SEMESTER IV
Paper: PHS-A-CC-4-9-TH
Lasers: Ruby Laser and He-Ne Laser

1 Properties of Laser Beams

1.1 Spatial and Temporal Coherence

All wavetrains emitted by atoms or molecules have a finite length L or time span τ. At a distance greater than L or after a time τ two photons emitted from two coherent sources cannot maintain their constant phase relationship. So the coherence of the two sources depends on space and time. These are called spatial and temporal coherence. The relation between L and τ is $\tau = L/c$.

The coherence condition in a laser beam is maintained upto a certain length of the beam. This type of coherence is called the spatial coherence. The length upto which the coherence is maintained is called coherence length (L).

There is also a certain time interval over which the coherence condition is maintained. This type of coherence is called the temporal coherence. The time upto upto which the coherence is maintained is called coherence time τ.

The angular spread $\Delta\lambda$ for a laser beam is very small than the ordinary light beam. So the value of L and hence τ is very large for a laser beam. Therefore a laser beam maintains spatial and temporal coherence very well than any ordinary light beam.

1.2 Directionality

An ordinary source of light (like a sodium lamp) radiates in all possible directions. On the other hand, the output from a laser may be very close to an ideal uniform plane wave whose divergence is primarily due to diffraction effects.

The waves from stimulated emission by different atoms chain up in phase so as to form a continuing sine wave character over a much larger time τ than for a spontaneous emission. For a spontaneous emission $\tau \sim 10^{-10}$ sec, while that for a laser beam is $\sim 10^{-8}$ s to 10^{-6}s. Hence the spectral line width $\Delta\lambda$ is smaller for a laser beam. So a laser beam is relatively monochromatic.

In the usual sources of light a directional beam is obtained by collimation. The beam has two contributions to the angular spread: (i) θ_1 due to diffraction at the aperture of the collimatinfg lens and (ii) θ_2 which equals the angle subtended by the source size at the centre of the collimating lens.

For a laser beam the atoms separated laterally emit in phase agreement. This spatial coherence reduces θ_2 to nearly zero. The atoms or molecules emit in the same direction and also they agree in phase. Hence the only spread is θ_1. That is why a LASER beam is highly directional.

2 Ruby Laser

This is the first optical laser constructed by Maiman in 1960. It is a solid state three level pulsating laser. A single cylindrical crystal of Ruby was used whose two ends were flat, out of which one of the ends was completely silvered while the other end was partially silvered so that they can act fully and partially reflecting surfaces. Ruby consists of

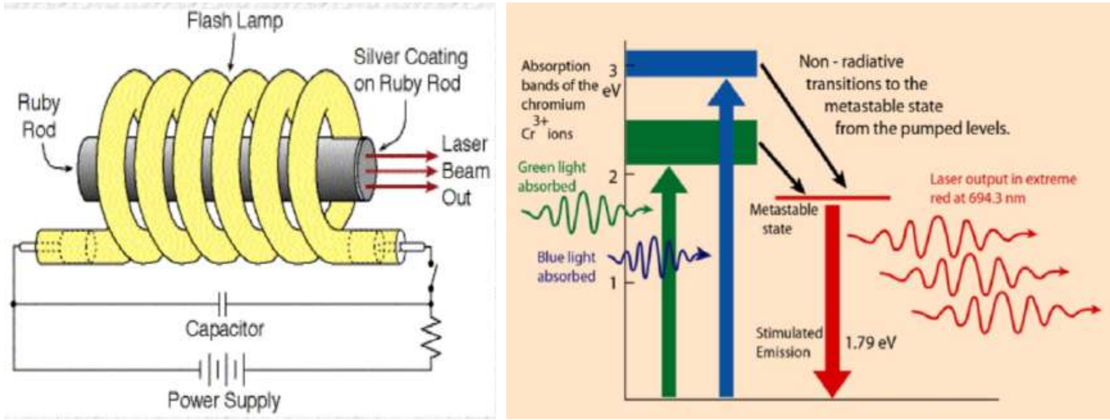

Figure 1: *Ruby Laser & The energy level diagram of Ruby Laser*

Aluminium Oxide (Al_2O_3) doped with chromium impurities. These impurity chromium ions give rise to the lasing action. The space between theses two faces is known as the resonant cavity in which light (photon) intensity can be built up by multiple reflections and through stimulated emission. The ruby rod is surrounded by a helical xexon flash light tube with an excitation source in the form of a power supply.

In this laser chromium ions are active centres which are responsible for the laser transition. The energy states of the Cr ions are shown in Fig 2. The chief characteristics of the energy levels of a Cr ion are that the bands have a lifetime which is $\leq 10^{-8}$ sec, where as the metastable state has a lifetime $\sim 3 \times 10^{-3}$ sec. In the normal state most of the chromium ions are in the ground sate. The Chromium ion in its ground state can absorb a photon (having wavelength $\sim 550nm$) and make a transition to one of the states in band (Marked green here). It could also absorb a photon (wavelength $\sim 400nm$) and make a transition to one of the states in the band (Marked blue here). In either case, it immediately makes a non-radiative transition in a time interval $\leq 10^{-8}$ sec to the metastable state. Since the metastable state has a very long lifetime, the no. of atoms in this state goes on increasing and one may achieve population inversion between the metastable state and ground state. Once population inversion is achieved, light amplification can take place.
In the original set up of Maiman, the flash lamp (filled with Xe- gas) was connected to the capacitor which was charged to a few kilovolts. the energy stored in the capacitor was discharged through the Xe lamp in a few milli-seconds. This results in the production of power, which is of the order of few megawatts. Some of this energy is absorbed by the chromium ions resulting in their excitation and subsequent lasing action.

3 He-Ne Laser

The helium-neon laser, fabricated by ali Javan and his coworkers, is the first sucessful gas lasers. It consists of a long and narrow discharge tube filled with about 1 torr (1 mm of Hg) of helium and about 0.1 torr of neon. This gas mixtures forms the lasing medium. The mixture is enclosed between a set of mirrors forming a resonant cavity. One of the mirrors is completely reflecting, while the other is partially reflecting. The energy level diagram of a He-Ne laser is shown in the figure 3.

When a discharge is passed through the gas mixture, electrons are accelerated down

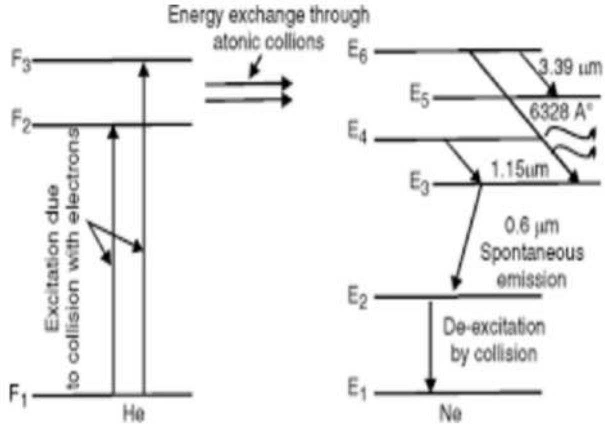

Figure 2: *The energy levels of He-Ne Laser*

the tube. These accelerated electrons collide with the He-atoms and excite them to higher energy levels F_2 and F_3 from F_1. These F_2 and F_3 happen to be metastable. Moreover F_2 and F_3 corresponds approximately to some of the excited levels of Ne. Thus, when the He atoms in the levels F_2 and F_3 collide with Ne atoms in the ground level E_1 an energy exchange takes place. as a result the Ne atoms get excited to the levels E_4 and E_6, and the He atoms are deexcited to the ground level F_1. Because of the long lifetimes of the level F_2 and F_3, this process of energy transferhas a high probability.
Thus the neon excited level E_4 and E_6 are populated and hence a state of population inversion is created between the levels E_4 (orE_6) and the lower lying energy levels E_3 (orE_5). The various transitions lead to emission of wavelengths of 3.39 μm, 1.15μm and 6328$\mathring{A}$. The first two correspond to the infrared region, while the last wavelength lies in the visible region. Specific frequency selection may be obtained by employing mirrors which reflect only a small band of frequencies about the frequency of interest.

The excited neon atoms drop down from the level E_3 to the level E_2 by spontaneous emiting a photon around $\lambda = 6000\mathring{A}$. The pressure of the two gasses in the mixture are so chosen that there is an efficient transfer of energy from He to Ne atoms. Since the level E_2 is metastable, there is a finite probability of the exitation of Ne atoms from E_2 to E_3 leading to a quenching of the population inversion. When a narroow tube is used, the Ne atoms in the level E_2 collide with the walls of the tube and get deexcitecd to the level E_1. The typical power output of the He-Ne LASERs liw between 1 to 50 mW of continuous wave for inputs about 5-10 W. It is to be noted that the light obtained from a He-Ne laser is much more monochromatic than that obtained from a Ruby Laser.

Book Suggested:Lasers; Theory and Applications, K. Tyagrajan and A. K. Ghatak
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