Case (i) *If T is +ve* $N_1 = N_2 e^{+ve}$

For example, If $N_2 = 5$ and if $(E_2 - E_1)/K_B T \approx 2$,

Then, $N_1 = 5 \cdot e^{+2}$

$N_1 = 36.9$

$\therefore N_1 > N_2$ Since $36.9 > 5$

Case (ii) *If T is -ve* $N_1 = N_2 e^{-ve}$

For example, If $N_2 = 5$ and if $(E_2 - E_1)/K_B T \approx 2$,

$\therefore$ $N_1 = 5 . e^{-2}$

$N_1 = 0.6766$

$\therefore$ $N_2 > N_1$ Since $5 > 0.6766$

This shows that the number of atoms in excited state can be made more than the number of atoms in the ground state only under negative temperature.

But, the negative temperature is practically not possible. Therefore population inversion can be achieved by some other artificial process known as **pumping process.**

Active medium: *The medium in which the population inversion takes place is called as active medium.*

Active centre: *The material in which the atoms are raised to excited state to achieve population inversion is called as active centre.*

2.8 PUMPING METHODS

Pumping: *The process of raising more number of atoms to excited state by artificial means is called as pumping process.*

There are several methods by which the population inversion (pumping) can be achieved. Some of the most commonly used methods are

(a) Optical pumping
(b) Direct electron excitation (Electric discharge)
(c) Inelastic atom-atom collision.
(d) Direct conversion
(e) Chemical process

(a) Optical pumping: Here the atoms are excited with the help of photons emitted by an external optical source. The atoms absorb energy from the photons and raises to excited state. (e.g) Ruby Laser, Nd-YAG Laser.

(b) Direct electron excitation: The electrons are accelerated to very high velocities by strong electric field and they collide with gas atoms and these atoms are raised to excited state (e.g.) Gaseous ion lasers (argon laser), Helium-Neon (He-Ne) laser, CO_2 Laser etc.

(c) Inelastic atom-atom collision: In this method a combination of two types of gases are used, say A and B, both having same (or) nearly coinciding excited states A* and B*.

During electric discharge 'A' atoms get excited due to collision with electrons. The excited A* atoms now collide with 'B' atoms so that B goes to excited state B* (e.g) Helium-Neon laser, CO_2 laser

$$e^- + A \longrightarrow A^*$$
$$A^* + B \longrightarrow B^* + A$$

(d) Direct conversion: Due to electrical energy applied in direct band gap semiconductor like GaAs etc., the combination of electrons and holes takes place and electrical energy is converted into light energy directly. (e.g) Semiconductor laser.

(e) Chemical method: Due to some chemical reactions, the atoms may be raised to excited state. (e.g) Dye laser.

2.9 OPTICAL RESONATOR

The optical resonator constitutes an active medium kept inbetween a 100% reflecting mirror and a partially reflecting mirror as shown in fig. 2.6.

This optical resonator acts as a feed back system in amplifying the light emitted from the active medium, by making it to undergo multiple reflections between the 100% mirror and the partial mirror. Here the light bounces back and forth between the two mirrors and hence the intensity of the light is increased enormously. Finally the intense, amplified beam called LASER is allowed to come out through the partial mirror as shown in fig.2.6.

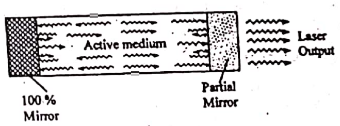

Fig. 2.6

2.10 FLOW CHART FOR LASER ACTION

The flow chart for the laser action is as shown in fig. 2.7. Initially by some means of pumping process atoms in the active medium are allowed to go from ground state to excited state and hence the population inversion is achieved.

At this stage a spontaneously emitted photon, so called stimulating photon incident on the excited atoms in the active medium and initiates the stimulated emission.

The light emitted due to stimulated emission, stimulates more number of atoms in the active medium to come from the excited state to the ground state and hence more number of photons are emitted from the active medium. Thus amplification of light begins.

This amplified light travels back and forth between the 100% mirror and the partial mirror in the optical resonator and hence an intense amplified beam of light, so called LASER is emitted through the partial mirror.

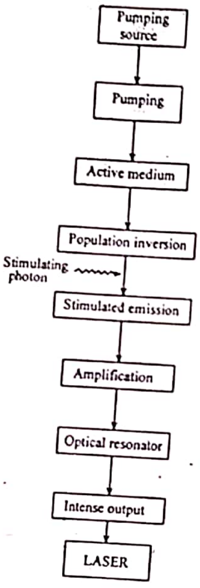

Fig. 2.7

2.11 TYPES OF LASERS

Lasers are classified into five major categories based on the type of active medium.

(i) **Solid state laser**

It is classified into two types
(a) 3 level laser (e.g) Ruby laser
(b) 4 level laser (e.g) Nd-YAG laser

(ii) **Gas Lasers**
Examples: CO_2 laser, He-Ne laser.

(iii) **Semi conductor laser**
Example: GaAs (Gallium Arsenide laser)

(iv) **Liquid lasers**
Example: Europium benzoyl acetonate dissolved in alcohol.

(v) **Dye laser and chemical lasers**

2.12 Nd-YAG [Neodymium-Yttrium Aluminium Garnet] LASER

Characteristics of Nd-YAG laser

Type	-	Doped insulator laser [Solid state laser]
Active medium	-	Yttrium Aluminium Garnet [$Y_3Al_5O_{12}$]
Active centre	-	Neodymium [Nd^{3+} ions]
Pumping method	-	Optical pumping
Pumping source	-	Xenon flash lamp
Optical Resonator	-	Ends of the rods polished with silver and two mirrors, one of them is totally reflecting and the other is partially reflecting.
Power output	-	2×10^4 watts
Nature of output	-	Pulsed
Wavelength emitted	-	1.064 μm.

Introduction: Nd-YAG laser is a doped insulator laser. ***It is a four level system*** in which the active medium is taken in the form of a crystal. Here the crystal is intensionally doped during its growth. Those type of lasers has number of energy levels with same energy. The laser is used to generate high power intensity.

Principle: *The term "Doped Insulator Laser" refers to the active medium, yttrium aluminium garnet doped with neodymium Nd^{3+}. The neodymium ion has many energy levels. Due to optical pumping these ions are raised to excited levels. During the transition from metastable state to E_1 state, the laser beam of wavelength 1.064 μm is emitted.*

Construction: The active medium is made as a rod which has yttrium aluminium garnet [Y_3 Al_5 O_{12}] doped with a rare earth metal ion neodymium Nd^{3+}. The Nd^{3+} ions normally occupies the yttrium ions and provides the energy levels for both the lasing transitions and pumping. This rod is placed inside a highly reflecting elliptical cavity as shown in fig.2.8.

A close optical coupling is made by placing the xenon flash lamp near by the laser rod, in such a way that most of the radiation from the flash tube passes through the laser rod due to the elliptical cavity. The flash tube may be switched ON and controlled with the help of a capacitor. The discharge of capacitor is initiated using a high voltage source.

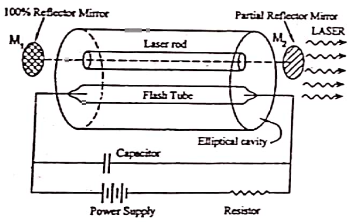

Fig. 2.8

The optical resonator is formed by grinding the ends of the rods and coated with silver accompanied by two mirrors, one is 100% reflecting and the other is partially reflecting which is included to increase the efficiency of the output beam.

Working

1. The xenon flash lamp is switched ON and the light is allowed to fall on the laser rod.
2. The intense white light excites the neodymium (Nd^{3+}) ions from the ground state to various energy levels above E_2. Hence the atoms are raised to group of higher levels in E_3 as illustrated in the energy level diagram fig.2.9.

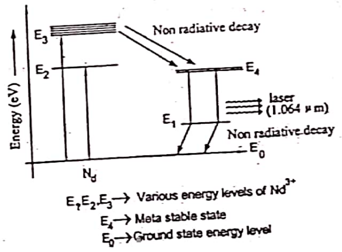

Fig. 2.9

3. From these energy levels the ions make non-radiative decay and is gathered in a state called as meta stable state, until the population inversion is achieved.
4. Once the population inversion is achieved, the stimulated emission builds up rapidly.
5. Hence, pulsed form of laser beam of wavelength 1.064 μm is emitted during the transition from E_4 to E_1 (lower).
6. A large amount of heat is produced by the flash tube during the working. Hence cooling arrangement is made either by blowing air (or) circulating water over the crystal.

Applications of Nd-YAG Laser

1. It is used in transmitting signals to a longer distances.
2. It is used in long haul communication system.
3. It is also used in the endoscopic applications.
4. It plays a vital role in remote sensing applications.

NOTE: For continuous laser beam the xenon flash lamp may be replaced with quartz - halogen lamps.

UNIT 2

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2.13 HELIUM - NEON LASER

Characteristics of He-Ne LASER

Type	:	Gas laser
Active medium	:	Mixture of Helium and Neon in the ratio 10:1
Active centre	:	Neon
Pumping method	:	Electrical pumping
Optical Resonator	:	Pair of concave mirrors
Power output	:	0.5 - 50 mW
Nature of output	:	Continuous waveform
Wavelength	:	6328Å

Introduction: This laser is discovered by Ali Javan an USA scientist. He-Ne laser is designed for getting a continuous laser beam. Light with high coherence, higher directionality and higher mono-chromacity can be obtained from it. But the output power is generally in the order of few milliwatts.

Principle: *This laser is based on the principle of stimulated emission, produced in the active medium of gas. Here, the population inversion is achieved due to the interaction between the two gases which have closer higher energy levels.*

Construction: It consists of a gas discharge tube, which is made up of quartz and is filled with the mixture of helium under a pressure of 1mm of Hg and Neon under the pressure of 0.1mm of Hg. The ratio of the He-Ne mixture is 10:1 (i.e) the number of He atoms is greater than the number of Ne atoms.

The electrodes at the ends of the discharge tube are connected to the radio frequency oscillator to produce electrical discharge in the He-Ne mixture as shown in fig.2.10.

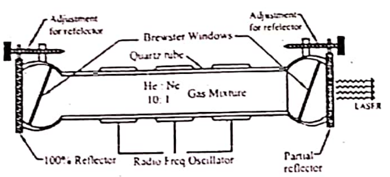

Fig. 2.10 He-Ne Laser

The end faces of the discharge tube are tilted at the brewster angle and are called as Brewster windows. It is used to produce plane polarized light by reflecting the perpendicularly polarized light. A fully reflecting and partial reflecting concave mirror is placed at the left and right ends of the discharge tube respectively, which acts as a resonant cavity.

Working

1. By electrical discharge in a gas tube, the ground state helium atoms are excited to higher energy levels.
2. The excitation occurs due to the collision of discharged electrons with helium atoms.
3. The excited helium atoms collide inelastically with the neon atoms which have close energy level as that of the helium energy level.
4. Therefore the Helium atom delivers its energy to Neon atoms by the process known as resonant collision energy transfer.
5. This resonant energy transfer takes place because the corresponding energy levels of helium ($2s^1$ and $2s^2$) are almost closer to the Neon energy levels (2s and 3s).
6. The probability of energy transfer from Neon to He decreases because of high pressure in He than Ne and also because of its density in the mixture.
7. Thus some of the He atoms are de-excited and come back to ground state.
8. The excited states of neon are shown by energy bands.

Designation given	1s	2s	3s	2p	3p
Electronic configuration	$2p^5 3s$	$2p^5 4s$	$2p^5 5s$	$2p^5 3p$	$2p^5 4p$

9. We have two sets of sub levels (3s and 2s) and (2p and 3p) between these levels three predominant laser transition takes place as shown in fig.2.11.

UNIT 2

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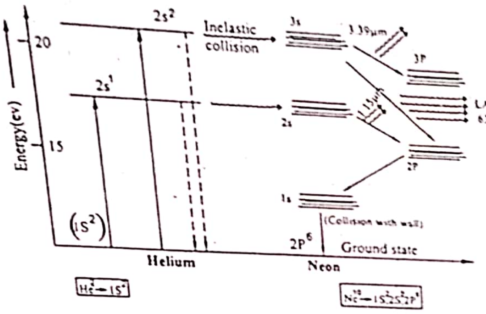

Fig. 2.11 Energy Level Diagram

10. First resonant energy transfer is made from $2s^1$ to 3s and stimulated emission takes place between 3s and 2p, emitting 6328Å wavelength of radiation.
(Note: Since 3s to 2p has higher energy difference, the laser light emitted is of lower wavelength).
11. Stimulated emission between 3s to 3p gives 3.39 μm (33912Å which lies in infra red region) of radiation.
12. Stimulated emission between 2s to 2p gives 1.15 μm (11523 Å which also lies in infra red IR region) of radiation.
13. The atoms undergo transition from 2p to 1s giving photons by spontaneous emission.
14. The transition from 1s to ground level takes place by nonradiative process.
15. Since the electron density in 3s and 2s levels of Neon is always greater than the other levels of Neon. We get continuous laser output of wave length 6328Å with few milliwatt power.

ALTER - He-Ne Laser energy level diagram

An alternate energy level diagram for He-Ne laser is as shown in fig.2.12.

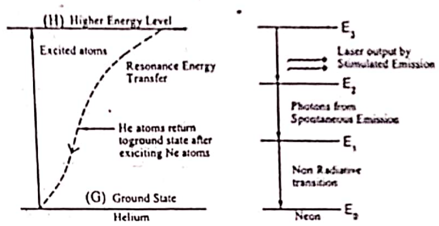

Fig. 2.12 He-Ne Laser Energy Level Diagram

Where *G - Ground state of He ($1s^2$)*
H - Excited state of He $2s^2$, $2s^1$
E_3 - Sublevel of Ne (3s) [$2p^5 5s$], $2s[2p^5 4s]$
E_2 - Sublevel of Ne (3p) [$2p^5 4p$], $2p[2p^5 3p]$
E_1 - Sublevel of Ne (1s) [$2p^5 3s$]
E_0 - Ground state of Ne [$2p^6$]

Applications of He-Ne Laser

1. Because of its high power it is used in open air communications.
2. It is used to produce holograms (3D photographs).
3. It is used in determining the size of tiny particles.

2.14 CARBON-DI-OXIDE [CO_2] LASER

Characteristics of CO_2 Laser

Type	:	Molecular Gas Laser
Active medium	:	Mixture of CO_2, N_2 and Helium (or) Water vapour
Active centre	:	CO_2
Pumping method	:	Electric discharge method
Optical Resonator	:	Metallic mirror of gold (or) silicon mirrors coated with aluminium
Power output	:	10 KW
Nature of output	:	Continuous (or) pulsed
Wavelength of the output	:	9.6 μm & 10.6 μm (96000Å & 106000Å)

Introduction: An Indian Engineer C.K.N.Patel designed the CO_2 laser. We know in the case of atoms, electrons can be excited to higher energy levels. The distribution of electrons in the shells and sub-shells define the electronic state of the molecule (eg. He-Ne laser).

Besides these electronic energy levels, the molecule can have other energy levels also due to rotation and vibration of the molecule (CO_2) they give rise to various rotational and vibrational energy levels, as shown in fig.2.13.

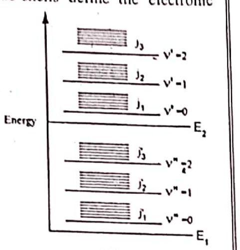

Fig. 2.13

Where,

E_1E_2 - Electronic energy levels

v', v'' - Vibrational energy levels

j, j' - Rotational energy levels.

Principle: *The transition between these vibrational and rotational energy levels leads to the construction of molecular gas laser. Here the Nitrogen atoms are initially raised to excited state. The nitrogen atoms delivers the energy to CO_2 atoms which has closest energy level to it. Then, transition takes place between the vibrational energy levels of the CO_2 atoms and hence laser beam is emitted.*

The molecular gas laser can have two types of transitions

(i) Transition between vibrational states of the same electronic state (fig.2.14).

(ii) Transition between vibration levels of different electronic state (fig.2.15).

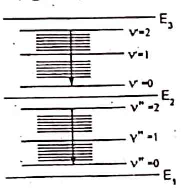

Fig. 2.14

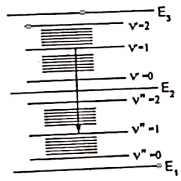

Fig. 2.15

NOTE : *No need to write the introduction and to draw these figures, if CO_2 LASER is asked for 8 marks.*

CO_2 laser of satisfies the first condition (i.e.) here the laser transition occurs between *vibrational energy levels of the same electronic state.*

Fundamental modes of vibration of the CO_2 molecule

There are three fundamental modes of vibration.

1. Symmetric stretching mode (10°0)
2. Bending mode (01°0, 02°0)
3. Asymmetric stretching mode (00°1, 00°2)

i) Symmetric stretching mode (10°0)

Here the carbon atom is stationary and the oxygen atoms oscillate (or) vibrate along the axis of the molecule as shown in fig.2.16 (simultaneously it approaches (or) departs with respect to the carbon atom). The state of vibration is given by 3 integers (mn'q) here (10°0), which corresponds to the degree of excitation.

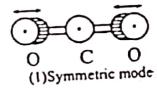

Fig. 2.16

ii) Bending mode (01°0, 02°0)

Here the atoms will not be linear, rather the atoms will vibrate perpendicular to the molecular axis as shown in Fig 2.17. This gives rise to two quanta of frequency represented by (01°0, 02°0).

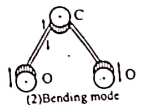

Fig.2.17

The Interactive animation of this concept can be viewed in the CD.

iii) Asymmetric stretching mode (00°1, 00°2)

Here all the three atoms will vibrate. Here the oxygen atoms vibrate in the opposite direction to the vibration direction of carbon atom as shown in Fig.2.18, which gives the quanta of frequency (00°1 and 00°2)

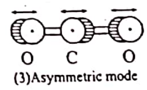

Fig.2.18

NOTE: *In general the Quanta of frequency is represented as mn'q*
m → Quanta of frequency, when CO_2 is in symmetric stretching mode.
n → Quanta of frequency, when CO_2 is in bending mode.
q → Quanta of frequency, when CO_2 is in Asymmetric stretching mode.
l → Angular momentum about the axis of the molecule.
Since rotational energy is not considered l = 0.

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Construction

It consists of a discharge tube in which CO_2 is taken along with nitrogen and helium gases with their pressure level of 0.33:1.2:7 mm of Hg for CO_2, nitrogen and the He respectively. Nitrogen helps to increase the population of atoms in the upper level of CO_2, while helium helps to depopulate the atoms in the lower level of CO_2 and also to cool the discharge tube.

The discharge is produced by D.C. excitation. At the ends of the tube Sodium chloride/Brewster windows are placed as shown in fig. 2.19. Confocal silicon mirrors coated with Aluminium (or) metallic mirror of gold is employed for proper reflection, which form the resonant cavity. The output power can be increased by increasing the diameter of the tube.

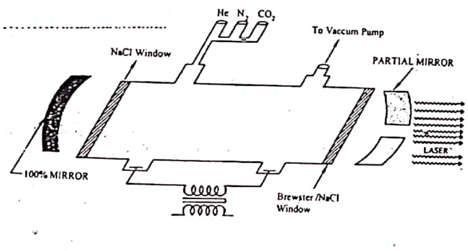

Fig. 2.19 CO_2 Laser

The interactive animation of this concept can be viewed in the CD.

Working

1) The discharge is passed through the tube first, the Nitrogen atoms are raised to excited state

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

2) The excited N_2 atoms undergo resonant energy transfer with CO_2 atom and raises $CO_2(00^01)$ to excited state due to closer energy level of CO_2 (00^01) and Nitrogen.

$$N_2^* + CO_2 \rightarrow CO_2^* + N_2$$

3) When transition takes place between 00^01 to 10^00, laser of wavelength 10.6μm is emitted as shown in fig.2.20.

4) Similarly, when transition takes place between 00^01 and 02^00 laser beam of wavelength 9.6μm is emitted as shown in fig.2.20.

5) Since $00^01 \rightarrow 10^00$ has a higher gain than $00^01 \rightarrow 02^00$ transition, usually the laser beam of wavelength 10.6μm is produced more.

6) When the gas flow is longitudinal power output is 50 to 60 watts but if the gas flow is perpendicular to the discharge tube the output power may be raised to 10 kilowatt/m.

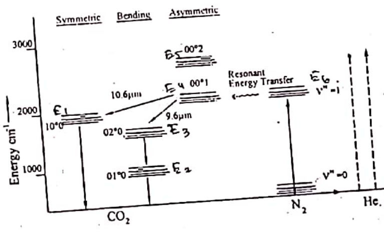

Fig. 2.20 Energy Level Diagram

The interactive animation of this concept can be viewed in the CD.

7) This type of CO_2 laser is known as TEA laser (Transversely Excited Atmospheric Pressure Laser).

8) The contamination of carbon monoxide and oxygen will also have some effect on the laser action. To avoid this the unused gases can be pumped out and fresh CO_2 must be pumped inside the discharge tube.

> **NOTE :** The upper energy level of Helium cannot be seen in the energy level diagram, because it occurs very far from the ground state energy level.

UNIT 2

Applications of CO_2 Laser

1. This laser has applications in medical field such as neurosurgery, microsurgery, treatment of liver, lungs and also in bloodless operations.

2. It is widely used in open air communication.

3. This laser also have wide applications over military field.

2.20 HOLOGRAPHY 6·5M M 2M6.

(The word "***Holography***" is derived from a greek word. In greek '*Holos*' means 'whole' and '*graphein*' means 'to write', in other way we can say 'graphy' means 'recording'. Therefore Holography means recording the complete information about an object in a holographic plate (photographic plate).]

We know, in ***Photography*** if we want to take photograph, we have to illuminate the light over the object. Then the light reflected from the object has to be focussed onto the photographic film with the help of a lens system in the camera. This gives rise to a real image of the object in the form of a negative. Thus, after washing and developing the negative, we will get a 2-dimensional image of the object.

Holography *is similar to this technique. Here we can construct a 3-dimensional image of an object using a laser beam. That image is called as a* ***Hologram***. In this hologram we can see the front, side and top etc., portions of the object, similar to what we see in video games (or) 3D-films.

UNIT 2

Types of holographic techniques

There are different holographic techniques by which we can make holograms. They are

(i) Optical holography.
(ii) Acoustical holography.
(iii) X-ray holography.
(iv) Microwave – holography.
(v) Double expanded holography.
(vi) Real time holography.
(vii) Time average holography.

Let us discuss the construction and reconstruction of a hologram by optical holography using laser beam.

Construction of Hologram

Principle : *Two beams, one from the object (object beam) and the other from the laser source (reference beam) are super imposed on a holographic plate to form an image called hologram.*

Working

A monochromatic source of Laser is made to fall on a beam splitter (B) with the help of a condensing lens (C). The beam splitter splits the incident beam into two beams viz. (i) Reference beam (R) and (ii) Object beam (O) as shown in fig.2.27.

The reference beam will directly fall on a holographic plate (Photographic Plate) and the object beam after gets scattered by the object will fall on the holographic plate.

Therefore the two beams i.e., the reference beam and the object beam will interfere with each other and the interference pattern is recorded on the holographic plate. This on developing and processing we get a *hologram*.

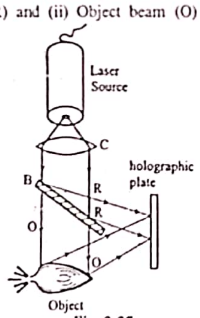

Fig. 2.27

The Interactive animation of this concept can be viewed in the CD.

UNIT 2

Precautions

During the construction of a hologram, the following precautionary measures has to be taken.

(i) The distance travelled by the reference beam and the object beam should be almost equal.

(ii) Ratio of light intensity between the reference beam and object beam should be 3:1.

(iii) Total darkness should be maintained, while loading the holographic plate.

(iv) The total setup has to be kept in a vibration less table, to avoid vibrations due to the natural seismic vibrations of the Earth.

Reconstruction of a Hologram

Principle

A beam of light (reading beam) having the same wavelength as that of the reference beam used for constructing the hologram, is made to fall over the hologram. This beam is diffracted by the hologram, which inturn gives rise to a 3-dimensional image in the field of view.

Working

During the reconstruction process, the object is first removed and the laser beam is switched ON. The laser light (~~reference beam~~) will now act as a reading beam (R_B). This reading beam is made to fall on the hologram as shown in fig.2.28.

Now, due to diffraction the observer can clearly see a 3-dimensional image through the hologram. Here, the image appears as if the object is really present. Therefore, the observer can move his head side wise or an just change the position of the eye ball, so that he can enjoy the full view of the image. Hence the hologram is reconstructed.

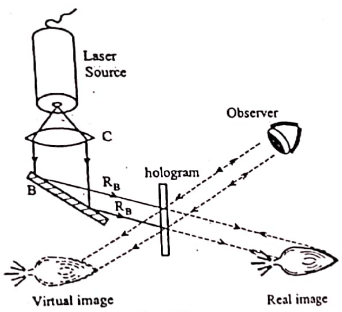

Fig. 2.28

The interactive animation of this concept can be viewed in the CD.

Precautions

The following precautionary measures are followed during the reconstruction of a hologram.

(i) The object should be removed carefully.

(ii) The reading beam should have same wavelength as that of the reference beam.

(iii) Hologram should not be disturbed.

NOTE: *While reconstructing the hologram, it is not so that laser light alone should be used, instead we can use any other monochromatic sources like sodium vapour lamp (or) ordinary beam, with the condition that it should have same wavelength as that of the reference beam used for constructing the hologram.*

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Applications of holography

1) They are used in the production of photographic masks.
2) Holography can be used in non-destructive testing.
3) It is used in the identification of finger prints.
4) It is also used in data processing, optical signal processing etc.

2.21 DIFFERENCES BETWEEN A PHOTOGRAPHY & HOLOGRAPHY

M 2M-9

S.No	Photography	Holography
1.	Photography is a 2-Dimensional recording process.	Holography is a 3-Dimensional recording process.
2.	Ordinary light can be used for recording.	Only Laser beam should be used for recording (or) constructing a hologram.
3.	It is based on lens systems.	It is a lensless system.
4.	Amplitude alone can be recorded.	Both Amplitude and Phase can be recorded.
5.	Image is recorded totally.	Image is recorded bit by bit.
6.	Image has poor resolution.	Image has very high resolution.
7.	To get the positive of the image it needs printing.	Since we can directly view the positive through the hologram there is no need of printing.
8.	No need of vibration less table	Needs a vibration less table.

CHAPTER 3

Laser

3.1. INTRODUCTION

Laser, Laser, Laser—the word is uttered even by children now-a days. The word is already accepted as a real word having verb form "to lase". Actually the word **Laser** is an acronym for "Light Amplification by Stimulated Emission of Radiation". Each word is carrying a definite information.

After the appearance of laser in 1960, the initial statement from some workers was that laser was a solution in search of a problem or at best it could be used for solving trivial problems. But after years of research and development, diverse applications of laser in the fields such as manufacturing industry, defense system, scientific and medical applications, communication and information processing, entertainment, meterology, sensor, optical switching and thousands of other areas have been found. The main properties of laser as compared to conventional light sources, are its intensity, directionality, monochromatism and coherence. A particular application of laser, therefore, utilizes one or more of these unique properties. In several applications its use has improved the speed and efficiency of the earlier methods while in others, it presents the only solution. Table 3.1 illustrates a short history of Laser, mentioning year, achievement and related achiever.

Table 3.1 Short History of LASER

Year	*Achievement*	*Achiever*
1917	Theoretically proved the existence of a process termed as stimulated emission	Albert Einstein
1954	Invented *MASER* using stimulated emission process.	Charles H. Townes, J.P. Gordon & H.J. Zeiger (USA), Nikolay Basov and Aleksandr Porkhorov (USSR)
1958	Proposed to extend Maser concept to optical frequencies	Charles Townes and Arthur Schawlow
1960	First optical *LASER* : Ruby crystal energy source: Flash Lamp	Theodore H. Maiman
1961	First Gas Laser : He-Ne	Ali Javan et al.

Year	*Achievement*	*Achiever*
1961	Neodymium Laser	Johnson and Nassau
1962	First Semiconductor Laser	Robert N. Hall
1963	CO_2 Laser	Kumar Patel
1964	First Ion Laser : Argon Ion Laser	William B. Bridges
1966	First tunable Laser : Organic Dye	Sorokin and J.R. Lankard
1970	First UV Laser (Molecular Hydrogen)	Hodgson Waynant
1975	First rare-gas halide excimer laser (Xenon Fluoride)	Ewing et al.
1975	First quantum well laser (GaAs Semiconductor)	Ziel et al.
1976	First free-electron laser	John M.J. Madey et al.
1979	First broadly tunable laser (Alexandrite laser)	Walling et al.
1985	First soft X-ray laser (Highly ionised Se plasma)	D.L. Matthews et al.

This chapter includes short information about the nature of laser and its principle, different types of laser and citation of a few of the thousands of applications for lasers. Lastly but not the least , it is appropriate to mention about the hazards of careless use of lasers.

3.2. LASER NATURE AND BRIGHTNESS

The enormous growth of laser technology has stimulated a broad range of scientific and engineering applications that exploit some of the unique properties of laser light. These properties are derived from the distinctive way laser light is produced in contrast to the generation of ordinary light. For example, in an ordinary sodium vapour lamp the atoms spontaneously emit photons (*i.e.*, light) at irregular times in random directions. There, wave fronts are produced in 'packets', by randomly born photons with unrelated births. The result is a non-synchronised light emission resulting in isotropic illumination of incoherent light over a broad spectrum.

Lasers are often termed as **monochromatic, coherent** and **collimated** sources of light. The parameters *i.e.*, Monochromaticity, Coherence, Directionality, and. High Intensity of laser source are as follows:

- **Monochromaticity :** Monochromatic means same frequency or wavelength. The wavelength width of the laser emission is generally confined in the range of 10^{-7} to 10^{-2} Å for high quality stable laser to a poor quality laser, whereas, in thermal sources wavelength spread is of the order of 10^3 Å (1 Å $=10^{-8}$ cm).

- **Coherence :** Not only is laser light monochromatic but also its constituent photons are all of the same phase giving the coherent character to the laser light. The light *produced by an Light Emitting Diode (LED) equipped with an optical filter, may well* be a monochromatic radiation but not coherent. The coherence of laser is due to its uniphase wavefront arising due to its diffraction limited operation. The special coherence exists over the whole area of the wavefront. Fig. 3.1 illustrates the incoherent and coherent nature of light.

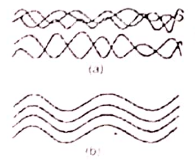

Fig. 3.1. (a) Incoherent light having no phase relationship
(b) Coherent light from laser source.

- **Directionality :** Again because of the collimated properties of laser, it can travel over large distances without being dispersed. The laser essentially sends out plane waves in a very narrow angular extent governed by the diffraction at the mirror ends of the source. For example. HeNe laser has a beam divergence angle in the order of 0.6^0 *i.e.*, milli radian.
- **High Intensity :** Lasers are extremely bright in comparison to more conventional sources. The emission of photon from typical lasers range over 10^{16}–10^{28} photon/sec, whereas, thermal sources emit at the rate of 10^{12} photon/sec.

Comparing the brightness of a laser with that of light received by Earth from Sun [as shown in Table 3.2], it can be said that the laser is brighter than the Sun. These monochromatic, coherent and collimated characters make the laser beam very special helping its use in various applications.

Table 3.2 : Laser Brightness with Respect to Light Received by Earth from Sun

Properties	*Sun*	*LASER*
Brightness (lumen/cm², steradian)	1.5×10^{5}	2.04×10^{7}
Spectral Brightness (lumen/cm², steradian, nm)	500	10^{8}

3.3. PRINCIPLES OF LASER

To explain the acronym "LASER", it is better to discuss each letter of the word **L A S E R**. *i.e.*, "Light **A**mplification by **S**timulated **E**mission of **R**adiation":

Light. Light is an electromagnetic wave. The word "Light" does not mean only visible light, it may be any other form of electromagnetic wave *i.e.*, infrared or ultraviolet light which are invisible.

Amplification. Amplification means gain in intensity. In LASER, the light is being amplified by a particular process called stimulated emission of radiation.

Next the question asked the meaning of the statement "stimulated emission of radiation". Now to explain this, it is better to include discussions on the processes, Stimulated absorption, Spontaneous emission before Stimulated emission as follows :

- **Stimulated absorption.** We know that electrons exist at specific 'energy levels' or 'states' characteristic of a particular atom or molecule as shown in Fig. 3.2. These energy levels can be imagined as orbits around the nucleus of an atom. Usually the atoms exist in the lowest energy state *i.e.*, 'ground state'. Now, electrons of the atoms from the ground state can be pumped to higher energy levels *i.e.*, outer orbits by providing energy in different ways. This is depicted in Fig. 3.3, where two energy

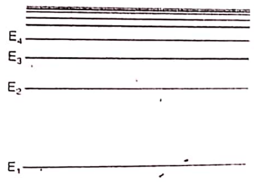

Fig. 3.2. Energy level diagram of an atom with various allowed states. The lowest energy state, E_1, is the ground state. All others are excited states.

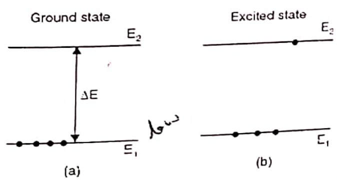

Fig. 3.3. (a) and (b) represent the states before and after the stimulated absorption of a photon by an atom respectively. The dots represent electrons. One electron is transferred from the ground state to the excited state when the atom absorbs a photon whose energy $h\nu = E_2 - E_1$.

states are considered for simplicity. When energy supplied to atoms is equal to the gap between the energy levels, then only electrons from lower energy state can move to the higher energy level. *i.e.*, in this situation, the supplied energy (E_s) must be, $E_s = E_2 - E_1$. If energy pumping is done by light, then, depending on the material

being used, specific wavelengths of light are absorbed to excite the electrons. This is known as stimulated absorption process.

- **Spontaneous emission.** In contrast to the absorption process, the emission process can occur in two different ways. Firstly, if an electron spontaneously decays from higher to lower energy states *i.e.*, from outer to inner orbit, it emits a photon having energy equal to the energy difference between the two energy states. This is called spontaneous emission (Fig. 3.4) process. The frequency or wavelength of emitted radiation is precisely related to the amount of energy released. In this situation also, depending on the material being used, specific frequency (ν) or wavelength (λ) is emitted at the time of de-excitation i.e., spontaneous emission process. Therefore, the energy of the emitted radiation (E_e) must be, $E_e = E_2 - E_1 = h\nu = hc/\lambda$.

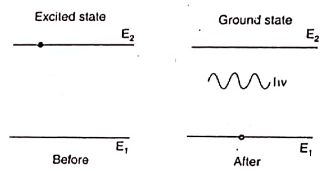

Fig. 3.4. Diagram representing the spontaneous emission of a photon by an atom that is initially in the excited state E_2. When the electron falls to the ground state, the atom emits a photon whose energy $h\nu = E_2 - E_1$.

- **Stimulated emission.** Next type of emission process is Stimulated emission. Actually, it is possible to force an emission process by means of a photon. That means a photon of definite energy (E) can force an electron to move from higher to lower energy states having the same energy difference, yielding another photon, where, $E = h\nu = E_2 - E_1$. This second process results in the two photons (incoming and emitted) of the same energy *i.e.*, same frequency or wavelength (monochromatic) and furthermore, these two photons will be in the same phase (coherent). This is known as stimulated emission process (Fig. 3.5). Therefore, an excited atom can relax to a stable state by releasing

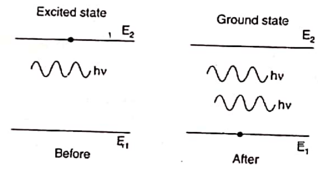

Fig. 3.5. Diagram representing the stimulated emission of a photon by an incoming photon of energy $h\nu$. Initially, the atom is in the excited state. The incoming photon stimulates the atom to emit a second photon of energy $h\nu = E_2 - E_1$.

a photon which is identical in energy, direction, and phase with the incident photon. These two photons can in turn interact with other excited atoms. Thus started with one photon, we can have two, four, eight photons and so on. This amplification corresponds to a build up of photons in the system as a result of the chain reaction of events.

Next, there is another important condition for the production of Laser, that is called **population inversion.** An incident photon can cause atomic transitions either upward (stimulated absorption) or downward (stimulated emission). Both processes are equally probable. When light is incident on a system of atoms, there is usually a net absorption of energy because there are many more atoms in the ground state than in the excited states in the case of thermal equilibrium. Actually, when the system is in thermal equilibrium, the distribution of energy states at a given temperature follows the well known Boltzmann's law as

$$N = N_0 e^{-E/kT}$$

where, N and N_0 are the populations in a given energy state E and in the ground state (E = 0) and k is the Boltzmann's constant and T the absolute temperature. It is clear from the above equation that the population is maximum in the ground state and decreases exponentially as one goes to higher energy states as depicted in Fig. 3.6 (a). Therefore, in a normal situation, there are more atoms in the ground state ready to absorb photons than there are atoms in the excited states, ready to emit photons. However, if the situation is just reverse, *i.e.*, there are more atoms in an excited state than in the ground state as illustrated in Fig. 3.6 (b), a net emission of photons can result. Such a condition is called population inversion. This, in fact, is the fundamental principle involved in the operation of a laser. Thus if we don't have a lot of excited atoms to start with, there is not much probability of obtaining of substantial amount of stimulated emission. Therefore, to get a laser to work, we need to have a population inversion. This can be done by providing an initial energy to the atoms by passing electrical current or illuminating it with a bright light pulse or using other laser sources.

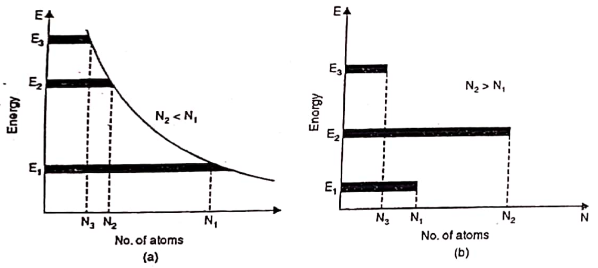

Fig. 3.6. (a) Populations at different energy states of atoms
(b) Population invertion through pumping process.

The phenomenon of stimulated emission was first used by Townes in 1954 in a construction of a micro wave amplification device called the MASER, an acronym for Microwave Amplification by Stimulated Emission of Radiation. At about the same time, a similar device was also proposed by Prochorov and Basov. The maser principle was later extended to the optical frequencies by Schawlow and Townes in 1958, which led to the realisation of the device now known as the laser. The first successful operation of a laser device was demonstrated by Maiman in 1960 using ruby crystal.

Actually 43 years before the invention of laser, Einstein predicted the concept of laser theoretically in 1917, at the time when electronics was unheard of, transistors didn't exist and vacuum valves were still a novelty. He predicted that under certain circumstances, an incident photon could generate another one, of exactly the same energy *e.g.*, the same frequency. Einstein also mentioned that in this type of emission both photons, old and new, would be in phase having same polarization with propagation in the same direction.

Thus, laser light originates from atoms, ions, or molecules through a process of stimulated emission of radiation. In any laser device the laser medium is contained in an enclosure or cavity which organizes the normally random emission process into an intense directional, monochromatic and coherent wave. A schematic diagram of a laser design is depicted in Fig. 3.7. The three main components of a laser device are as follows:

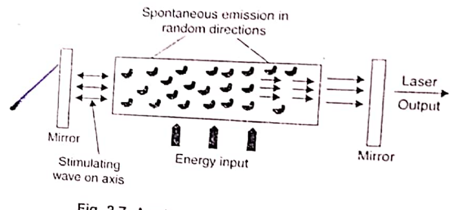

Fig. 3.7. A schematic diagram of a laser design.

- **Active medium :** The active laser medium consists of a collection of atoms, molecules or ions. The excited state of the active laser medium must be having a meta stable state, which means its lifetime (~ 10^{-8} sec) must be long compared to the usually short lifetimes of excited states. When such is the case, stimulated emission will occur before spontaneous emission. The medium may be solid, liquid or gas.
- **Pumping Device :** The active medium must be in a state of population inversion i.e., more atoms in an excited state than in the ground state. The pumping is done, as for example, by electrical discharge for gases, current injection for semiconductors, flash lamps for solid state and even by inducing other laser devices.
- **Optical Resonator :** The emitted photons must be confined in the system long enough to allow them to stimulate further emission from other excited atoms. This is achieved by the use of reflecting mirrors at the ends of the system. One of the two end mirrors is made totally reflecting, and the other is slightly transparent to allow photons to

Characteristics of lasers can be vastly different considering different aspects which vary as follows :

- *Size* : from tenths of millimetres to tens of meters
- *Power* : from microwatts (10^{-3} watt) to gigawatts (10^9 watt)
- *Cost* : from few hundred to many millions of rupees
- *Pulse duration* : from 10^{-14} second to continuous wave.

All the above mentioned lasers work on the same principle but the lasing material or the mechanism for energy pumping vary. An overview of different types of lasers are given below.

3.4.1. Gas Laser

Gas lasers generally have a wide variety of characteristics. For example, some gas lasers emit feeble power below 1 mw, but other commercial gas lasers emit power of the order of kilowatts. Some lasers can emit continuous beam for years ; others emit pulses lasting a few nanoseconds. The output wavelengths may vary from deep ultraviolet (UV) through the visible and infrared (IR) to millimetre waves. Most common example is Helium Neon laser.

3.4.1.1 *Helium-neon (HeNe) Laser*

The schematic diagram for HeNe laser is shown in Fig. 3.9. HeNe laser at wavelength of 632.8 nm is the most common of all the visible output lasers and this red wavelength has become the standard for HeNe laser. Commercially available HeNe lasers operating at the 632.8 nm [nm = Nanometer = 10^{-9} meter] wavelength can be obtained with continuous wave (CW) outputs ranging from 0.5 mW to 50 mW and because of this power range, these lasers are safe for laboratory experiments and artistic displays. Some HeNe lasers have interchangeable sets of mirrors for operation at 1.15 μm and 3.39 μm. The laser medium is a mixture of helium and neon gases. An electrical discharge is used to excite the medium to a higher energy level.

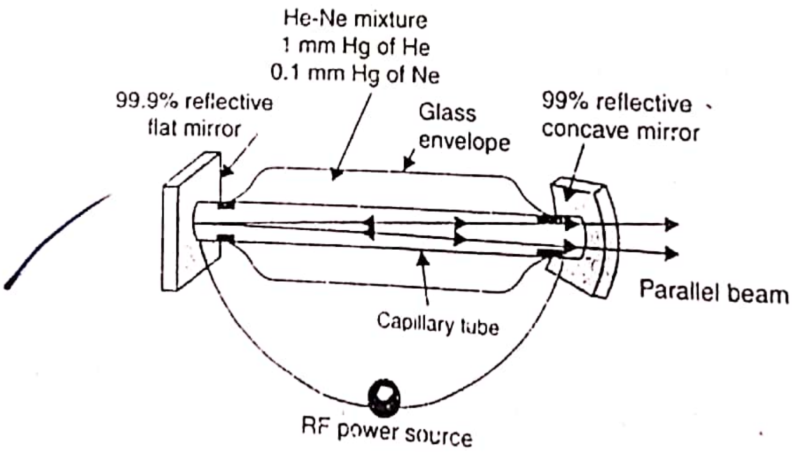

Fig. 3.9. Typical He-Ne gas Laser.

The pumping action takes place in a complex and indirect manner. First the helium atoms are excited by the discharge to two of the excited energy levels as shown in Fig. 3.10. These two levels happen to be very close to the 3s and 2s levels of the neon atoms. When the excited helium atoms collide with the neon atoms, energy is exchanged, pumping the neon atoms to the respective levels. The atoms at the neon 3s level eventually drops down to the 2p level ; as a result, stimulated emission is taking place and light of wavelength 632.8 nm is emitted. The atoms at the 2s level, on the other hand, drops to the 2p level by emitting light at 1.15 mm. However, the atoms at the 3s level may instead drop down to the 3p level, by emitting light at 3.39 mm.

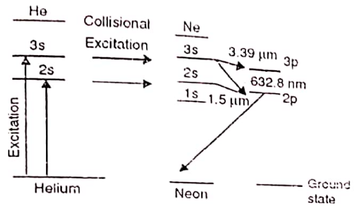

Fig. 3.10. Energy levels of Helium neon laser.

3.4.2 Solid State Laser

A solid state laser is one in which the atoms that emit light are fixed within a crystal or a glassy material. In the community of laser scientists, semiconductor (though crystalline material, *i.e.*, solid) lasers belong to a separate category. Ruby laser, the first laser invented by Maiman in 1960, was a solid state laser. Another example of solid state laser is Neodymium yttrium-aluminium-garnet (Nd:YAG).

3.4.2.1 *Ruby Laser*

The atoms that emit light in solid state lasers are dispersed in a crystal or a piece of glass that contains many other elements. The ruby, the solid state laser (694 nm) was the first laser constructed by T.H.Maiman at the Hughes Laboratories, California in 1960. Ruby is basically Al_2O_3 crystal containing about 0.05% (by weight) of chromium atoms. Al^{3+} ions in the crystal lattice are substituted by Cr^{3+} ions. Cr^{3+} ions constitute the active centres whereas the aluminium and oxygen atoms are inert. Although the operation of solid state lasers has been refined greatly since then, the same basic principles underlie the operation of the entire family of solid state lasers. Arrangement of the laser is shown in Fig. 3.11. The crystal is shaped into a rod, with reflecting mirrors placed at each end. Light from an external source (like a pulsed

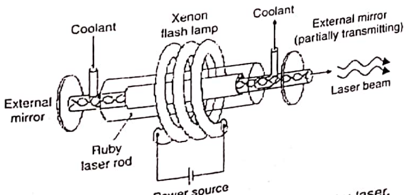

Fig. 3.11. Schematic diagram of a pulsed ruby laser.

flash lamp, a bright continuous arc lamp, or another laser) enters the laser rod and excites the light-emitting atoms. The two mirrors which form a resonant cavity in the laser rod, provides the feedback needed to generate a laser beam that finally emerges through the output mirror. The energy level diagram is shown in Fig. 3.12. Ruby lasers are operated in pulsed fashion with repetition rates of one pulse per second and energy as high as 100 joules per pulse.

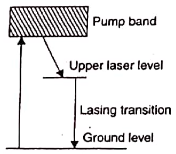

Fig. 3.12. Energy level diagram for Ruby laser.

3.4.2.2 *The Neodymium yttrium-aluminium-garnet (Nd :YAG)*

The Neodymium-aluminium-garnet (Nd :YAG) laser is a good example of the most commonly used solid state lasers. The laser medium is made up of yttrium- aluminium-garnet, with trivalent neodymium ions present as impurities. The neodymium-YAG laser uses triply ionised Nd as lasant and the crystal YAG (yttrium-aluminium-garnet) as the host. The laser transition involved, corresponds to a wavelength of 1.06 μm, in the near infrared region and is pumped optically using high pressure gas-discharge lamps or diode laser. The energy level diagram is shown in Fig. 3.13. These lasers are capable of average power outputs up to 1 kW.

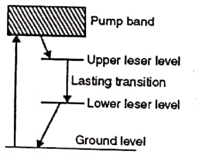

Fig. 3.13. Energy level diagram for Nd in YAG.

3.4.3. Semiconductor Laser

A unique and the most important type of laser in terms of opto- electronics applications is the semiconductor laser. For the uniqueness of its qualities, semiconductor diode laser is having numerous applications such as two way video, audio and data transmission, information storage and processing etc. Its uniqueness is for the following factors :

- miniature in size (mm × mm × mm) and so natural integration capabilities with micro electronic circuitry
- efficient
- inexpensive

- can be directly driven and modulated by electrical currents
- covering a wide spectral range (IR, visible and near UV)
- availability of powers ranging from a few milli Watt to a few Watt
- large gain spectral width
- tunability over several 100 Angstrom

Semiconductor laser emits light at various wavelengths like ultra violet, red and infra-red and research is underway for development of blue and green semiconductor laser.

The light amplification by the process of stimulated emission is not exactly in the form that is discussed earlier. A semiconductor laser uses special properties of the transition region at the junction of a *p*-type and a *n*-type semiconductors. In semiconductor materials, as a result of the extensive interaction of energy between atoms, the energy levels form bands. Energy band diagrams for an *n*-type and a *p*-type semiconductors are depicted in Fig. 3.14.

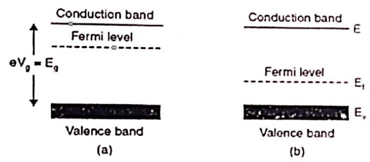

Fig. 3.14. Energy band diagram : (a) a *n*-type semiconductor; (b) a *p*-type semiconductor.

The energy gap between the valence band and the conduction band is designated by E_g and is measured in electronvolts. The Fermi level E_f is the level that divides the occupied from the unoccupied levels.

In a p-n junction, as shown in Fig. 3.15, the energy levels readjust so that the E_f band is the same throughout the junction. The valence band E_v and the conduction band E_c of the *p*-type semiconductor are higher than the corresponding bands of the *n*-type semiconductor. In case of forward bias *i.e.*, if a positive voltage is applied on the *p* side, the electrons on the *n* side will be attracted by the applied voltage and will cross into the junction region. There they recombine with the holes that have been pushed into the junction region by the positive bias. This process will continue as long as the external circuit is on, because the electrons and holes that have recombined are continuously replenished.

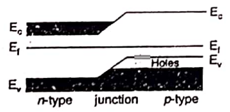

Fig. 3.15. A *p-n* junction energy band diagram.

When the electrons and holes recombine, they emit energy in the form of photons. The junction transition region in which this process takes place is therefore the source of radiation, and may be viewed as equivalent to the E_2 and E_1 transition levels as discussed earlier (Fig. 3.5).

To obtain stimulated emission and amplification from this region, the equivalent of population inversion needs to be created, for which a high density of electrons and a high density of holes must exist simultaneously in the junction region. To achieve this, heavily doped *p-n* junctions are used in semiconductor lasers. Fig. 3.16(a) and (b) show respectively

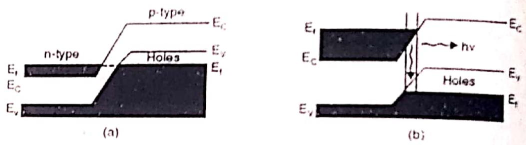

Fig. 3.16. Energy band diagram : A heavily doped *p-n* junction, (a) without and (b) with an applied bias voltage.

the resultant energy levels of a heavily doped *p-n* junction without biasing voltage and a transition region with a high concentration of electrons and holes with a forward bias across the *p-n* junction. This region serves as a population inverted medium, which amplifies the radiation emitted within it through electron - hole recombination. A *p-n* junction semiconductor laser is illustrated schematically in Fig. 3.17. The shaded area is the transition region where the laser action takes place. This region is about 1-2 mm thick, and tens of micrometers long. As a result, the emission is squeezed into a thin plane, leading to an elliptical cross-section of the beam. An example of semiconductor laser is Gallium Arsenate (GaAs) laser, it is *p-n* junction diode laser with the *p*-type and *n*-type regions heavily doped. Fig. 3.18 illustrates (a) simple homojunction and (b) double heterojunction semiconductor GaAs laser respectively.

Fig. 3.17. A *p-n* junction semiconductor laser.

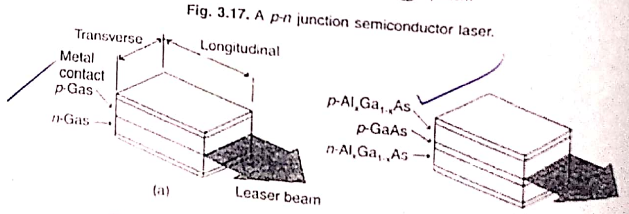

Fig. 3.18. Semiconductor laser (a) Simple homojunction GaAs laser, (b) Double heterojunction (DH) GaAs laser.

Specifically semiconductor diode lasers are useful for :

- *Information transmission* : like Optical fibre communication system
- *Information storage* : for examples, optical disk players for audio, video and optical disk data storage system
- *Information collection and processing* : like, laser printers, laser bar-code scanners and image scanning and measurement systems.

3.4.4. Other Laser devices

3.4.4.1 *Ion and Metal Vapour Laser*

The ion lasers, as the name implies, use ionised rare gases as the active medium. It is the excited states of the ions that are involved in the lasing process. Examples are ionised argon (Ar), xenon (Xe) and krypton (Kr) gas. They are operated at high temperature and they produce laser light in the infrared, visible or ultraviolet regions. The power levels of these lasers vary from milliwatt to several watts. Excitation is a two collision process—the first collision ionises the atom, the second provides the necessary excitation. Transitions between highly excited states of the singly ionised argon atom can be used to obtain number of visible (or near visible) wavelengths between 0.35 mm and 0.53 mm. The argon laser is one of the most important lasers in use today. Some gas lasers are also labelled as ion lasers.

Many types of metal vapour lasers are there, *e.g.*, HeCd and HeSe which are the most important commercial ones. The HeCd laser has wavelengths at 0.441 μm in the blue and 0.325 μm in the UV. The power output of these metal vapour lasers is in the range of 50–100 mW range. Some applications of such lasers are light shows, full colour image generation, spectroscopy etc.

3.4.4.2 *Carbon Dioxide Laser (CO_2)*

There are several types of carbon dioxide gas lasers but the active medium in all of them is usually a mixture of carbon dioxide, nitrogen and other gases like helium. Most CO_2 gas lasers can produce pulses of laser having power in billions of watt at 10.6 μm and that is why it is capable of vaporising any material. The carbon dioxide laser is a molecular laser in which molecular vibrations rather than electronic transitions provide the mechanism for lasing action. There are several types of CO_2 lasers.

One type of CO_2 laser of increasing importance is the so-called "TEA" laser; the letters denote a system "Transversely Excited at Atmospheric pressure." The name of the laser implies the special structure. In a TEA CO_2 laser, the gas mixture is near atmospheric pressure in a rectangular shaped transverse discharge tube. Actually the gas flows at right angle to the axis of the laser tube. It means that the electrical discharge direction is perpendicular to the optical axis. The gas flows in and out of the laser cavity at a much faster rate and it allows excess heat to be removed quickly. TEA lasers are having various sizes and they produce intense, short pulses of microsecond duration. It is used in industry for heat treatment.

3.4.4.3 *The Excimer Laser*

They also belong to a family of gas lasers that produce nanosecond long powerful pulses at UV region (308, 248 or 193 nm) of electromagnetic spectrum. These lasers use mixture of gases. The interest in excimer lasers principally of heavy noble gases (Xe, Kr, Ar) and the halogens (F, Cl, Br, I) is due to the relatively efficient production of their excited state by electron beam collisions and the fact that their emission wavelengths lie in the ultraviolet ($0.2 < \lambda < 0.4$ μm) region of the spectrum, a region not covered well by other types of lasers. The important excimer laser gases are krypton fluride, xenon fluride, argon fluride and xenon chloride. It can generate billion watt of power pulses.

3.4.4.4 *The Liquid (Dye) Laser*

Dye lasers, as the name suggests, use liquid organic dyes. Liquid dye laser beam covers a wide range of wavelengths and thus have the great advantage of being tunable. The user can select a fine tuned wavelength as required. Liquid dye lasers can emit laser beams from 250nm (UV) through the whole visible spectrum to 1800 nm (IR). In the liquid dye laser, the dye is the active medium. It is usually dissolved in a liquid solvent such as alcohol or ethylene glycol (antifreeze). The source of energy for a liquid dye laser is usually a flash lamp or another laser like argon or a krypton ion laser. An example of a liquid dye laser is the rhodamine 6G laser. The emitted light from the rhodamine 6G laser is having a broad range of frequencies from 570 to 655 nm which includes the orange colour light of 590nm. This laser is tunable using optical lenses and prisms to select the desired wavelength. This capability is of great value in certain types of spectroscopic investigations in and near visible wavelengths. Liquid dye lasers are used for investigation process in chemical reactions.

3.4.4.5 *The Free Electron Laser*

The conventional microwave sources produce waves at wavelength $\lambda \geq 1$ cm. and the different types of lasers operate at infrared and optical wavelengths. Hence, there remained a big void of sources in the range 1 cm $\geq \lambda \geq 30$ μm. Free electron laser emerged as versatile device of megawatt power that filled the entire void and proved to be suitable for satellite communications, precision radar and plasma heating in thermonuclear fusion device. FEL also produces tunable radiation at infrared, optical wavelengths and even much shorter wavelengths upto X-rays.

In a Free Electron Laser (FEL), the kinetic energy of a relativistic electron beam is transformed into laser radiation. This transformation takes place when the electron beam passes through an alternating magnetic field that forces the electron to move in an oscillatory path. The resultant electromagnetic radiation (Laser) travels along the system axis. The electron

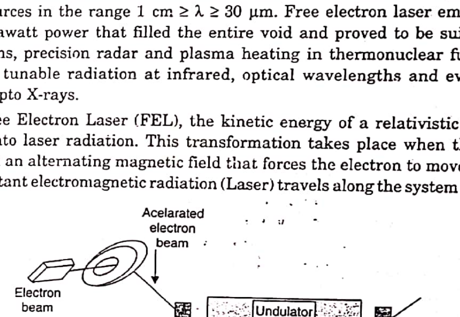

Fig. 3.19. Schematic representation of a free electron laser.

beam is produced by a particle accelerator and the magnetic field is produced by a specially designed magnet. A schematic diagram of a FEL is shown in the Fig. 3.19.

3.4.4.6 *Chemical Laser*

Some lasers are stimulated by chemical reactions instead of an outside source of energy. Chemical lasers most often utilise gases as active medium and the end products of the reaction are excited energy states that are capable of emitting photons. Some chemical lasers can produce pulses of energy as enormous as 200 gigawatts. (~ of 10^{12} *i.e.*, Billion watt). Among the most important chemical lasers are systems that utilize hydrogen fluoride (HF) and deuterium fluoride (DF) as the active laser molecule. These devices offer several attractive features, including both CW and pulsed operation; fairly large output powers; shorter IR lasing wavelengths (3–4 μm). Chemical lasers are becoming increasingly important as a research tool and probably will be available in the commercial market in the near future.

3.5. VARIOUS APPLICATIONS OF LASER

From its invention in 1960, laser has provided magic solutions to numerous problems. Applications of lasers exist throughout our society, and new uses are discovered almost daily. Starting from measurement of the distance to the moon with incredible accuracy, it can also repair detached retinas in the human eye, can stop bleeding deep inside a patient's body and even can be used in cancer treatment and genetic engineering. It slices through heavy steel as if it were cheese and that is why it is having lots of applications in industry too. Lasers read supermarket bar code labels in automatic cash registers and register books in modern library. As weapons for defensive purposes, powerful lasers can also destroy air planes. It is also used widely to promote scientific progress, like its use in fusion power plants which can provide the human race with much of its required energy for the years to come.

The uses of lasers today is so far reaching and widespread that a comprehensive enumeration is impossible. A major application of laser in the field of communications will be discussed separately in the following chapter. The following are a few of the thousands of applications for lasers :

3.5.1. Applications in Industry

Of course, the laser beam used in industry is invisible but laser tools can cut a variety of materials. Because of laser, it is possible to weld, cut and drill metals perfectly for industrial use. Laser machining/welding is being performed with efficient high power CO_2 laser beam (Fig. 3.20). Advantages are like low noise, dust, fume and vibration levels, the ease of starting a cut in the middle of a work piece and so on. It also eliminates the need for a wide range of cutting tools. Application of laser leads to higher yields with superior product quality. The various material processing methods using laser are :

- **Surfing:** Lasers are very effective for heating discrete areas very rapidly. Generally 1.0 kW CW CO_2 laser is used
- **Welding :** Two types of laser welding *i.e.*,CW and pulsed, are done with CO_2 and Nd-YAG lasers having power 500 W or more

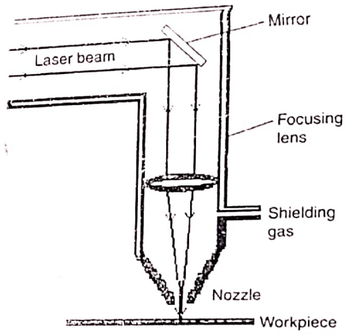

Fig. 3.20. Schematic diagram for beam focusing head design for laser welding.

- **Cutting :** Industrial cutting is done with CW or pulsed CO_2 with high repetition rate. Nd : YAG laser is specially used in the manufacture of aircraft engine parts
- **Drilling :** Low power CO_2 lasers are used to perforate polythene to make air beds for burn patients, drilling holes in babies bottle nipples, aerosol nozzles, etc.
- **Resistor trimming :** Laser triming consists essentially of vaporising the material away from many electronic components and circuits. It can also be used for scrabing ceramics. It is normally done with a Q-switched CW Nd : YAG laser
- **Laser Marking :** Nd : YAG lasers are increasingly used for marking a variety of materials where controlling is done by computer. Among its wide ranging applications are vernier callipers, gauges, thimbles, labels made of plastic laminates, reactor and aircraft components , electronic components, radio and car dash logos, typewriter keyboards, ball bearing races, turbine blades etc.
- **Laser soldering :** By using laser, high and reliable quality joints are obtained. Both CO_2 and Nd : YAG are suitable for this.
- **Surface alloying and cladding :** Alloying is a process by which the surface of a material is first melted, then additional elements are added to the melted area, thereby changing the composition of the surface. Common substances are low alloys steel or stainless steel with coating materials like cobalt or nickel. Cladding thickness using multi-kilowatt lasers are between 0.1 and 5.0 μm in a single pass.
- **Others :** Other uses include deposition of thin films using ablative sputtering, annealing, photolithography for the production of integrated circuit chips etc.

Fig. 3.21(*a*) and Fig. 3.21(*b*) show the above mentioned industrial applications of laser. The important point is that the interaction of a laser beam with the workpiece depends on the parameters of laser and material. Laser beam parameters are wavelengths, laser nature (*i.e.*, pulsed or continuous), focused spot size, mode structure etc. Material parameters are reflectance, absorption coefficient, specific heat, thermal conductivity, thermal diffusivity, latent heat, melting point etc.

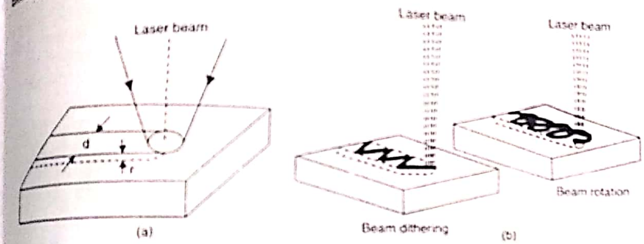

Fig. 3.21. (a) Defocused laser beam used in workpiece for heat treatment
(b) Focussed laser beam is used for application of surface treatment

For different industrial uses of laser, the laser beam has to be transmitted to numerous workstations and it is required to be manipulated about the workpiece. In this respect fibre optic delivery system is used as shown in Fig. 3.22. The optical fibre assemblies used for welding are protected by substantial and robust sheathing, which includes a flexible steel tube and nylon jacket.

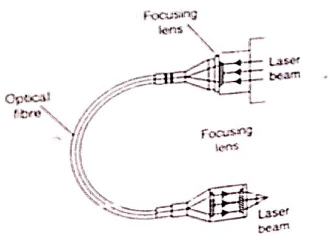

Fig. 3.22. A fibre optic beam delivery system.

Major advantages of using laser in industry are :

- There is no mechanical contact between the tool and the work ; hence there is no possibility of breakage or wear of tool
- Precision location is ensured by focusing of the beam
- Very small holes can be drilled in very hard materials like diamond
- Large mechanical forces are not exerted upon the work piece

- The laser head need not be in close proximity for performing cutting and drilling operations in locations of difficult accessibility
- Any solid material which can be melted without deposition can be cut with the laser beam

The limitations are :

- It cannot be used to cut metals that have high conductivity or high reflectivity *e.g.*, aluminium, copper and their alloys
- Work tables should be made from metal which is not affected by laser beam
- Output energy from laser is difficult to control precisely

3.5.2. Applications in Medicine and Surgery

As laser light can be concentrated into spots, the laser has found applications not only in diagnosis but also in surgery and other forms of treatment. Laser surgery has been known since the mid-1960s, when the first retinal lesions were being successfully repaired. Today, laser surgery is a vast field of activity as a cutting tool. Fig. 3.23 shows the schematic diagram of beam delivery system used in surgery with CO_2 lasers. The various application areas cover gynaecology, tonsils removal, drilling and cutting bone tissues, stopping of gastric bleeding, removal of birth marks and dermatology. The laser scalpel attacks fewer cells than a steel knife and evaporates them quickly. Since laser beam can be sent down readily through optical fibres and fibres can be introduced into arteries using catheters, it becomes possible to treat

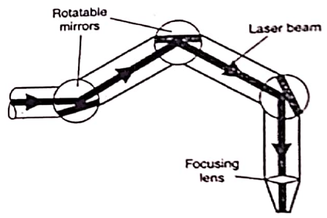

Fig. 3.23. Schematic diagram for CO_2 laser beam delivery system in surgery.

coronary artery blockages using lasers (Fig. 3.24). The optical fibres transmitting the laser beam can remove the plaque, a fatty material built up on the arterial wall, blocking the blood flow. In addition, laser has extensive use in R & D activities in medical science. The laser beam induces changes in cells, but is opposed to destroying them ; as such this is applicable in genetic engineering. Beside this, in laser acupuncture, the thousand-year-old silver and gold needles are replaced by fine, micro manipulator-oriented laser beams. Again because of its high level of precision, excimer laser can change the shape of the cornea to change its refractive power to the desired state and thus correcting the refractive error of eyes with minimal thermal damage to the surrounding tissues. Even in root canal therapy, the dentist can insert the laser fibre into the root canals, remove the infected tissue by vaporising it and destroy totally and effectively the bacteria causing the infection. All these things are done giving less pain and destruction to healthy parts of the tooth of the patient. The Table 3.3 lists some characteristic wavelengths of the lasers used in medical science.

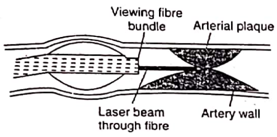

Fig. 3.24. Removal of arterial plague using laser radiation carried down an optical fibre inserted into the artery. A viewing fibre bundle is also incorporated.

Table 3.3 : Different Types of Lasers Used in Medical Science

Laser	*Wavelength (nm)*	*Nature*
CO_2	10,600	Infrared
Er : YAG	2,940	Infrared
Ho : YAG	2,060	Infrared
Nd : YAG	1,300	Infrared
Nd : YAG	1,064	Infrared
Ruby	694	Red
Dye	632	Red
	577	Yellow
	504	Green
He-Ne	632	Red
Gold vapour	632	Red
Cu vapour	632	Red
Krypton	578	Green
Argon	488	Blue
	575	Green
Excimer	193–351	UV
Free-electron	193–351	Variable

Infrared is invisible to the eye, so while using infrared lasers a visible laser like HeNe is used to fix the target plane. An important point is that precautions should be taken for using lasers in medical science. Lasers giving outputs in various wavelengths and of various powers are used in different fields of medical science. Not only the power and wavelength of the laser, but also the type (pulse or continuous) and the duration of exposure may affect tissues with different physical phenomenon. Fig. 3.25 is the schematic diagram of an instrument used in medical science for detection and surgical works. All these are related to laser and optical fibre which are used either to illuminate the spot or to transport laser to burn the unwanted elements.

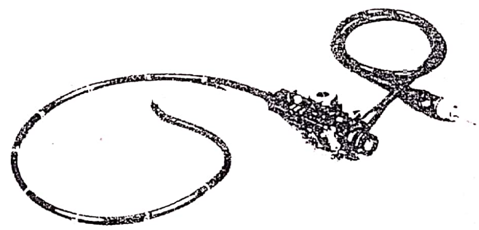

Fig. 3.25. The schematic diagram of an optical fibre related instrument used in medical surgery.

3.5.3. Applications in Three-Dimensional Imaging by Holography

Byte, Bytes

A conventional photograph is only a flat record of a real image projected onto a photographic film. The three dimensional character (*i.e.*, the phase information) of the object is almost entirely lost during such photographic recording process. A hologram on the other hand is a special three-dimensional photography, a 'photograph' of an object that retains information about the phases of waves coming from the object through the use of laser. During the recording process, two waves superimposes, one coming from the object and another coherent reference wave, both originating from the same laser source. These two waves produce interference fringes in the plane of the photographic medium. This record carrying the information of amplitude and phase of the object is known as hologram, which means "whole" in Greek language. In the reconstruction process of image, the hologram is illuminated by the same type of laser wave which is used in the recording of hologram. Fig. 3.26 (a) and Fig. 3.26(b) respectively demonstrate the experimental arrangements for producing hologram and reproducing image from the hologram using same laser.

Holo- whole   GB, MB, KB

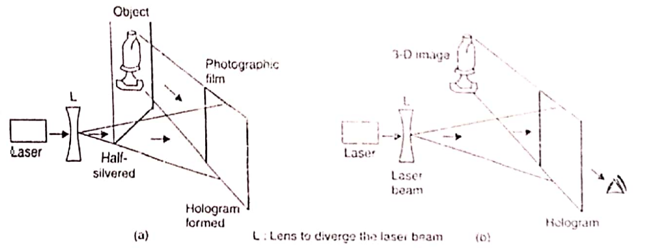

Fig. 3.26. (a) Experimental arrangement for making a hologram ; (b) Experimental arrangement for viewing 3D image using same laser source.

The idea of holography was invented by Dennis Gabor in 1947 but its use became possible only after lasers were available. Today, it is used in a multitude of ways including three-dimensional representation of objects, fingerprint identification and laser beam scanning. Credit cards often have reflection holograms (Fig. 3.27) printed on them. They make the cards very difficult for forgers to copy. Also, the publisher of a book, now-a-days, prefers to use hologram to establish the genuineness of the publication.

Fig. 3.27. Hologram on a credit card.

3.5.4. Applications in Entertainment Industry (Audio, Video Compact Disc)

The entertainment industry too uses lasers in the form of audio, video compact disc and laser show. All information, whether pictorial, verbal, alphabetical or numerical is reduced to strings of binary "zeros" and "ones". The Fig. 3.28(a) shows a compact disc. Compact disk (audio, video or data storage) uses a laser (GaAlAs) for writing very high density digital data onto a fine layer of a metallic bismuth compound, the recording medium. For reading the disk, the same laser is used in combination with a detector (PIN photo diode). Writing the data onto the fine layer of a bismuth compound is done by means of ablation. A tiny circular matt area obtained by burning out a hole in the high-shine bismuth layer represents "one" as digital storing while the unburnt location denotes a "zero". The data are recorded on a continuous, tightly wound spiral, pre-grooved bismuth base. On the top of both surfaces of the CD, glass layers of 1.1 μm are placed for strengthening and protective purposes. The data holes have a

diameter of 0.6 μm and the distance in between the tracks is 1.6 μm. This arrangement corresponds to a bit density of 3×10^{10} bits/mm^2. Fig. 3.28(b) shows cross section of pits.

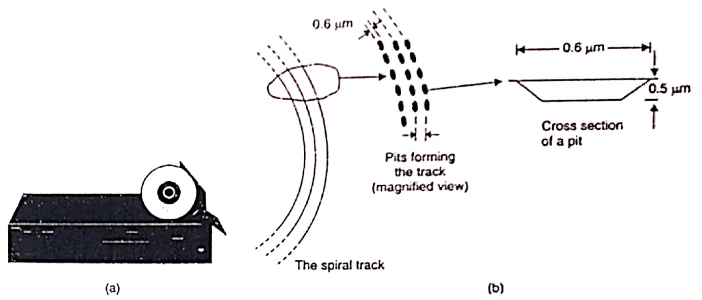

Fig. 3.28. Schematic diagram of (a) Compact disc with player, (b) Cross section of a pit.

A compact disk is having capacity of 640 million Bytes (1 million Byte = 1 MB = 10^6 Bytes, 1 Byte = 8 bits). It can even store information contained in an encyclopaedia and that is why now encyclopedia is available in compact disk (CD). To explain this fact, we can do calculation roughly like this : for storing one letter or character for 8 bit system, one byte is required. Therefore, for the contents of one page of having ~ 20 lines and each line containing of ~ 10 words and each word of approximately 5 characters, we need at least $(1 \times 5 \times 10 \times 20)$ bytes = 1000 bytes, *i.e.*, 1 kilo bytes (1 kB) storage capacity. Thus it is clear (Table 3.4) that one compact disk having capacity of 640 MB (1 million Byte = 10^6 Bytes) can hold the text content of 1280 books, each of 500 pages, which by itself is a small library. Therefore, first the microfilm, then the magnetic disks and now the optical compact disk (CD) have drastically reduced the volume required for information storage.

The CD player consists of a set of servo systems that make the laser beam accurately focus on the surface of the CD and track across the fine surface of the CD when the CD is made to rotate at a correct speed. Motors perform simple mechanical operations to drive the CD, optical assembly and the loading/unloading system.

The main advantage of using a CD is that its fine track is not easily damaged and does not wear out in use as there is no hard needle or stylus touching the surface of the CD. There is no direct contact between the reading mechanism and the disk surface as the signals are being read from the disk through a reflected beam of laser light. Fig. 3.29 demonstrates the basis of readout from an optical disc.

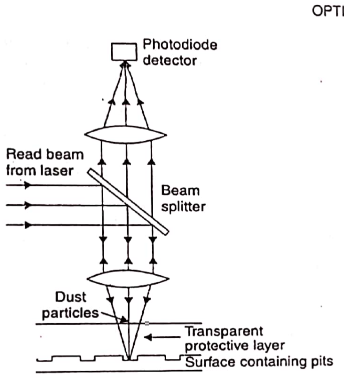

Fig. 3.29. The diagram depicts the basis of read out from an optical disk. The laser beam is focused on the surface of CD containing information in forms of pits. The reflected laser beam is focused on the photodiode which extracts the information in the form of electrical digital pulses. Even dust particles on the protective layer do not affect the read out.

Table 3.4 : Capacity of Compact Disk

Capacity of one Floppy (5¼)	→1.2 MB
Capacity of one Floppy (3½)	→ 1.44 MB
Capacity of one Compact Disk (CD)	→ 640 MB
1 Letter/Character	→ 1 Byte
5 Characters (= 1 Word)	→ 1 × 5 = 5 Bytes
10 Words (= 1 Line)	→ 5 × 10 = 50 Bytes
20 lines (= 1 Page)	→ 50 × 20 = 1000 Bytes = 1kB
500 Pages (= 1 Book)	→ 1kB × 500 = 500 kB = 0.5MB
1,280 Books (1 Small Library)	→ 0.5 × 1280 = 640 MB

Additional advantages of CDs are that the listener/viewer can skip from one song/video frame to another with great precision. There is another type of new optical storage disks, called Digital Versatile Disk (DVD). Unlike CDs, it contains two layers of data pits. Adjustment of the position of the lens permits the player to read information from either the upper or lower information layer of a DVD.

3.5.5 Applications in Supermarket's Bar Code, the Librarian's magic wand

A patch of black-and-white stripes (Fig. 3.30) which would look like a miniature zebra crossing, appeared on some packages of consumer goods from the beginning of the decade of

"80s" and by now, its presence on the supermarket goods is almost universal. Reading a bar code by a scanner is much faster and more accurate than keying in the information in the cash register by looking at the text label given on the article. Advantages of using bar codes in other fields include increased patient safety through label checks on medicine bottles. The bar code is also widely used by libraries in lending and returning books. Several codes are at present in use. The most frequently encountered one is the Universal Product Code (UPC). This bar code can be read in both the left-to-right and right-to-left directions. In addition, the beauty of the system lies in the method of decoding the information. The laser bar-code scanner has two major parts : a laser (LED chip) and a detector (a photo diode + transistor chip). The bar code is held in front of the laser beam. The laser light is absorbed by the black lines of the bar code and is reflected by the white lines of the bar code. Finally the reflected light is reaching the detector which transforms it into an electrical signal made of low and high states which is translated into digital signal and get fed into the computer enabling viewing of the information on the computer screen or taking out a print.

Fig. 3.30. A diagram of UPC version of bar code.

3.5.6. Applications of laser as a sensor device

Light is having wave character, therefore it can demonstrate the physical properties like interference and wave modulation. As laser light has a well-defined phase, a wide variety of applications are possible based on interference or wave modulation. Such applications include sensing and measuring of various kinds of physical parameters like temperature, mechanical pressure, frequency and electrical current intensity etc. Some discussions are made in this respect in chapter 2 and the experiments are included in chapter 5.

3.5.7. Applications in Laser Printing

Laser is also used in printer to get high quality printing. A schematic diagram of a laser printer in shown in Fig. 3.31. The laser printer is based on the principle of xerography. The laser printers are page printers. A page of text or pictures is composed at a time. The image to be printed is broken up into dots and these dots are projected through a semiconductor laser beam and a series of lenses onto a revolving drum having a light sensitive surface. This modulated laser light is focused and scanned repeatedly across a rotating drum having a photosensitive surface made up with selenium/cadmium sulphide (CdS) which is initially electrostatically charged by corona discharge method at the 'surface charging station'. When the modulated laser beam strikes the surface, selenium/CdS becomes conducting due to the phenomenon of photo conductivity and hence the charges leak away from the struck region producing a 'charge image' corresponding to the pattern carried by the scanned laser beam. Next the rotating drum passes through the 'developing station' where it comes into contact with charged carbon particles of the toner and a real black and white image of the charge pattern is formed on it. This image is then transferred to the rotating paper under heat treatment at the 'transfer station' and thus, printing takes place finally on the paper. The resolution of print image can be more than the order of 300 dpi (dots per inch).

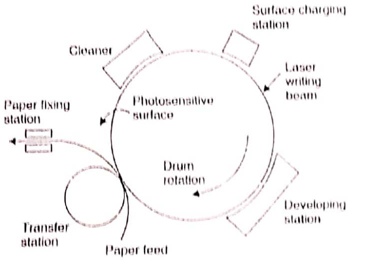

Fig. 3.31. Schematic diagram of a photoconductive drum assembly used in a Laser Printer.

3.5.8. Application in Law Enforcement

Lasers have also several uses in law enforcement like detection of violation of speed limit by individual vehicles, detection of finger print. Police uses laser speed gun to detect accurately how fast a vehicle is moving by detecting the time lapse between the transmission of the laser beam and reception of the reflected beam coming from the moving car (as shown in Fig. 3.32).

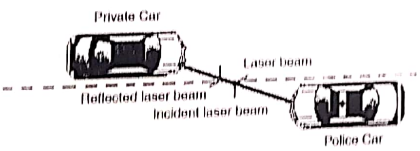

Fig. 3.32. Laser's use in law enforcement.

Binoculars equipped with a pulse laser (Fig. 3.33) can be used by a soldier to measure the distance of a target. The soldier sights the target and shoots an invisible pulse of laser radiation toward it. The time taken by the pulse to be reflected back to the range finder is measured and electronically converted into the distance and displayed.

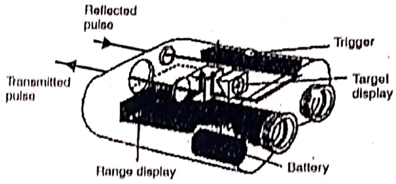

Fig. 3.33. Binocular equipped with pulsed laser.

3.5.9. Application in Environmental Study

Lidar is akin to radar. Lidar is an acronym of **Light Detection and Ranging.** It is used mainly for probing the atmosphere *i.e.*, for Weather forecasting and pollution study. Lidar systems essentially study the laser beam scattered from the atmosphere. The arrival of laser revolutionised the atmospheric study using coherent light beams. Pulses of laser are sent and the radiation that is scattered by various particles present in the atmosphere are picked up by the receiver. The scattered light gives the information regarding the particles present in the atmosphere with a sensitivity that is much more than that obtainable from microwave radars. Fig. 3.34 represents the block diagram of a lidar system. An excimer based Lidar system can give information of ozone levels in the atmosphere.

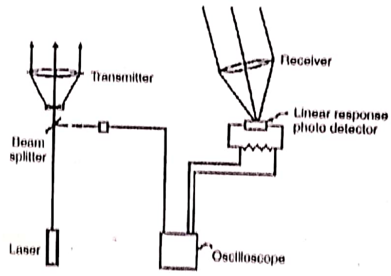

Fig. 3.34. Block diagram of a pulsed LIDAR system.

3.5.10. Application in Military Activities

The extremely concentrated power of laser can be used for destructive purpose also. Thus, there are certain inherent possibilities in the use of a laser for military applications. Since the light beam is capable of sharp focus, from its position above the earth, the beam can be directed at a satellite or missile that is to be destroyed. Thus the laser may be used as a portable battlefield device. For military purposes, radar can also be combined with a missile destruction system.

3.5.11. Application in Decorative Uses

Universal laser systems Inc. is the innovator and the largest manufacturer of various decorative pieces. The computer controlled laser system is already available for decorative purposes and industrial uses as follow :

- *Engraving* : like, rubber stamp, decorative etching, pen and gifts, plaques and award, plastic name badges, desk accessories, leather and glass
- *Marking* : like, bar coding, identification tags and
- *Cutting* : like, wood, acrylic, rubber, leather, fabric, paper, laminated plastic, plastic film, ceramic, coated metal glass, stencils, patterns and gaskets

Rubber stamp engraving is very popular. It is a direct digital method for producing rubber stamps without going through a labour intensive photographic process. Once the stamps are designed in the graphics software, they are printed by the Universal laser system (ULS) where the rubber is engraved. ULS provides special software and hardware to allow the laser systems to perform this job.

3.5.12. Application in Meteorology

The introduction of lasers, specially visible wavelength gas lasers , has dramatically increased the scope of optical meteorology. Advantages of optical meteorology are high resolution, 'non-contact' capability, high scanning speed, measurement in inaccessible sites, measurement in severe and aggressive environments, lightness and ease in setting up. Sensing in meteorology is based on interference and heterodyne frequency shifting. Various applications are as follow :

A. Optical alignment : The brightness of a 1-5 mW HeNe laser is sufficient as the beam is easily visible in an ambient background or daylight upto a distance of several hundred meters from the laser. This feature alone has led to a large number of relatively straight forward alignment applications. Very accurate settings in the direction of alignment can be obtained using quadrant detector as illustrated in Fig. 3.35. In this type of detectors, the photo sensitive area is divided into four quadrants, each of them produces signal when laser beam falls on it. For laser beam of small diameter, a small displacement between the quadrant detector and the beam produces a large imbalance output signal which is of great help for alignment setting. Fig. 3.36 shows another type laser scanner system used for leveling purpose. The beam expander expands the beam and the pentaprism turns the laser beam through a

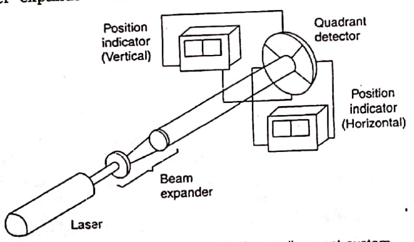

Fig. 3.35. Schematic diagram of a laser alignment system.

right angle. This type of system can be used during the installation period of wall or ceiling tiles.

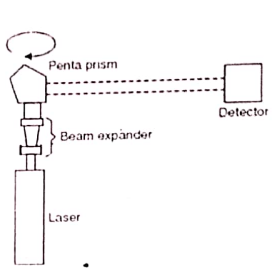

Fig. 3.36. Diagram of a laser scanner system used for leveling.

B. Distance measurement : The most common application of laser is distance measurement. Direct optical interferometry is used over short distances and beam modulation echo-pulse technique is used for long distances.

- **Interferometric Technique.** The basic interferometric technique (Fig.3.37) utilises a modified Twyman-Green Interferometer. The collimated output beam is split equally by a beam splitter oriented at 45° to the wavefront. The separated plane wavefront beams are reflected upon themselves by cube corner prisms behaving like mirrors and recombined by another beamsplitter. If the two separated beams travel a different total path, they will interfere with each other when recombined.

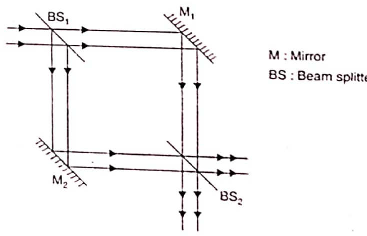

Fig. 3.37. Mach Zehnder Modulation.

- **Beam Modulation Technique.** Due to atmospheric turbulence, interferometric measuring methods are limited to distance of not more than about 100 m. For greater distances, amplitude modulation method is better. The beam from an HeNe or GaAs laser is amplitude modulated at a certain frequency and projected to the target whose distance is to be measured. The light reflected by the target is received by a telescope and sent to a detector as illustrated in Fig. 3.38. The phase of the modulation of the return beam is different from that of the emitted beam because of the time taken for the light to travel to the target and back. The phase shift is related to the path length 2L by

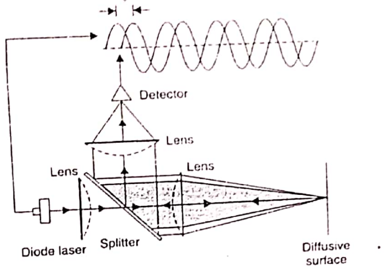

Fig. 3.38. Diagram of a laser finder that uses an amplitude modulated laser. ϕ is the phase shift of the modulated beam.

$$\Phi = 2\pi(2nL)/\lambda_0$$

where n is the refractive index of the atmosphere and λ_0 is the modulation wavelength of laser in vacuum.

- **Pulse-Echo Technique.** Distance can also be measured by timing the round-trip transit time for a very short pulse of light reflected from a distance target. The system consists of a pulse laser, a telescope to collect the reflected light, a photo detector and an accurate timer as depicted in Fig. 3.34. An accuracy of 5 m in ranges of 5–10 km is possible in this method.

C. Velocity Measurement : Measurements of the velocity of the fluid can be made by laser Doppler velocitymetry. The HeNe laser beam scattered from the particles carried along by the fluid flow is measured. The frequency of the scattered light is slightly Doppler shifted and it is proportional to the fluid velocity. By this technique, velocities ranging from a few centimeters per second to hundreds of meters per second can be measured. A typical dual-beam optical system is shown in Fig. 3.39. Light from a low power (~ 5 mW) HeNe laser passes through a beam splitter which gives two parallel beams of similar power.

Within the region of overlapping beams, fringes will be formed. The distance between the fringes , S is given by

$$S = \lambda/[2 \sin(\theta/2)]$$

If a particle passes across the fringe field with a component of velocity V (cm/sec) in a direction perpendicular to the fringe field, the signal at the detector will be modulated at the frequency

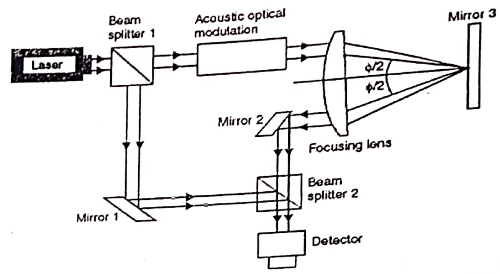

Fig. 3.39. Block diagram of a laser doppler system that uses the reference beam technique to measure the velocity of a moving object.

$$f = 2V[\sin(\theta/2) \times 10^5/632.8] \text{ Hz}$$

The output from the detector is fed to a spectrum analyser whose output is recorded on a storage oscilloscope or chart recorder.

D. Angular rotation measurement : The measurement of the rate of rotation using laser gyroscope is now quite well established and the so called ring gyro is used in military and commercial aircraft. The gyro has a ring configuration using an equilateral triangle, in which two laser beams travel in opposite directions as illustrated in Fig. 3.40. The wavelength of operation of laser to adjusted such that total distance around the path is an integral number

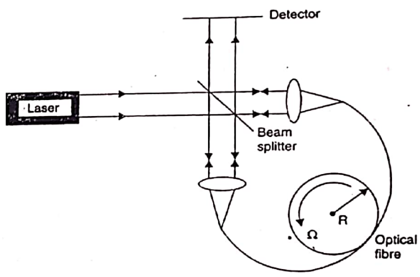

Fig. 3.40. Sagnac interferometer for rotation measurement.

of wavelengths. Any change in the length of the ring results in a change in wavelength. The axis of rotation is through the point which is junction of the perpendicular bisectors of the sides of the triangle and normal to the plane of the triangle. The two counter rotating beams have slightly different wavelengths and frequencies to satisfy the condition that the round trip path length should be an integral multiple of wavelength. The difference in frequencies which can be detected by beating the two beams together at the output point is a measure of the rotation.

3.5.13. Application in Scientific Research

Last, but certainly not the least, of the human endeavours in which lasers play an important role is the entire field of scientific research. This encompasses physics, chemistry, biology and various atomic studies. For example, lasers offer an opportunity to investigate the basic laws of interaction of atoms and molecules with electromagnetic waves of high intensity. Laser is also being employed for separating the various isotopes of an element. This LIS (laser isotope separation) has enormous use for the large scale enrichment of uranium in nuclear power reactors. Even, genetic research using laser is quite popular. The most prominent of which is perhaps atomic fusion, which ushered in the hope of becoming a new source of energy for mankind. In inertial confinement fusion, a powerful burst of fusion energy is produced by focusing high powered laser beam on a tiny pellet of fuel as illustrated in Fig. 3.41. Another use of laser radiation is to cool atoms and atomic ions to very low temperatures and this can be done by suitable arrangement of the frequency and position of the laser beam. The laser cools small specimens to very low temperatures, in some cases about 1 microkelvin.

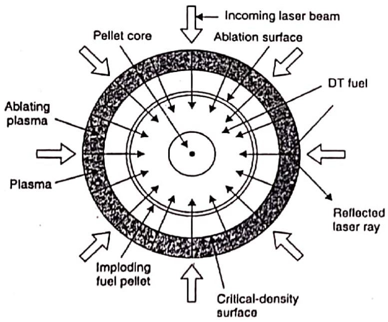

Fig. 3.41. Schematic illustration of the laser fusion process where a spherical pellet of nuclear fuel is irradiated symmetrically with intense laser beams.

3.5.14. Application in Wireless Communication

Semiconductor lasers with optical fibre are widely used in Telecommunication (Fig. 3.42). These optical communication is discussed in detail in chapter 4. Beside optical fibre, wireless communication using laser is also being used in LAN. In case of wireless LAN, sometime, infrared technology is used. This technology is similar to the one that is used in TV set remote control. The transmitter uses simple inexpensive IR LEDs and a photodiode is used as receiver. There are two types of IR LANs:

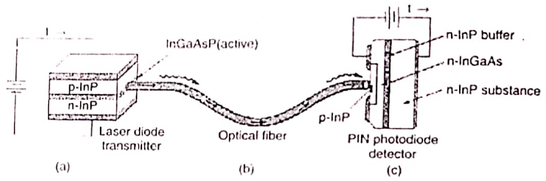

Fig. 3.42. Basic elements of a fibre optic communication system. (a) In GaAsP laser transmitter, (b) Optical fibre for transmitting light ; (c) PIN photodetector.

- **Direct beam IR LANs.** This is referred to as line of sight links which involves the transmission of highly focused narrow IR beam that connect one terminal to another. Obviously the receiver and transmitter must be properly aligned. It gives longer range and higher data rates upto 10 Mbps. It is best suited for fixed terminals and specially for large file transfers. Different optical arrangements used for this purposes are shown in Fig. 3.43.

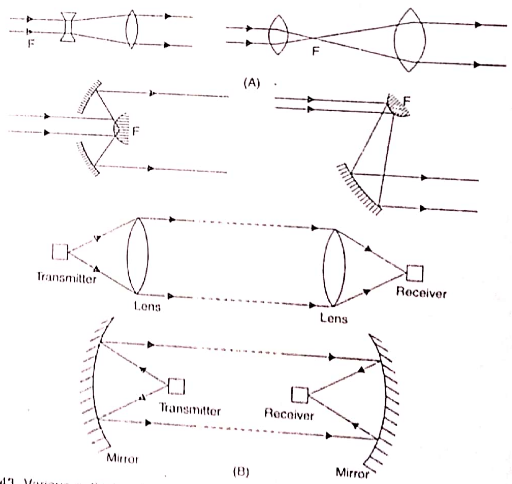

Fig. 3.43. Various optical systems used for expanding the electromagnetic signal for free space communication (A) Transmissive (B) Reflective.

- **Diffused IR LANs.** It provides ease of installation as the transmission of signals are in all directions. Because of multiple paths involved, data transmission rates are limited to about 1 Mbps. For example, sometime, laptops have in-built IR transceiver chip which enable communication between portable laptop and a fixed terminal, printer or any peripheral. The main advantage of using infrared is the reduced cost. Disadvantage is the limited range, *i.e.*, transmission is interrupted when obstacles are present because infrared does not penetrate solid matter.

3.6. THE POWER RANGE OF LASER

Table 3.5 displays the characteristics of typical lasers and their various uses. A glance at the table shows that some lasers generate kilowatts of continuous wave power and some others are capable of producing megawatts, gigawatts and even terawatts of pulsed peak power.

Table 3.5 : Characteristics of different types of lasers

Type of Laser	*Peak Power*	*Pulse Nature**	*Wavelength*	*Uses*
Gas				
HeNe	1 mW	CW	633 nm	Supermarket Scanners, hologram, alignment operations, industries, nondestructive testing (like surface flaw), roughness, medical applications and communication
Argon	10 W	CW	488 nm	Entertainment, Medical (eye), Spectroscopic, material processing, holographic work
CO_2	200 W	CW	10.6 µm	Cutting and Welding, open air communication, LIDAR, surgery
CO_2 TEA	5 MW	P	10.6 µm	Heat treating
Nitrogen	0.01 MW	P	337 nm	Scientific studies
Semiconductor				
GaAs	5 mW	CW	840 nm	CD players, measuring instruments, optical communication
AlGaAs	50 mW	CW	760 nm	Laser printers
GaInAsP	20 mW	CW	1.3 µm	Fibre communications
Solid State				
Ruby	100 MW	P	694 nm	Live holography, Medical applications
Nd:YAG	50 W	CW	1.06 µm	Semiconductor processing, Material processing, Ophthalmology

Type of Laser	*Peak Power*	*Pulse Nature**	*Wavelength*	*Uses*
Nd:YAG (QS)	50 MW	P	1.06 µm	Medical applications
Nd:YAG (ML)	2 kW	P	1.06 µm	Short-pulse studies
Nd:Glass	100 TW	P	1.06 µm	Laser fusion
Ion				
Argon ion	2 W	CW	350 nm	Medical applications
Argon ion	20 W	CW	488–514 nm	Medical applications
Krypton ion	1 W	CW	350 nm	Medical applications
Kripton ion	6 W	CW	647 nm	Medical applications
Xenon ion	—	P	540 nm	
Vapour				
Copper vapour	50 W	P	510, 578 nm	Medical applications
Gold vapour	10W	P	628 nm	Medical applications
Dye				
Ring dye	100 mW	CW	Tunable	Spectroscopy study
Rh6G(ML)	10 kW	P	600 nm	Scientific studies, Medical applications
Chemical				
HF	150 W	P or CW	3 µm	Weapons destruction and Industrial applications
DF	100 W	P or CW		Environmental polluton monitoring
Excimer				
AlF	10 MW	P	193 nm	Materials processing
XeCl	50 kW	P	375 nm	Medical applications
ArF	50 W	P	193nm	Medical applications
KrF	100W	P	249 nm	Medical applications
XeF	30 W	P	351 nm	Medical applications
Free electron	~ nW	P	193–351 nm	Medical applications

* P : Pulsed ; CW : Continuous wave ; QS : Q-switch ; ML : Mode lock