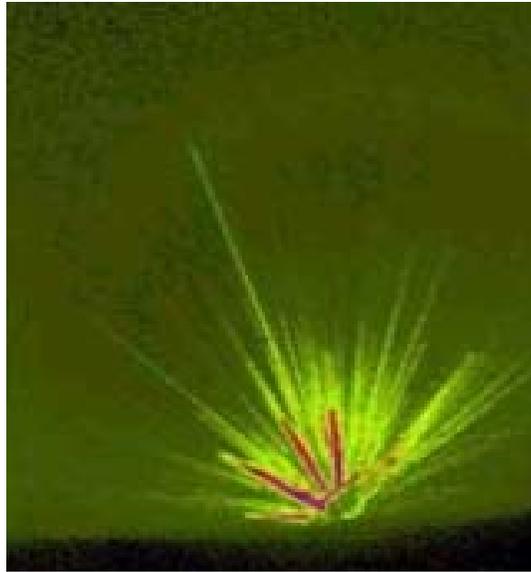


# LASER AND ITS APPLICATIONS

**Popular Science & Technology Series**



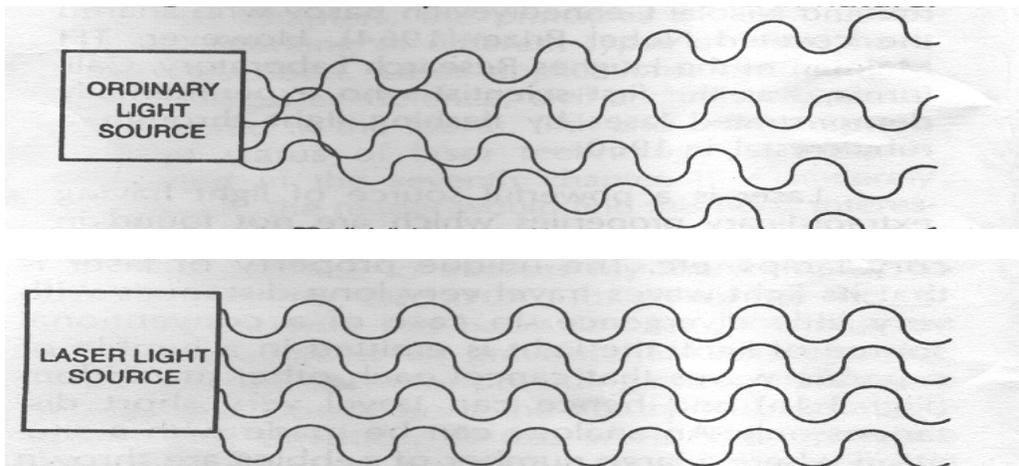
# Laser and its Applications

## 1. Introduction

No other scientific discovery of the 20th century has been demonstrated with so many exciting applications as laser acronym for (Light Amplification by Stimulated Emission of Radiation). The basic concepts of laser were first given by an American scientist, Charles Hard Townes and two Soviet scientists, Alexander Mikhailovich Prokhorov and Nikolai Gennediyevich Basov who shared the coveted Nobel Prize (1964). However, TH Maiman of the Hughes Research Laboratory, California, was the first scientist who experimentally demonstrated laser by flashing light through a ruby crystal, in 1960.

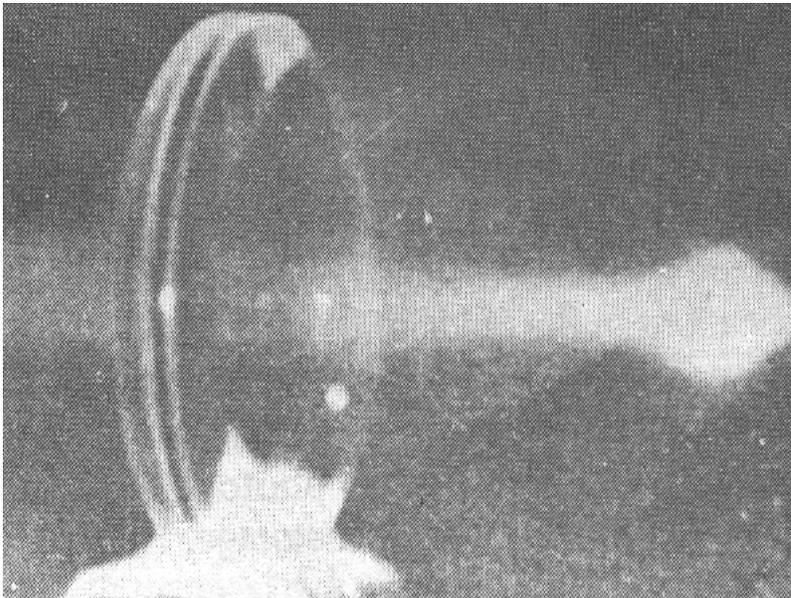
Laser is a powerful source of light having extraordinary properties which are not found in the normal light sources like tungsten lamps, mercury lamps, etc. The unique property of laser is that its light waves travel very long distances with e very little divergence. In case of a conventional e source of light, the light is emitted in a jumble of e separate waves that cancel each other at random (Fig. 1.1a) and hence can travel very short distances only. An analogy can be made with a situation where a large number of pebbles are thrown It into a pool at the same time. Each pebble generates a wave of its own. Since the pebbles are thrown at random, the waves generated by all the pebbles cancel each other and as a result they travel a very short distance only. On the other hand, if the pebbles are thrown into a pool one by one at the same place and also at constant intervals of time, the waves thus generated strengthen each other and travel long distances. In this case, the waves are said to travel coherently. In laser, the light waves are exactly in step with each other and thus have a fixed phase relationship (Fig. 1.1b).

It is this coherency that makes all the difference to make the laser light so narrow, so powerful and so easy to focus on a given object. The light with such qualities is not found in nature.



A high degree of directionality and monochromatic is also associated with these light beams. Therefore, in a laser beam the light waves not only are in the same phase but also have the same color (wavelength) throughout their journey. The beam of the ordinary light spreads out very quickly. On the other hand, the laser beam is highly collimated and spreads very little as it 'Fig. travels through space; even after traveling to the , surface of the moon the spread of laser light has been found to be only about 3 km across. Hypothetically, if ordinary light was able to travel to the so moon, its beam would have fanned out to such an extent leading to a diameter of the light on . the moon as much as 40, 000 km.

Another remarkable feature of laser is the concentration of its energy to extremely high intensities, the intensity remaining almost constant over long distances because of low divergence. If a laser beam with a power of a few megawatts ( $10^6$  W) is focused by a lens at a spot with a diameter of 1/1000th of a centimeter, the beam intensity increases to a few hundred billion watts per sq. cm. This concentrated energy is so intense that it easily ionizes the atmospheric air to create sparks (Fig. 1.2). With the beam focused from a high power laser, even the hardest material like "diamond can be melted in a fraction of a second.



These unique characteristics of laser have made it an important tool in various applications. The initial notable application of laser was made c on the lunar ranging experiment of Apollo II Mission of 1969, when an array of retro reflectors was mounted on the surface of the moon and pulses from a ruby laser were sent from the earth. The reflected beams were received by suitable detectors and by measuring the time taken by the pulses in going from the earth to the moon and back, the distance of the moon from the earth was calculated to an accuracy of 15 cm.

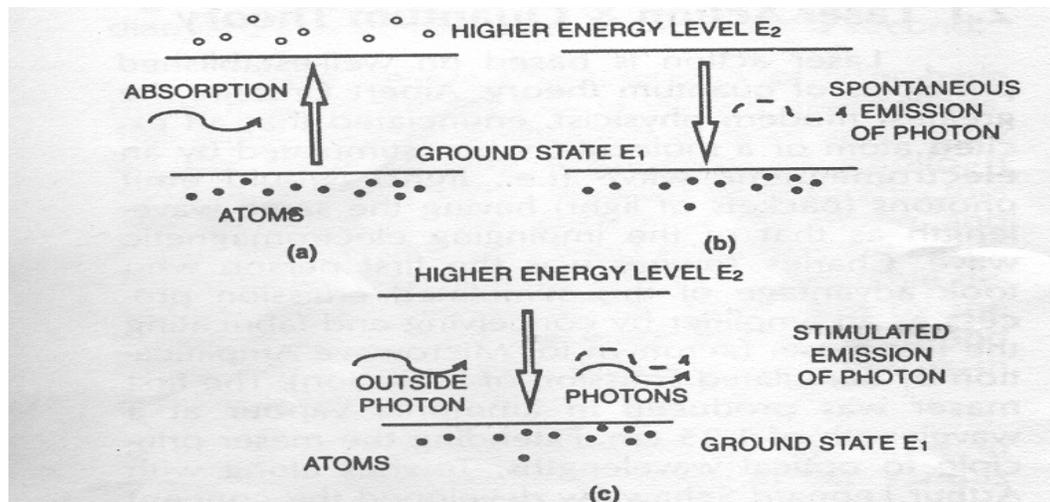
After the first demonstration of laser in 1960, new applications of lasers in the various field are announced almost every day. Laser finds applications In the fields of communication, Industry, medicine, military operations, scientific research, etc. Besides, laser has already brought great benefits in surgery, photography, holography, engineering and data storage. Though it is not possible to illustrate all the laser applications reported so far in this small book, the more important ones are covered in the Chapters on Laser Applications.

## 2. How Laser Works

### 2.1 Laser Action & Quantum Theory

Laser action is based on well-established principles of quantum theory. Albert Einstein, the greatest modern physicist, enunciated that an excited atom or a molecule, when stimulated by an electromagnetic wave (i.e., light), would emit photons (packets of light) having the same wavelength as that of the impinging electromagnetic wave. Charles Townes was the first person who took advantage of this stimulated emission process as an amplifier by conceiving and fabricating the first maser (acronym for Microwave Amplification by Stimulated Emission of Radiation). The first maser was produced in ammonia vapour at a wavelength of 1.25 cm. Extending the maser principle to optical wavelengths, Townes along with Arthur Leonard Schawlow developed the concept of using a laser amplifier and an optical mirror cavity to provide the multiple reflections necessary for rapid growth of light signal into an intense visible beam.

#### 2.1.1 Principle of Laser Action



Every atom, according to the quantum theory, can have energies only in certain discrete states or energy levels. Normally, the atoms are in the lowest energy state or ground state. When light from a powerful source like a flash lamp or a mercury arc falls on a substance, the atoms in the ground state can be excited to go to one of the higher levels. This process is called absorption. After staying in that level for a very short duration (of the order of  $10^{-8}$  second), the atom returns to its initial ground state, emitting a photon in the process. This process is called spontaneous or a emission.

The two processes, namely, absorption and , spontaneous emission, take place in a conventional light source, In case the atom, still in Its urns to excited state, is struck by an outside photon having precisely the energy necessary for spontaneous emission, the

outside photon is augmented by the one given up by the excited atom, Moreover, both the photons are released from the same excited state in the same phase, This process, called stimulated emission, is fundamental for laser action (Fig, 2.1). Thus, the atom is stimulated or induced to give up its photon earlier than it would have done ordinarily under spontaneous emission, The laser is thus analogous to a spring that is wound up and cocked, It needs a key to release it, In this process, the key is the photon having exactly the same wavelength as that of the light to be emitted.

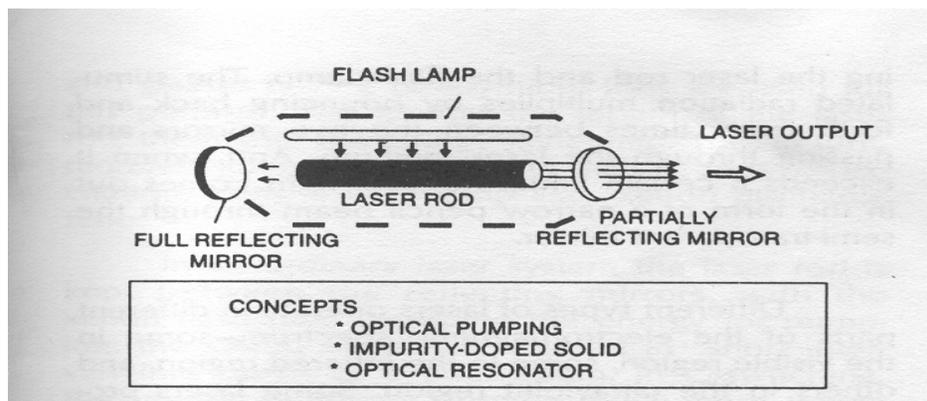
### 2.1.2 Amplification & Population Inversion

When favorable conditions are created for the stimulated emission, more and more atoms are forced to give up photons thereby initiating a chain reaction and releasing vast amount of energy, This results in rapid build up of energy of emitting one particular wavelength (monochromatic light), traveling coherently in a precise, fixed direction. This process is called amplification by stimulated emission.

The number of atoms in any level at a given time is called the population of that level. Normally, when the material is not excited externally, the population of the lower level or ground state is greater than that of the upper level. When the population of the upper level exceeds that of the lower level, which is a reversal of the normal occupancy, the process is called population inversion. This situation is essential for a laser action. For any stimulated emission, It is necessary that the upper energy level or metastable state should have a long life time, i.e., the atoms should pause at the metastable state for more time than at the lower level. Thus, for laser action, pumping mechanism (exciting with external source) should be from a such, as to maintain a higher population of atoms in the upper energy level relative to that in the lower level.

### 2.1.3 Designing a Laser

A laser generally requires three components for its operation: (a) an active medium in the form of a laser rod, with energy levels that can be selectively populated; (b) a pumping process to produce population inversion between some of these energy levels; and (c) a resonant cavity containing the active medium which serves to store the emitted radiation and provides feedback to maintain the coherence of the radiation (Fig. 2.2).



The main problem in designing a laser is to involve produce a sufficiently high population of atoms in the excited state. For this, many ingenious ways fully all have been evolved. The most common method of cent re excitation is by sending an intense beam of light from a flash lamp or a continuous source of light through the material in the form of a cylindrical rod or a container tube with a suitable gas. Only those materials which can be pumped to achieve population inversion, are used to give laser radiation. The existence of states whose mean life times are relatively long so as to help pile up considerable energy in the excited levels, is necessary. Long life time of a level and the sharpness of the spectrum lines usually go together, and so, the materials that can be best used to give laser radiation are crystals with sharp lines, and gases at low pressure.

An important aspect of the laser operation involves the design of a resonator cavity to maximize the process of stimulated emission. Two carefully aligned mirrors, one having more than 99 percent reflectivity and the other having less reflectivity, are placed at either end of the cavity containing the laser rod and the flash lamp. The stimulated radiation multiplies by bouncing back and forth many times between the two mirrors and passing through the laser medium. And, when it exceeds a certain limit, the laser light comes out citation in the form of a narrow pencil beam through the semi-transparent mirror.

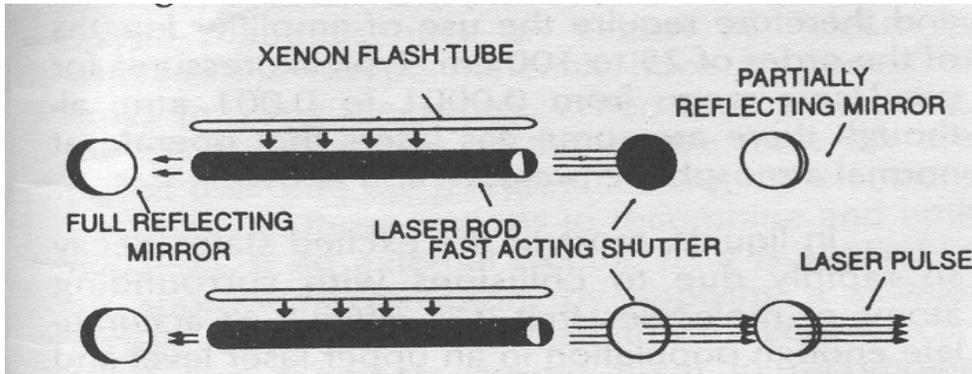
Different types of lasers operate in different xenon f parts of the electromagnetic spectrum-some in the visible region, some in the infrared region, and others in the ultraviolet region. Some lasers produce continuous light beams while others give pulses of light (of less than millisecond duration). Basically, there are two types of lasers-the continuous wave (CW) laser and the pulsed beam allow laser. In the CW laser, the light is emitted as a, steady continuous beam, generally, with less intensity. Gas lasers belong to this category. On the other hand, the pulsed lasers produce powerful bursts of light of short duration. Crystals, glass and liquid types of lasers belong to this category. Normally the solid state lasers operate intermittently, mainly due to the large amount of heat developed In the crystal.

#### **2.1.4 Increasing the Laser Power**

The power of an ordinary pulsed laser can be Increase enormous by Q-switching or Q-spoiling, a technique known to be used for some of its applications in range finding, drilling, and cutting. In such systems, the power of the laser beam ranges from a few million to a few hundred billion watts and usually some rare earth crystals and glasses having neodymium ions are used for back and this purpose. The greater the length of the laser rod, the higher the energy generated. This, in turn, requires hundreds of joules in milliseconds for excitation,- using a flash lamp like xenon discharge tube.

In an ordinary laser system the laser rod is kept between the reflecting mirrors, with the xenon flash tube providing the energy for pumping; the stored energy is released in short intervals into bursts of a laser beam. In Q-switching, lasers pro- the amount of energy stored is much more, which is achieved by interposing a fast acting shutter in duration). between one end of the laser rod and the partially reflecting mirror (Fig. 2.3). The shutter

does not allow the laser radiation to be released for a predetermined time. After sufficient energy is stored in the energy level, the shutter is opened for a very short interval of about a nanosecond (one-billionth of a second) and all the stored energy is released as one giant pulse. This technique can be compared to a river dam where the lifting of a sluice gate releases water in a gush.



There are several ways of blocking and unblocking the optical paths between the mirrors. Different types of Q-switches like rotating prism, polarizing device, and dye solutions are employed. The tremendous energy released in this way can pierce through not only thick metallic plates but also the hardest material like diamond.

### 2.1.5 Inversion Mechanisms

Population inversion, which gives rise to laser action, is brought about in different media by various mechanisms. In gases, metal vapors, and plasmas, the inversion is brought out by applying a voltage drop across the elongated gain medium thereby producing an electric field that accelerates the electrons. These rapidly moving electrons then collide with gas atoms and excite them to a number of excited energy levels. Some of these levels decay faster than the others, leaving population inversions with some higher levels. If the population in the excited levels is high enough, then the gain may be sufficient to make a laser. Most gas lasers have relatively low gains and therefore require the use of amplifier lengths of the order of 25 to 100 cm. Typical pressures for gas lasers range from 0.0001 to 0.001 atm, although there are some gas lasers that operate at normal atmospheric pressure and above.

In liquids, most of the excited states decay so rapidly due to collisions with surrounding atoms or molecules that it is difficult to accumulate enough population in an upper laser level and to achieve significant gain. Fluorescent dyes are the best liquid media for lasers; their excited energy levels are populated either by flash lamps or by lasers.

In solid state lasers, population inversions are brought out by implanting impurities (which give the laser action) within a host material, such as a crystal or a glass and then exciting them with a suitable light. The impurity concentration is usually in the range of 0.01-3.0 per cent. In most of the solid state lasers, the impurities are in the form of ions in which the energy states are shielded from the surrounding atoms so that the energy levels

are narrow. A flash lamp is used to excite the ions to a large number of upper energy levels. The excited ions decay quickly to the next stable upper level where they stay for considerable time (of the order of milliseconds) before terminating to the lower energy level, leading to the stimulated emission of radiation. Inversions in semiconductors are produced when a p-n junction is created by joining two slightly different semiconducting materials, viz., n- and p-type materials (similar to a transistor). n-type materials have an excess of electrons whereas the p-type materials have an excess of holes (missing electrons). When they are joined, excess electrons of the n-type materials are pulled over into the p-region causing the electrons and holes in those regions to recombine and emit radiation. If an external electric field is applied in an appropriate direction, by applying a voltage across the junction, more electrons and holes can be pulled together causing them to recombine and emit more radiation producing inversion.

### **2.1.6 Laser Beam Properties**

The use of a laser for various applications depends upon the beam properties of laser, such as direction, divergence, and wavelength or frequency characteristics, which can be adjusted by the laser components. The features affecting the beam properties of laser include: size of the gain medium, location, separation and reflectivity of the mirrors of the optical cavity, and presence of losses in the beam path within the cavity. Some of these features determine the unique properties of the laser beam, referred to as laser modes. The laser modes are wavelike properties relating to the oscillating character of the beam as the beam passes back and forth through the amplifier and grows at the expense of existing losses. The development of laser modes involves an attempt by competing light beams of similar wavelengths to fit an exact number of their waves into the optical cavity. For example, a laser mode of green light having a wavelength of exactly  $5 \times 10^{-5}$  cm will fit exactly 1,000,000 full cycles of oscillations between laser cavity mirrors separated by a distance of exactly 50 cm. Most lasers have several modes operating simultaneously in the form of both longitudinal and transverse modes which give rise to a complex frequency and spatial structure within the beam which otherwise appears as simple pencil-like beam of light.

### 3. Lasers -Their Types & Characteristics

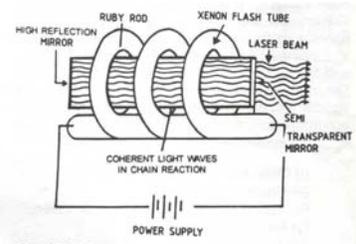
The first laser action was demonstrated in a ruby crystal by Maiman, in 1960. Since then, a large number of materials in various media have been found to give laser action at wavelengths in the visible, ultraviolet and infrared regions. These include various gases, solids, liquid, glasses, plastics, semiconductors, and dyes. In addition to the ruby crystal, many other crystals doped (introduced as an impurity) with rare earth ions have light been found to give extremely good laser output. The crystals are grown in specially designed furnaces with the desired compositions and then cut and polished into cylindrical laser rods with the faces optically flat and parallel to each other. The numerous types and designs of lasers are steadily increasing and can be broadly classified according to their production techniques. The broad categories are:

- (i) Optically Pumped Solid-State Lasers
- (ii) Liquid (Dye) Lasers
- (iii) Gas Lasers
- (iv) Semiconductor Lasers
- (v) Free Electron Lasers
- (vi) X-ray Lasers, and
- (vii) Chemical Lasers

#### 3.1 Optically Pumped Solid-State Lasers

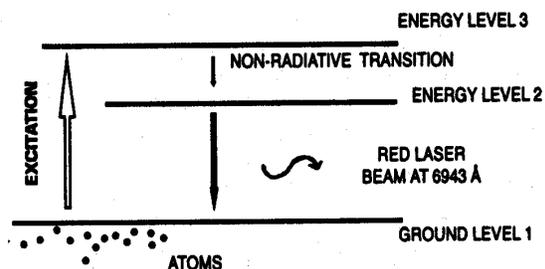
##### 3.1.1 Ruby Laser

Ruby laser is historically the first one to be discovered; It gives laser radiation on a pulsed length ( $1 \text{ nm} = 10^{-9} \text{ m}$ ). It consists of a ruby rod xenon flash tube, a suitable cavity to reflect the light from flash tube to the ruby rod, and a high voltage power supply to give electrical energy to the flash tube. Maiman's laser set-up is shown in Fig. 3.1.



During his experiment, Maiman found that the ideal composition for the ruby crystal is five atoms of chromium for every ten thousand atoms of aluminum, i.e., a concentration of 0.05 percent. The ruby rod used was 4 cm long and 1/2 cm in diameter and the ends were ground to a high degree of flatness and parallelism. One end was silvered making it a mirror (almost 100 percent reflective) to reflect all the rays of light striking it. The other end of the rod was partially silvered; the laser beam was emitted through that end. The ruby rod was surrounded by a helical xenon flash lamp and both of them were held inside a cylindrical cavity, coated with a reflective material. The light from the xenon flash tube was focused by the cylindrical cavity onto the ruby rod, thereby exciting the chromium atoms which were responsible for the laser action.

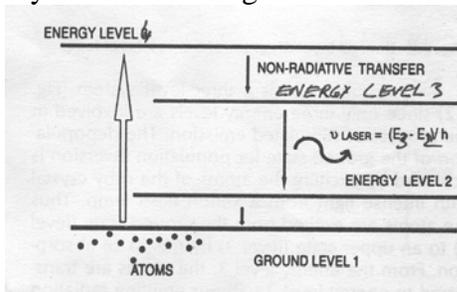
The ruby laser is a three-Level system (Fig. 3.2) since only three energy levels



are involved in the process of stimulated emission. The depopulation of the ground state for population inversion is achieved by exciting the atoms of the ruby crystal with intense light from a xenon flash lamp. Thus the atoms are excited from the ground state (level 1) to an upper state (level 3) by means of absorption. From the energy level 3, the atoms are transferred to energy level 2 without emitting radiation (non-radiative transfer). The energy level 2 is called met stable level since the atoms stay at this level for a longer interval of time. Finally, the atoms return to the ground state from the met stable level through the process of stimulated emission giving rise to an intense laser light at 6943Å. The laser beam comes out in the form of a pulse of very short duration (about a millisecond). The continuous wave operation of the system is very difficult to achieve. Only 1 to 2 per cent of the input is utilized to obtain the laser action. The rest is dissipated as heat and is therefore wasted. In Q-switched mode, the power up to 500 MW has been achieved. Since this laser requires considerable input energy to give laser action, it is now being used only for limited applications in the areas of holography, high speed photography, etc.

### 3.1.2 Rare Earth Ion Lasers

A large number of lasers have been discovered using the rare earth ions doped in suitable crystal lattices or glasses as the active elements. These lasers are based on a system in



which four energy levels are involved to produce stimulated emission. The laser action takes place between the met stable level and a lower energy level which is slightly above the ground state (Fig.3.3). Due to this advantageous situation, population inversion is achieved easily. Of the 14 rare earth elements used, triply-ionized neodymium has been found to be the most

important. Absorption bands suitable for optical pumping are relatively abundant. Strong laser emission is obtained in the near infrared region at 1.06 micrometer wavelength with continuous power of over 1000 W and with pulsed power as high as several MW (1 MW = 10<sup>6</sup> W). The most prominent among the neodymium lasers are Nd:YAG (Neodymium Yttrium-Aluminium-Garnet) and Nd:Glass (Neodymium in Glass) lasers.

### 3.1.3 Nd: YAG Lasers.

YAG is formed from a mixed oxide system having a composition of Y<sub>3</sub>Al<sub>5</sub>O<sub>12</sub>. Using Czochralski method, the crystal is grown in a specially designed furnace by dipping a rotating seed into a crucible of molten material and withdrawing it at a constant speed. Iridium crucible is used because of high melting point of YAG (1910-1970°C). The optimum concentration of neodymium in YAG is about one percent

The YAG crystal growth difficulties limit the size of the laser rods to approximately 1 cm in diameter. However, the YAG host has the advantage of having a relatively high thermal conductivity to dissipate the heat generated, thus allowing these crystals to be operated at high repetition rates of the order of many pulses per second. With a

continuous source of excitation like tungsten lamp or krypton arc lamp, continuous laser output of about 1 kW power could be obtained.

Due to these excellent properties, Nd:YAG laser is extensively used in many industrial applications like drilling of holes in solid objects, welding of metals and alloys, etc, and also in medical applications like eye surgery, treatment of cancer, etc.

### **3.1.4 Nd: Glass Lasers**

Nd:glass is an important laser material for high energy applications. It affords considerable flexibility in size and shape and can be obtained in large homogeneous pieces. Glass is a compound of oxides; the non-metal oxides, such silicon dioxide, phosphorus pent oxide and boron oxide are its main constituents. It is possible to obtain a large variety of properties due to the existence of different metal oxides, which alter the structure in various ways. These components as well as the laser activators are mixed and heated to melt in a furnace when the required laser glass is formed.

The major disadvantage of glass is that it produces in homogeneously broadened lines which are wider than those found in crystals. This raises the threshold, as a larger Inversion is required for the same gain. Another disadvantage of glass is its low thermal conductivity. Due to this' there exists a limitation to use it for CW operations or high repetition rate applications. Nd:YAG is generally preferred to Nd:glass for CW operations. The broadening of fluorescence and absorption lines provide an advantage for use in Q-switch and amplifier applications. Glass lasers, usually operated in a pulsed mode, are used in the military and material processing applications. Glass lasers with amplifier chains are capable of producing very high energy and are therefore used in laser fusion.

Another type of neodymium laser is the GSGG:Cr<sup>3+</sup>:Nd<sup>3+</sup> laser. It uses a crystal of gadolinium-scandium-gallium garnet, co-doped with chromium and neodymium ions. Since chromium has good absorption bands in the visible region, the pumping efficiency is increased; and due to efficient energy transfer from chromium to neodymium, the CW laser action is achieved much more easily than in Nd:YAG or Nd:Cr:YAG lasers

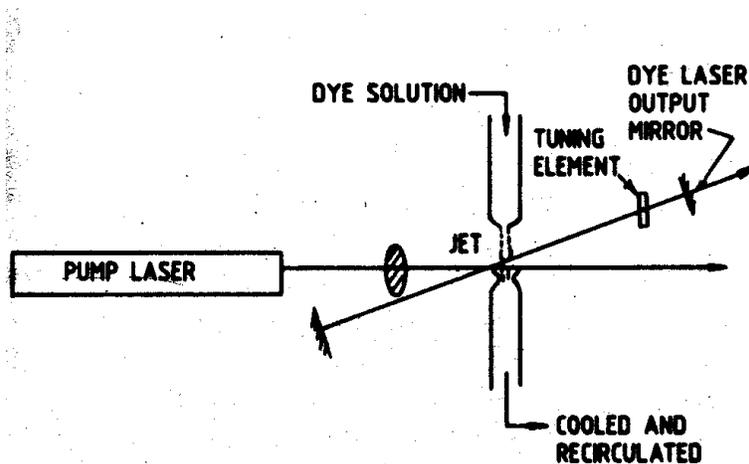
### **3.1.5 Tunable Solid-State lasers**

In these four-level solid-state lasers, laser transitions of the transition metal ions like Cr<sup>3+</sup>, Ti<sup>3+</sup>, Ne<sup>3+</sup>, are employed that terminate on excited vibration levels of the ion in the host lattice. As with the ruby (Al<sub>2</sub>O<sub>3</sub>) laser, the alexandrite (BeAl<sub>2</sub>O<sub>4</sub>) laser employs Cr<sup>3+</sup> ion and the laser transition can terminate on a variety of final vibration states, giving laser radiation at a number of wavelengths in a given spectral range. At the other (output) end, a diffraction grating is operated to obtain the laser radiation at the desired wavelengths. Thus, the alexandrite laser is tunable from 700 to 818 nm, i.e., in the extreme red region and has pulsed output energies similar to those in the ruby laser, The titanium sapphire (Ti:Al<sub>2</sub>O<sub>3</sub>) laser, with titanium as the active ion in the host lattice of the sapphire, has a broader tunability (from 600 nm to beyond 1, 1 μm (i.e. infrared region). It has operated

continuously at power levels up to 1.7 W and has given laser pulses of a few hundred millijoules.

### 3.1.6 Liquid (Dye) lasers

Liquid lasers are similar to the solid-state lasers in that they consist of a host material (in this case a solvent such as alcohol) in which the laser (dye) molecules (such as rhodamines or coumarins) are dissolved at a concentration of one part in ten thousand. Dyes exhibit a very high degree of fluorescence, i.e., when the dye is exposed to ultraviolet light, it glows with characteristic colour depending on the nature of the material. Different dyes have different emission spectra or colours. As a result, dye lasers cover a broad wavelength range from the ultraviolet at 320 nm to the infrared at about 1500 nm. A unique property of dye lasers is the broad emission spectrum (typically 30-60 nm) over which the gain occurs. When this broad gain spectrum is combined with a diffraction grating or a prism as the cavity mirrors, the dye laser output can be a very narrow frequency beam (10 GHz or smaller). Frequency tuning over even larger ranges is accomplished by inserting different dyes into the laser cavity.



Dye lasers are available either in pulses (up to 50-100 MJ) or as continuous output (upto a few watts) in systems that are pumped by either flash lamps or other lasers, such as frequency-doubled or tripled YAG lasers or argon ion lasers. Since the dye degrades slightly during the excitation process, most of the dye lasers are arranged to have the dye circulated from a much larger reservoir. A typical dye laser set-up is shown in Fig.3.4.

The dye lasers are used mostly for applications where tunability of the laser frequency is required either for selecting a specific frequency that is not available from one of the solid-state lasers or for studying the properties of a material when the laser frequency is varied over a wide range. Therefore, the dye laser becomes an important tool for spectroscopy, photochemistry, pollution monitoring, Isotope separation, etc. Another important application of dye lasers is for producing ultra short optical pulses by a technique known as mode locking. In this process, the longitudinal modes of a dye laser (as many as 10,000) are made to oscillate together (in one phase) causing the individual

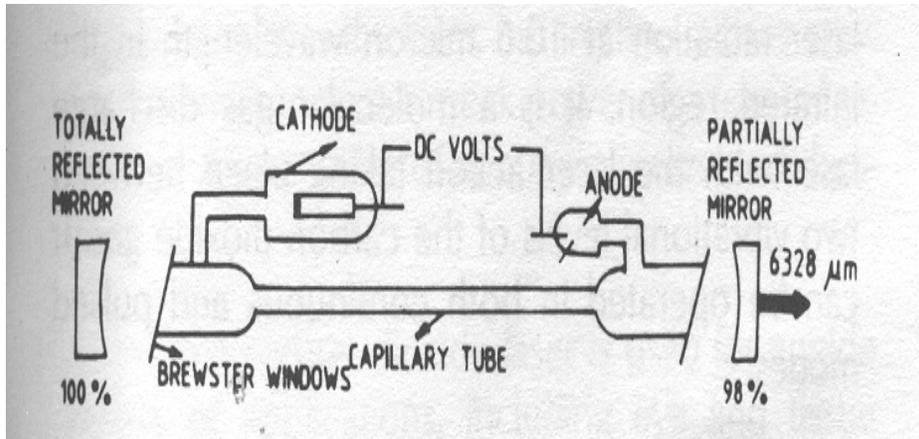
pulses as short as 50 femtosecond ( $5 \times 10^{-14}$  s) to emerge from laser. These short pulses find application in studying very fast processes in solids and liquids and perhaps also in optical communication. The dye lasers are less expensive than the solid-state lasers and are relatively easy to maintain for regular operation.

### **3.1.7 Gas Lasers**

The gas lasers have a gas or a mixture of gases as their light-amplifying substance. Helium-neon, argon ion, and carbon dioxide lasers are the most widely used gas lasers. Javan, Bennett and Herriott succeeded in demonstrating the first gas laser towards the end of 1960-a few months after the Maiman's discovery of the ruby laser. They used a helium-neon mixture (90 per cent helium and 10 per cent neon) as the active material. In most cases, the gas is contained in a glass or quartz tube about 25-100 cm long and the gas molecules are excited in an electric glow discharge. With a few exceptions, these lasers receive their energy input via collisions of gas atoms with high-energy electrons. This energy is provided by applying a high voltage between electrodes located within the gaseous-medium to accelerate the electrons to the necessary high energies. The gas lasers are of continuous type and normally have high coherence. But, they are considerably less powerful as compared to the pulsed solid-state lasers.

### **3.1.8 Helium-Neon Laser**

The helium-neon laser is the most widely used of all lasers mainly because it is much cheaper than the solid-state lasers and yields highly coherent radiation required for many applications. In this system (Fig. 3.5), an electrical discharge is given in helium contained in a discharge tube at a pressure of about 1 torr with an admixture of neon at about 0.1 torr. The discharge excites the helium atoms to their first excited level above their ground state. Since the neon atoms also have the excited level very nearly equal to that of the helium atoms, the excited energy of the helium atoms is transferred to the neon atoms by resonance transfer due to collisions between them. These excited states decay radiatively to lower energy neon states giving rise to continuous laser emission in the red region at 632.8 nm with output power in the range of milliwatts ( $10^{-3}$  W). The helium-neon laser is also capable of giving laser radiation at a few more wavelengths in the visible and infrared regions. This laser is used in surveying, engineering construction, supermarket checkout scanners, printers, holography and many other such applications.



### 3.1.9 Argon and Krypton Ion Lasers Carbon Dioxide Laser

The carbon dioxide laser was discovered in 1963-64 by CKN Patel, a brilliant Indian scientist working at the Bell Laboratories, USA. It is undoubtedly a very important laser because of its high efficiency and high power capacity. It gives laser radiation at 10.6 micron wavelength in the infrared region. It is a molecular gas discharge with the laser action taking place between two vibrational levels of the carbon dioxide gas. It can be operated in both continuous and pulsed modes.

In a typical carbon dioxide laser, a suitable mixture of carbon dioxide, nitrogen and helium gases is taken in a gas discharge tube and excited electrically with the help of a power supply as in the case of the helium-neon laser. The nitrogen molecules are excited by collisions with electrons to their first excited vibrational state from which the excitation is resonantly transferred by molecular collisions to excite carbon dioxide molecules to a particular vibrational state. These molecules, in turn, undergo radiative transition to the lower vibrational levels giving rise to laser radiation. The helium gas not only helps to populate the upper state but also assists to empty the lower state of carbon dioxide, thus increasing the efficiency of the carbon dioxide laser.

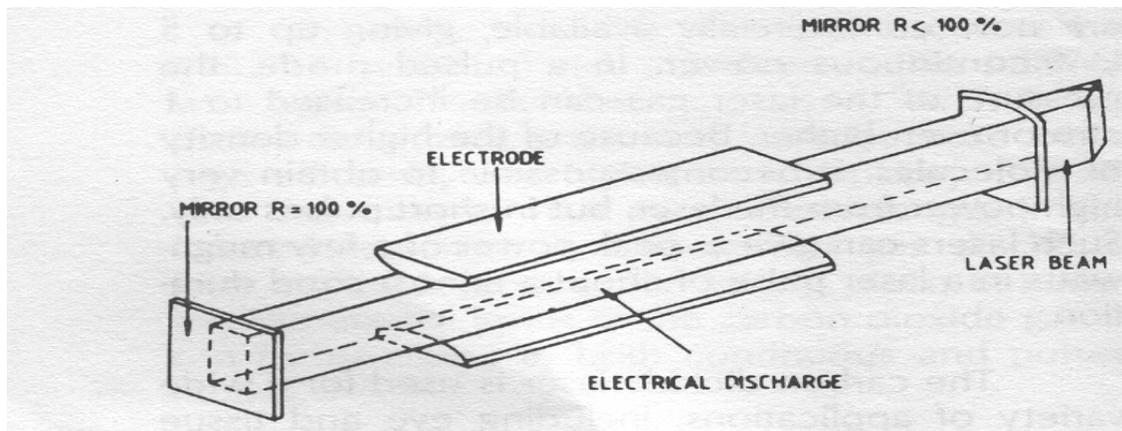
Because of the heat generated due to continuous excitation, the power available from this laser is limited to about 75 W per metre of tube length. To overcome this difficulty, the gas is made to flow at high velocity through the discharge region, which carries away the heat generated rapidly. Such fast-flow carbon dioxide lasers are now commercially available, giving up to kW continuous power. In a pulsed mode, the pressure of the laser gas can be increased to 1 atm or even higher. Because of the higher density of molecules, it becomes possible to obtain very high power from the laser, but in short pulses only. Such lasers can give a peak power of a few megawatts in a laser pulse of about a nanosecond duration.

The carbon dioxide laser is used for a wide variety of applications, including eye and tissue surgery, welding, cutting and heat treatment of materials, laser fusion, and beam

weapons. Rocks and granites crumble into pieces with a 1.2 kW carbon dioxide laser. One day, such a laser may be used to drill underground tunnels.

### 3.1.10 Excimer Laser

The excimer lasers are pulsed gas lasers that use a mixture of a rare gas and a halogen as the active medium. Excimers are molecules that exist only in the excited state; the population of the ground state of the molecule is always zero. As a result it is relatively easy to obtain population inversion and get high efficiency. The excimer lasers operate primarily in the ultraviolet region in mixtures of rare gases (argon, krypton, or xenon) with halide molecules (chlorine or fluorine). These include argon fluoride laser at 193 nm, krypton fluoride laser at 248 nm, xenon chloride laser at 308 nm, and xenon fluoride laser at 351 nm. A schematic diagram of excimer laser is shown in Fig. 3.6.



The excimer lasers typically produce short pulses of peak power 10-20 MW with repetition rates of up to 1000 pulses per second. These lasers are very efficient (up to 50 per cent) and provide useful energy in the wavelength regions where other types of powerful lasers are not available. The laser gas is mixed with helium gas so that the mixture has a pressure of about 2-4 atm. Excitation occurs by electron dissociation and ionisation of the gas molecule to produce argon, krypton or xenon ions. These ions react with the halide molecules pulling off one of the atoms of that molecule to create an excited diatomic molecule, also called the excimer molecule. The excimer lasers are widely used for laser surgery, drilling of holes in metallic objects, pumping of dye lasers, and lithography.

### 3.1.11 Semiconductor lasers

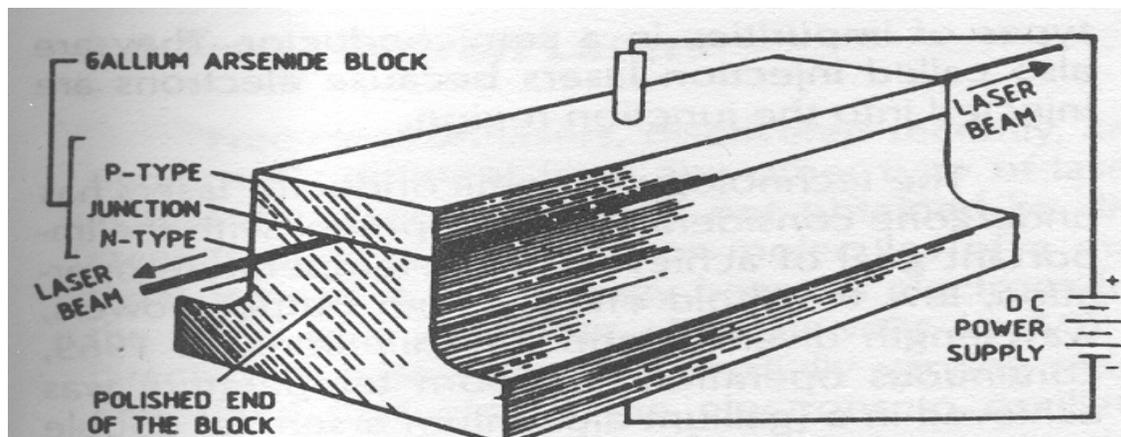
The semiconductor or diode lasers are the smallest of all the known lasers; they have a size of a fraction of a millimeter. The laser consists of a semiconducting crystal, such as gallium arsenide, lead selenide, etc, with parallel faces at the ends to serve as partially-reflective mirrors. The entire laser package is very small and can be incorporated into an integrated circuit board, if required.

A semiconductor, as the name implies, is half-way between a conductor and an insulator (non-metal), so far as its electrical conductivity is concerned. The semiconducting materials containing gallium and arsenic compounds have been found to generate infrared rays when the current is passed through them. This implies that these semiconductors convert electrical energy into photons. But, these were ordinary incoherent light rays and were not produced by the 'laser action'. However, when the gallium arsenide crystal is through it, the laser action does take place. Many semiconductors serve as laser materials and they have been made to 'lase' under the stimulation of electricity instead of light which is used for the other solid-state lasers.

There are two types of semiconductors, viz., n-type and p-type. To understand the functioning

of these devices, it is necessary to know the nature of the electronic energy states in a semiconductor. A typical semiconductor has bands of allowed energy levels separated by forbidden energy gap region. In an intrinsic semiconductor, there are just enough electrons present to fill the uppermost occupied energy band (valence band) leaving the next higher band (conduction band) empty. In an n-type semiconductor, a small amount of impurity is added intentionally so that the material is made to have an excess of electrons, which thus becomes negative. On the other hand, by adding a different type of impurity in a p-type semiconductor, the material can be made to have an excess of holes (vacancy of electrons), which thus becomes positive

The semiconductor laser consists of a tiny block (about one square millimetre in area) of gallium arsenide (Fig. 3.7). When the p- and n-type layers are formed in an intimate contact, the interface becomes a p-n junction. When direct current is applied across the block, the electrons move across the junction region from the n-type material to the p-type material, having excess of holes. In this process of dropping of the electrons into the holes, recombination takes place leading to the emission of radiation. The photons travelling through the junction region stimulate more electrons during the transition, releasing more photons in the process. The laser action takes place along the line of the junction. Due to the polished ends of the block, the stimulated emission grows enormously and a beam of coherent light is emitted from one of the two ends. With a gallium arsenide laser, a continuous beam of a few milliwatts power is easily obtained.



The semi conducting lasers are also called junction lasers or junction diode lasers because they produce laser energy at the junction of two types of impurities in a semiconductor. They are also called injection lasers because electrons are injected into the junction region.

The technology of semiconductor lasers has undergone considerable development with the important goal of achieving room-temperature operation, low threshold energy, high output powers, wavelength diversity and long lifetimes. In 1969, continuous operation at room temperature was achieved in a (gallium aluminium arsenide) double heterostructure laser. With further improved developments, device lifetimes of tens of years were obtained with output in the range of tens of milliwatts and with operating wavelengths from 0.7 to 1.8 microns (1 micron =  $10^{-4}$  cm). By constructing a row of p-n junctions positioned next to each other, all the separate gain media can be forced to emit together in a phased array to produce an effective combined power output. In this way, gallium aluminium arsenide diode lasers have been operated continuously at room temperature with output in the range of several watts. In addition, electrical to optical power conversion efficiencies of greater than 50 per cent have been obtained.

The semiconductor lasers, being simple in construction and light in weight with compact units and requiring little auxiliary equipment, are very suitable for applications where high powers are not required. They are primarily used in the area of communication in which the near-infrared laser beams can be transmitted over long distances through low-loss optical fibres. In addition, they have found a large market as reading devices for compact disc players.

### **3.1.12 Free-Electron Lasers**

Free-electron lasers, discovered recently, are significantly different from any other type of laser in that the laser radiation is not obtained by discrete transitions in atoms or molecules of a material. Instead, a high-energy beam of electrons (of the order of one million electron volts (meV)) is directed to pass through a spatially varying magnetic field that causes the electrons to oscillate back and forth in a direction transverse to the direction of their beam, at a frequency related to the energy of the electron beam.

This oscillation causes the electrons to radiate at the oscillation frequency and to stimulate other electrons also to oscillate and radiate at the same frequency, in phase with the original oscillating electrons thereby producing an intense beam of light emerging from one end of the device. Mirrors can be placed at the ends of the magnetic region to feed the optical beam back through the amplifier to stimulate more radiation and cause the beam to grow. The frequency is tunable by variation of electron energy and the laser radiation can be generated at any wavelength from the ultraviolet to infrared regions.

A great advantage of the free-electron laser is that a high average output power of the range of a few kilowatts can be obtained in the continuous mode. Although still more of a laboratory curiosity, it shows good promise of high energy applications especially in the medical field.

### 3.1.13 X-Ray Lasers

In contrast to lasers operating in the visible and infrared regions, the x-ray lasers offer a considerable challenge to the present day technology. In the x-ray region, i.e., below a few nanometers ( $10^{-9}$  m) wavelengths, the transmission and reflection properties of materials are very poor and as a result severe constraints are imposed on the cavity design. Also, there are limitations to achieve sufficient laser action from the Medium. For a visible laser, the characteristic energies are of the order of electron volts with excitation time of  $10^{-9}$  s, so that a moderately fast electrical circuitry feeding a weakly ionised discharge can be used as a lasing medium. In contrast, in the x-ray region energies of the order of kilo electron volts (keV) and time scales of the order of  $10^{-15}$  s require inner shell electronic transitions of some materials or highly stripped ions as medium, pumped by a source of time duration much less than a picosecond ( $10^{-12}$  s). In particular, very high energy densities are required to achieve the stimulated emission from the medium. For these reasons, the x-ray lasers use a subsidiary laser or a particle beam to excite the medium. A multi-joule visible laser can directly pump the gain medium through inversion produced in the laser-heated plasma or indirectly by using the x-rays from a laser plasma to pump a separate x-ray laser medium. Thus x-ray laser action has been achieved in selenium at about 21 nm. In some experiments conducted recently at the Lawrence Livermore National Laboratory, USA, the tiny metal targets illuminated by extremely short and intense laser pulses have produced laser emissions at 15.5 nm. Current research involves the efforts to improve the very low efficiency of x-ray lasers as well as to develop new potential x-ray laser systems for military application

### 3.2 Chemical Lasers

In the search of alternative methods to the conventional excitation of materials with light sources, scientists have found that the intense light produced by reactive chemicals can be used for laser excitation. A chemical laser produces a high energy beam from the energy released in the reaction of two or more chemicals. It converts the free energy produced by a chemical reaction into a specific excitation of some product species. Such chemical reactions can be brought about with the aid of gamma rays, electrons, photons etc. Flames can also be used as a source of excitation to initiate laser action. Explosive gas mixture, which may also be used to excite laser radiation in the gas itself, is another pumping source.

Chemical laser is potentially a very efficient compact device. In a typical chemical laser, nitrogen is heated by an electric arc and mixed with sulphur hexafluoride. The heated mixture is then forced through a set of nozzles and hydrogen is injected into the exhaust. Lasing takes place when the exhaust passes between two mirrors

The laser emission was obtained in the infrared region with the help of the energy produced by the reaction of hydrogen and chlorine. The hydrogen fluoride laser is another very powerful chemical laser which produces laser radiation at wavelengths from 2.6-3.5  $\mu\text{m}$ . A mixture of hydrogen and fluorine is used in this laser. When the fluorine molecule is dissociated optically or by discharge or by electron beam pumping, a chain of

chemical reactions takes place reducing the vibrationally-excited hydrogen fluoride molecule. Since there are no hydrogen fluoride molecules in the lower state in the beginning, the population inversion is easily achieved and the laser action takes place. The deuterium fluoride laser is another important chemical laser. Its working is similar to that of the hydrogen fluoride laser. It produces laser radiation in the region 3.5-4.1  $\mu\text{m}$ .

The chemical laser produces such a large amount of energy in relation to its size that it very much in the running as a potential laser weapon. Weight by weight, chemical energy sources yield about 1,000,000 joules per pound as against the conventional electrical pumping sources which yield about 100 joules per pound. Because of their high efficiency and very powerful beams, chemical lasers are being developed for star war programme by the US to destroy the enemy missiles during their journey in space

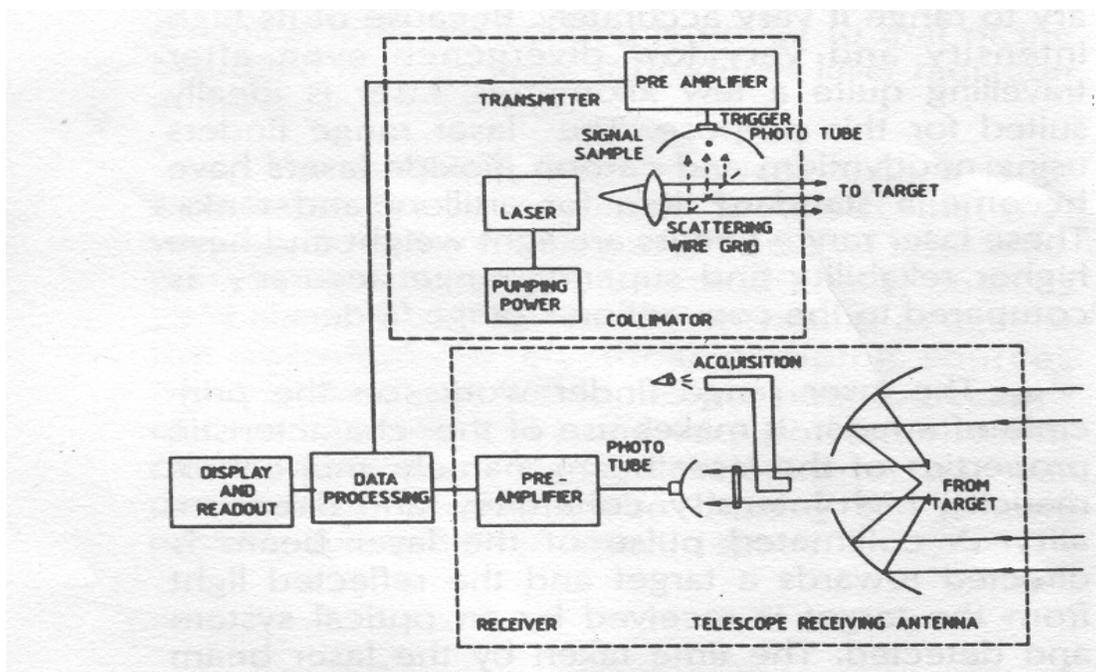
## 4. Laser Application I: Defense

### 4.1 Laser Range Finder

To knock down an enemy tank, it is necessary to range it very accurately. Because of its high intensity and very low divergence even after travelling quite a few kilometres, laser is ideally suited for this purpose. The laser range finders using neodymium and carbon dioxide lasers have become a standard item for artillery and tanks. These laser range finders are light weight and have higher reliability and superior range accuracy as compared to the conventional range finders.

The laser range finder works on the principle of a radar. It makes use of the characteristic properties of the laser beam, namely, monochromaticity, high intensity, coherency, and directionality. A collimated pulse of the laser beam is directed towards a target and the reflected light from the target is received by an optical system and detected. The time taken by the laser beam for the to and fro travel from the transmitter to the target is measured. When half of the time thus recorded is multiplied by the velocity of light, the product gives the range, i.e., the distance of the target.

The laser range finder is superior to microwave radar as the former provides better collimation or directivity which makes high angular resolution possible. Also, it has the advantage of greater radiant brightness and the fact that this brightness is highly directional even after travelling long distances, the size of the emitting system is greatly reduced. The high monochromaticity permits the use of optical band pass filter in the receiver circuit to discriminate between the signal and the stray light noise.



A typical laser range finder can be functionally divided into four parts: (i) transmitter, (ii) receiver, (iii) display and readout, and (iv) sighting telescope. An earlier version of a laser range finder is schematically shown in Fig. 4.1. The transmitter uses a Q-switched Nd:YAG laser which sends out single, collimated and short pulse of laser radiation to the target. A scattering wire grid directs a small sample of light from the transmitter pulse on to the photodetector, which after amplification is fed to the counter. This sample of light starts the counter. The reflected pulse, received by the telescope, is passed through an interference filter to eliminate any extraneous radiation. It is then focused on to another photodetector. The resulting signal is then fed to the counter. A digital system converts the time interval into distance. The range, thus determined by the counter, is displayed in the readout. The lighting telescope permits the operator to read the range while looking at the target

Special circuits have been used to eliminate Spurious signals with the help of range gating and to make the use of laser range finder Possible under all weather conditions for which the targets can be seen visually through the sighting telescope. The modern versions of the laser range finders Use either high repetition pulsed Nd:YAG laser or carbon dioxide laser with range gating system. In ranging a target about 10 km away using these systems, an accuracy within 5 m is easily obtained. The laser range finders of medium range (up to 10 km) are used in several Defence areas, including

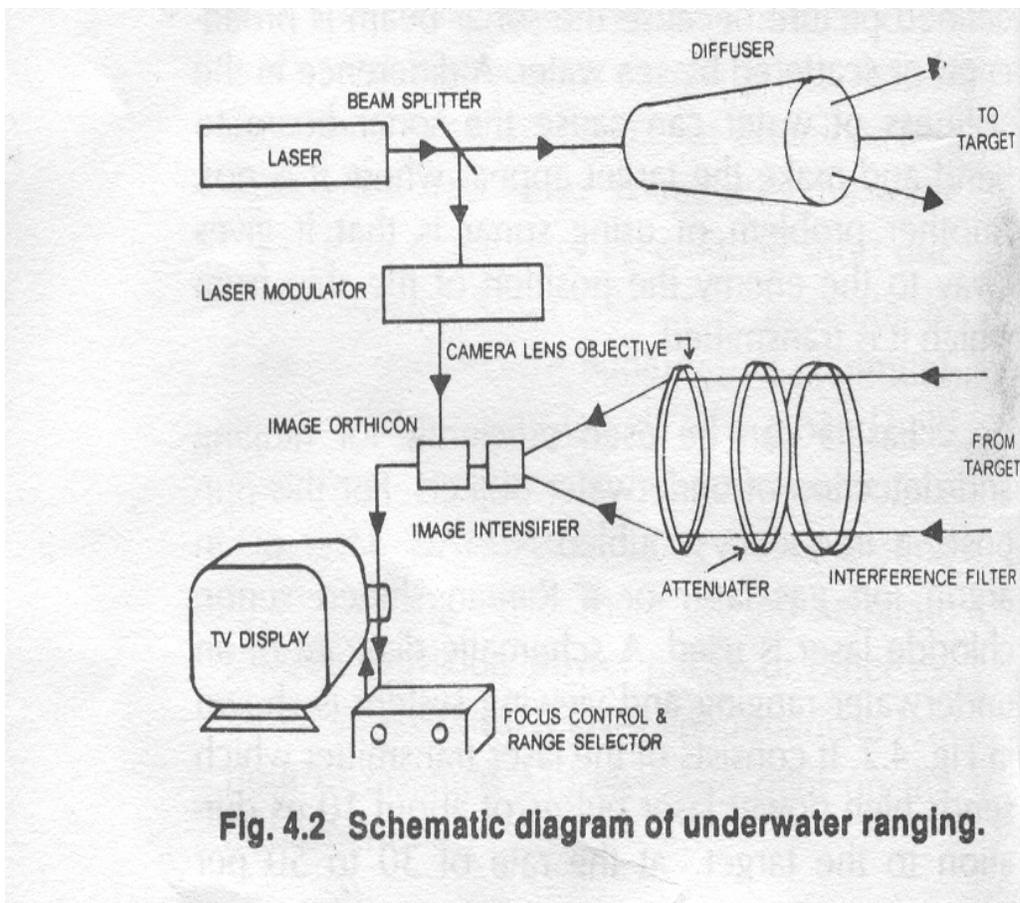
- Tank laser range finder for artillery, an armoured vehicle, or a truck.
- Portable laser range finders, used in the field artillery fire control systems. These are intended for field application in conjunction with artillery fire control systems
- Airborne laser range finder, pod-mounted and servo-positioned for the Air Force. In any airborne weapon system, one of the i.e., the distance of the target. The laser range finder combines the characteristic features of a laser with gyroscope stabilisation to provide an equipment which is more accurate and has a faster response than any other means of deriving air-to-surface or air- to-air range. At the same time, it is more compact than any radar.
- The laser walkie-talkie range finder, a compact small instrument, weighing less than 4 kg, useful to range objects at distances less than 5 km. This range finder uses the semiconductor diode laser In emitting short duration pulses. With this, it is possible to which transmit and receive audio/visual communications, or pinpoint targets with a hand-held laser, even from unsteady environment in a helicopter or on a ship being tossed around by the rolling seas. There are no separate tripods, unwieldy power packs, or other external accessories.It gives an immediate readout of distance and elevation right on the instrument.

## 4.2 Underwater Laser

Lasers can also be used as a source of underwater transmission. For this purpose, a laser giving radiation in the blue-green region is most suitable as the transmission in this region is maximum for sea water. The attenuation in underwater transmission is due to (i) absorption by materials in water, (ii) scattering by suspended particles, and (iii) variation in optical density along the light path. The blue-green lasers have assumed much importance in the systems related to naval applications.

At present, the submarines have to rely on a sonar to find the enemy crafts and to avoid the underwater objects. This has serious limitations. The whales, dolphins and other marine life give false signals. A typical sonar cannot give a well-defined picture because the sonar beam is broadened or scattered by sea water. A difference in the saltiness of water can cause the sonar beam to bend and make the target appear where it is not. Another problem of using sonar is that it gives away to the enemy the position of the ship from which it is transmitted.

Lasers can be used efficiently for ranging and detection



**Fig. 4.2 Schematic diagram of underwater ranging.**

of underwater objects. For this purpose, a frequency doubled *Nd:YAG* laser or an argon ion gas laser or a Raman shifted xenon chloride laser is used. A schematic diagram of an underwater ranging and viewing system is shown in Fig. 4.2. It consists of the laser transmitter which sends high power laser pulses of about 10 ns duration to the target at the rate of 30 to 50 per second through a beam splitter and a diffuser. A small amount of the laser light reflected by the beam splitter is made to fall on the photodiode ranging and display circuit to start the time interval counter. The reflected light from the target is collected by telescopic optics after stray radiation is eliminated by an interference filter. A range gating circuit helps to avoid unwanted echoes. The reflected pulse from the target is intensified by the image intensifier and the output is fed to image orthicon, which gives the display of the object. In this way, both the range and the image of the target are obtained. With high power release of several megawatts power, underwater ranging is possible up to 500 m in clear water.

Lasers can also be used for communication between submarines ensuring absolute privacy and in guidance systems for torpedoes and other unmanned underwater vehicles. Recent underwater laser communication has been established via satellite, i.e., from ground-to-satellite and then to underwater station.

### **4.3 Laser-Guided Anti-Tank Missile (ATM)**

A missile can be guided and controlled by an infrared beam emitted from a laser, with extremely small divergence. This can be achieved in four ways:

- (i) The laser beam is used to illuminate the target tank; the anti-tank missile (ATM) then homes on to the target, as the latter has become a source of back-scattered radiation.
- (ii) The laser beam is used to provide guidance instructions to the missile, i.e., it provides the command link.
- (iii) The missile rides the laser beam which is kept pointing along the collision course to the target.
- (iv) The missile itself carries a laser scanner and seeker for active homing on to the target.

In the first case, the laser target designator is a pulsed *Nd:YAG* laser. The laser beam is so modulated that the receiver, a four quadrant detector in the missile, is able to calculate any divergence of the missile trajectory from the beam axis and correct the deviation by altering the fins of the missile. The guidance unit consists of both optical and electronic equipment. This enables the gunner to aim the infrared guidance beam for firing the missiles.

The system in which the missile is a beam rider designed to ride the laser pointing in the direction of the target, is more attractive. A missile can carry four detectors at the wing tips looking towards the rear of the missile. The detectors determine the central axis of the laser beam and keep the flight path of the missile along it. The wavelength of the laser

should be such that is the least absorbed by the plume of the sustainer motor. Thus in a laser designator, the laser by virtue of its narrow beam illuminates a chosen target. A receiver in a bomb or a missile seeks the target illuminated from the scattered laser radiation and homes on to it. In the Vietnam war and in the recent Iraqi war, the Americans used laser guided missiles with pinpoint accuracy to destroy the enemy targets.

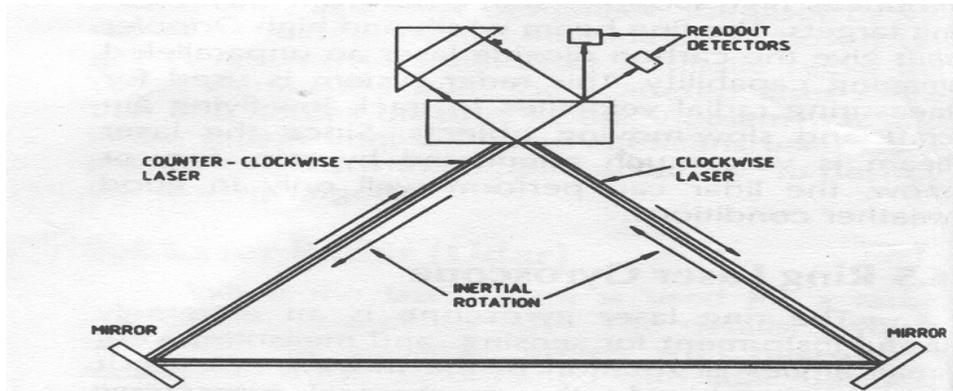
#### **4.4 Laser Radar (Lidar)**

When the laser beam is used for a radar application, it is called lidar. The details, which could not be achieved earlier with microwave radars, can now be obtained with lidar. Besides, the laser beam can be focused with lenses and mirrors easily whereas microwaves need huge antenna for focusing. As a beacon or a radar, the advantages of utilising small antenna and components are obvious. With a lidar, the dimension and the distance of the target can be obtained with higher accuracy, which is not possible with the conventional microwave radar. The lasers used in lidars are of carbon dioxide, Q-switched neodymium, or gallium arsenide semiconductor type.

The great advantage of the use of carbon dioxide lasers for radar application is their capacity to produce high power output with requisite spectral purity. The coherent carbon dioxide laser tips radar functions essential like a coherent microwave radar except for the fact that the carbon dioxide laser beam has a frequency of a few thousand times more than that of the X-band radar and at it a sharp beam width of a few microradians. The high frequency of the carbon dioxide laser also produces high *Doppler shift* even from slow-moving targets. The fine beam width and high *Doppler shift* give the carbon dioxide laser an unparalleled imaging capability. This radar system is used for and measuring radial velocities to track low-flying aircraft and slow-moving objects. Since the laser beam is very much attenuated by rain, fog, or snow, the lidar can perform well only in good weather conditions.

## 4.5 Ring Laser Gyroscope

The ring laser gyroscope is an extremely useful instrument for sensing and measuring very small angles of rotation of the moving objects. It has now replaced the mechanical gyroscopes used in most of the aircraft (both civil and military) and also in long range guided missiles. The main advantages of the ring laser gyroscope are: (i) non-existence of moving parts, (ii) high g capability, and (iii) higher reliability as compared to the mechanical gyroscope. In addition, the laser gyroscope is capable of wide dynamic range and rapid reaction time, the characteristics required for missile guidance.



The ring laser gyroscope basically consists of a ring cavity around which two laser light beams travel in opposite directions. The operation of the ring laser gyroscopes is based on the so-called Sagnac effect by which rotation of an object is sensed by an interferometric technique. A schematic diagram of the ring laser gyroscope.

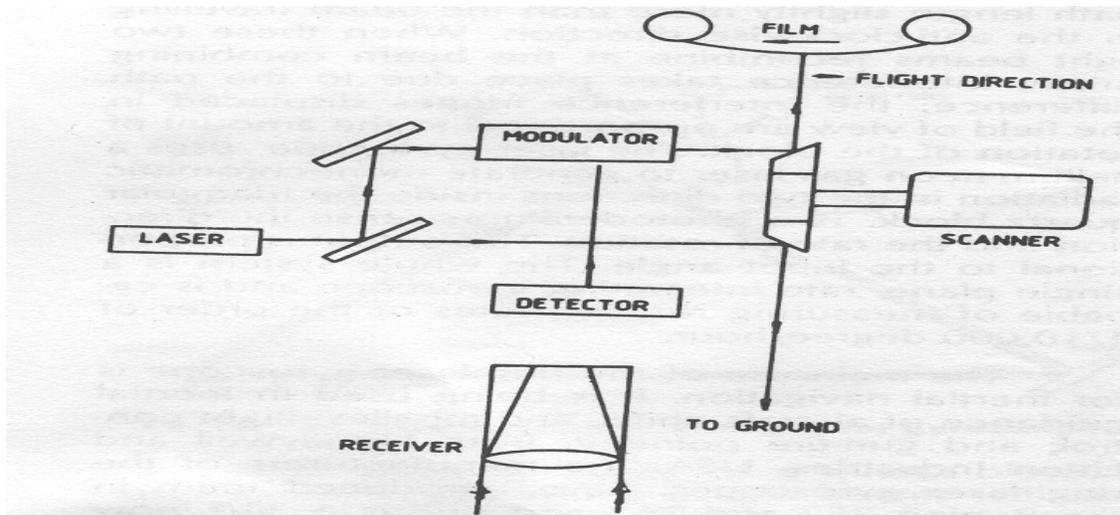
In a triangular cavity of a quartz block, a laser beam is split into two light beams with the help of suitable mirrors. These two light beams travel in opposite directions in the same path of the cavity, one in the clockwise and the other in the anti-clockwise direction. The two light beams then pass through a beam splitter and a beam combiner, behind which a readout detector is placed. If the cavity which is acting as an interferometer is stationary, the two light beams travel the same distance in the opposite directions without any path difference and hence no interference takes place. However, if the block is rotated clockwise about an axis through the centre and perpendicular to the plane of the interferometer, the beam travelling in the clockwise direction travels a path length slightly more than the beam travelling in the anti-clockwise direction. When these two light beams recombine at the beam combining prism, interference takes place due to the path difference; the interference fringes displaced in the field of view are proportional to the amount of rotation of the block. The laser gyroscope uses a helium-neon gas laser to generate monochromatic radiation in the two directions inside the triangular quartz block. Two photodetectors sense the direction and the rate of rotation. The output is proportional to the input angle. The whole system is a single plane, rate-integrating gyroscope and is capable of measuring rotation rates of the order of  $1/10,000$  degree/hour.

The main use of the ring laser gyroscope is for inertial navigation. It is being used in inertial guidance of aircraft, ships, and missiles; flight control; and gun-fire pointing. Both Honeywell and a Litton Industries, USA, the manufacturers of the ring laser gyroscopes, have introduced them in the Boeing 757 and 767 and Airbus A 310, now in production. These gyroscopes are ideally suitable for the various guided missile applications the Defense sector also.

#### 4.6 Air Reconnaissance

Lasers can be used as a secretive illuminators for aerial reconnaissance during night with high precision. Earlier it was done using a camera, equipped with either magnetic flares or powerful strobe lights with their cumbersome power supplies. For this purpose, a helium-neon laser or a gallium arsenide semiconductor laser is used. Two properties of the laser, namely, its narrow beam and its radiance or brilliance are of importance in this particular application.

The block diagram of the laser camera is shown in Fig. 4.4. One of the beams passes downwards through a six-sided prism scanner towards the earth. The prism scans through a selected angle at right angles to the direction of the flight of the aircraft. The other beam passes through a Pockels cell modulator. On emerging from the modulator, the beam strikes the prism scanner and is then reflected towards and recorded on the film.



The laser beams reflected from the target area are picked up by a Schmidt lens, which images the light on to a photodetector. The video output of the photodetector, corresponding to the reflectivity of the observed terrain, drives the modulator. Thus, the returned beam modulates the original beam. The pictures thus obtained are comparable in resolution with those taken under daylight conditions. Thus, the enemy targets can be photographed at night under high secrecy during the flight of the aircraft. The laser camera system was tested successfully by the United States Air Force Tactical Air Reconnaissance Centre.

## 4.7 Communications

A very useful and interesting application of laser is in the field of communications, which takes advantage of its wide bandwidth and narrow beam width over long distances. The laser beams can be created in a range of wavelengths from the ultraviolet to the infrared regions of the electromagnetic spectrum. The colour of the emitted light is relatively not important. The infrared region is preferred by the military, as it is more difficult to detect. The advent of semiconductor lasers has made possible the use of lasers for signal transmission. They are excited directly by electric current to yield a laser beam in the invisible infrared region.

A particular aspect of laser transmission, which makes it preferable to the ordinary radio waves for military purposes is the strict secrecy provided by the narrow beam width. Since no unwanted reception outside the narrow bundles of rays is possible, a high degree of secrecy can be maintained between two points, and thus, an interception-proof communication network can be realised. Besides, laser communication system is immune from jamming and from interference by spurious radio noise.

The optical laser has a great potential for use in long distance communication. Since the capacity of a communication channel is proportional to the frequency band width, at optical frequencies, the information carrying capacity is many times more than that is possible at lower frequencies. This and the fact that the laser is a generator of highly coherent beams which are powerful and sharply directed, make it ideally suited for communications.

In this regard, microwave technique offers direct competition to the laser as it has been perfected already to a high degree. Moreover, the optical frequency waves suffer a considerable disadvantage in case of atmospheric transmission since they are attenuated considerably by snow fog, and rain. Therefore, the laser communication through the atmospheric medium is effective only in clear weather conditions, with no obstacles interrupting the beam between the transmitting and the receiving stations.

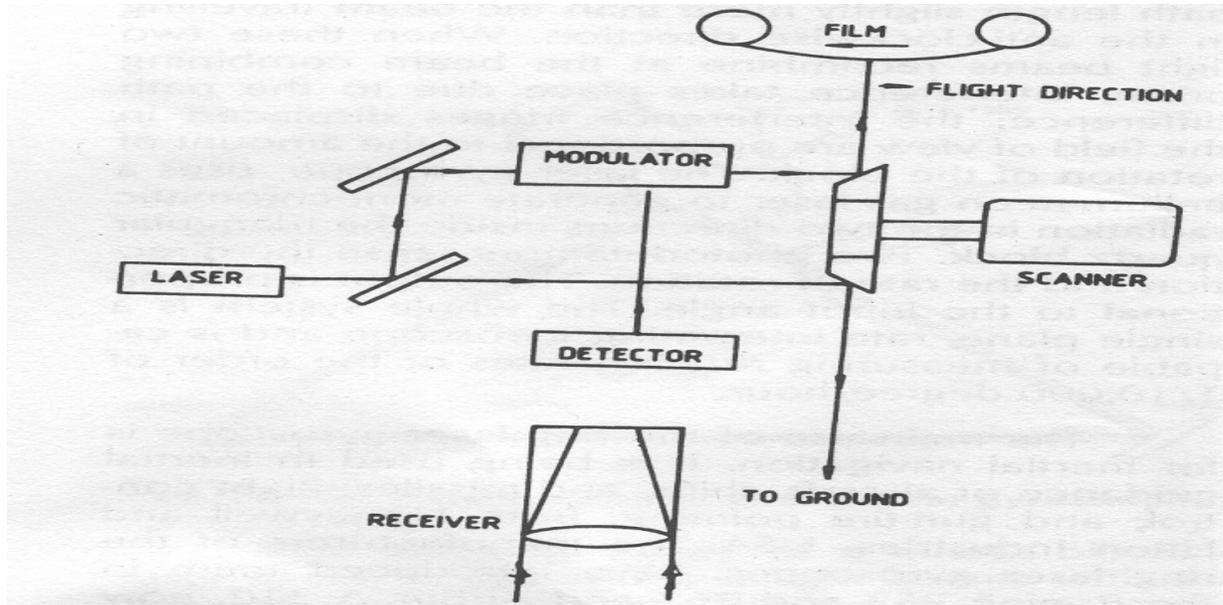


Figure 4.5 shows the principle behind the long distance communication system, which involves multiplexing the simultaneous transmission of different messages over the same pathway. For example, a channel for transmitting an individual human voice requires a frequency band extending from 2000 to 4000 cycles per second. For modulation of the signal without the addition of any noise, the carrier wave should be of a very narrow spectral width. This single frequency carrier wave is then successively modulated by a large number of voice signals to create a new composite single wave. With the help of special electrical networks, several broad communication bands are combined for simultaneous transmission over a single intensity pathway. On the other side of the line, a similar network separates the single signal into its component broad bands which are demodulated into individual telephone calls.

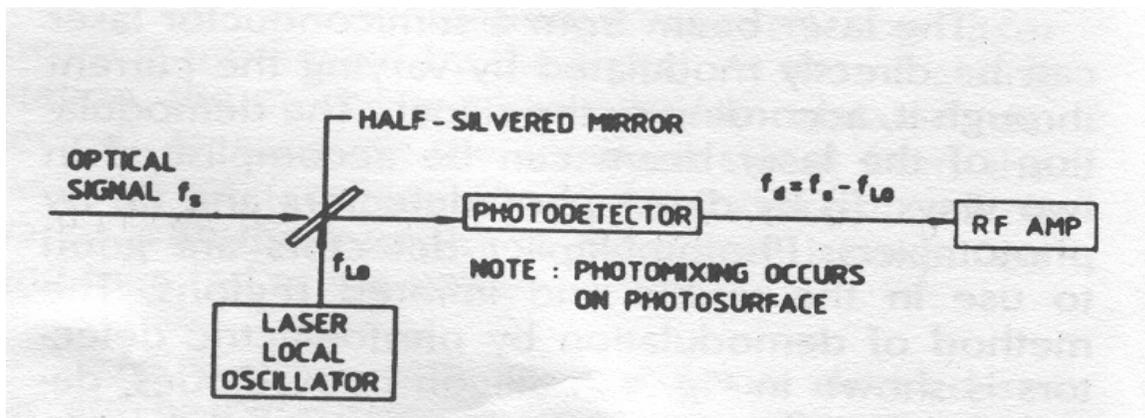
Thus considerable economy and efficiency in communication is achieved through multiplexing process. Since an individual communication channel requires the same bandwidth regardless of the region of the spectrum in which it is located, it is quite obvious from the above that the visible and near-infrared laser frequencies, which are about 1,000,000 times the frequency of the millimetre waves, offer great economy for communication.

For communication purposes, the laser beam is modulated by the signal. At the receiving station, the modulated beam is demodulated (detected) to separate the required signal from the laser beam (carrier). The output current, which varies with the intensity of the signal, is amplified and then fed to the speaker.

Most of the optical modulators devised so far are based on the variations in the refractive index of the substance used according to the signal wave. The continuous laser output from a laser passes through a polarisation modulator (KDP crystal) as shown in Fig. 4.6. Ring electrodes are placed on the crystal and an electric field proportional to the signal wave is applied to the crystal, parallel to the axis. Due to the change in refractive index of the crystal, which follows the electric signal, there is change in polarisation of the light beam. As a result of this, the intensity of the light coming out of the analyser also changes, according to the signal.

The laser beam from a semiconductor laser can be directly modulated by varying the current through it, according to the signal. The demodulation of the laser beam can be accomplished in two ways: (i) by direct photodetectors and (ii) by photomixers. Photomultiplier detectors are good to use in the visible and infrared regions. The method of demodulation by photoelectric detectors is shown in Fig. 4.7. Silicon photodiodes, developed rapidly after the discovery of the laser, have a peak response at about 8500-9000 Å (one Å =  $1 \times 10^{-8}$  cm). This being the spectral region of the gallium arsenide lasers, the silicon photodiodes can be used as sensitive detectors in that region.

Demodulation by optical heterodyne detection is done by superposing on the incoming incident signal, a beam of light from an unmodulated laser called a local oscillator and allowing the resulting combined beam to fall on a photoemissive surface of the photodetector as shown in Fig. 4.8. The electron current from the detector is modulated at a frequency equal to the difference between the signal and the local oscillator frequencies. When this is fed to an audio speaker, the input signal of the communication is reproduced.

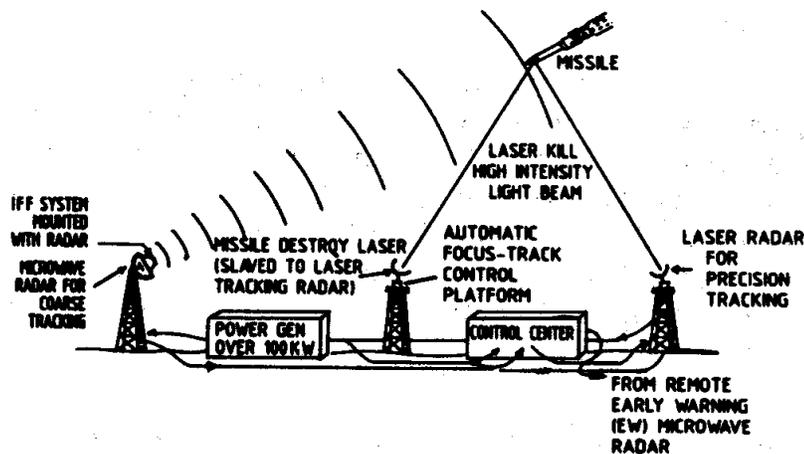


Laser communication through open atmosphere is possible only when there is line of sight between the transmitter and the receiver and that too in good weather conditions. To circumvent these difficulties, laser communication through the medium of optical fibre has been achieved in recent years. This aspect has been treated in Chapter V.

#### 4.8 Anti-Missile Defence System (Star Wars)

In an antimissile defence system, laser is used to dispose the energy of warhead, not by vaporising or melting it, but by partially damaging the missile, say by drilling a hole. Tremendous energy is required to completely burn the missile, which is not practicable. If a guided vane of a missile is fractured, several vibrations will be developed in the air frame thereby disintegrating major sensitive portion of the missile.

Two types of anti-missile defence systems have been visualised. One such system, laser kill system is completely earthbound (Fig. 4.9). Here, an early warning microwave radar gives a rough position of the approaching missile. Then a lidar aligned to the target by the tracking radar gives the precise position of the missile. This data is fed on to another high intensity laser beam which actually does the killing. To exploit the laser's killing capability, a high speed servo system and a complex focusing system are essential.



The other anti-missile defence system is the orbiting space station, equipped with detecting, tracking and killing laser devices. An infrared homing system on the laser weapon is used to close on an enemy vehicle and then fire a high energy laser beam. Firing by laser weapons would not change the positional or altitude stability of the space station. It is predicted that the lasers would ultimately make inter-continental ballistic missiles (ICBM's) obsolete.

There are, however, many limitations in the utilisation of laser in its anti-missile role. The power required is very prohibitive and as a result huge power stations are required for the operation. At present, huge power of more than 100 kW in the continuous mode is being obtained from the gas dynamic carbon dioxide lasers and some other chemical lasers, developed in the US and Russia. This amount of laser power is sufficient to destroy an enemy vehicle or a missile.

The SDI or Star Wars is the US programme aimed at defending itself and its allies against

the ICBM strikes through space. The concept of strategic defence is concentrated at a three-layered defence system in which the enemy missile can be destroyed in the boost, or the mid-course, or terminal phase. Each layer of defence employs several alternatives of weapon systems. Laser is one such important system.

For detecting and destroying missiles, different types of high power lasers, such as gas dynamic carbon dioxide, excimer, x-ray, free-electron, and chemical lasers can be used. In one such programme, the us scientists are developing 5 to 10 MW deuterium fluoride lasers for destroying the ICBM. In the ground-based laser systems, laser beams will be directed towards a large mirror in geosynchronous orbit. From there, the beams will be directed towards a moving mirror in low orbit which will reflect the beams on to the missile to destroy it. The nuclear-pumped x-ray lasers are also being considered for destroying missiles in the boost phase.

#### **4.9 Laser Proximity Fuze**

The proximity fuze, developed in the US using a solid-state laser, detonates the missile warhead when it comes within the range of its target. The higher manoeuvrability of the missile is expected to improve its performance a great deal in close in aerial combat. It is also claimed that the proximity fuze and the warhead will enable the missile to destroy its target without hitting it directly.

#### **4.10 Laser Beacon**

The present infrared light sources, being used as ground beacons to identify the ground points, are inefficient and not much reliable. Using a lensless diode array, a laser beacon can made multi-directional. The laser beacons are light in weight, efficient and have long life. Another advantage is that the pulses can be used ground beacons so that the air-dropping of supplies can be done at the given locations efficiently

#### **4.11 Weapon Firing Simulator**

If we take into account the cost of ammunition and large land that is required to fire it, basic training of the tank gunners is very expensive. A simulator technique, which does not sacrifice the acquisition of the basic skills during trials, has been developed in which the main weapon has been replaced by a laser. The technique is known as the weapon firing simulator.

The simulator, installed in the machine gun mount of the vehicle, produces a single burst intense red light when the firing circuit of main weapon is activated. On seeing this bright spot of light, which is visible momentarily in optical system of the vehicle, the trainee is able to lay his gun sights accurately to track the targets. It also enables one to check the accuracy and proficiency of the crew in operating the vehicle's main weapons system.

## 5. Laser Applications II: Civil

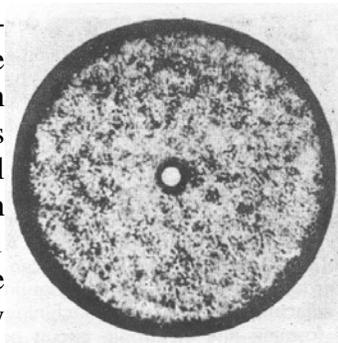
Since a laser beam can be controlled and located much more precisely than an arc or a flame, the intense heat generated by its absorption in various materials is used for high precision welding, drilling, and micromachining. No distortion is caused in the material welded by laser because it produces minimum shrinkage. Traditional welding has its limitations; certain materials cannot be welded by the conventional means. Laser technology has enabled reliable welding of gold with silicon and germanium, aluminium with nickel, tantalum with copper and several other metals used in electronic equipment. With laser, it is even possible to join metallic and non-metallic material.

Introduction of microcircuits into electronic equipment and thin film technology necessitated reliable spot welding like microwelding used in microelectronic circuits and watch parts. In such cases where heat-affected zone is minimum and welds of microsize are required, spot welding of high quality can be achieved by lasers without causing any damage to the delicate metals and ceramics being welded. Successful laser welding of high strength alloy steels, carbon-rimmed steel, tin-plated mild steel, etc has been achieved 2-5 kW continuous wave carbon dioxide laser.

### 5.1 Laser Drilling

Laser drilling of metals is based on a face-heating phenomenon. The absorbed intensity is transformed into heat within the penetration depth of laser radiation. And when the illuminated spot on the surface reaches boiling temperature, material removal starts due to the processes of vaporisation and melt expulsion. Laser enables drilling of a diamond die in a few minutes as against 20 hours taken by conventional methods. There is no wastage in the process and the saving in terms of the cost of diamond dust helps in recovering the financial outlay on such a drilling system.

Laser light energy is primarily applied in effecting micro-openings in rubies and diamonds. Without heating the entire machined unit, now possible to drill filament canals in refractory materials. Laser drilling of holes in a diamond takes 2 to 3 minute as against 2 to 3 days taken by conventional drilling. A laser installation in Russia drills holes with diameters and depths from 0.005 to 0.8 mm and depths from 1 to 3 mm, respectively, in diamonds of any size and shape. The plus point about laser drilling is that it does not cause any damage to the diamond or any other processed material. A typical hole drilled in a ruby disc is shown in Fig: 5.1.



For laser drilling, usually pulsed carbon dioxide, *Nd:YAG* or alexandrite laser is used. Special operations like drilling of holes with diameter less than 0.5 mm using conventional techniques are difficult. However, the pulsed laser microdrilling is quite successful for such operations, both for metals and non-metals. The *Nd:YAG* laser emits at 1.06  $\mu\text{m}$  and the alexandrite laser is tuned at 755 nm. For some metals, the alexandrite

laser consistently gives a cleaner entrance hole with more roundness and finer edges than is obtained with *Nd:YAG* laser. The superior performance of alexandrite laser is due to its shorter wavelength and continuous spiking of its output. The absorption of most materials increases with shorter wavelengths, giving alexandrite laser an edge over the *Nd:YAG* or laser in many material processing applications.

## **5.2 Laser Micromachining**

In the recent years, lasers have also found applications in the field of microelectronics where the laser beam interacts directly with circuit boards and semiconductor chips containing memory and logic circuits. Such laser processing applications have made possible due to development of lasers with increasing stability, high repetition rates, wavelengths well into ultraviolet region, and short pulse durations. These features make it possible to heat discrete micrometer-sized regions reliably and repeatedly to very high temperatures. When applied to local regions of a silicon chip, laser heating can occur without producing damage to neighbouring material or adjacent circuitry. Laser machining is capable of forming tiny electronic circuit patterns directly on to ceramic substrates in one step. The process makes use of a laser assisted by a computer so that it is programmed to describe type of circuit pattern to be machined.

Modern lasers and their associated automatic control equipment are being used for trimming the electrical circuits. The techniques used to switch and move the laser beam are automatically controlled, every operation is designed with object of saving time. For example, it can be arranged to test parts of the circuit while the beam position is being changed. Faster trimming operations can also be achieved by using laser at a higher power.

## **5.3 Laser Cutting**

Continuous wave lasers like carbon dioxide gas lasers are extensively used for cutting a wide range of materials, such as graphite, diamond, tungsten, carbide, all metallic foils, ceramics, sapphire, and ferrite. In most cases, continuous cutting is carried out with assist gases like oxygen, carbon dioxide, or air, which produces both mechanical and chemical action intensifying the thermal effects. This gas-assisted cutting is applicable to the metals of thickness up to 5 mm with cut-widths down to 30  $\mu\text{m}$ . The most promising field of laser cutting is the cutting of steels of small thickness (several millimeters) and also of non-metallic materials.

Use of laser cutters in the garment industry, a new and very useful application of the lasers, has been introduced recently in the developed countries. With the aid of computers, lasers can cut clothing many times faster than the tailors using old techniques. It is now possible to slice the through several layers of thick cloth accurately and in a short time using a laser cutter. The laser system also consists of a computer, programmed with cutting instructions and patterns for various to garments. The laser beam, focused on the material cuts through the fabric, leaving impeccably he smooth edges.

## 5.4 Laser Hardening

The principle of laser hardening is the irradiation of material surface for a short time. Heat is conducted into a metal causing quick heating of a thin layer. During the heating period, a high temperature gradient is built up in the surface zone followed by a rapid self-quenching by the cool sub-surface material. The complete hardening cycle takes about 1 to 2 s. The conventional surface hardening processes, such as flame hardening or induction hardening, often cause a amount of distortion so that the work piece becomes waste or there are high additional costs.

Medium and high carbon plain steels more than 0.3 per cent carbon are generally well suited to laser hardening. Their maximum hardness is a function of their carbon content. Amount of alloying elements, such as chromium manganese or molybdenum increases the hardenability. The advantage of laser hardening of steels is the possible substitution for expensive alloy steels. With the development of new techniques, lasers are now also being used to harden several other industrial products.

Normally for hardening a track width few millimeters, an output of more than 1 kW from the laser is considered desirable. Recent many laboratories engaged in laser application and research work all over the world, multi watt lasers have been installed. For heat treatment and hardening, usually a continuous wave beam from a carbon dioxide laser is used. To avoid accidents, safety precautions like use of laser goggles are essential.

## 5.5 Metrology

With its high degree of coherence monochromaticity, laser is ideally suited in metrology- the science and system of measurements for measuring lengths, velocities and optical characteristics of various media. An accurate method of measuring distances is in terms wavelength of light. A conventional technique uses an instrument called interferometer for optical measurements (surface flatness, parallelism of mirrors, variation of refractive index, etc).

Using a helium-neon gas laser as the light source in the interferometer, the highest accuracies are possible in the various optical measurements. In fact, the international standard of length, i.e., one meter is calibrated with the help of a frequency-stabilised laser. In the Apollo II mission, American astronomers aimed laser beam on the moon and determined the distance of the moon from the earth to an accuracy within one foot. This type of refinement in optical measurements will enable scientists to measure precisely the factors like lunar orbit motion, lunar radius, and fluctuations in the earth's rotation rate. Ultimately, it will be possible to say definitely, whether the continents on the earth are drifting and if so to what extent. With the help of a laser altimeter, the precise height of an aircraft at a given time and also the rates of its ascent and descent can be determined with high accuracy.

The ordinary altimeter depends on air-pressure changes for its readings and thus is not dependable at low-flying levels. The radio altimeter (a radar which reflects radio microwaves received from the ground) has limited accuracy for short distances. Laser altimeter, working on the principle of laser range finder, sends short laser pulses towards the ground from the aircraft and the reflected pulses are detected. Time taken by the laser pulses to travel to ground and back is measured and expressed in terms of height. The device has been used to measure heights up to 3000 m from an aircraft with an accuracy of 1 m. Cloud altitude meter with a laser is being used to find the range of the cloud accurately. It also works on the principle of a range finder. The light pulse from a laser is sent upwards in the air and the time taken for the pulse to hit the cloud and its detection after reflection, gives the distance of the cloud. The range has to be determined in both clear and bad weather conditions like haze or fog. Since the cloud particles have size of about a micron, the scattered intensity would be more for visible wavelengths. Hence, ruby laser emitting powerful red pulses is highly suitable for this purpose. With this system, it is possible to determine the height of the clouds up to 10 km with an accuracy of  $\pm 5$  m.

## **5.6 Laser for Surveying**

A breakthrough in surveying has been achieved by using laser light with geodimeter, a surveying instrument. Previously, a mercury vapour lamp was used to flash a beam of light from one point to another. Lasers have enabled the US coast and geodetic survey teams to map about 5 per cent more terrain in a given time while improving the accuracy to within 1 cm in 10 km.

The Spectra-Physics of the US has developed a geodimeter which uses helium-neon gas laser. The instrument called geodimeter combines the unique properties of laser light and automatic precision receiver electronics into an instrument capable of greater accuracy, longer range and faster measurements.

## **5.7 Civil Engineering**

The negligible divergence of the laser beam stimulated a number of ideas for providing hitherto impossible accuracy and sensitivity in the alignment of tools. Serving as an optical axis, the beam guides the machines used for levelling the concrete facing of the airfields, checking the verticality of the framework of tall buildings, sinking mines, and cutting tunnels from two ends and joining them without tilt.

In Moscow, a laser centring device was used to control the vertical axis during the construction of a TV tower with a precision of 6 mm. In the US, a hard rock boring machine has cut a tunnel, 6.5 m in diameter and 2 1/4 km long, without deviating from its planned course more than 1.58 cm in any direction. This feat was accomplished with the help of the laser beam.

Laser direction finders are widely used in coal mines. In view of the high rate of digging in coal mining, the biggest difficulty is to maintain accurately the given direction, which is achieved using a highly directional laser beam. Similarly, geodolite is used for the detection and measurement of the deformation of large dams and bridges.

## **5.8 Optical Fibre Communication**

The communication using light as signal carrier and optical fibres as a transmission medium is termed optical fibre communication. Since the the first commercial installation of a fibre optic system in 1977, the applications of optical fibre communication have increased enormously. Today, every major long distance telecommunication company is spending millions of dollars on optical fibre communication systems. In an optical fibre communication system, voice, or data are converted into a coded pulse of light using a suitable light source. This stream is carried by optical fibres to a regenerating or receiving station. At the final receiving station, the light pulses are converted into electrical signals, decoded, and then converted into the form of original information.

In future, fibre optics is going to be the choice for many communications applications. The biggest advantage of a light wave system is its tremendous information carrying capacity. There are already systems that can carry several thousand simultaneous conversations over a optical fibres, thinner than human hair. In addition to this extremely high capacity, the light guide cables are light weight, immune to electromagnetic interference, and very cheap when compared to copper cables.

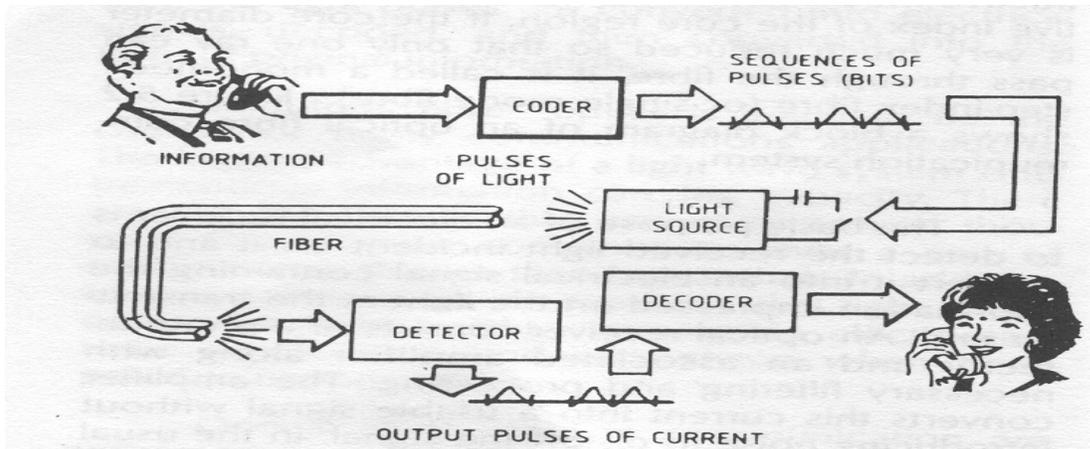
Optical fibres used in communication waveguides made of transparent dielectrics whose function is to guide light over long distances. An optical fibre consists of an inner cylinder of glass called the core, surrounded by a cylindrical shell of glass of lower refractive index, called the cladding.

Optical fibres may be classified in terms of the refractive index profile of the core and whether one mode (single mode fibre) or many modes (multimode fibre) are propagating in the fibre. If the core, which is typically made of a high-silica-content glass, has a uniform refractive index, it is called a step-index fibre. If the core has a non-uniform refractive index that gradually decreases from the centre towards the core-clad interface, the fibre is called a graded-index fibre. The cladding surrounding the core has a uniform refractive index that is slightly lower than the refractive index of the core region. If the core diameter is very much reduced so that only one ray can pass through the fibre, it is called a monomode step-index fibre (or single mode fibre). Figure 5.2 shows a block diagram of an optical fibre communication system.

The basic purpose of an electrical receiver is to detect the received light incident on it and to convert it into an electrical signal containing the information impressed on the light at the transmitter end. An optical receiver consists of a photodetector and an associated amplifier along with necessary filtering and processing. The amplifier converts this current into a usable signal without introducing noise to distort the signal. In the usual fibre optic communication systems, the photodetector used is either a semiconductor pin or avalanche photodiode (APD).

## 5.9 Applications of Optical Fibre Communications

Due to the unique advantages of the optical fibre communications, namely, the tremendous information carrying capacity, freedom from electromagnetic interference, light weight of fibres, longer distance between repeaters, and freedom from signal leakage and crosstalk, this new technology is finding immense applications in the of telecommunications. Already, the telecommunications market for optical fibres has exploded in several developed countries, like USA, UK, France, Denmark, Germany, Japan, etc. The need for greater circuit capacity coupled with the problem of congested duct space led to the initial applications of optical fibre communication for the inter-office trunk in the big cities. Today, the biggest market for optical fibre is the long distance communication. Japan has already completed its long distance routes using single mode fibres. In the US, thousands of kilometres of optical cables are being installed by giant companies, like AT&T, GTE, BELL, etc. Submarine optical fibre cable across the Atlantic Ocean are operational for the last few years.



A system with an *AlGaAs* laser for 850 nm wavelength and a graded-index multimode fibre is applied to intra-city networks with bit rates of 32- 140 Mb/s and with transmission spans shorter than 10 km. For distances more than 10 km, a system with in *GaAsP* laser operating at 1 300 nm wavelength and with a graded-index multimode or single mode fibre is preferred in inter-city networks with bit rates higher than 100 Mb/s. When more telecommunication channels are required in a metropolis, the optical fibre telecommunication system is quite effective because the special fibre cables which give more bandwidth can easily replace the existing metal-wire cables in the duct Majority of the present companies use single mode fibres that operate at 1300 nm wavelength with

future upgradability to 1500 nm where the attenuation loss will be the least. Already, commercial systems have been installed with bit rates as high as 565 Mb/s which is equivalent to 7680 two-way conversation over a pair of fibres. Since fibres have very high capacity and can transmit voice, data and video, efforts are underway to install fibres into individual houses, with universal information system. Systems are already in use that provide continuing interactive service smoke and heat detectors to automatically alert fire alarms, police alarms and medical alert alarms to summon aid. There is also a potential for completely automating all the control needs of household.

Networks using optical fibres to transmit voice, video and data within a building or within industrial complexes and university campuses have been offered by several vendors. These systems are called local area networks and they can improve communication inside a high-use area, reduce the bulk of the copper cables, and eliminate congestion in computer rooms.

Optical fibre communications are also being used for industrial applications, such as process control in nuclear, petrochemical, chemical and food industries and numerical control in large data systems in airways, shipping, railways, gas and oil transportation. Another industrial use of fibre optics is computer applications. Fibres are ideally suited for internal links that require very high data rates of the order of gigabits per second (Gb/s). Auxiliary equipment require lower data rates and hence can be handled both by fibres or copper wires. Fibres offer the added advantage of longer distance network and error-free operation; because their transmission is unaffected by the electromagnetic noise. They will be used in greater volume as inter- and intra-computer links.

Optical fibres are also very useful in Defence applications. Fibres can be used for data links in aircraft with tremendous reduction in weight and increased information capacity. Such aircraft include surveillance and attack aircraft and strategic air command bombers. Similar applications exist for inter- and intra-ship communications, submarine mobile command centres, ship-to-satellite communication links and all types of missile guidance systems. All the above types of applications exist today, making the military applications a large market for fibre optics communications.

Another interesting application is for sensors. In general, a sensor system consists of an electronic control module, sensor head and fibre optic cable. The sensor head senses pressure, temperature, velocity and reaction and converts it into a change in the optical signal which is then analysed to measure the desired change by the electronic control unit.

Lasers have great potential in TV and the cinema. Instead of microwaves as the carrier, laser beam can be used for the transmission of television programmes through optical fibre cables. Since the channel capacity is very high, many TV programmes can be accommodated in a single laser beam.

## 5.10 Data Storage

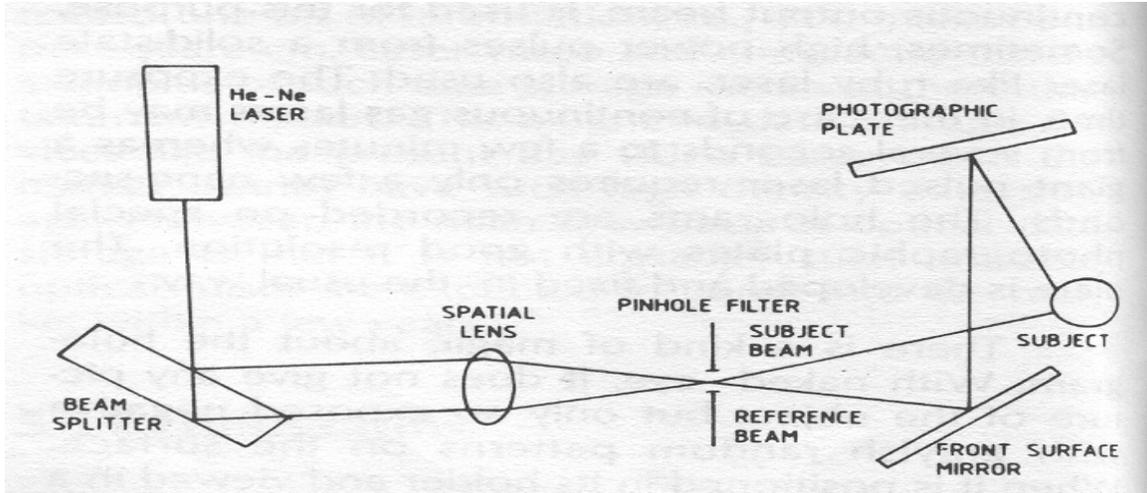
The storage of higher density of data is possible by using optical techniques. The storage medium is generally a thin film of metal whose optical properties change when it is illuminated with a powerful write laser. The less powerful read laser reads the change in optical property as the required information. Since laser beam can be focused on the spots smaller than one micro diameter, it takes less than one square micro record one bit of information, i.e., 100 million per square cm. Laser video and compact disc! examples of such data storage media in the entertainment market. The magnetic data storage vices like the present day video cassettes in market cannot have such high density data age. However, the main drawback of optical storage is that it is not erasable; such eras optical discs are expected to come into the market within a few years.

## 5.11 Holography

Another important application of laser beam is the production of true three-dimensional pictures in space without the use of lens. The record of this three-dimensional image of the object on a film is called a hologram. For this pose, the phenomenon called interfere produced due to interaction of two beam monochromatic light waves under certain conditions, is used. The interference pattern is produced by mixing two beams of the laser light. laser light is split into two beams. One beam called the reference beam, is directed toward photographic plate. The other beam is dire towards the object to be recorded, so that slilitably reflected from the object. The refer. beam and the reflected beam are made to with each other to form an interference patter the photographic plate.

To get a high quality hologram, radiation of in high coherence is required. Generally, the helium-neon gas laser which gives highly coherent and Its I continuous output beam, is used for this purpose. re Sometimes, high power pulses from a solid-state laser like ruby laser, are also used. The exposure time, in the case of continuous gas lasers may be from several seconds to a few minutes whereas a giant pulsed laser requires only a few nano-seconds. The holograms are recorded on special le photographic plates with good resolution. The plate is developed and fixed in the usual way.

There is a kind of magic about the hologram. With naked eye, it does not give any picture of the object but only an exposed negative with grayish random patterns on the surface. When it is positioned in its holder and viewed in a monochromatic light beam, such as that produced by laser, the random patterns are transformed into le a sharp and detailed three-dimensional image of b- the object. The image looks like a solid object hanging in space in three dimensions; the viewer may change the angle of view by moving his head from side to side or up and down.



Holography is being used for non-destructive testing, holographic information storage, display devices and pattern matching procedures for 'a such tasks as credit card and identity card verification. Holographic methods can also be used for is secret communication of information by recording e the holograms of secret documents, maps and objects, and restructuring the images only at the receiver end. Interference holography can be used to measure accurately how structures deform under the effect of mechanical stress or thermal gradient.

Standard holograms may be used in industrial production processes to check high precision components with regard to their shape dimensional accuracy. First, a hologram is from a masterpiece according to the method shown in Fig. 5.4. The reconstructed image ( hologram serves as a kind of reference. The to be inspected (the deviations of which are checked), is placed at the spot where the master was earlier placed. If the specimen is now exposed in the same way as the master and watched through the developed hologram, small deviations of shape with reference to the original are indicated by interference lines on the specimen. a study of the sensitivity of the interference method (any deformations of the laser light result in an Interference line), even the mistakes within the component ( e.g. cracks, cavities, etc) are indicated in the interference link patterns.

Some day, holographic technique may even be used for target recognition from air to ground and we may eventually have holographic movies and television, giving better appreciation of the objects projected to the viewers.

## 5.12 Medical Applications of Lasers

Lasers are extensively used in medicine and surgery. The first practical application was in eye

surgery, where laser was used to weld detached retina and photocoagulate the blood vessels that

grow into the region in front of the retina, thereby blocking vision. The laser beam easily passes through transparent portions of the eye, including Cornea and lens to the region of its intended use where its energy is absorbed for treatment. Retina is a sensitive membrane inside the eyeball. Its detachment from the surrounding choroid coat initiates due to a hole in the retina caused by an injury or degenerative changes during the old age. This makes the thick fluid vitreous humour seep and fill itself between the retina and chord oat. The pressure between the retina and choroid coating damages the retina which Soon gets detached from the optic nerve at the back of the to cause blindness.

Before the invention of laser, this delicate operation was done by irradiation of the eye with a xenon arc lamp or even by focusing the sunlight on to the choroid coat. This method involved exposure time to concentrate sufficient he the site of the detached retina. The process cumbersome, painful and relatively slow. Be the patient had to be anaesthetised to prevail eye from moving. Using a high energy pulsed laser, like Nd:YAG, the intense laser light focused as a tiny spot at the detached retina 'welding' it to the underlying choroid coat of the a short time (of the order of one-thousandth of a second). The operation is painless and doe affect the surrounding healthy tissues. Laser also be used to burn out small tumours on the surface of the eye and also those in the vessels of the eye. It is being used to treat coma, cataract, sealing of the retina and even viral diseases of the eye.

The laser cane which is a boon for blind persoi1S operates on the principle of a radar. Two lasers within the cane provide pulses of infrared light which are reflected from points, a short distance in front of the cane. Each reflected beam returns to a photocell inside the cane. The two photocells activate pins in the handle. When the path is smooth, the two pins vibrate steadily. Any hole or other obstacle scatters the light from at- least one of the lasers and stops the vibrations, thus warning the user. The device operates on four small batteries which last up to ten hours. It allows a blind person to scan the area ahead of him and have an idea of the object's shape, distance and dimensions by variations in pitch and intensity of the tone it emits

Lasers are increasingly being used for the treatment of many different types of cancer. A laser is less damaging than x-ray therapy and surgery; and in many cases, it is quite effective. The use of lasers to remove certain forms of cancerous growth in the body has heralded an era of knifeless and bloodless surgery. It is very effective in curing the diseases of gynaecology, ear, nose, throat, tongue, palate, and cheeks. It is curative in most early cancers, and in late cancers, it is useful in reducing the tumours to facilitate surgery.

Photodynamic therapy (POT), a new exciting form of cancer treatment, combines laser with light-sensitive dye, hematoporphyrin derivative (HPD). This substance, derived from the cow's blood, travels throughout the body of the patient and settles in the malignant tissues. A red light from argon pumped dye laser, focused on the area activates HPD, and the energized substance releases a highly reactive chemical that destroys the cancer cells. Reports indicate that POT is 80 to 90 per cent successful in causing total or neartotal regression of tumours, even after all other forms of therapy have failed. It is highly selective for a diseased tissue, leaving healthy cells relatively untouched.

At some medical centres in the US,searchers have used laser to treat colonic and other types of gastrointestinal cancer. Using endoscope, the laser energy is used to destroy neo-plastic tissue while preserving bowel wall integrity. In some cases, rectal polyps were removed using the CW argon laser, delivered with a power of 4-5 W.

With the development of optical fibres lasers are being used for heart surgery. A common problem with the arteries is the build up of plaque on their interior walls. The plaque, consisting fatty material, calcium, etc, blocks the coronary. arteries reducing the blood flow through the This results in Angina pectoris, a condition that afflicts millions of people worldwide. If the coronary artery is partially blocked, the situation can sometimes be improved by using a method called angioplasty. When substantial blockage of the coronary artery is observed, a laser beam se through the optical fibre could be used to vapourise the plaque, opening a clear channel for smooth flow of blood. This method is called laser angioplasty or vascular recanalisation. Usually argon-ion, Nd:YAG, and carbon dioxide lasers al used for this purpose.

Another important use of the fibre-optic laser catheter is in the treatment of bleeding ulcers. The laser light can photocoagulate blood, thereby causing the cession of bleeding. For this purpose among the three important lasers(carbon dioxide, Nd:YAG and argon-ion), the Nd:YAG laser is preferred because it penetrates deep into the tissue and its effects are not localised at the surface. Using a laser endoscope, small tumours in the urinary bladder are destroyed. Similarly, Nd:YAG and dye lasers are also used to rapidly heat and shatter urinary stones in the kidney

Laser can also be used for dental treatment Laser beam is useful for charring tooth decay through a painless process called laser glazing. The beam from a high repetition pulsed laser can be focused on dark decayed areas of teeth cavities to destroy the infection in the affected areas in a fraction of a second.

## 6. Laser Applications III :Miscellaneous

### 6.1 Laser Printing

For the last few years, there has been tremendous increase in the use of computers as an aid to the management, processing and dissemination of information. The use of computers in generating bank statements, insurance, telephone and electricity bills as well as publicity brochures advertising mass-produced goods are typical examples of this development. The peripheral device required by the computer for all these applications is the printer. Today, use of computers in large data processing installations places very high demand on printers as regards its speed, character flexibility, and print quality. The conventional impact printers can no longer meet these demands because of their limited speed and character flexibility. In the new generation printers, printing method is based on the principle of electrophotography. Since the light source in such printers is a laser, these devices are called laser printers.

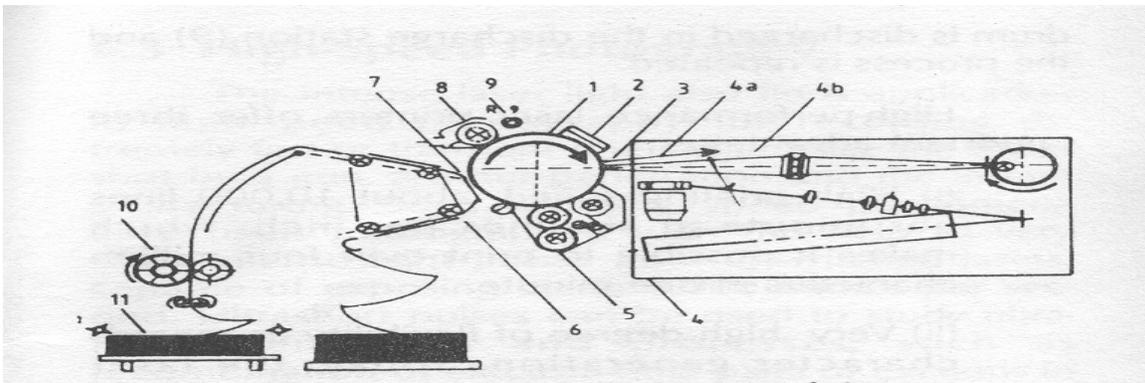


Figure 6.1 is a schematic diagram of a laser printer. A photoconductor drum (1) at the centre rotates at a constant angular speed. Its surface is treated with a photoconductive coating material like hydrogenated amorphous silicon. In the dark, this photoconductor has a very high electrical resistance which drops when the coating is exposed to light. The surface of the photoconductor drum is electrically charged by means of the charge corotron (2) and the charged layer is then rotated past the write exposure station (3). Only those locations on the drum surface at which the Information to be printed is to appear are exposed. Two exposure facilities transmitting current computer data and the information to be repeated on each print page (company letterhead, tables, bill forms) are available (4). As a result of exposure, the surface charge flows to ground inside the drum leaving a latent electrostatic charge pattern. The developer station (5) contains an electrostatically charged toner. The paper transport (6) moves the paper up to the drum and to the transfer station (7). The paper and toner charges are of opposite polarity so that the toner is attracted by the paper and adheres to it. The photoconducting drum is discharged in the discharge station (9) and the process is repeated.

High-performance laser printers offer three important advantages:

- (i) High printing speed, about 10,000 lines per minute at six lines per inch, which makes it possible to print over four million characters in one minute.  
Very high degree of flexibility as regards character generation. Today, the laser printers have character sets of several hundred different characters. Since the print characters are stored electronically, the only consideration limiting the number of characters available in the printer. is the cost I of the necessary memory space.
- (ii) Excellent print quality.

## **6.2 Seismography**

In its seismographic application, i.e., detection of earthquakes and underground nuclear blasts, the instruments using lasers are ten times more accurate than the conventional devices. This laser application is based on the principle of Doppler shift in the frequency of the light scattered from a moving substance. The scattered beam is mixed with the part of the incident beam in a detector and the beat frequency is determined, which gives the measure of the movement of the earth's crust.

## **6.3 High-Speed Photography**

The intense laser light also finds application in high-speed photography for recording extremely fast or transient phenomena like the bullet shot by a gun, armour penetration and the instant of fracturing. Such lightning speed phenomena have been photographed with the help of very short intense light pulses from Q-switched lasers, capable of exposing up to 9,000 frames per second. Ultrashort pulses can be used to study ultrafast phenomena and processes, such as recombination of electron-hole pairs or excitons in semiconductors.

## **6.4 Scientific Research**

Lasers have opened new fields of investigation in science and technology. It has given physics a versatile tool for the study of interaction of light and matter. The powerful beam of laser has become an important tool for spectroscopic analysis. A laser system, known as microprobe, is used for exciting emission from solid samples for spectrographic analysis.

In 1928, Prof. CV Raman discovered a new phenomenon, known as Raman Effect. by which molecular structures of different substances can be investigated by passing monochromatic light through them. He found that when light passes through a transparent substance, it is scattered and emerges with a change of frequency caused due to the vibration of molecules in the substance. This produces additional lines (known as Raman lines) in the scattered light spectrum. The discovery of laser is a great boon for recording the Raman spectra. The use of lasers has enabled recording of Raman lines within seconds, which otherwise would require long exposure times of or few hours using

ordinary light sources. The analysis of Raman lines gives the fundamental properties of the substances.

Similarly, lasers can also be used for analysing liquids. A laser beam, when passed through a liquid, gives several colours (wavelengths) and the process is called fluorescence. The study of the fluorescence spectra thus obtained gives the properties of the liquids.

Lasers offer attractive possibilities in terms of the exploration of molecular structure and determination of nature of chemical reactions. A laser beam can initiate and hasten a chemical reaction. Since different reactions require different wavelengths of light, a 'tunable' laser (i.e., a source whose wavelength can be altered as in radio tuning) is of immense help to a chemist. Tunable lasers, particularly dye lasers, now cover the entire visible spectrum and have revolutionised optical spectroscopy. In photochemistry, lasers with short duration pulses are highly useful for inducing and monitoring ultrafast chemical reactions more efficiently than by any conventional method.

Laser also finds application in biological research. Using laser techniques, biological studies have been carried out in enzymes, proteins, cellular components and isolated cells, microorganisms, tissue culture, isolated physiological systems individual organs, etc. Using a ruby laser coupled with a microscope, single cells have been irradiated with laser beams focused on to a spot of the order of one micron to destroy individual chromosomes, thus making available a highly delicate instrument for genetic studies.

It is also possible to produce laser beams as narrow as the diameter of a protein molecule and use it to alter genetic properties of living organisms.

## **6.5 Environmental Studies**

The constituent gases and vapours in the atmosphere can be detected and measured with lasers by means of at least three selective mechanisms. These are: ( 1) selective absorption of laser light which spectrally matches the natural absorption characteristics of the molecule, (2) resonance or fluorescence scattering of laser light, and (3) Raman scattering.

The absorption lines of water vapour in the atmosphere are very close to the emission wavelength of ruby lasers. By tuning the wavelength of a ruby lidar, one can observe the change in backscatter caused by absorption within the water vapour lines. With the availability of tunable dye lasers, it is easier to take advantage of resonance scattering which helps to identify the constituents of the atmosphere. In recent years, the laser techniques have been well established for the purpose of environmental monitoring, cloud height detection, and urban pollution studies.

## **6.6 Nuclear Fusion**

Thermonuclear fusion is the process by which huge energy is produced in the sun and stars. It is the process by which nuclei of light elements such as deuterium (an isotope of hydrogen) are fused (or joined) together to produce heavier elements like helium. In this reaction, a large quantity of energy and neutrons are released.

For thermonuclear fusion to take place, a temperature of about one million degrees centigrade is required. Today, this is achieved by the implosion of the atoms of the material by a focused high energy laser beam. Thermonuclear reaction has several advantages over the fission process. Firstly, the immense energy comes from a very small quantity of material. Secondly, the supply of fusion fuel is virtually inexhaustible as deuterium can be extracted cheaply from the world's oceans. Thirdly, there is no problem of atmospheric pollution. It will be simpler and easier to make a hydrogen bomb which will be 'clean', i.e., its explosion will be free from the lingering effects of radioactive fallout.

## **6.7 Fire Detection**

Laser's application in fire detection is based on the principle that a laser beam is affected by hot gases emanating from a fire. A focused laser beam is directed across an open space near ceiling level from one side of the room to the other. It is reflected back to a photocell from a mirror fixed on the opposite wall. Any fire starting below this level will cause turbulent hot air to rise. The laser beam, normally steady, is refracted by the temperature gradients in the hot gases and is displaced from its usual position on a photocell. The deflection can be made to trigger an alarm. Results have indicated that the laser beam system is at least as fast as the most sensitive fire detection systems in use worldwide.

## **6.8 Intrusion Alarm**

A gallium arsenide diode laser can be used to set up an invisible fence to protect an area. An infrared laser beam (in combination with an optical detector) can seal a path, an area or a volume against infiltrators. When the invisible beam is interrupted by an intruder trying to approach the protected area, it sets off a remote alarm. The laser alarm has many advantages over the conventional electric alarm. The infrared beam, being invisible, cannot be spotted by the intruder. The narrowness of the beam minimised false alarms by the passage of birds, small animals and objects floating in the air.

## **7. Status of Laser Development in India**

The research and development work in the field of lasers started in our country 28 years back on a very small scale at a few research laboratories of the Defence Research & Development Organisation, Bhabha Atomic Research Centre, National Physical Laboratory, IIT, Kanpur, and IISc, Bangalore. Later, a number of research laboratories and teaching institutions also entered into this area. A Study Group on Lasers, constituted in 1971 by DRDO, and INSA Laser Committee constituted under the Chairmanship of Prof. P Venkateswarlu in 1976 (the author was a member of the two committees) made detailed studies to assess the status of R&D work on laser at both international and national levels and gave suitable recommendations for development of lasers and laser systems in the country. In 1988, Dr DD Bhawalkar, Director, Centre for Advanced Technology (CAT), Indore, gave a status report on lasers to the Science Advisory Council to the Prime Minister. Very briefly the current status of the laser work in the country is outlined below:

### **7.1 Ruby, Nd:YAG and Nd:Glass Lasers**

Laser rods of ruby, Nd:glass, flash lamps and hard coated laser mirrors, have been developed indigenously at the Defence Science Centre (DSC), Delhi, and the solid state lasers giving peak power output of a few megawatts have been developed for Defence applications. BARC has also developed these lasers with mainly imported components, Laser range finders with Nd:YAG or Nd:glass as the active element have been developed at Instruments Research Development Establishment(IRDE), Dehradun and DSC. CAT, is developing a high power Nd:glass laser for atomic energy application,

### **7.2 Helium-Neon Laser**

Helium-Neon lasers of low power output (2- 5 mW) with lifetimes of a few thousand hours have been developed at IISc, NPL, and Bharat Electronics Ltd., Bangalore. The technology has been transferred by NPL to M/s Laser Instruments, New Delhi and by BARC, Bombay to ECIL, Hyderabad. they started production of these lasers commercially about 20 years back but stopped production since their performance is far from satisfactory. BEL also made an attempt about 10 years back and stopped production due to lack of sufficient technology

### **7.3 Carbon Dioxide Laser**

Carbon dioxide lasers giving an output power in the range 10-100 W have been developed at BARC IIT, Kanpur, IRDE and DSC, Central Electronics Ltd. (CEL) and Jyoti Ltd. have started commercial production of these lasers around 1975 but have stopped production by 1982. CAT has developed transverse carbon dioxide laser with 3.5 kW power.

## **7.4 Semiconductor Laser**

BARC and Solid State Physics Laboratory (SPL), Delhi have developed low power gallium-arsenide lasers with a view to use them for applications in communication and ranging. BARC demonstrated communication over 20 Km distance using laser. Further work is necessary to develop these lasers with heterostructures and to improve their efficiency.

## **7.5 Materials**

Basic laser materials like ruby, Nd:phosphate glass and lithium niobate are being developed at DSC for Defence applications, Central Glass and Ceramics Research Institute, Calcutta(CGCRI), has also developed good quality Nd:silicate glass for commercial applications. The development of gallium-arsenide and Nd:YAG crystals is under process at SPL. Several establishments and institutes like DSC, IRDE, IISc, NPL, BARC, IIT, Kanpur and BEL have established optical workshops including coating facilities to fabricate laser components. Good experience has been gained to fabricate laser rods and hard coated laser mirrors at DSC

## **7.6 Fibre-Optic Communication**

In 1980, a panel on Optical Fibre Communication System constituted by the Electronics Commission recommended the introduction of optical fibre communication in India. With this in view, CGCRI took up an R&D project on indigenous development of optical communication fibre. In 1982, a System Appraisal Group for Optical Fibre and Cables comprising representatives of the Department of Electronics, Ministry of Defence, IIT, De/hi, Telecommunication Research Centre (TRC) and Hindustan Cables Ltd. recommended setting up of R&D and manufacturing facilities of optical fibres and cables at HCL through collaborative arrangement. It was decided to manufacture at HCL the multimode graded index fibre with 3 to 5 db/km loss and bandwidth up to 100 MHz. Similarly, the production of optical fibre has been started at OPTEL, Bhopal with foreign collaboration. In 1983, a Committee on Optical Fibres and Cables (COFC) was constituted by the Ministry of Communication to finalise the technical specifications for optical fibres and cables required not only for communications, but also for Defence and other sectors.

The Department of Communications has Successfully installed the optical fibre cable and an 8 Mb system to provide junctions between two exchanges in the Pune Telephone system. TRC has taken up a design of an indigenous 34 Mb system to be installed between Thana and Powai in the Bombay Telephone system. Efforts are on the way to introduce optical fibre communication several trunk routes in the country. Facilities for characterisation of optical fibres have been set up at HCL and IIT, Delhi.

## **7.7 Need to Develop Laser Technology in India**

There are large gaps in the development of laser technology and its production between our country and other developed countries. Efforts in this area have been so limited in our country that they are not even equal to the efforts made at one major institution in the USA. Not a single reliable laser system is commercially available in the country. Though some institutions in our country have fabricated some experimental lasers on a laboratory scale, reliable operation of these lasers has still been a problem. As an outcome of status report of SAC to PM, a National laser Programme has been started recently.

Advantages of lasers for various applications in our country are well known and laser research has been recognised as one of the frontier areas to be developed in the 8th Five Year Plan. It is high time for our country to intensify the R&D efforts in the identified areas with time bound pro- Grammies and start the production of lasers for mass applications.