LASER 4

4.1 INTRODUCTION

The word Laser is an abbreviation for 'Light Amplification by Stimulated Emission of Radiation'. It is one of the most important discovery of 20th century. The word Laser is also used for a device that emits a narrow intense beam of light which differs from ordinary light and has very special applications. Output of a laser can either be a continuous beam of low to medium power or pulses of intense radiation.

The first laser was built in 1960 by Theodore Maiman and other scientists in California (U.S.A.), although the essential ingredients for lasers were provided by Einstein in 1917. At present various types of lasers have been developed using liquids and solids. Before describing the operation of a particular laser, it is important to discuss the following three transition phenomenon given by Einstein.

4.2 SPONTANEOUS EMISSION

It is well known that there are various energy levels in an atom. Ground state of the atom is the minimum energy state and it is the most stable state. When the atom gets suitable thermal energy, its valence electron (say of energy E_1) jumps to higher energy level (say to energy E_2) called excited level. Electrons in this level are also called atoms in its excited state. Life time of electron in the excited state is very small, of the order of 10^{-8} sec, hence the electron within this time falls back to lower energy level E_1 by emitting a radiation. This process is called spontaneous emission. The frequency, ν of the emitted radiation is given by

$$\nu = \frac{E_2 - E_1}{h} \qquad \text{...(4.1)}$$

where h is the Planck constant. We also say that in this transition a photon of energy $h\nu$ is emitted. If there are large number of atoms in the upper energy level then the emitted radiations will have randomly different initial phases and directions and the emitted radiations will be incoherent.

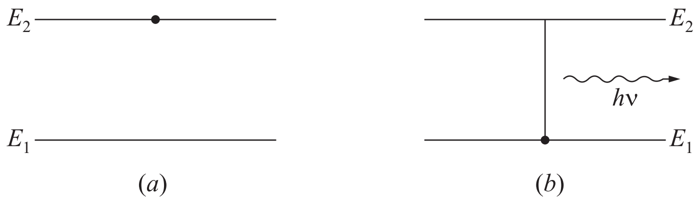

Fig. 4.1. (*a*) Initial state, (*b*) Final state

4.3 STIMULATED EMISSION

If an atom is in an excited state of energy E_2 and an incident photon of suitable energy ($h\nu = E_2 - E_1$) may cause the atom (electron) to jump to lower energy state ($\approx E_1$) emitting an additional photon of same frequency, same phase and in the same direction. Thus now two photons each of energy equal to $E_2 - E_1$ are present. This kind of transition is called stimulated emission of radiation. This is shown in Fig. 4.2.

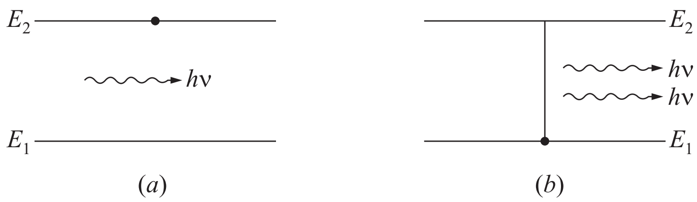

Fig. 4.2. (*a*) Initial state (*b*) Final state

4.4 ABSORPTION OF RADIATION

If an atom in its ground state of energy E_1 and radiation of suitable energy ($h\nu = E_2 - E_1$) is given such that the atom goes to excited state E_2 *i.e.,* its electron jumps from E_1 level to higher energy state E_2 by absorbing a quantum of radiation or photon. This kind of transition is called the absorption of radiation. This is shown in Fig. 4.3.

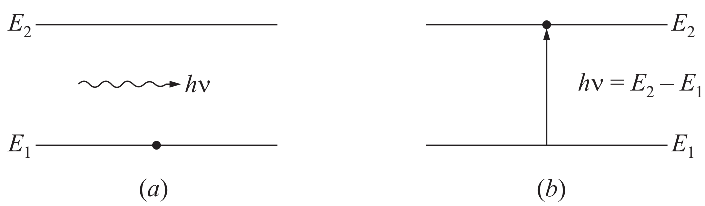

Fig. 4.3. (*a*) Initial state (*b*) Final state

4.5 RELATION BETWEEN EINSTEIN'S A AND B COEFFICIENTS

Let us consider an enclosure containing atoms which are in thermal equilibrium or in steady state. Let N_1 and N_2 are the number of atoms per unit volume called population in energy levels E_1 and E_2, respectively. Here E_2 is greater than E_1. In thermal equilibrium three processes of transition described above will take place.

1. Spontaneous Emission: According to Einstein the probability of spontaneous emission from energy level E_2 to energy level E_1 per unit time is denoted by

$$(P_{21})_{\text{spontaneous}} = A_{21} \qquad ...(4.2)$$

A_{21} is called the Einstein's A coefficient of spontaneous emission of radiation. Thus the number of photons of energy $E_2 - E_1$ emitted per second by spontaneous emission in the system is equal to N_2A_{21}.

2. Induced Emission: According to Einstein the probability of induced emission from energy level E_2 to energy level E_1 per unit time can be written as

$$(P_{21})_{\text{induced emission}} = B_{21}\, u(\nu) \qquad ...(4.3)$$

Here B_{21} is called the Einstein's B coefficient of induced emission of radiation and $u(\nu)$ is the energy density of the radiation of frequency ν. Then the number of photons of energy $h\nu$ emitted per second by induced emission in the system is equal to $N_2\, B_{21}\, u(\nu)$.

3. Absorption of Radiation: According to Einstein the probability of absorption of energy for transition from energy level E_1 to energy level E_2 per unit time can be written as

$$(P_{12})_{\text{absorption}} = B_{12}\, u(\nu) \qquad ...(4.4)$$

Here B_{12} is called the Einstein's B coefficient of absorption of radiation and $u(\nu)$ is the energy density of the radiation of frequency ν. Then the number of photons of energy $h\nu$ absorbed per second in the system is equal to $N_1B_{12}\, u(\nu)$.

In the thermal equilibrium state (*i.e.,* steady state) total number of photons absorbed per second should be equal to the total number of photons emitted per second. It can be written as

$$N_1B_{12}\, u(\nu) = N_2\, B_{21}\, u(\nu) + N_2A_{21}$$

or
$$u(\nu)\, [N_1B_{12} - N_2B_{21}] = N_2A_{21}$$

or
$$u(\nu) = \frac{A_{21}}{B_{21}} \frac{1}{\left(\frac{N_1}{N_2}\frac{B_{12}}{B_{21}} - 1\right)} \qquad ...(4.5)$$

According to Maxwell-Boltzmann distribution the number of atoms N_1 and N_2 in the energy states E_1 and E_2, respectively, in the steady state at temperature T are given by

$$N_1 \propto e^{-E_1/kT} \quad \text{and} \quad N_2 \propto e^{-E_2/kT} \qquad ...(4.6)$$

Here k is the Boltzmann constant. Therefore

$$\frac{N_1}{N_2} = e^{+(E_2 - E_1)/kT}$$

but $E_2 - E_1 = h\nu$ (energy of the photon emitted or absorbed).

$$\therefore \qquad \frac{N_1}{N_2} = e^{+h\nu/kT} \qquad ...(4.7)$$

Substituting the value of $\frac{N_1}{N_2}$ in Eqn. (4.5), we get

$$u\,(\nu) = \frac{A_{21}}{B_{21}} \frac{1}{\left(e^{h\nu/kT}\,\frac{B_{12}}{B_{21}} - 1\right)} \qquad ...(4.8)$$

Planck derived an expression for $u(\nu)$ in the following form

$$u(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{h\nu/kT} - 1} \qquad ...(4.9)$$

Comparing Eqns. (4.8) and (4.9) for $u(\nu)$, we get

$$B_{12} = B_{21} \qquad ...(4.10)$$

and

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} \qquad ...(4.11)$$

Relation (4.10) shows that transition probability of absorption is equal to transition probability of induced emission. Relation (4.10) has also been proved in semiclassical theory of radiation by using perturbation theory. Equation (4.11) shows that A_{21}/B_{21} is proportional to ν^3. This is the ratio of Einstein's *A* coefficient of spontaneous emission and Einstein's *B* coefficient of induced emission.

4.6 POPULATION INVERSION

It is well-known that the process of spontaneous emission is independent of external radiations. Einstein proved theoretically that transition probability of absorption is equal to transition probability of induced emission between same two levels. If the number of atoms N_1 in lower state (energy E_1) is more than the number of atoms N_2 in the upper state (energy E_2) then in the presence of external radiations of frequency $(E_2 - E_1)/h$, the absorption dominates over emission. On the other hand, if N_1 is less than N_2 then the emission dominates. In general at room temperature N_1 is greater than N_2, so the absorption is more than emission. In some materials if the life time of any upper state (level) is of the order of 10^{-3} sec, called metastable state, then it is possible to have that material with $N_2 > N_1$. If this happens, then the population inversion takes place in the medium. These materials are called active materials and they can be used for lasing transition. Thus for laser action population inversion is necessary.

Population of a particular energy level of atoms is given by Maxwell-Boltzmann distribution function as

$$N \propto e^{-E/kT} \qquad ...(4.12)$$

where *N* is the number of atoms in the state whose energy is *E*, *T* is the temperature of the material and *k* is the Boltzmann constant. Using this relation we get

$$\frac{N_2}{N_1} = e^{-(E_2 - E_1)/kT} = e^{-h\nu/kT} \qquad ...(4.7)$$

Since $E_2 > E_1$, therefore $N_2 < N_1$ under normal conditions. As mentioned above for laser action N_2 should be more than N_1.

The process by which atoms are raised from lower level to upper level is called the pumping. Following are the commonly used methods of laser pumping:

(*a*) Optical pumping

(*b*) Electrical pumping

(*c*) Chemical pumping.

(a) Optical Pumping: In this process the population inversion is achieved by using strong source of light such as gaseous discharge, flash lamp or arc lamp. This process keeps more atoms in the upper excited (metastable) state. This process is suited to solid state (*e.g.* Ruby) and liquid (*e.g.,* dye) lasers.

(b) Electrical Pumping: In this process the population inversion is achieved by using an intense electrical discharge in the medium which is in the gaseous form. This process is suited to gas lasers and semiconductors. The discharge converts the gas into plasma and the population of the upper level also increases.

(c) Chemical Pumping: In this process the population inversion is achieved by using suitable chemical reaction in the absence of any other source of energy. For example, in the reaction $A + B \rightarrow AB^*$, AB^* is the excited vibrational state of AB molecule.

4.7 LASER ACTION

Following are the three main things required for laser action:

(1) An active material is required in which population inversion can be attained.

(2) An specially designed cylindrical tube or rod fitted with mirrors at the two end surfaces which help in increasing the light intensity by multiple reflections. One end is completely silvered while the other end is partially silvered so that an intense beam can emerge out of it.

(3) Pumping system is required to achieve population inversion.

At first sight it appears that a system with two levels only can be used for lasing action and population inversion can be achieved through interaction of the material with a sufficiently strong *e.m.* field of frequency $\nu = (E_2 - E_1)/h$. Such type of interaction does not work. At thermal equilibrium level 1 is more populated than level 2, hence absorption will dominate over induced emission. With passage of time the population of both the levels will become equal and then the rate of absorption will be equal to rate of emission and the material will then become transparent. This situation is often referred to as two level saturation. Thus with the use of just two levels 1 and 2, it is impossible to produce a population inversion.

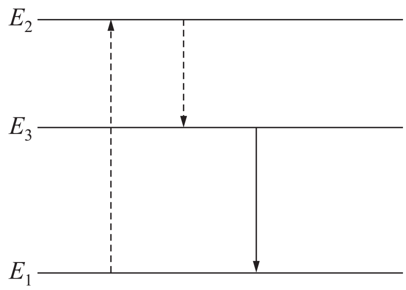

Fig. 4.4

In order to understand laser action, let us consider three energy levels E_1, E_2 and E_3 as shown in Fig. 4.4. Here E_1 is the ground state, E_2 is the normal excited state of life time about 10^{-8} sec and E_3 is the meta stable state of life time of the order of 10^{-3} sec. With the help of pumping system active material in the ground state E_1 is continuously excited to E_2 state. From this state they immediately relax down to the intermediate energy level E_3 which is metastable state so the atoms stay there for a long time. Net effect of it is that the population of E_1 decreases and population of E_3 increases continuously *i.e.,* population inversion between states E_1 and E_3 takes place. This is the necessary condition for laser action. Now if an atom from level E_3 jumps down to E_1 level by spontaneous emission then a photon of energy $E_3 - E_1$ (or radiation of frequency $\nu = \frac{E_3 - E_1}{h}$) is released. When these photons of frequency ν are incident on the atoms in the excited state, the atoms are forced to undergo transitions from excited state E_3 to their ground state E_1. These forced photons (radiations) are in the same phase and direction as the incident photons (radiations). This emission is called induced emission or stimulated emission. These emitted radiations amplify the light which is named as laser. The word LASER stands for 'Light Amplification by Stimulated Emission of Radiation'.

In actual laser instrument the active material is placed between a pair of reflecting mirrors (*e.g.,* plane parallel mirrors) forming what is known as 'Resonator Cavity'. Usually one of the two mirrors is made partially transparent so as to get a useful output in the form of intense laser beam.

4.8 MAIN FEATURES OF LASER

The most striking features of a laser are the following:

(a) Directionality: A conventional source of light (like a sodium lamp or an incadescent bulb) emit radiations in all directions. An aperture is used in front of such a source to get a narrow beam of light, whereas laser emits radiations only in one direction. Thus laser has high degree of beam directionality.

For a typical laser, the beam divergence is found to be less than one milliradian. It means that laser beam spreads less than one millimeter for every meter travelled by it. For example, the spread of laser beam sent from earth to moon (384400 km) is just few kilometers.

(b) Intensity: The light from a conventional source spreads out uniformly in all the directions. At distance of 30 cm from a 100 watt bulb, power entering* the eye is less than $\frac{1}{1000}$ watt. On the other hand the laser gives out light into a narrow beam and its energy is concentrated in a small region. Therefore even a laser of 1 watt would appear thousand times more intense than 100 watt ordinary bulb.

*Light per cm^2 from a bulb of 100 W at 30 cm away

$$= \frac{100}{4\pi r^2} = \frac{100}{4\pi \times 30^2} = \frac{1}{36\pi} = \frac{1}{113} \text{ watt/cm}^2$$

If the area of the eye's lens is about $\left(\frac{1}{3}\right)^2$ cm^2, then the power entering the eye is

$$\frac{1}{9 \times 113} = \frac{1}{1017} \text{ W} < \frac{1}{1000} \text{ W.}$$

(c) Monochromaticity: The light emitted by a laser is extraordinary monochromatic. Monochromaticity (single wavelength) of a laser light is much more than that of any conventional monochromatic source. Broadening of the emitted light from a source is the result of non-monochromaticity.

An inspection of a line emitted by an ordinary monochromatic source reveals that it has a spread (or width) over a frequency range of thousands of mega Hertz (~ 10^{10} Hz) whereas the spread (or width) of laser light is almost negligible (~ 500 Hz). This is shown in Fig. 4.5 for the monochromatic light of frequency ν_0 (say $\simeq 5 \times 10^{14}$ Hz $= \frac{3 \times 10^8}{\lambda}$ m.

or
$$\lambda = \frac{3 \times 10^8}{5 \times 10^{14}} \text{ m} = 6000 \text{ Å})$$

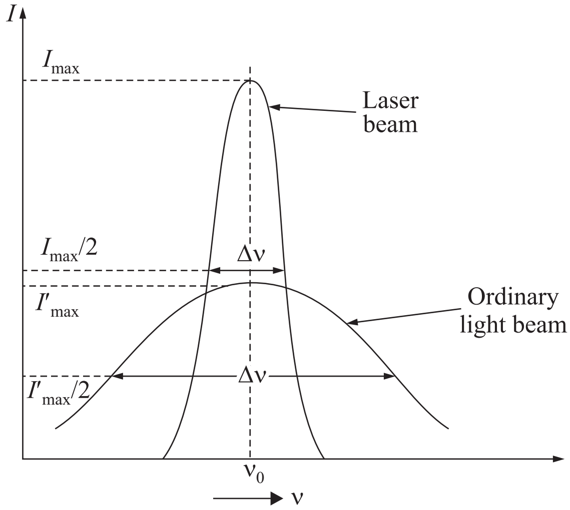

Fig. 4.5. Band widths for laser and ordinary light beam

The spread in laser beam is largely due to the presence of 'spontaneous' emission in addition to stimulated emission.

(d) Coherence: Coherence is a measure of the degree of phase correlation that exists in the radiation field of a light source at different locations and different times. Due to stimulated emission in laser the photons are emitted in the same phase and there is very high degree of coherence in laser as compared to the conventional coherent sources. The wave front of the light emitted by conventional monochromatic light source change from one point to the other and varies from instant to instant. Corresponding to these there are two concepts of coherence, namely spatial coherence (on lateral coherence) and temporal coherence (or longitudinal coherence).

(i) Spatial Coherence or Lateral Coherence: To understand spatial coherence consider two points P_1 and P_2 which, at time $t = 0$, lie on the same wave front of some given electromagnetic wave and let $E_1(t)$ and $E_2(t)$ be the corresponding electric fields at these points. According to definition the difference between the phases of the two fields at time $t = 0$ is zero. If this difference in phase remains zero at any time $t > 0$, we would say that there is perfect coherence between these two points *i.e.,* we will say that the wave has perfect spatial coherence. Thus if the electric fields at any two different

points on the *e.m.,* wave front has constant phase difference over any time t, then perfect coherence is said to occur.

The concept of spatial coherence can be understood by Young's double slit experiment as shown in Fig. 4.6. Here S is a point source, S_1 and S_2 are equally spaced pinholes. Now on the screen T near the central position O one would get interference fringes of good contrast. Let us now consider another point source S' placed near S and there is no phase relationship between the waves from S and S'. Now the interference pattern on the screen T will be due to super position of intensity coming from sources S and S' through the pinholes S_1 and S_2. If S' is moved slowly away from S, the contrast of fringes becomes poorer. For a particular distance SS' such that $S'S_2 - S'S_1 = \frac{\lambda}{2}$, the interference maximum produced by S falls on the interference minimum produced by S' and vice versa. At this position of S' the interference fringes due to S will just disappear and uniform illumination on the screen is observed. From the geometry of the Fig. 4.6.

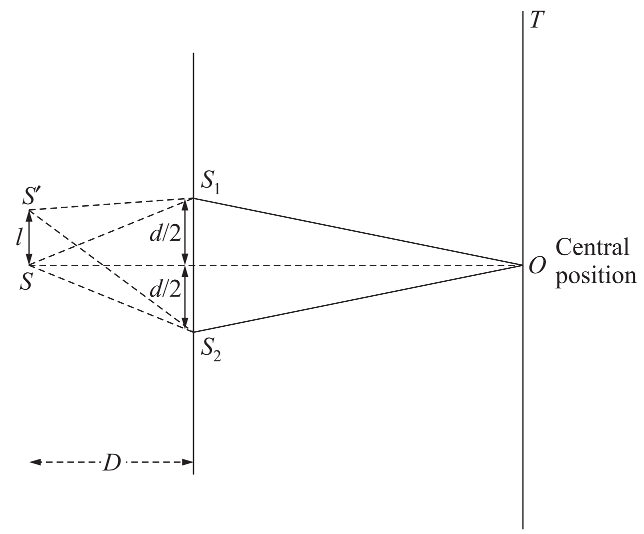

Fig. 4.6. Young's double slit experiment to study the spatial coherence of a light source

$$S'S_2 = \sqrt{D^2 + \left(\frac{d}{2}+l\right)^2} = D\left[1 + \frac{1}{2D^2}\left(\frac{d}{2}+l\right)^2\right]$$

and
$$S'S_1 = \sqrt{D^2 + \left(\frac{d}{2}-l\right)^2} = D\left[1 + \frac{1}{2D^2}\left(\frac{d}{2}-l\right)^2\right]$$

$$\therefore \qquad S'S_2 - S'S_1 = \frac{D}{2D^2}(dl + dl)$$

or
$$S'S_2 - S'S_1 = \frac{ld}{D} = \frac{\lambda}{2} \qquad ...(4.13)$$

where $l = SS'$, d is the distance between pinholes S and S_2 and D is the distance of the pinholes from the sources S and S'. Equation (4.13) gives

$$l = \frac{D\lambda}{2d} \qquad ...(4.14)$$

Therefore for an extended source of width l, fringe pattern will be observed if

$$l << \frac{\lambda D}{d} \qquad ...(4.15)$$

Equivalently, for an extended source (of width l) the interference pattern of good contrast will be formed if the separation of the two point sources, d is

$$d << \frac{\lambda D}{l} \qquad ...(4.16)$$

Now l/D is the angle subtended by the source at the slit as shown in Fig. 4.7 *i.e.,*

$$\theta = \frac{l}{D} \qquad ...(4.17)$$

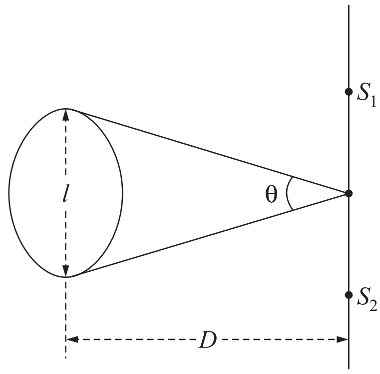

Fig. 4.7

Substituting the value of $\frac{l}{D}$ in Eqn. (4.16), we get

$$d << \frac{\lambda}{\theta} \qquad ...(4.18)$$

In practice the pinhole S_1 is fixed and pinhole S_2 is moved to see the reduction in fringe contrast. The area over which the pinhole S_2 shows the interference fringes is called the 'Coherent Area' of light wave. The distance d_t between the pinholes for which the fringes just disappear is called transverse, lateral or spatial coherence length, Thus

$$\text{spatial coherence length} = d_t = \frac{\lambda D}{l} = \frac{\lambda}{\theta}. \qquad ...(4.19)$$

(ii) Temporal Coherence or Longitudinal Coherence: Temporal coherence refers to the correlation between electric fields at a point at two different times.

To understand temporal coherence, let us consider electric field of the electromagnetic wave at a given point P at time t and $t + \tau$. If, for a given time delay τ, the phase difference between the two field values remains the same for anytime t ($t < \tau$), we say that there is 'Temporal Coherence' over time τ. If this occurs for any value of τ, the *e.m.* wave is said to have perfect time coherence. If this occurs for a time delay τ such that $0 < \tau < \tau_c$, the *e.m.* wave is said to have partial time coherence with coherence time equal to τ_c as shown in Fig. 4.8, which shows a sinusoidal electric field undergoing phase jumps at time interval equal to τ_c.

The distance travelled by the wave train during time τ_c is called temporal or longitudinal coherence length *i.e.,* longitudinal coherence length = $l = C\,\tau_c$ ...(4.20)

where C is the speed of light. In fact the band width Δv is related to the coherence time τ_c of the *e.m.* wave by the relation

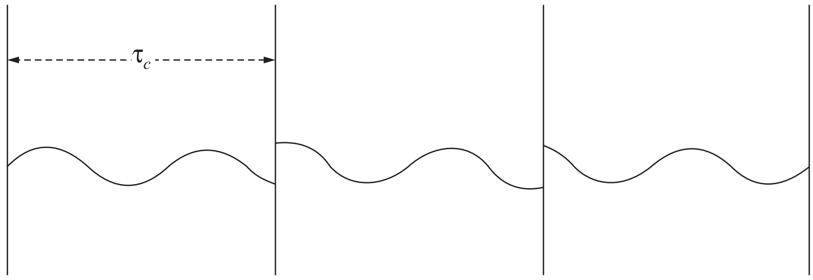

Fig. 4.8. Example of an e.m. wave with a coherence time τ_c

$$\Delta\nu = \frac{1}{\tau_c} \qquad ...(4.21)$$

Thus the concept of temporal coherence is directly connected to monochromaticity.

Temporal coherence can be studied by using Michelson interferometer. For mercury vapour lamp and He-Ne (Helium-Neon) laser, the typical temporal or longitudinal coherence lengths are 0.50 m and 300 m, respectively.

4.9 HELIUM-NEON LASER

The helium-neon (He-Ne) laser is the first gas laser operated successfully in 1961, by Ali Javan and his co-workers at Bell Telephone Laboratories in U.S.A. It consists of the following main components.

1. Active Material: Mixture of helium and neon gases in the ratio 7 : 1 at total pressure of 1 torr (1 torr = 1 mm of Hg column) is used as an active material. However, this ratio 5 : 1 to 10 : 1 may be taken. In the mixture helium is used for population inversion only whereas levels of neon are involved in laser action.

2. Resonator Cavity: Resonator cavity is made of quartz tube of about 80 cm length and 1 cm diameter. The gas mixture is enclosed between a pair of mirrors. One mirror is completely reflecting (99.99% reflectivity) and the other mirror called the output mirror is partially transmitting (about 90% reflectivity).

3. Exciting Source: Exciting source for creating discharge in the tube is the high voltage radio frequency such as Tesla coil.

As is shown below its operation involves four energy levels—three of neon and one of helium.

Operation: The working of the He-Ne laser is based on the fact that neon has excitation energy levels very close to meta-stable energy levels of helium. Few energy levels of He and Ne excited states are shown in Fig. 4.10.

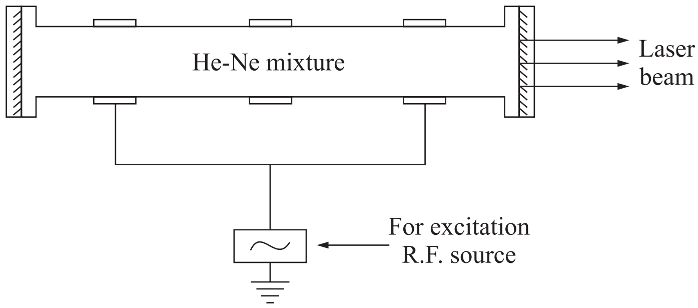

Fig. 4.9. He-Ne laser

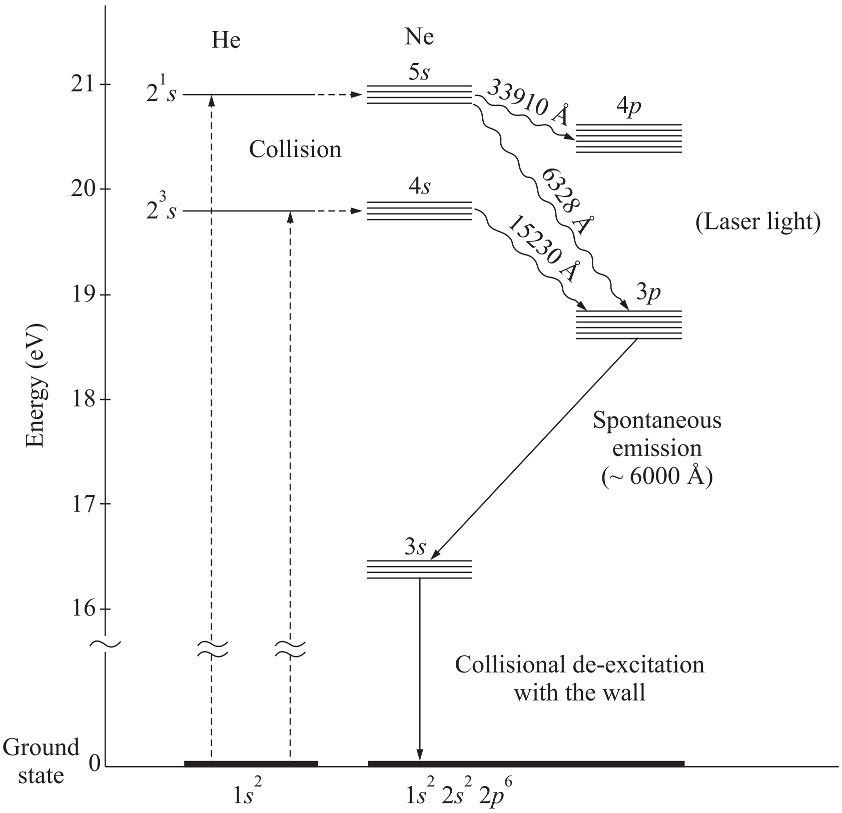

Fig. 4.10. Few energy levels of He and Ne excited states

Ground state of helium is $1s^2$. In the first excited state one of the electron goes to $2s$ level or the excited states are 2^3s (triplet) and 2^1s (singlet). Both the states (2^3s and 2^1s) of He are metastable states because $2^3s \rightarrow 1^1s$ is forbidden due to change in multiplicity or flip in the spin and $2^1s \rightarrow 1^1s$ transition is also forbidden by electric dipole transition. Ground state of Ne is $1s^2\ 2s^2\ 2p^6$ and the first few excited states are $[1s^2\ 2s^2\ 2p^5]\ 3s^1$, $4s^1$, $5s^1$, $3p^1$ or $4p^1$. When electric discharge is passed through the gas the electrons collide with the helium and neon atoms and excite them to the higher levels of both helium and neon. The helium excited states (2^3s and 2^1s) being metastable states accumulate population whereas neon has radiative decay and they come to ground state. These excited He atoms collide with Ne atoms

and transfer the energy to excite Ne to 4*s* and 5*s* levels which have nearly the same energy as 2^3s and 2^1s levels, respectively, of He atoms. Thus there is resonant energy transfer. Since significant population can be built up in 4*s* and 5*s* levels, they prove suitable candidates as upper levels for laser transition. Taking account of the selection rules possible transitions are those to *p*-states. Transition from 5*s* to 4*p*, 4*s* to 3*p* and 5*s* to 3*p* result in the emission of radiation having wavelengths 33910 Å, 15230 Å and 6328Å, respectively. Out of these 6328 Å corresponds to visible light of He-Ne laser. The terminal 3*p* level decays radiatively with a life time of 10^{-8} sec to the 3*s* level of long life time. Because of long life of 3*s* state, atoms in this state tend to collect with time. These atoms after collision with electrons in the discharge may be excited back to 3*p* state which thus reduces the inversion and can even quench it. This situation may be avoided by taking tube of small diameter and then neon atoms in 3*s* state are de-excited by colliding with the wall of the tube.

Typical power output in He-Ne lasers lie between 1 and 50 mW of continuous wave for input of about 5 to 10 W. The output shows a strong dependence on the discharge current. The power supply is thus matched with the tube.

4.10 SEMICONDUCTOR LASER

The semiconductor laser is also sometimes called as the junction laser or the diode laser. These lasers use semiconductors as the lasing material. A number of semiconductors can be used for *p-n* junction. When this junction is forward biased then the electrons drift from *n*-region into the *p*-region and the holes drift from the *p*-region into the *n*-region. They soon recombine near the junction and in this process they release* excess energy in the form of heat or light. In the case of silicon and germanium this recombination energy is released in the form of heat so these materials are of no use for laser action. In gallium arsenide most of this recombination energy is released in the form of light, therefore gallium-arsenide is usually used in semiconductor lasers.

First doped semiconductor was fabricated in 1962, by using gallium-arsenide in the form of diffused *p-n* junction. *p-n* junction is formed by diffusing aluminium (acceptor impurity) to wafers of *n*-type Ga-As. Just like in other laser systems, there can be three interaction processes.

(*i*) An electron in the valence band can absorb the incident radiation and can be excited to the conduction band. This process would create electron-hole pair.

* If the energy gap or band gap is equal to 1 e.v., then the wavelength of the emitted radiation due to pair annihilation is

$$\lambda = \frac{hc}{E_g} \text{ because } E_g = h\nu = \frac{hc}{\lambda}$$

$$= \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1 \times 1.6 \times 10^{-19}} \text{ m} = 12400 \text{ Å}$$

These radiations are in the far infrared region. If the band gap is equal to 1.6 e.v. (say), then λ of emitted radiation is

$$\lambda = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{1.6 \times 1.6 \times 10^{-19}} \text{ m} \simeq 7700 \text{ Å, which is in the visible region.}$$

(*ii*) An electron from the conduction band can jump spontaneously to valence band and in this process it emits radiation.

(*iii*) Incident radiation may induce electrons of the conduction band to jump into the valence band. In this process it emits radiation.

If now by some mechanism a large density of electrons is created in the bottom of the conduction band and simultaneously in the same region of space a large density of holes is created at the top of the valence band then an optical beam with a frequency slightly greater than E_g/h will cause a larger number of stimulated emission as compared to absorptions and thus can be amplified. This can be achieved by cutting wafers, the Al diffused *n*-type Ga-Al into small chips with optically flat and polished parallel ends perpendicular to the plane of junction. These surfaces are coated to increase the reflectivity. As shown in Fig. 4.11 the remaining faces are made rough to avoid the leakage of laser beam. At low currents it acts as LED (light emitting diode). When current reaches the threshold value, a population inversion is achieved between filled electron levels near the bottom of conduction band. It is found that when the forward current density is more than the threshold current density (~ 50,000 Amp/cm^2) the stimulated emission rate will exceed the absorption rate and the amplification will overcome the losses in the cavity and laser will begin to emit coherent radiation. Taking the typical cavity length 300 μm × 100 μm the required threshold current is 15 Amp.

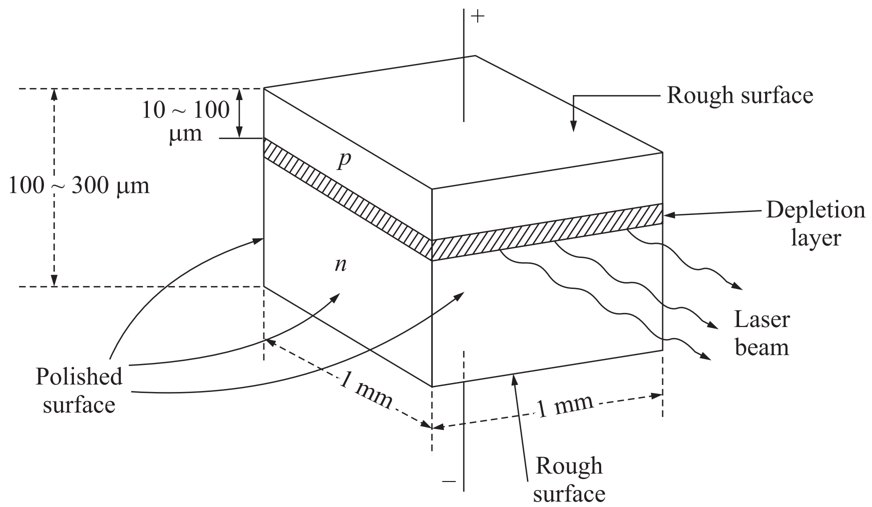

Fig. 4.11. Semiconductor laser

Now-a-days semiconductor lasers are based on the double heterojunction in which thin active layer of a semiconductor with a narrow band gap is sandwiched between two larger band gap semiconductors. Fortuitously the refractive index of semiconductor decreases with an increase in bandgap. Thus the refractive index of the central active layer of GaAs is higher than the surrounding region. This change in refractive index helps in the confinement of the emitted optical radiation to the active region because of total internal reflections at the boundaries. The double heterojunction used here also reduces the value of the threshold current density to 2000–4000 Amp/cm^2 or the current required is only about 60 mA because the current is restricted within small lateral size of the active region.

4.11 APPLICATIONS OF LASER

Lasers are widely used for the following purposes:

1. Measurement of distances: With the help of laser beam, distances can be accurately measured such as the distance of moon from earth.
2. Communication: Lasers play the essential role in using thin strands of glass fibres to transmit light signals that can be received and translated into communication format.
3. Material Processing: Lasers are used in cutting, welding and drilling with more accuracy and precision in even very hard materials because of their very high intensity.
4. Medical Science: Lasers are used to burn up brain tumour and to remove tattoos. Laser welding is also used reconnect blood vessel. Eye surgeons also use laser for ophthalmic operations like treatment of cataract, glaucoma and diabetic retinopathy.
5. Applications in Physics and Chemistry: Laser can be used to study the non-linear optics with special mention of harmonic generation and stimulated scattering. Lasers are also used for producing irreversible chemical change *i.e.,* laser photochemistry.
6. Lasers are used in printing technology.
7. Lasers are used effectively and efficiently in holography to analyse holograms with more precision.
8. Laser beam being of very high energy, has been mentioned as potential "death ray" type of incendiary weapon for use against energy missiles.

SOLVED EXAMPLES

Example 1: *Calculate the coherence length of a laser beam for which the band width* $\Delta v = 3000$ *Hz. Speed of light* $c = 3 \times 10^8$ *m/sec.* **(M.D.U., 2001, 2003, 2006)**

Solution: Given band width $\Delta v = 3000$ Hz

∴ Coherence time $\tau_c = \dfrac{1}{\Delta v}$ (See Eqn. 4.21)

$$= \frac{1}{3000} = \frac{10^{-3}}{3} \text{ sec.}$$

∴ Coherence length $l = c\tau_c$

$$= 3 \times 10^8 \times \frac{10^{-3}}{3} \text{ m}$$

$$= 10^5 \text{ m} = 100 \text{ km.}$$

Example 2: *For an ordinary source, the coherence time* $\tau_c = 10^{-10}$ *second. Obtain the degree of non-monochromaticity for wavelength* $\lambda_0 = 5400$ *Å.* **(M.D.U., 2002)**

Solution: Coherence time $\tau_c = 10^{-10}$ sec.

∴ Band width $\Delta v = \dfrac{1}{\tau_c} = \dfrac{1}{10^{-10}} = 10^{10}$ Hz

CHAPTER 4

For wavelength $\lambda_0 = 5400\ \text{Å} = 5400 \times 10^{-10}$ m

Frequency $v_0 = \dfrac{3 \times 10^8}{5400 \times 10^{-10}}$ Hz $= \dfrac{1 \times 10^{16}}{18}$ Hz

Degree of non-monochromaticity is given by

$$\frac{\Delta v}{v_0} = \frac{10^{10}}{\frac{1}{18} \times 10^{16}} = 18 \times 10^{-6} = 1.8 \times 10^{-5}.$$

QUESTIONS

1. Explain the terms: Spontaneous and stimulated emission, population inversion, optical pumping. (*M.D.U.*, *2009*)

2. Discuss the essential requirements for producing laser action. Describe a He-Ne laser. (*M.D.U.*, *2009*)

3. Describe the principle, construction and working of He-Ne gas laser. (*M.D.U.*, *2008*)

4. Discuss Einstein's coefficients. Derive relation between them. (*M.D.U.*, *2008*)

5. What are the specialities of laser light? Give description of semiconductor laser. (*M.D.U.*; *Dec. 2009*)

6. Write a note on He-Ne laser. (*M.D.U.*; *Dec. 2008*)

7. Describe the construction and working of a semiconductor laser. (*M.D.U.*, *2007*)

8. Discuss the characteristic features of a laser beam. (*M.D.U.*, *2007*)

9. What do you mean by lesers? Describe laser action. What are the characteristics of a laser beam? (*K.U.*, *B.T.*, *2007*)

10. Discuss the salient characteristics of a laser beam. (*K.U.*; *B.T., 2005; N.I.T.K.U., 2007*)

PROBLEMS

1. A laser beam has band width of 1200 Hz. Obtain its coherence length.
[**Ans.** 250 km] (*M.D.U.*, *Dec. 2006*)

2. For an ordinary source, the coherence time $\tau_c = 10^{-10}$ s. Calculate the degree of non-monochromaticity for wavelength $\lambda_0 = 6000$ Å. [**Ans.** 2×10^{-5}]