JECRC Foundation

JAIPUR ENGINEERING COLLEGE AND RESEARCH CENTRE

JAIPUR ENGINEERING COLLEGE AND RESEARCH CENTRE

- Year & Sem – Ist Year , Ist Sem
- Subject – Engineering Physics
- Unit – Laser
- Department- Applies Science (Physics)

VISION

To become a renowned institute of outcome based learning and work towards academic, professional, cultural and social enrichment of the lives of individuals and communities.

MISSION

- Focus on valuation of learning outcomes and motivate students to inculcate research aptitude by project based learning.
- Identify based on informed perception of Indian, regional and global needs, the areas of focus and provide platform to gain knowledge and solutions.
- Offer opportunities for interaction between academia and industry.
- Develop human potential to its fullest extent so that intellectually capable and imaginatively gifted leaders can emerge in a range of professions.

Syllabus & Course outcomes of Laser

- **Syllabus:-** Einstein's Theory of laser action; Einstein's coefficients; Properties of Laser beam, Amplification of light by population inversion, Components of laser, Construction and working of He-Ne and semiconductor lasers, Applications of Lasers in Science, engineering and medicine.
- **Course outcomes :**

CO3:- Students will be able to learn all basic aspects of laser action, properties (coherence etc.), types of LASER devices and its applications in fiber optics, medical science and industry etc.

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CONTENTS

- Introduction of Laser
- Properties of LASER
- Relation between Einstein's Coefficient
- Component of Laser
- Types of Laser
  (1) He-Ne Laser
  (2) Semiconductor Laser
- Application of Laser
- Problems
- Lecture contents with a blend of NPTEL contents
- References/Bibliography

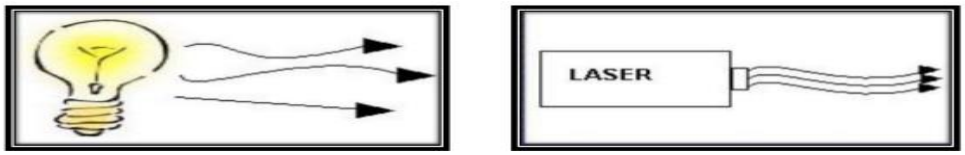
Lecture Plan

S. No	Topics	Lectures required	Lect. No.
1	General introduction of laser & it's properties	1	20
2	Mathematical derivation of Einstein's coefficients & Threshold conditions for laser action	1	21
3	Amplification of light by population inversion and components of laser	1	22
4	Construction and working He-Ne laser	1	23
5	Construction and working Semiconductor laser	1	24
6	Application of Laser in Science, Engineering and Medical Science	1	25

Introduction of Laser

- Invention of Laser was a breakthrough in the field of Physics in 20th century (in 1958 by Charles Townes and Arthur Schawlow).
- A Laser is a photonic device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation.
- The phenomenon of stimulated emission was predicted by Einstein in 1917.
- LASER is the acronym for Light Amplification by Stimulated Emission of Radiation.

Incandescent lamp VS Laser



1. Many wavelengths
2. Multidirectional
3. incoherent

1. Monochromatic
2. Directional
3. Coherent

Properties of LASER

Characteristics or Properties of Laser light

- Coherence
- High Intensity
- High directional
- High Monochromaticity

Laser light is highly powerful and it is capable of propagating over long distance and it is not easily absorbed by water

Einstein's Coefficients

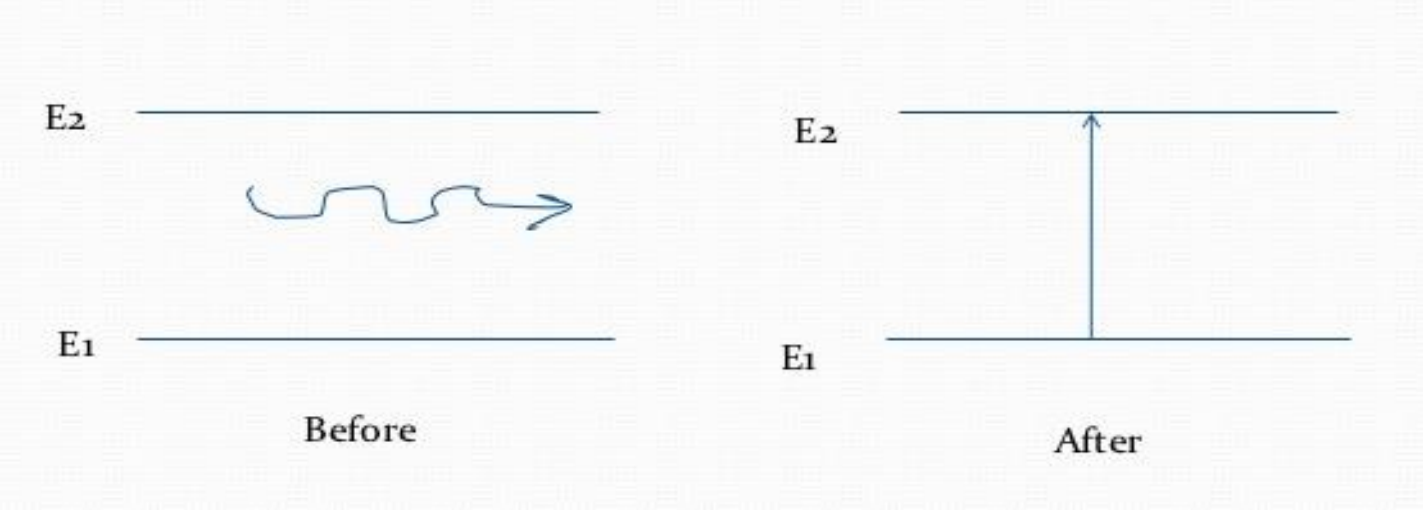
- When an external radiation is incident on a medium (solid, liquid or gas) , three process takes place simultaneously :

- Absorption
- Spontaneous Emission
- Stimulated Emission

Absorption

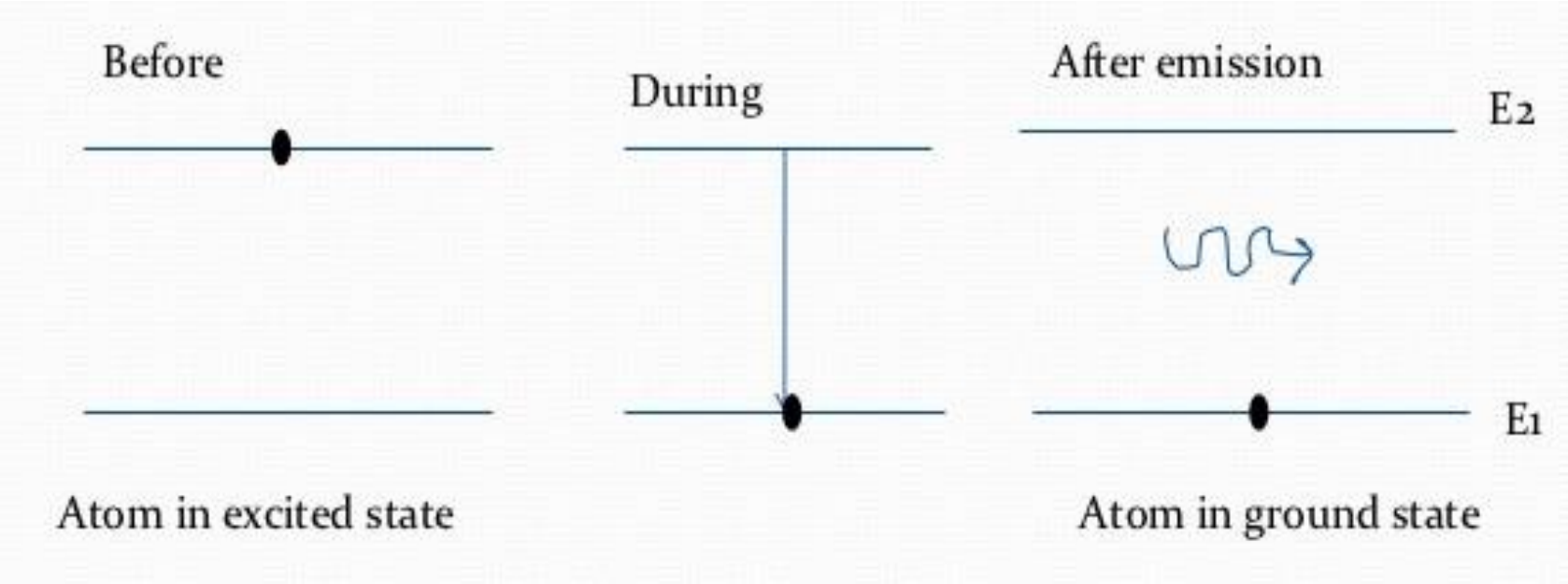
The process in which an atom sized system in low energy state is raised in to higher energy state by electromagnetic radiation which is quanta of energy is equal to the difference of energy of the two state is called absorption.

$$h\gamma = E_2 - E_1$$



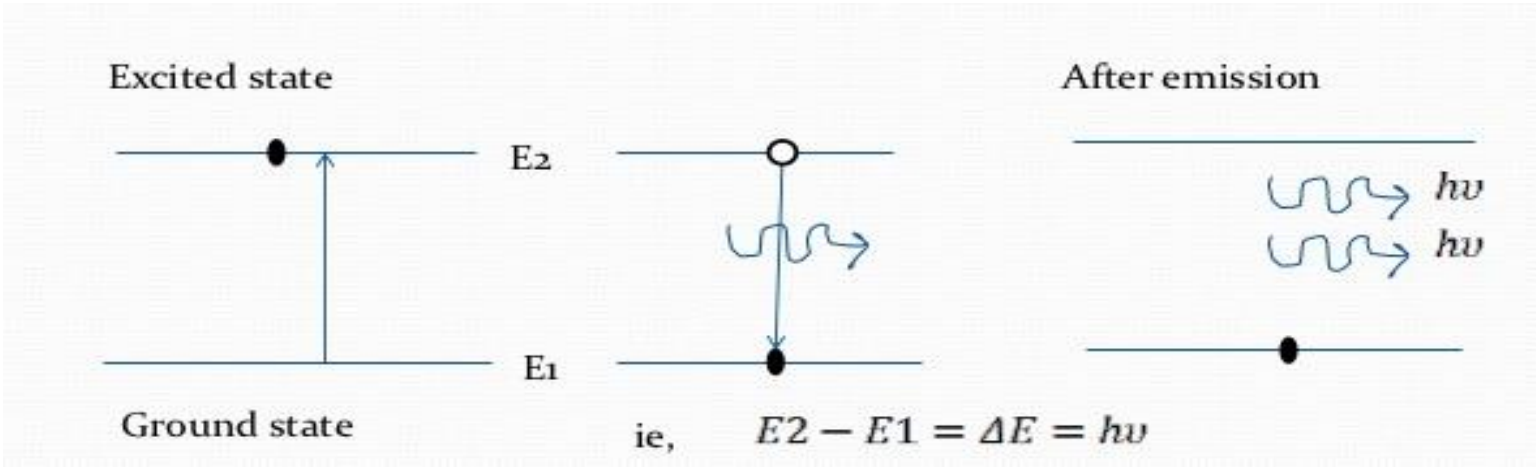
Spontaneous Emission

- In the atom initially at the upper state E_2, it can brought to E_1 by emitting a photon of energy $h\gamma$. This is known as spontaneous emission.



Stimulated Emission

- According to Einstein's under certain condition it is possible to force an excited atoms emit a photon by another photon and the incident light wave must be in same phase hence we get an enhance beam of coherent light



Relation Between Einstein's Coefficient

Let N_1 & N_2 be the no. of atoms in the ground state and excited state and $\rho(r)$ is the energy density per unit volume

Then the ratio of absorption per unit volume $= B12.\rho(r).N1$

Ratio of spontaneous emission per unit volume $= A21.N2$

Ratio of stimulated emission per unit volume $= B21.\rho(r).N2$

Where B_{12}, B_{21} and A_{21} are Einstein's coefficient under thermal equilibrium, the rate of absorption = rate of emission

$$B12.N1.\rho(r) = A21.N2 + B21.\rho(r).N2$$

$$\rho(r)[B12.N1 - B21.N2] = A21.N2$$

$$\rho(r) = \frac{A21.N2}{B12.N1 - B21.N2}$$

$$\rho(r) = \frac{A21/B21}{\frac{B12}{B21}.\frac{N1}{N2}} - 1$$

$$N1 = \text{No.}\, e^{\frac{-E1}{KT}} \qquad N2 = \text{No.}\, e^{\frac{-E2}{KT}}$$

$$\frac{N1}{N2} = e^{\frac{(E2-E1)}{KT}}$$

$$\rho(r) = \frac{A21}{B21}\left[\frac{1}{\frac{B12}{B21}\left[e^{\frac{(E1-E2)}{KT}}\right]} - 1\right]$$

$$B21 = B12 = 1 \qquad E2 - E1 = h\upsilon$$

$$\rho(r) = \frac{A21}{B21}\left[\frac{1}{e^{\left(\frac{h\upsilon}{KT}\right)} - 1}\right]$$

$$\rho(r) = \frac{8\pi h\upsilon^3\mu^3}{c^3}\left[\frac{1}{e^{\left(\frac{h\upsilon}{KT}\right)} - 1}\right]$$

$$\frac{A21}{B21} = \frac{8\pi h\upsilon^3\mu^3}{c^3}$$

Components of LASER

Active Medium

- This is the basic material in which atomic and molecular transitions take place leading to laser action.
- It is the medium where the stimulated emission take place.
- Depending the active medium lasers are classified into different type like solid, liquid or semiconductor laser.

Pumping Source

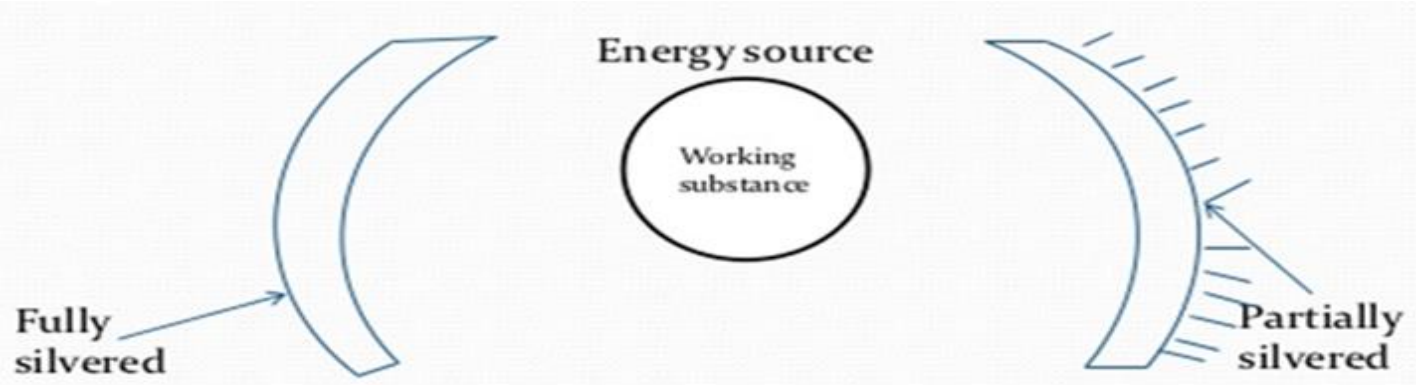
- With the help of energy source the system can be raised to an excited state, with the help of this source,
- The number of atom in higher energy state may be increased and hence the population inversion is achieved.
- The energy source may also be called pumping source.

Population Inversion

- It is the process of increasing exited electrons in higher energy level.
- Due to this process the production of laser is possible.
- The energy level between the ground state E_1 (1^{st} level) and exited E_3 (3^{rd} level) is known as metastable state E_2 (2^{nd} level).
- By optical pumping electrons from ground state jumps to exited state by absorbing Photon

Optical Resonator

- It is specially design cylindrical tube.
- Set of mirror at the end of which are silvered, one end being completely silvered at which the other is partially silvered.
- Photons are emitted parallel to the axis of the active medium undergoes multiple reflections between them so, the light intensity can be increased.



Three level laser

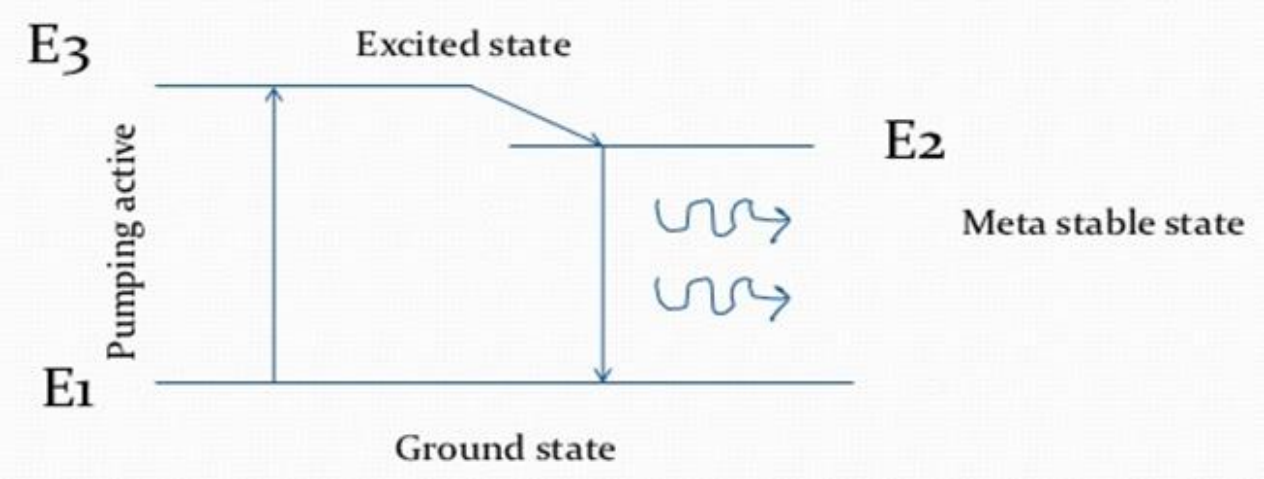
The simplest kind is three level laser which uses and assembly of atom or molecules that have three energy state E_1, E_2, E_3

Where

E_1 = Ground State

E_2 = Metastable State

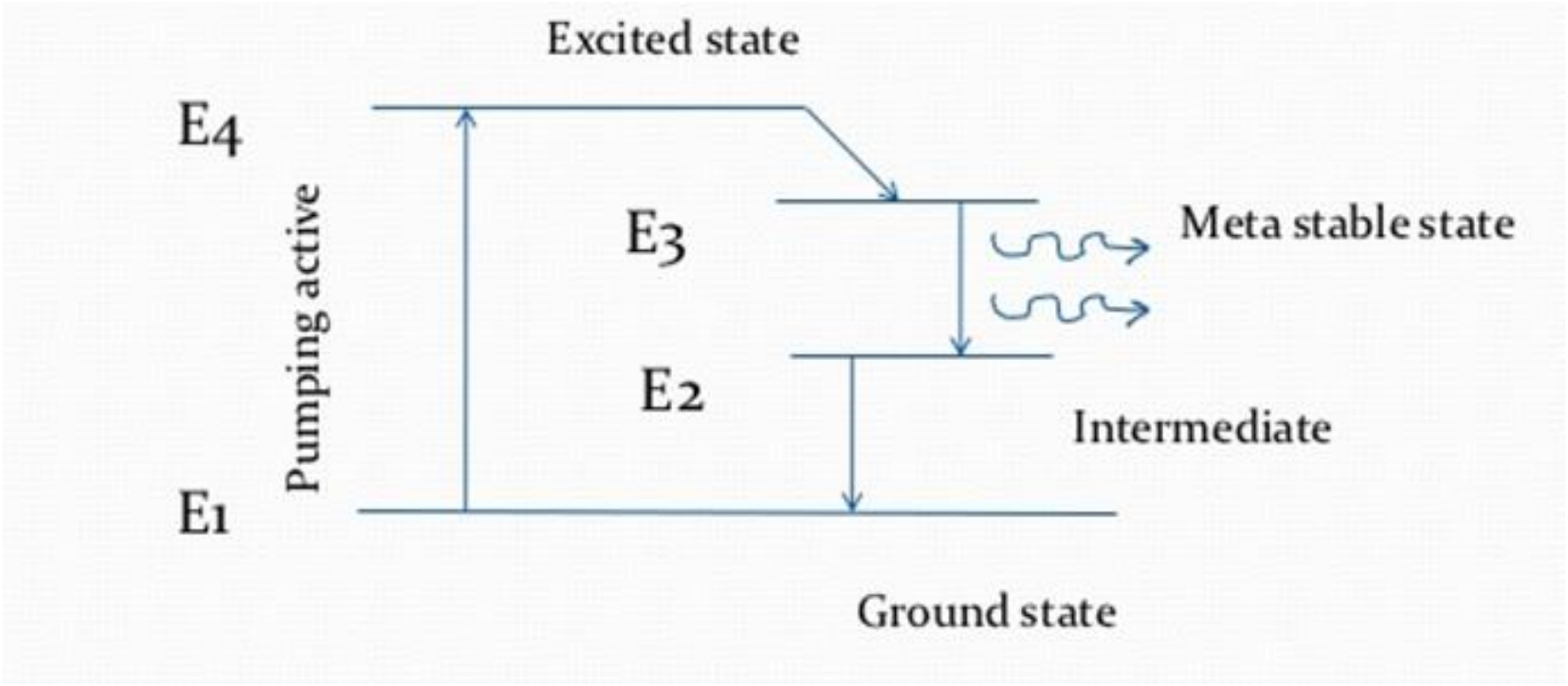
E_3 = Higher excited State



Four level laser

E_1 = Ground State E_2 = Intermediate State

E_3 = Metastable State E_4 = Higher excited State



Types of Laser

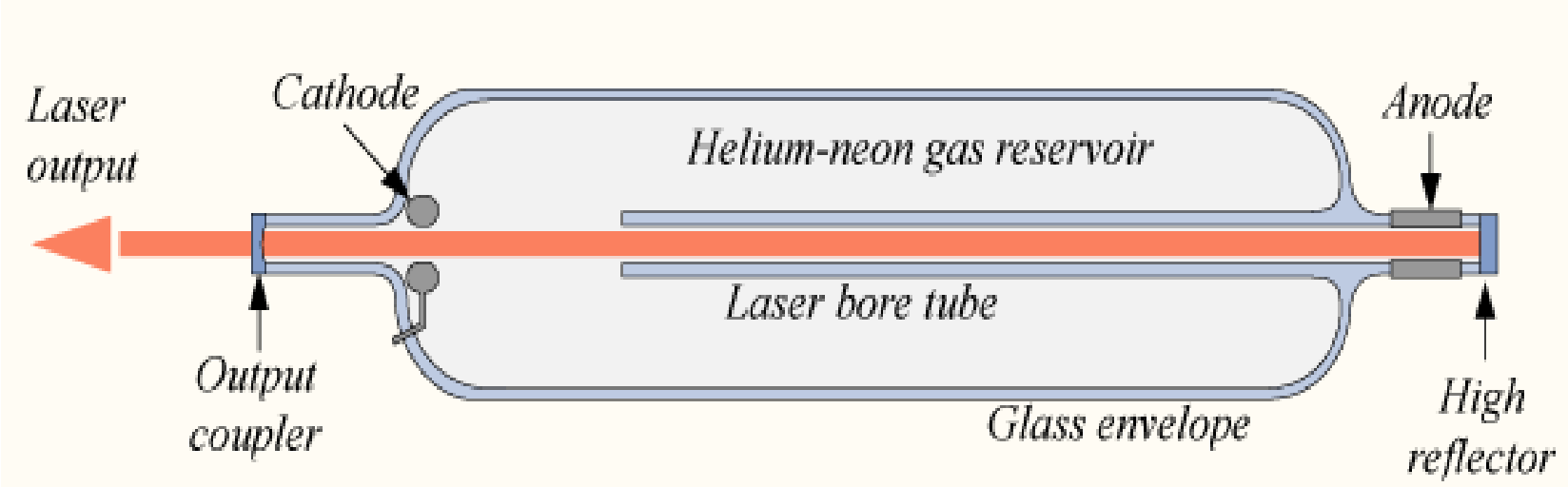
- On the basis of material used as active medium they are broadly divided in to four categories:

1) Solid State Laser e.g. Ruby Laser, ND: YAG Laser etc.
2) Gas Laser e.g. He-Ne Laser, Carbon Di-Oxide Laser etc.
3) Liquid Laser e.g. Dye Laser.
4) Semiconductor Laser e.g. Ga-As Laser.

Helium-Neon Laser

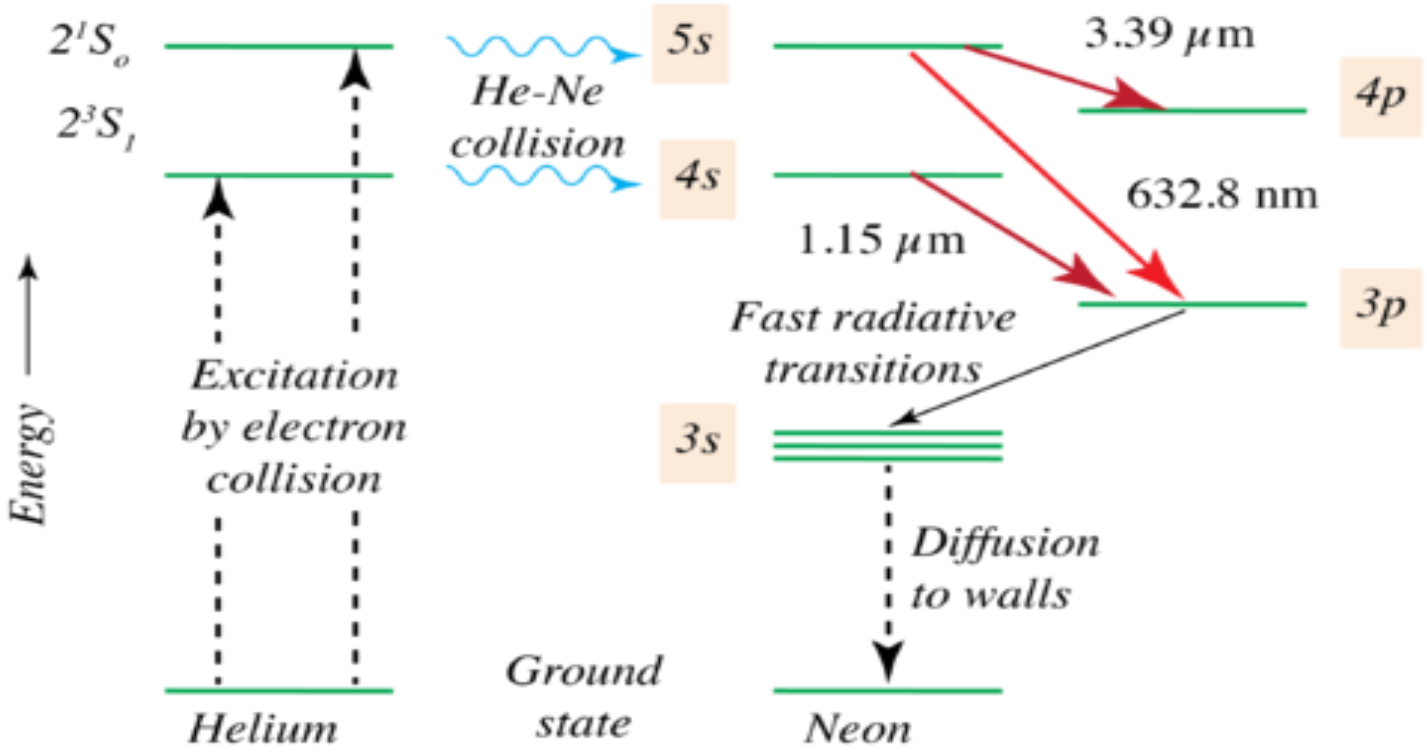
- Helium Neon Laser is the first gas Laser fabricated by Ali Javan and his coworker (William R. Bennett Jr. and Donald R. Herriott) in 1961.
- The low power He-Ne laser is used to demonstrate the experiments in laboratories.
- He-Ne Laser has four stage energy level system.
- In this laser electric discharge technique is used in pumping mechanism to produce population inversion in higher energy state.
- It operates in the continuous mode at the visible (Red colour) transition in neon of wavelength 6328 Å.

Construction of He-Ne Laser



1. He-Ne Laser is used a mixture of Helium and Neon in the ratio 10 : 1 with the pressure inside the tube is 1 mm of Hg (1 torr).
2. The mixture is kept in a thick Pyrex glass tube with internal diameter of about 1 cm and length of about 80 cm.
3. Two reflectors (dielectric coated spherical mirror) are placed at the end of discharge tube.
4. Pumping is achieved by an electric discharge to produce in the gas by means of electrodes, which are connected to a high frequency alternating current source.

Working of He–Ne Laser



1. When an electric discharge is passed through the gas, electrons travelling down the tube, collide with He atoms and excited them to F_2 and F_3 metastable state.

2. Some of the excited He atoms transfer their energy to ground state Ne atoms by collision.

3. Energy level F_2 (19.81 eV) and F_3 (20.61 eV) of He atoms are nearly equal to the energy level E_4 (18.70 eV) and E_6 (20.66 eV) of Ne atoms. Additional energy being provided by the kinetic energy of the atom.

4. By the continuous pumping (electric discharge), energy level E_4 and energy level E_6 of Ne atoms is highly populated and a state of population inversion is achieved.

5 The transition in Ne atom take place from higher metastable state to lower state with the emission of photon of different wavelength-

(a) higher metastable state E_6 to lower state E_5 with the emission of photon of wavelength 33900 Å

(b) higher metastable state E_4 to lower state E_3 with the emission of photon of wavelength 11500 Å

(c) higher metastable state E_6 to lower state E_3 with the emission of photon of wavelength 6328 Å.

6 First two transitions are infrared region but third transition is in visible region.

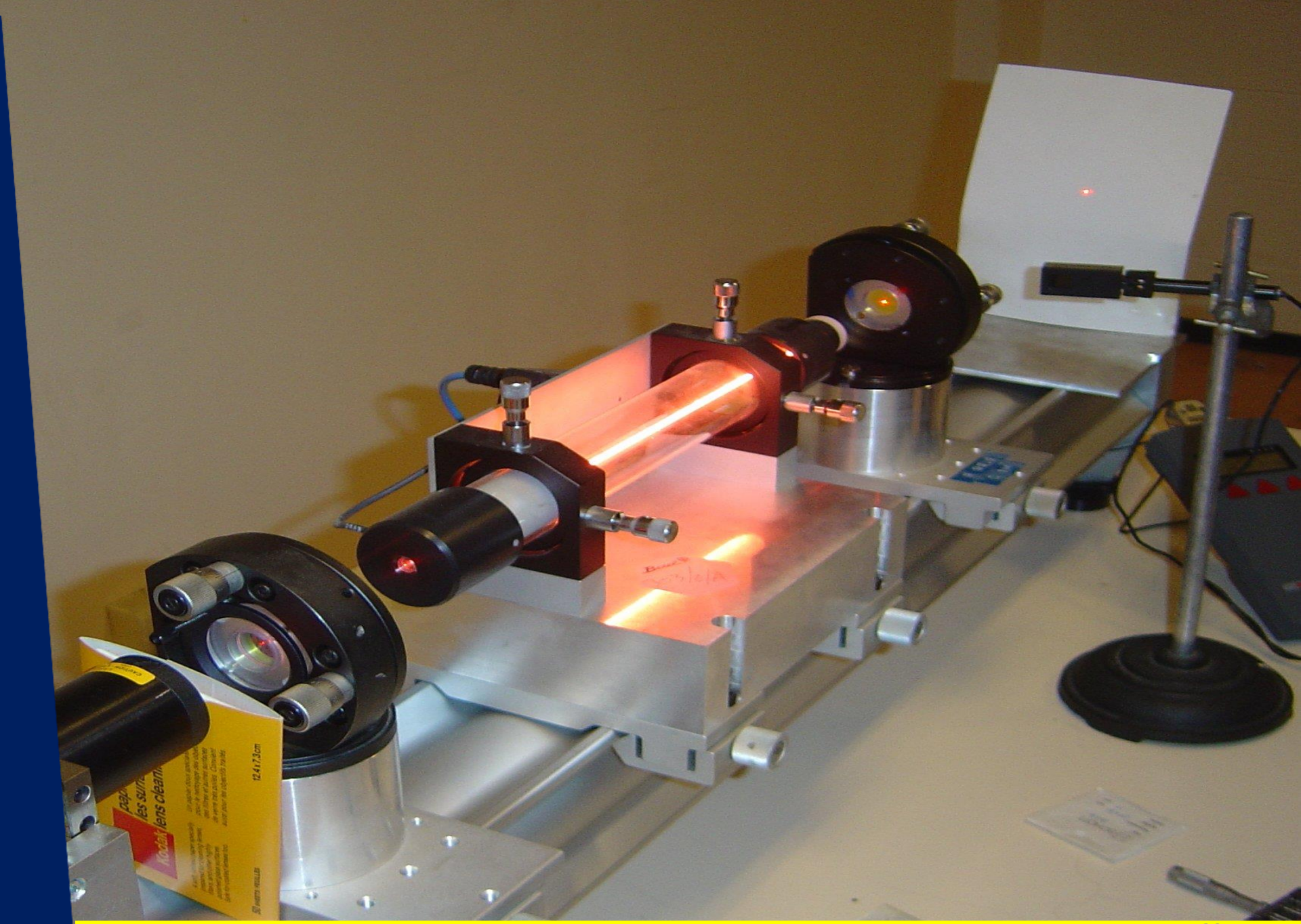
7 Another transition of photon from higher metastable state E_3 to E_2 is the wavelength of 6000 Å .

8 This transition provides incoherent photons.

9 Remaining excitation energy of atom is lost in the de-excitation process by collision with the tube and atom reach the ground state.

10 The high directivity of a laser beam is achieved by the parallel mirror fixed at the end of the discharge tube which makes the resonator cavity.

11 The gas lasers are found to emit light which is more directional and more monochromatic.


Kodak lens cleani
12.4 x 13cm

Applications

- The narrow red beam of He-Ne Laser is used in supermarket to read the bar codes.
- It is widely used in laboratories for demonstrations of experiments.
- The He-Ne Laser is used in Holography in producing the 3-D image of object.
- He-Ne Laser have many industrial and scientific uses and are often used in laboratory demonstration of optics experiments.

Semiconductor Laser

- Semiconductor diode lasers are specially fabricated by P-N junction diode, which emit coherent light by stimulated emission.
- First semiconductor laser was made by R. N. Hall and his coworkers in 1962.
- It is made from Gallium Arsenide (Ga-As) which operated at low temperature and emitted light in the near I R region.
- In 1970, semiconductor laser working at room temperature and in continuous wave mode are produced.
- Now P-N junction laser are made to emit light almost anywhere in the spectrum from UV to IR region.
- Diode laser are remarkable small in size, have high efficiency and operates at low power.

Components of Semiconductor LASER

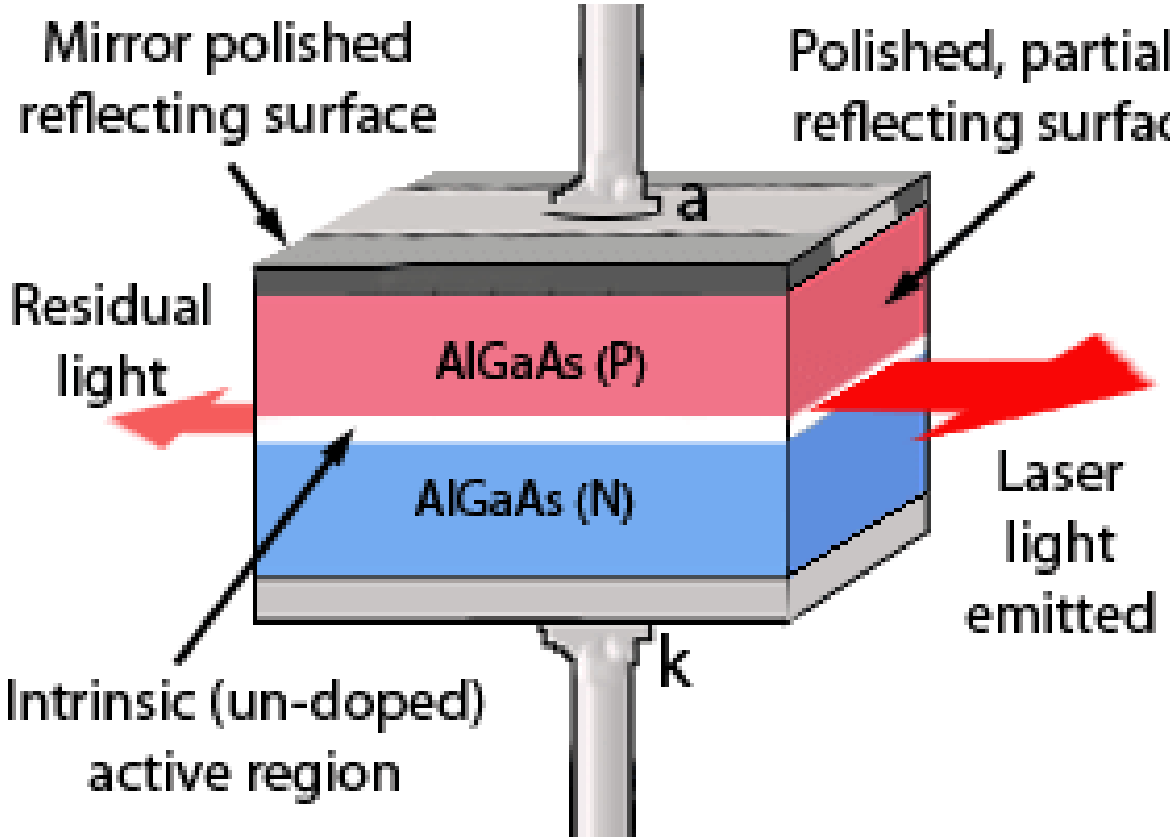
- **Active Medium :** Gallium and Arsenide is used as a working substance
- **Pumping :** When P-N junction diode is forward biased, the electrons from n region and holes from p region recombine with each other at the junction
- During the recombination process light radiations (Photons) is released from certain specified direct band gap semiconductors like Ga-AS.
- This radiation is called recombination radiation and the corresponding energy is called activation energy.

Components of Semiconductor LASER

Population Inversion:

- Conduction band play the role of excited level
- Valence band play the role of ground level
- Population inversion requires the presence of large concentration of holes in the valence band.
- A simple way to archive population inversion is to make a semiconductor in the form of a P-N junction diode from heavily doped P and N type semiconductors.

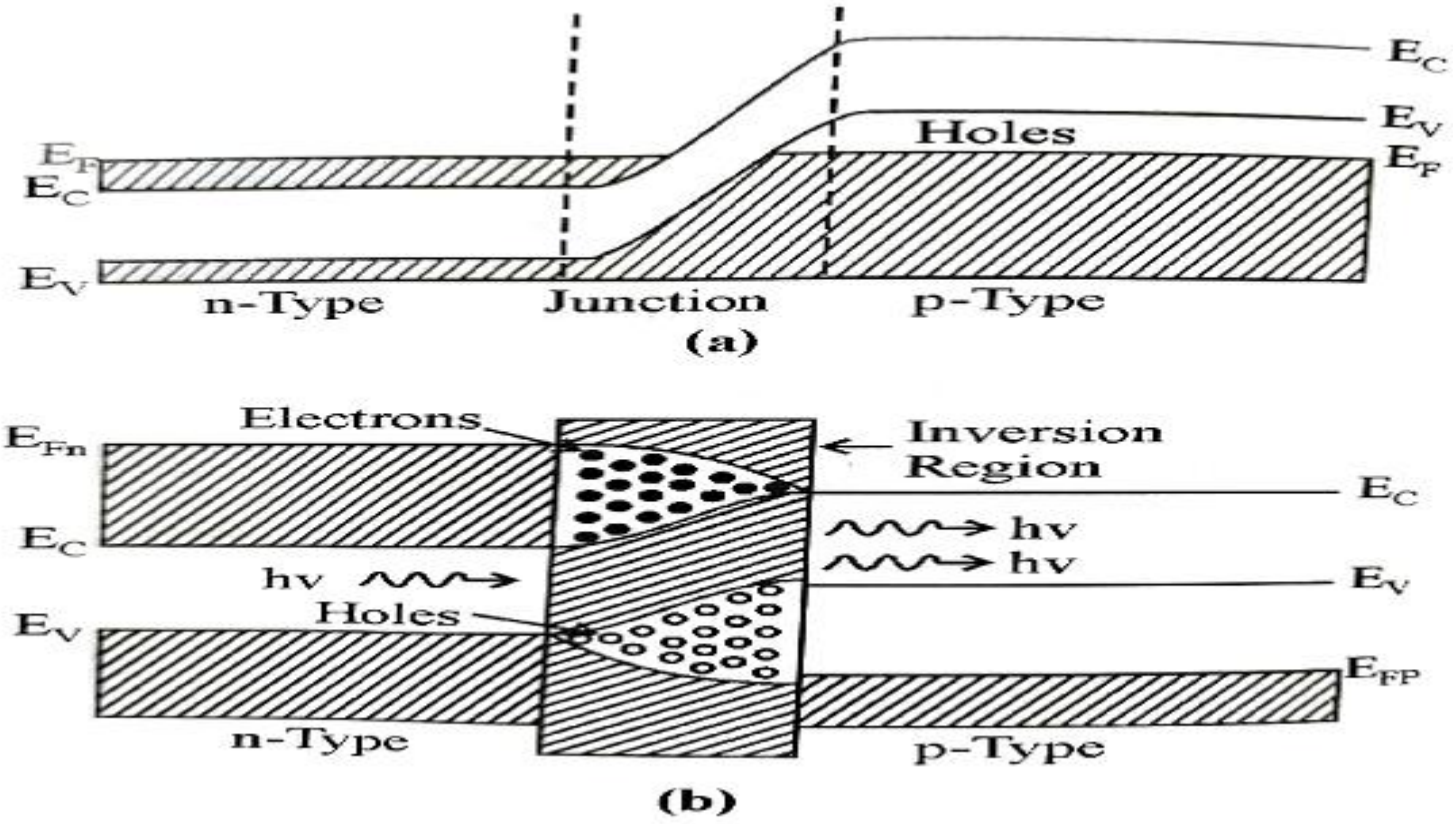
Construction of Ga-As Laser



Construction of Ga-As Laser

- The Gallium Arsenide laser is design in such a way that a piece of N-type Gallium Arsenide material is taken and a layer of natural gallium aluminum arsenide material is pasted. The third layer of P-type gallium arsenide material is pasted over that.
- The two ends of length wise are fully polished in order to amplify the light by cross reflection. Here one ends is partially the light by cross reflection. Here one ends is partially polished from where we get the laser beam.

Working of Ga – As Laser



Working of Ga – As Laser

- When the forward bias is applied to the metallic layer through contact points. The electric field is produced. This electric field causes the electrons to move from lower band of energy towards high band of energy level.
- Population inversion take place at the higher band of energy level and when the electrons falls back at the lower energy bands, it emits light, through the polished end of the laser.
- Cross reflection of the light take place which multiplies strength of laser beam. At the end strong beam of laser comes out through the partially polished end.

Achievement of Population Inversion

- When P-N junction diode is forward biased, then there will be injuction of electrons into the conduction band along N-side and production of more holes in valence band along P-side of the junction. Thus there will be more number of electrons in conduction band comparable to valence band, so population inversion is achieved.

- Therefore, when the electrons and holes are injected into the junction region from opposite side with forward biasing, then population inversion is achieved between levels near the bottom of the conduction band and empty level near the top of the valence band.

Applications

- Semiconductor diode laser used in CD and DVD players.
- Fiber optic transceivers are manufactured using alternating layer of various III-V and II-VI compound semiconductors to form lasing hetero structures.
- Used in laser printers and laser diodes.

Problems

- A laser beam has a wave length of $8x10^{-7}$ m and aperture $5x10^{-3}$m. The laser beam is sent to moon. The distance of the moon from the earth is $4x10^{5}$ Km. Calculate (i) The angular spread of the beam (ii) The areal spread when it reaches the moon.
- A laser beam has a power of 50 mW. It has an aperture of $5x10^{-3}$m and emits light of wavelength 7200 A. The beam is focused with a lens of focal length 0.1 m. Calculate the area and the intensity of the image.
- Find the intensity of a laser beam of 20mW power and having a diameter of 1.5 mm .
- A LASER beam of wavelength 6000 Å on earth is focused by a lens of diameter 2 m on the surface of moon . How big is the spot on the moon. (Given distance of moon from earth = $4x10^{5}$ Km)

Lecture contents with a blend of NPTEL contents and other platforms

- https://nptel.ac.in/courses/104/104/104104085/ by Prof. Manabendra Chandra, IIT Kanpur
- https://www.youtube.com/watch?v=FNp81kkxj5c by Prof. M. R. Shenoy, IIT Delhi.
- https://www.youtube.com/watch?v=2g25zn-ofck by Prof. R.K. Shevgaonkar, IIT Bombay.
- https://www.youtu.be/ r0tVSXBNaal by Prof. R. K Mangal, JECRC, Jaipur.

References and Bibliography

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- Engineering Physics by Prof. Y. C. Bhatt, Ashirwad Publications
- Optics by Subhramanium and Brij lal, S. Chand Publications.

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Thank You