (001) to E_4 (100)

This transition produces a laser beam of wavelength 10.6 μm.(far infrared region)

(ii) Transition E_5 ((001)) to E_3 (020)

This transition produces a laser beam of wavelength 9.6 µm. .(far infrared region)

Now the CO_2 molecules in excited state **E_3 and E_4 deexcites to energy level E_2 (010)** by collision with the ground state CO_2 molecules.

CO_2 **(100)** + CO_2 **(000)** → $2CO_2$ **(010)**

CO_2 **(020)**+ CO_2 **(000)** →$2CO_2$ **(010)**

These transition are so fast, such that number of CO_2 molecules in energy level E_2 keeps on increasing and which could hamper the population inversion condition. So in order depopulate(deexcite) energy level E_2 ,we use the Helium gas .When CO_2 molecules in energy level E_2 collide inelastically with He atom, and it deexcites to ground state .

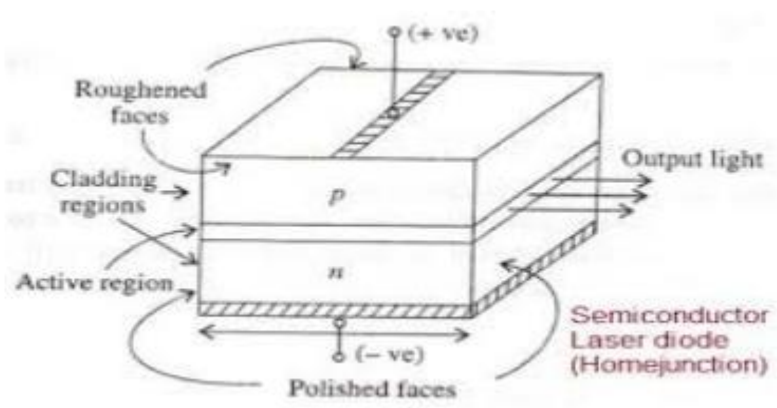
The output power of CO_2 laser is about 10kW - 60kW and it has high efficiency of about 40%. As the ends of the Quartz tube are fitted with Brewster windows, the laser output will be plane polarized.

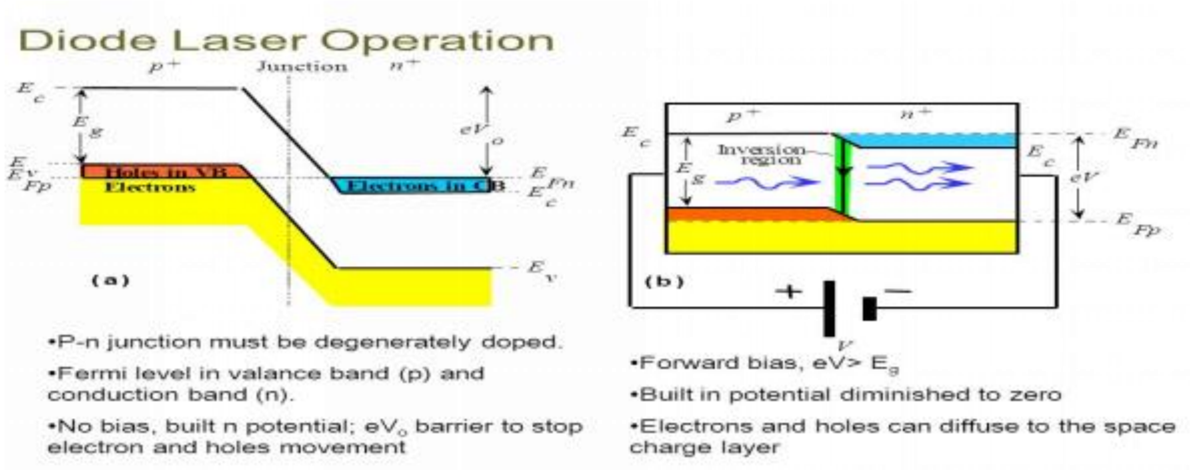
Applications : 1)Cutting 2)Welding and soldering 3)Removal of tattoos and skin lesions 4)Measuring properties of plasma 5)Spectroscopy 6)Satellite communication

3) Outline the principle and working of semiconductor laser.Write 5 applications of lasers.

Ans:.

SEMICONDUCTOR LASER





Semiconductor laser is a solid state laser. A heavily doped (degenerate)homojunction laser made of Gallium and Arsenide (GaAs laser) is shown in the figure. Homojunction means both p-type and n-type semiconductor are of same material(same band gap).In Degenerate p-type semiconductor Fermi level lies within valance band and in degenerate n-type semiconductor Fermi level lies with in the conduction band. At thermal equilibrium two Fermi level lies in same horizontal line on entire thickness of specimen. When forward bias is applied this Fermi level splits,it rises in n-region and moves down in p-region

Components of laser:
1)Pumping mechanism: Direct pumping (forward biasing)

2)Active medium: pn junction or depletion region

3)Resonant cavity: Fully and partially polished pair of opposite (parallel)faces of the pn junction laser act as resonant cavity

Working: When forward bias voltage is applied holes from the valance band of p-side are injected into n-side and electrons from the conduction band n-side are injected into p-side. these electrons and holes recombine at pn junction and produce radiative emission(light).At low bias current spontaneous emission dominant over stimulated emission. When the applied bias current is increased above a particular value called threshold current ,then population inversion occurs. At this condition stimulated emission become dominant over spontaneous emission and we get laser output beam through the partially reflecting surface of resonant cavity.

For GaAs laser threshold current is 50kA/cm^2.It emits light in wavelength range 830-850nm(Infrared radiation).The wavelength(λ) of output laser beam depends on the band gap 'E_g'. of the material used.

$E_g = h\upsilon = ch/\lambda$ OR $\lambda = ch/E_g$ (where h-plancksconstant, υ -frequency of emitted light, c-velocity of light).

Applications
1)Laser printers, CD players and barcode scanners **2)**Fibre optic communication system

5)Define absorption,spontaneous emission and stimulated emissions.

Ans:

Absorption: Consider a system of two energy level E1(ground state)and E2(excited state),with energy difference E2-E1=hυ.
If a photon of energy hf incident on the system then atom in the ground state receive this energy and jumps to excited state E2.This process of excitation of atoms to higher energy levels after receiving energy is called absorption

Rate of absorption = $B_{12}N_1U(\upsilon)$, (where B_{12}-Einstein's coefficient of absorption, N_1-number of atoms in ground state, $U(\upsilon)$- energy density of incident radiation (at unit frequency range about υ).

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