copy

Dr. T.H. Maimans fabricated Ist laser "Ruby laser" in 1960
It is a solid state laser of Red color : 694.3 nm of wavelength   [1]

Kuldeep Kaur

LASER

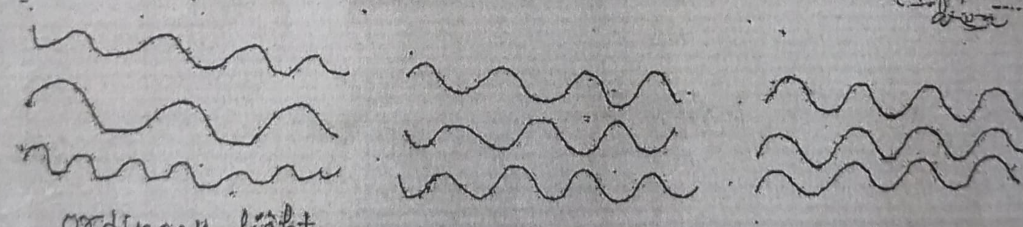
LASER

Light Amplification by Stimulated Emission of Radiation

Laser is a device that emit light (electromagnetic Radiation) through a process is called stimulated emission.

Laser beam have some remarkable properties,

1. The light is very nearly monochromatic (single wavelength)
2. The light is coherent, with the waves all exactly in phase with one another.
3. A laser beam diverges hardly at all. (Directional)
4. The beam is extremely intense, more intense by far than the light from any other source (High intensity) ∝ no. of photons
   then



ordinary light — monochromatic light — monochromatic Coherent light

Laser produces a beam of light whose waves all have the same frequency (monochromatic) and are in phase with one another (coherent). The beam is also well collimated and so spreads out very little, even over long distances.

Books

1) Applied physics → Beiser A, Ghatak A
2) Laser & Non-linear optics → B.B. Laud
3) optics → A. Ghatak
4) Practical → C.L. Arora
B.Sc. Physics

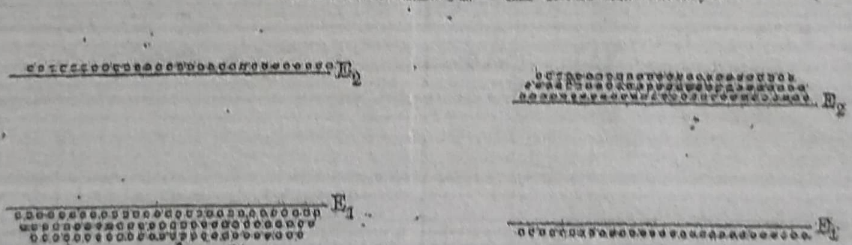
Differences between Stimulated and spontaneous emission of radiation

S.no	Stimulated Emission	Spontaneous emission
1	An atom in the excited state is induced to, return to the ground state, thereby resulting in two photons of same frequency and energy is called Stimulated emission	The atom in the excited state returns to the ground state thereby emitting a photon, without any external inducement is called Spontaneous emission
2	The emitted photons move in the same direction and is highly directional	The emitted photons move in all directions and are random
3	The radiation is highly intense, monochromatic and coherent	The radiation is less intense and is incoherent.
4	The photons are in phase, there is a constant phase difference.	The photons are not in phase (i.e.) there is no phase relationship between them
	The rate of transition is given by $R_{21}(St) = B_{21}\, u(\nu)\, N_2$	The rate of transition is given by $R_{21}(Sp) = A_{21}\, N_2$

Population Inversion:

Population Inversion creates a situation in which the number of atoms in higher energy state is more than that in the lower energy state.

Usually at thermal equilibrium, the number of atoms N_2 i.e., the population of atoms at excited state is much lesser than the population of the atoms at ground state N_1 that is $N_1 > N_2$.



At thermal equilibrium

population inversion

The Phenomenon of making $N_2 > N_1$ i.e, the number of particles N_2 more in higher energy level than the number of particles N_1 in lower energy level is known as Population Inversion or Inverted population. The states of system, in which the population of higher energy state is more in compression to the population of lower energy state are called negative temperature states.

Conditions of Population inversion.

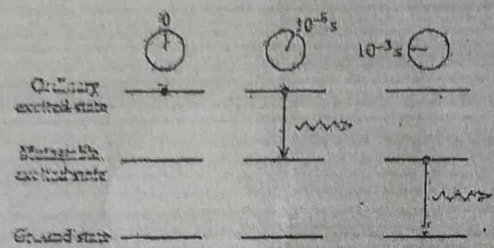
1. There must be at least two energy levels $E_2 > E_1$.

2. There must be a source to supply the energy to the medium.

3. The atoms must be continuously raised to the excited state.

Metastable State

The key to the laser is the presence in many atoms of one or more excited energy levels whose lifetimes may be 10^{-3} s or more instead of the usual 10^{-8} s. Such relatively long-lived states are called metastable (temporarily stable)



An atom can exist in a metastable energy level for a longer time before radiating than it can in an ordinary energy level.

An atom can be excited to a higher level by supplying energy to it. Normally, excited atoms have short life times and release their energy in a matter of 10^{-8} seconds through spontaneous emission. It means atoms do not stay long to be stimulated. As a result, they undergo spontaneous emission and rapidly return to the ground level; thereby population inversion could not be established. In order to do so, the excited atoms are required to 'wait' at the upper energy level till a large number of atoms accumulate at that level. In other words, it is necessary that excited state have a longer lifetime. A Meta stable state is such a state. Metastable can be readily obtained in a crystal system containing impurity atoms. These levels lie in the forbidden gap of the host crystal. There could be no population inversion and hence no laser action, if metastable states don't exist.

Pumping

The process to achieve the population inversion in the medium is called Pumping action. It is essential requirement for producing a laser beam.

The methods commonly used for pumping action are;

1. Optical pumping (Excitation by Photons)
2. Electrical discharge method (Excitation by electrons)
3. Direct conversion
4. In elastic atom – atom collision between atoms

Components of Lasers

1. Active Medium:

It is the material in which the laser action takes place. The active medium may be solid crystals such as ruby or Nd:YAG, liquid dyes, gases like CO2 or Helium / Neon, or semiconductors such as GaAs. This medium decides the wavelength of laser radiation. Active mediums contain atoms which can produce more stimulated emission than spontaneous emission and cause amplification they are called "Active Centers".

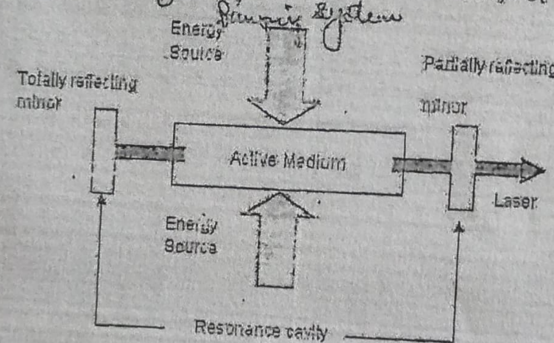
" Atoms are "active centers"

2. Pumping Energy Source (Excitation Mechanism):

Energy Source (Excitation mechanisms) pumps the active centers from ground state to excited state to achieve population inversion. The pumping by energy source can be optical, electrical or chemical depending on the active medium.

3. *Resonance Cavity:*

Resonance cavity consists of active medium enclosed between two parallel mirrors one is highly reflective mirror (100% reflective) and the other is partially transmissive mirror (99% reflective). It is basically a feedback device that reflects undesirable (off-axis)

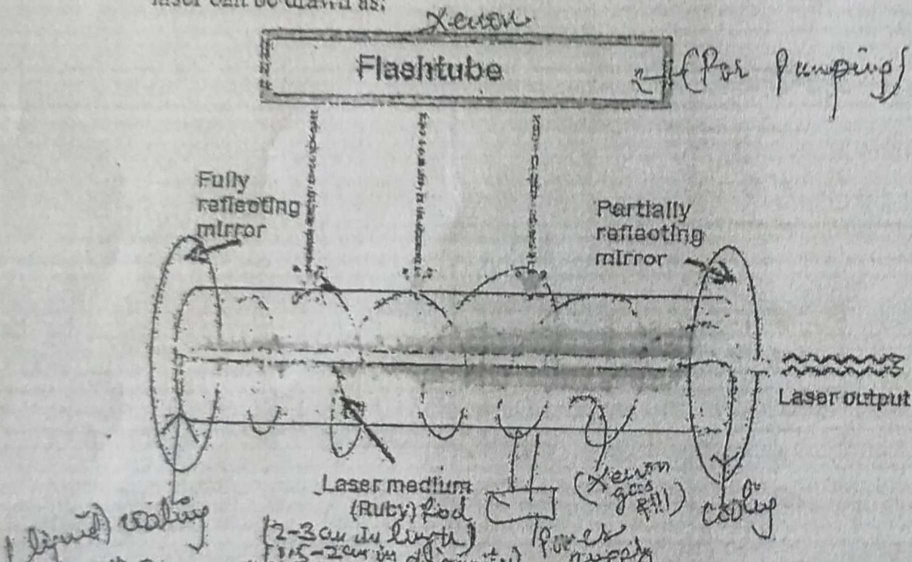


photons out of the system and directs the desirable (on-axis) photons back and forth through the active medium and in the process the number of photon is multiplied due to stimulated emission causing thereby ~~equilibrium~~ amplification.

Different Type of lasers

Ruby Laser (Solid state laser)

The first working laser was built in 1960 by Maiman, using a ruby crytal and so called the Ruby laser. Ruby belongs to the family of gems consisting of Al2O3 with various types of impurities. For example, pink Ruby contains 0.05% Cr atoms. The schematic diagram of ruby laser can be drawn as:



It consists of three parts:
1) An active medium
2) Resonant cavity (Two mirrors)
3) An exciting system, usually made up of the flash tubes for active population inversion + a power supply

Construction of Ruby Laser

The ruby laser consists of a ruby rod, which is made of chromium doped ruby material. At the opposite ends of this rod there are two silver polished mirrors. Whose one is fully polished and other is partially polished. A spring is attached to the rod with fully polished end for adjustment of wave length of the laser light. Around the ruby rod a flash light is kept for the pump input. The whole assembly is kept in the glass tube. Around the neck of the glass tube the R.F source and switching control is designed in order to switch on and off the flash light for desired intervals.

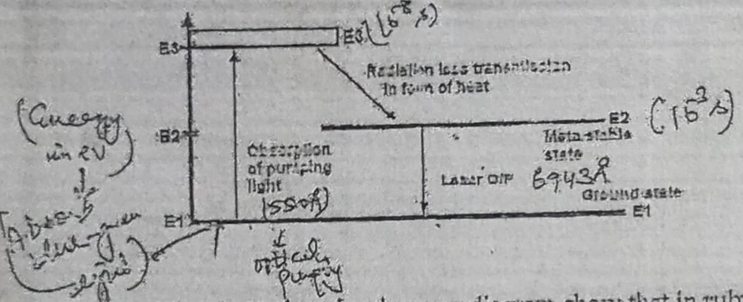
Operation of Ruby Laser:

When we switch on the circuit the R.F operates. As a result, the flash of light is obtained around the ruby rod this flash causes the electrons within ruby rod to move from lower energy band towards higher rod. ~~this flash causes the electrons within ruby rod to move from lower energy band towards higher energy band.~~ The population inversion take place at high energy band and electrons starts back to travel towards the lower energy band. During this movement the electron emits the laser light. This emitted light travels between the two mirrors where cross reflection takes place of this light. The stimulated laser light now escapes from partially

The Active material in the Ruby is Chromium ion. The color (pink or red) Ruby crystal depends upon the amount of Cr in it.

polished mirror in shape of laser beam. The spring attached with the fully polished mirror is used to adjust the wave length equal to λ/2 of laser light for optimum laser beam. The switching control of the R.F source is used to switch on and off the flash light so that excessive heat should not be generated due to very high frequency of the movement of the electron. (cooling liquid N_2)

Energy Level Diagram for Ruby Laser



The above three level energy diagram show that in ruby lasers the absorption occurs in a rather broad range in the green part of the spectrum. This makes raise the electrons from ground state E_1 to the band of level E_3 higher than E_1. At E_3 these excited levels are highly unstable and so (10^{-8} s) the electrons decays rapidly to the level of E_2. This transition occurs with energy difference $(E_1 - E_2)$ given up as heat (radiation less transmission). The level E_2 is very important for stimulated emission process and is known as Meta stable state. Electrons in this level have an average life time of about 5m.s before they fall to ground state. After this the population inversion can be established between E_2 and E_1. The population inversion is obtained by optical pumping of the ruby rod with a flash lamp. A common type of the flash lamp is a glass tube wrapped around the ruby rod and filled with xenon gas. When the flash lamp intensity becomes large enough to create population inversion, then stimulated emission from the Meta stable level to the ground level occurs which result in the laser output. Once the population inversion begins, the Meta stable level is depopulated very quickly. Thus the laser output consists of an intense spike lasting from a few Nano sec to μsec, after stimulated emission spike, population inversion builds up again and a 2nd spike results. This process continues as long as the flash lamp intensity is enough to create the population inversion.

Advantages of Ruby Lasers

- Beam diameter of the ruby laser is comparatively less than CO_2 gas lasers.
- Output power of Ruby laser is not as less as in He-Ne gas lasers.
- Since the ruby is in solid form therefore there is no chance of wasting material of active medium.
- Construction and function of ruby laser is self-explanatory.

O/P of Ruby laser :- In this for excitation of population inversion is supplied in the form of burst flashes or pulse of light. So ruby laser has a pulse O/P, hence called pulse laser

* The o/p of laser beam is not continuous but the light is emitted in pulses
* The monochromaticity may be affected by crystalline imperfection, thermal distortion & scattering.

Disadvantages of Ruby Laser

* In ruby lasers no significant stimulated emission occurs, until at least half of the ground state * A large amount of energy is required to trigger laser oscillator
* ~~electrons have been excited to the Meta-stable state.~~
* Efficiency of ruby laser is comparatively low.
* Optical cavity of ruby laser is short as compared to other lasers, which may be considered a disadvantage.
* ~~disadvantage.~~ Frequent cooling is required as a lot of energy is produced during operation.

Applications of ruby Laser:

* Due to low output power they are class-I lasers and so may used as toys for children's.
* It can be used in schools, colleges, universities for science programs.
* It can be used as decoration piece & artistic display.
* It is used for drilling brittle material, soldering, welding.
* It is used as a high power source of pulse coherent radiation in interferometry & in pulsed Holography.

(1) Problems: The ground state & Excited state of the laser is separated by 1.8 eV. Calculate the ~~no. of~~ ratio of no. of atoms in the E.S to G.S and wavelength of radiation emitted at 27°C.

Ans $E_2 - E_1 = 1.8eV = 1.8 \times 1.6 \times 10^{-19} = 2.88 \times 10^{-19} J$ $T = 27°C = 300 K$.

$K = 1.38 \times 10^{-23} J/K$, no of atoms in the energy level $E = N = e^{-E/KT}$

N_2 = no of atoms in E.S, N_1 = no of atoms in the G.S

$$\frac{N_2}{N_1} = e^{-(E_2-E_1)/KT} \Rightarrow \frac{N_2}{N_1} = e^{-(2.88 \times 10^{-19})/1.38 \times 10^{-23} \times 300} = 6.14 \times 10^{-31}$$

Thus $E = 6.14 \times 10^{-31}$

$$E_2 - E_1 = \frac{hc}{\lambda} = 6.14 \times 10^{-31} \Rightarrow \lambda = \frac{hc}{2.88 \times 10^{-19}} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{2.88 \times 10^{-19}}$$

$= 6900 Å$

(2) Find the ratio of population of higher energy state to lower energy state when the optical pumping is used at 27°C and photons of wavelength $6902 \times 10^{-8} m$ are emitted.

$T = 27°C$
$= 300K$

Ans $E_2 - E_1 = h\nu = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{6982 \times 10^{-8}} = 2.848 \times 10^{-21} J$.

∴ Population of energy $E = N = e^{-E/KT}$

$$\frac{N_2}{N_1} = e^{-(E_2-E_1)/KT} = e^{-(2.848 \times 10^{-21})/1.38 \times 10^{-23} \times 300} = 0.503$$

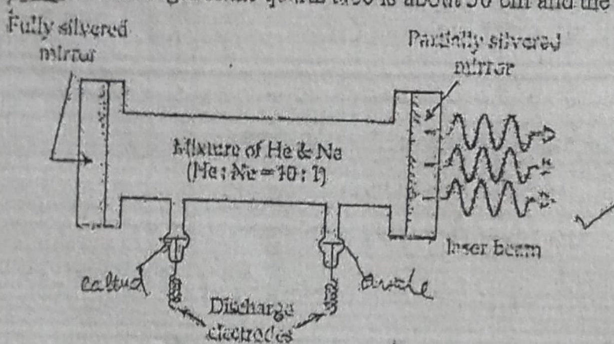
Ist Gas laser developed by Ali-Javan and his co-workers in 1961. He-Ne lasers are the most popular continuous wave la

Helium -Neon (He-Ne) Laser

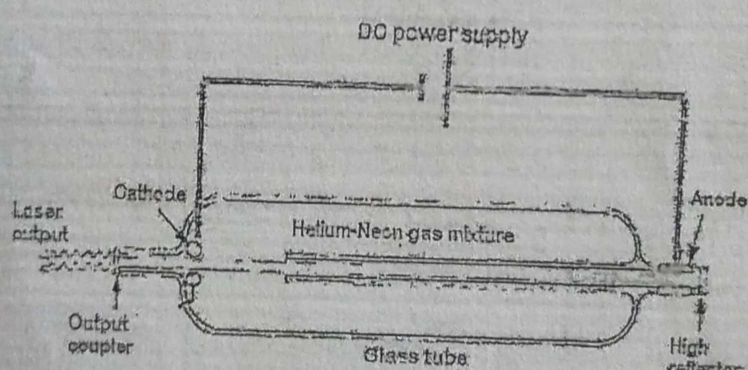
Construction:

(i) Active medium:

It is a gas laser, which consists of a narrow quartz tube filled with a mixture of helium and neon gases in the ratio 10:1 respectively, at low pressure (~0.1 mm of Hg). Ne atoms act as active centres and responsible for the laser action, while He atoms are used to help in the excitation process. The length of the quartz tube is about 50 cm and the diameter is about 1 cm.



He-Ne LASER

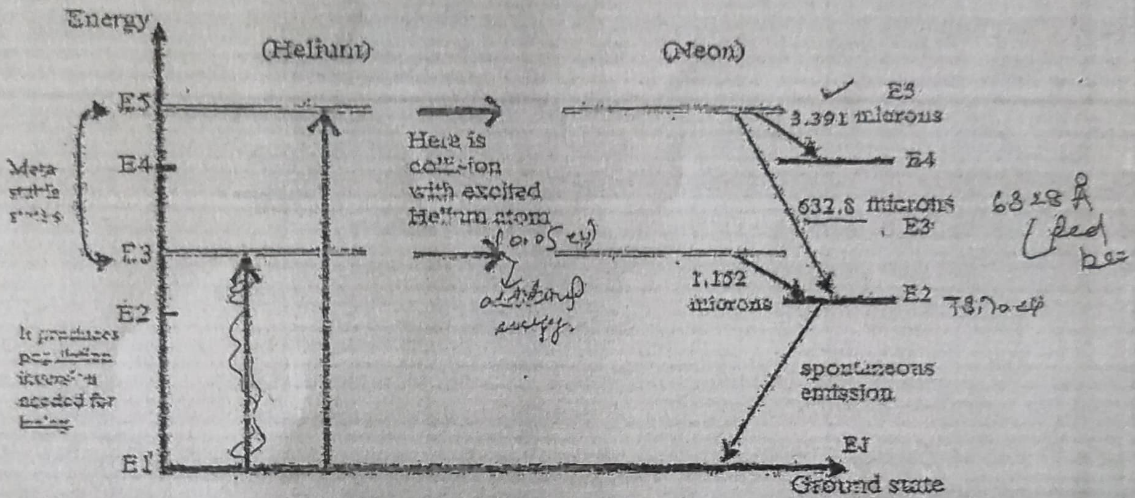


ii) Optical resonator:

To construct the optical resonator cavity, two parallel mirrors are placed at the ends of the quartz tube one of them is partly transparent while the other is fully reflecting. The spacing between the mirrors is adjusted such that it should be equal to the integral multiple of half-wavelengths of the laser light.

(iii) Pumping system:

The pumping is done through electrical discharge by using electrodes that are connected to a high frequency alternating current source.



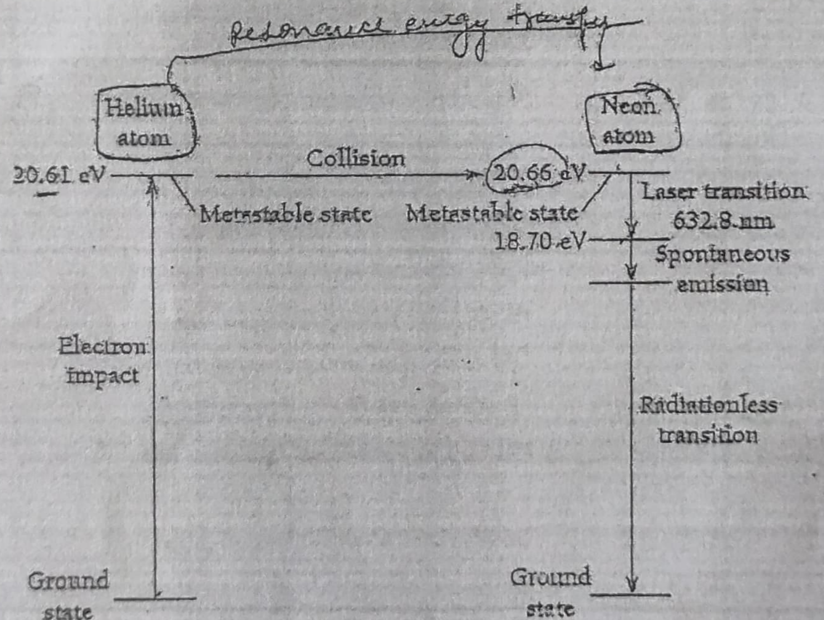


Figure: The helium-neon laser. In a four-level laser such as this, continuous operation is possible. Helium-neon lasers are commonly used to read bar codes.

The common helium-neon gas laser achieves a population inversion in a different way. A mixture of about 10 parts of helium and 1 part of neon at a low pressure (1 torr) is placed in a glass tube that has parallel mirrors, one of them partly transparent, at both ends. The spacing of the mirrors is again (as in all lasers) equal to an integral number of half-wavelengths of the laser light. An electric discharge is produced in the gas by means of electrodes outside the tube

low atomic no., broadening

connected to a source of high-frequency alternating current, and collisions with electrons from the discharge excite He and Ne atoms to metastable states respectively 20.61 and 20.66 eV above their ground states. Some of the excited He atoms transfer their energy to ground-state Ne atoms in collisions, with the 0.05 eV of additional energy being provided by the kinetic energy of the atoms. The purpose of the He atoms is thus to help achieve a population inversion in the Ne atoms.

The laser transition in Ne is from the metastable state at 20.66 eV to an excited state at 18.70 eV, with the emission of a 632.8-nm photon. Then another photon is spontaneously emitted in a transition to a lower metastable state; this transition yields only incoherent light. The remaining excitation energy is lost in collisions with the tube walls. Because the electron impacts that excite the He and Ne atoms occur all the time, unlike the pulsed excitation from the xenon flash lamp in a ruby laser, a He-Ne laser operates continuously. This is the laser whose narrow red beam is used in supermarkets to read bar codes. In a He-Ne laser, only a tiny fraction (one in millions) of the atoms present participates in the laser process at any moment.

Characteristics of He-Ne Laser

The He-Ne laser is a relatively low power device with an output in the visible red portion of the spectrum. The most common wavelength produced by He-Ne lasers is 632.8nm, although two lower power (1.152μm and 3.391μm) infrared wavelengths can be produced if desired. Majority of He-Ne lasers generate less than 10m watt of power, but some can be obtained commercially with up to 50m watts of power. For He-Ne lasers the typical laser tube is from 10 to 100 cm in length and the life time of such a tube can be as high as 20,000 hours.

Applications / Uses of He-Ne Laser

The Helium-Neon gas laser is one of the most commonly used laser today because of the following applications.

- He-Ne lasers are produced in large quantities from many years.
- Many schools / colleges / universities use this type of laser in their science programs and experiments.
- He-Ne lasers also used in super market checkout counters to read bar codes and QR codes.
- The He-Ne lasers also used by newspapers for reproducing transmitted photographs.
- He-Ne lasers can be use as an alignment tool.
- It is also used in Guns for targeting.

Advantages of He-Ne Laser

* operates without damage at higher temperatures
* He-Ne laser has very good coherence property.
* He-Ne laser can produce three wavelengths that are 1.152μm, 3.391 μm and 632.8nm, in which
* the 632.8nm is most common because it is visible usually in red color.
* He-Ne laser tube has very small length approximately from 10 to 100cm and best life time of 20.000 hours.
* Cost of He-Ne laser is less from most of other lasers.
* Construction of He-Ne laser is also not very complex. & high stability
* He-Ne laser provide inherent safety due to low power output.

Disadvantages of He-Ne Laser

The weak points of He-Ne laser are

* It is relatively low power device means its output power is low. ~~&~~ limited to low power task
* He-Ne laser is low gain system/ device.
* To obtain single wavelength laser light, the other two wavelengths of laser need suppression, which is done by many techniques and devices. So it requires extra technical skill and increases the cost also.
* High voltage requirement can be considered its disadvantage.
* Escaping of gas from laser plasma tube is also its disadvantage.

problems

(3) If wavelength of the laser beam is 6550Å, calculate the energy and momentum of photon.

$\lambda = 6550\,Å$

$$E = h\nu = \frac{hc}{\lambda} = \frac{6.63\times10^{-34}\times3\times10^{8}}{6550\times10^{-10}}$$

$$E = 3.03\times10^{-19} J$$

De-Broglie hypothesis

$$\lambda = \frac{h}{p} \Rightarrow p = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{6550\times10^{-10}}$$

$$= 1.012\times10^{-27} kg\,m/s$$

(4) Find the ratio of population of the two energy state of the active medium producing laser transition between which has wavelength 632 Assume temperature 300K

$$\Delta E = \frac{hc}{\lambda} = 3.143\times10^{-19} J$$

$$\frac{N_1}{N_0} = e^{-\Delta E/kT} = e^{-75.92} = 1.06 \times$$

(5) A certain ruby laser emits 1J pulses of light whose wavelength is 694nm. what is the minimum Cr^{3+} ions in the ruby laser.

$\lambda = 694nm$, $E = 1J$ $\quad E = n\frac{hc}{\lambda} \Rightarrow n = \frac{E\lambda}{hc}$

$$n = \frac{1\times694\times10^{-9}}{6.62\times10^{-34}\times3\times10^{8}} = 3.49\times10^{18}$$

The Hungarian-British physicist Dennis Gabor was awarded the Nobel Prize in 1971.

Greek words < Holos → whole, graphe → writing/drawing

PRINCIPLE OF HOLOGRAPHY

The basic principle of holography is to create the image using two simultaneous beams of light, that interfere with each other to form a complex image on a suitable photographic film. These two beams of lights are created by splitting a light source in two with one source reflecting light from the object to be photographed on the film and the other falling directly on it from the source. The image developed in this way is the hologram. The light source used for holography is usually a laser light.

When light from any source falls on the film hologram, it changes this light to reconstruct the light pattern of original object, creating a three dimensional image.
Holography operates in two stages namely recording and reconstruction. Recording is the process of making the hologram and reconstruction is the process of reading the hologram.

(A) RECORDING OF HOLOGRAM

The recording of hologram is based on the phenomenon of interference. . It requires a laser source, a plane mirror or beam splitter, an object and a photographic plate. A laser beam from the laser source is incident on a plane mirror or beam splitter. As the name suggests, the function of the beam splitter is to split the laser beam. One part of splitted beam, after reflection from the beam splitter, strikes on the photographic plate. This beam is called reference beam. While other part of splitted beam (transmitted from beam splitter) strikes on the photographic plate after suffering reflection from the various points of object. This beam is called object beam.

The object beam reflected from the object interferes with the reference beam when both the beams reach the photographic plate. The superposition of these two beams produces an interference pattern (in the form of dark and bright fringes) and this pattern is recorded on the photographic plate. The photographic plate with recorded interference pattern is called hologram. Photographic plate is also known as Gabor zone plate in honour of Denis Gabor who developed the phenomenon of holography.

Each and every part of the hologram receives light from various points of the object. Thus, even if hologram is broken into parts, each part is capable of reconstructing the whole object.