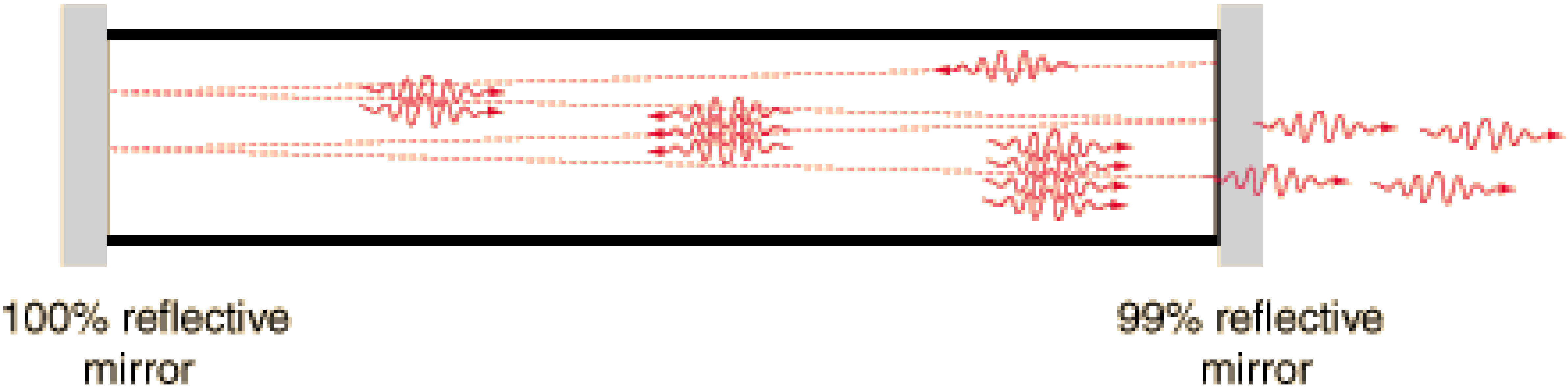
Module-2

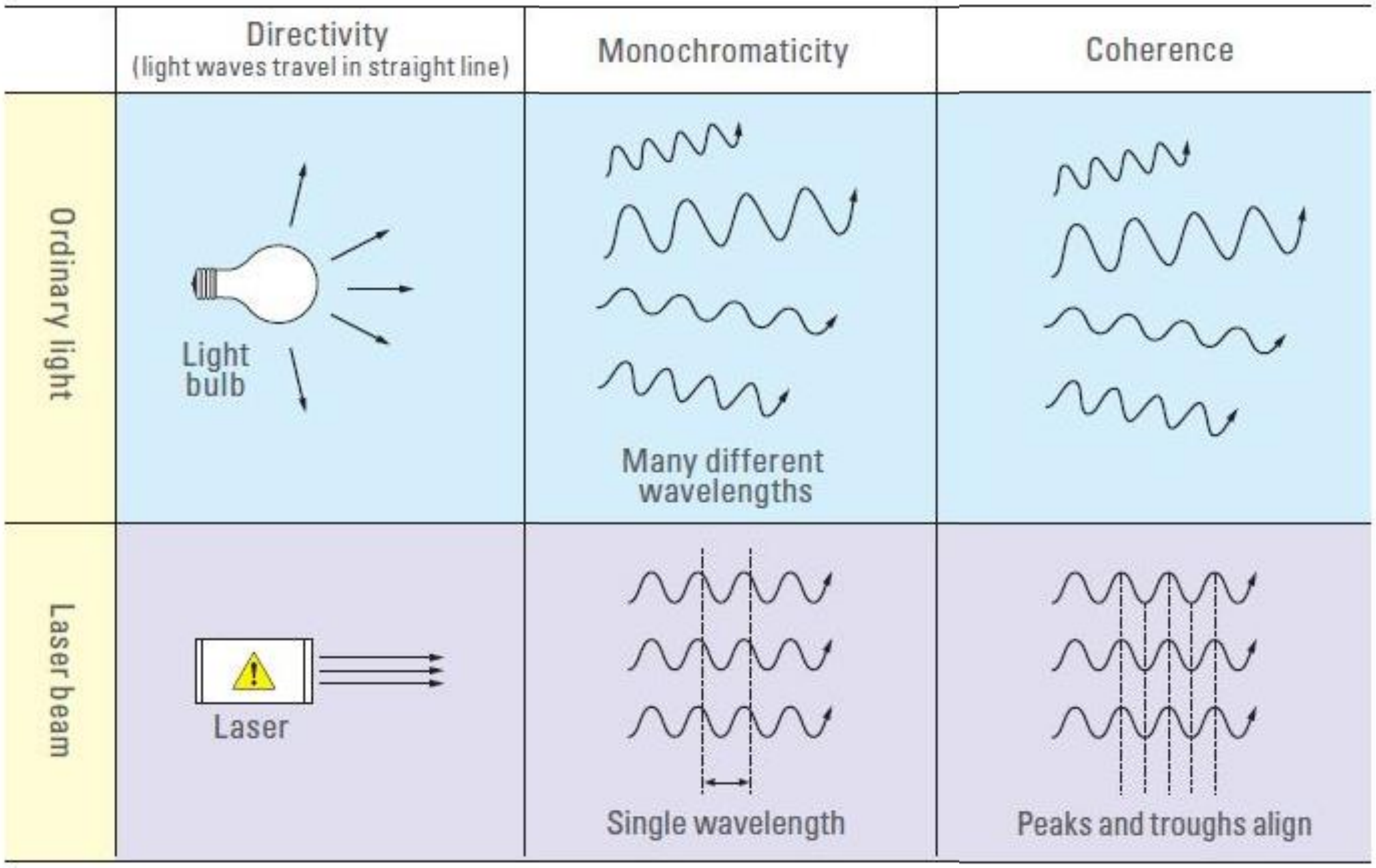
Diffraction (Laser and Optical fiber)

What is Laser?

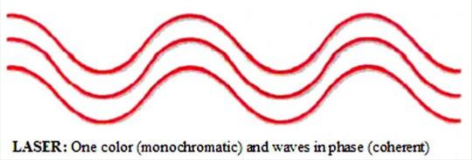
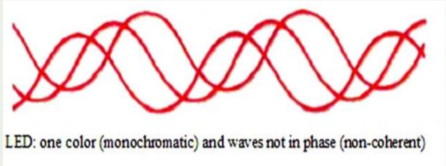
Light Amplification by Stimulated Emission of Radiation



What Is the Difference Between Ordinary Light and Laser Light?

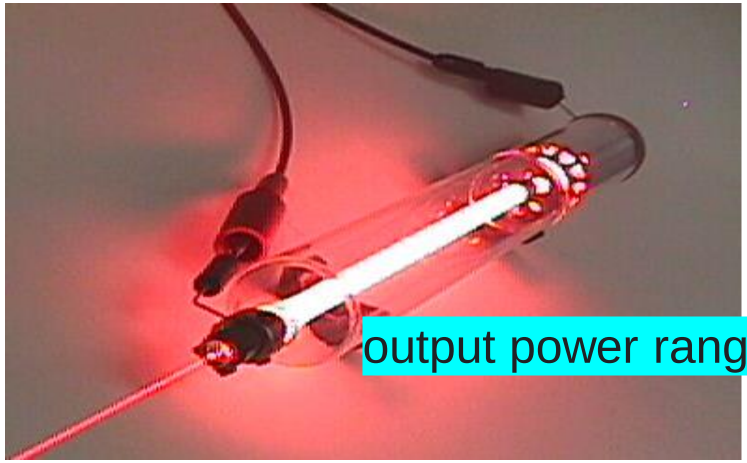


Laser & Ordinary Light Comparison:

LASER	ORDINARY LIGHT
Highly Monochromatic-Single wavelength	Polychromatic- More than one wavelength
Highly Coherent 	Not coherent 
Stimulated Emission is responsible	Spontaneous Emission is responsible
Highly Directional	Not directional
Have high energy	Have poor energy

- **Types of LASER**

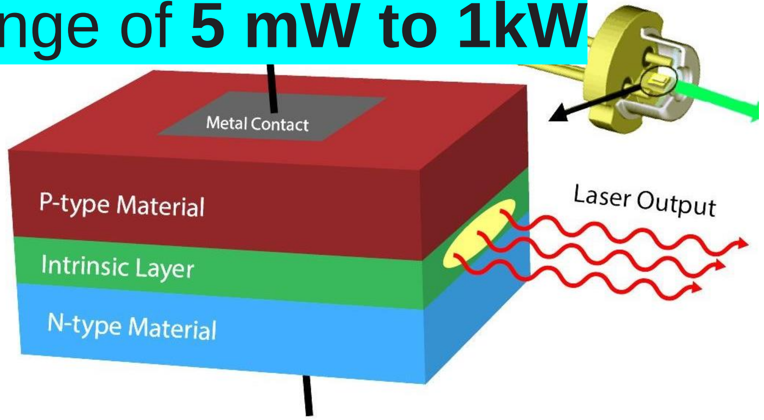
He Ne laser



output power range of **5–50 mW**

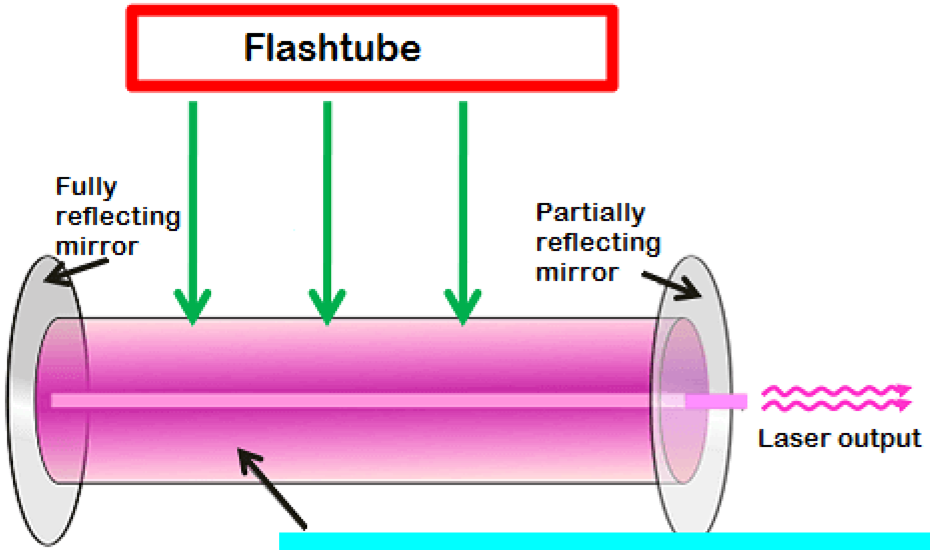
Semiconductor Diode laser

output power range of **5 mW to 1kW**



LASER DIODE CONSTRUCTION

Nd:YAG Laser

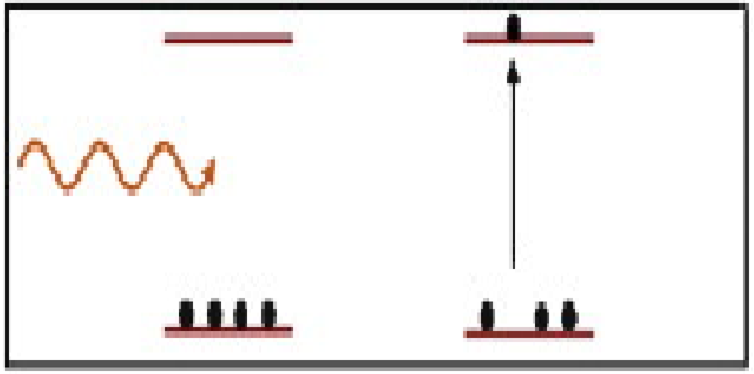


output power range of **kW–MW**

To understand the principal of working of laser

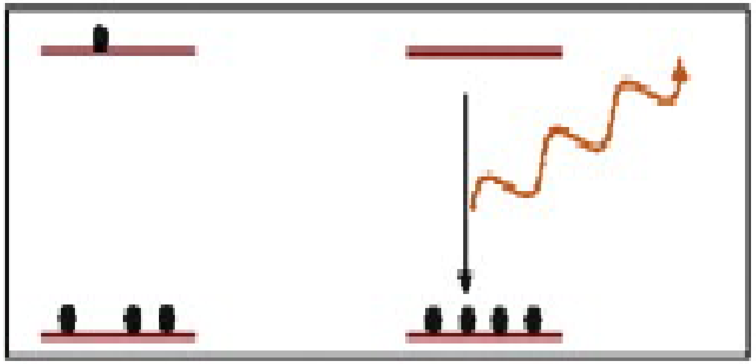
Lets understand

1. Stimulated Absorption



An atom in a **lower level absorbs a photon of frequency hv and moves to an upper level**.

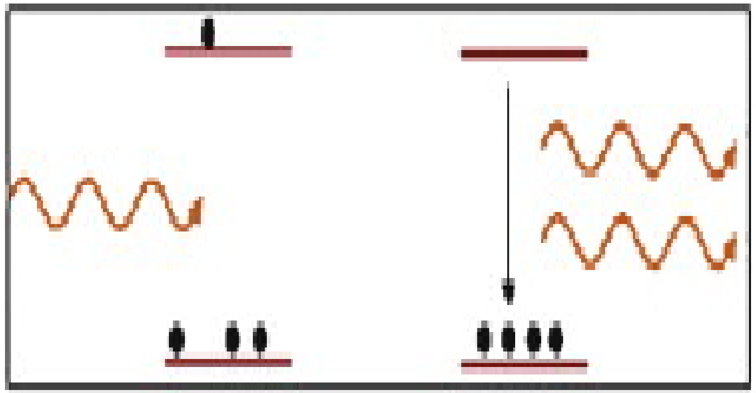
2. Spontaneous Emission



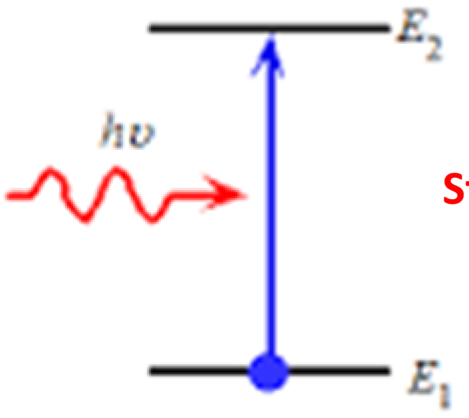
An atom in an upper level can decay spontaneously to the lower level and emit a photon of frequency hv

When an electron is in a higher energy level and returns to the ground state through an incident photon, a new photon is generated with exactly the same frequency and same phase.

3. Stimulated Emission

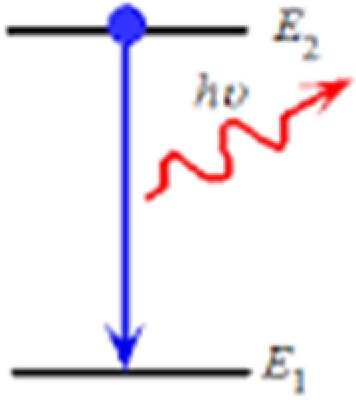


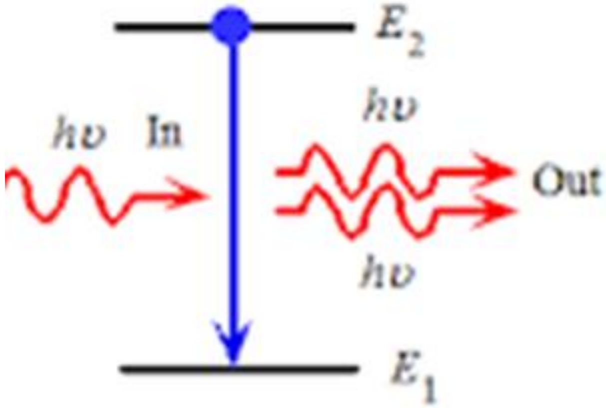
PEHCHAN KON



Stimulated Absorption

Spontaneous Emission



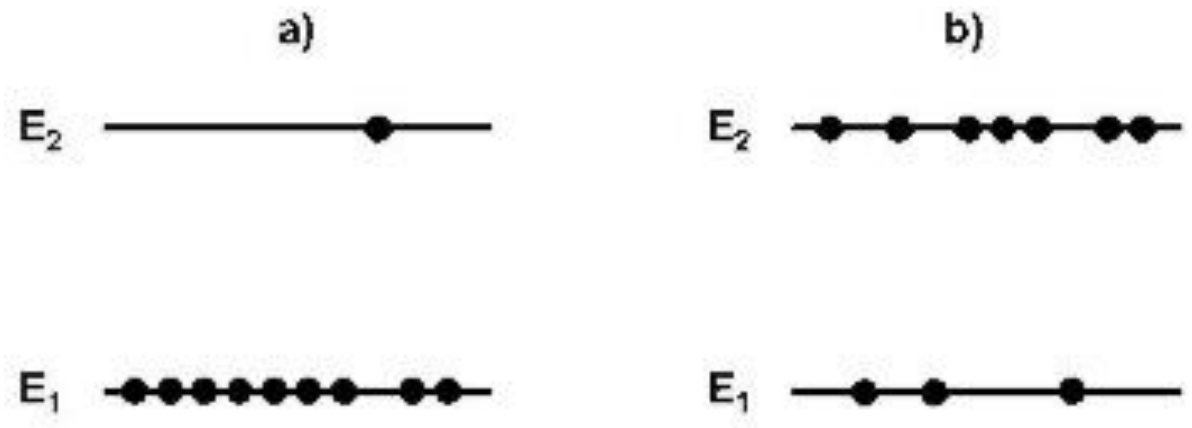


Stimulated Emission

For **stimulated emission** the atoms must present at a higher energy levels

Shortly, for stimulated emission, the population of atoms at higher energy levels must be greater than at lower energy levels.

Population inversion

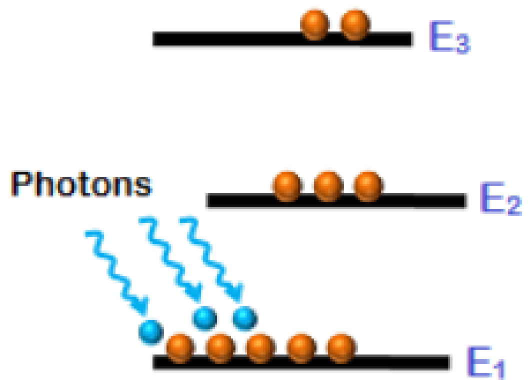


When no of atoms or electrons are more in higher energy level than lower energy level is called population inversion.

Pumping Process:

The process of increasing the number of atoms at higher energy levels from lower energy levels is called pumping process

Commonly used pumping types are: —

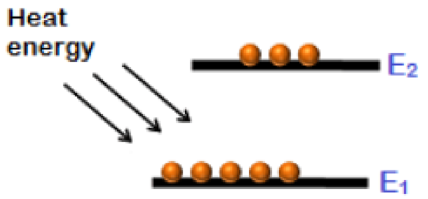


Optical pumping: light is used to raise the atoms from lower to higher energy states.

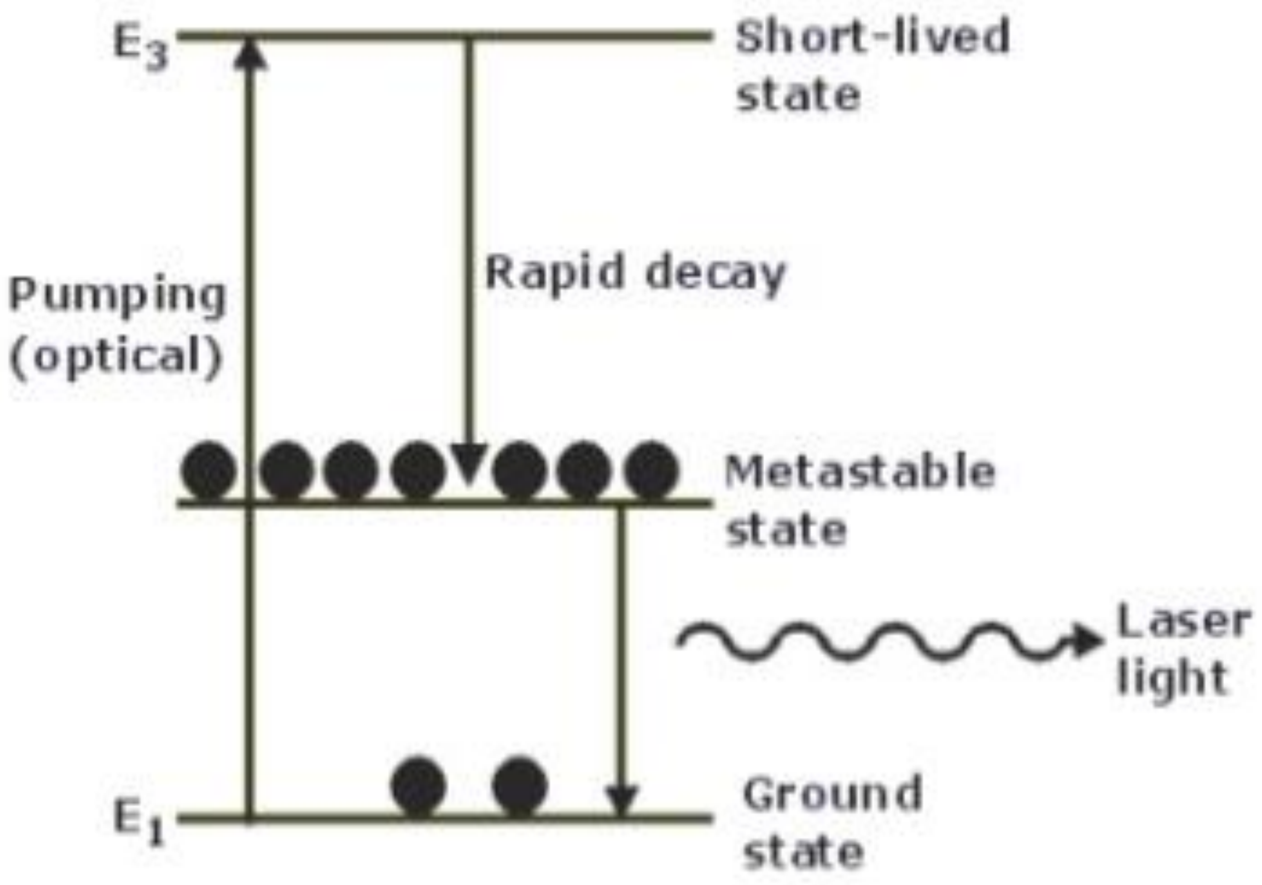
Chemical pumping: chemical reactions are used to raise the atoms at higher energy level.

Electrical pumping: A strong field is applied to the atomic system with the use of high voltage power supply. The high energy atoms collide with the atoms and transfer their kinetic energy to the later. As a result, atoms rise to the higher states

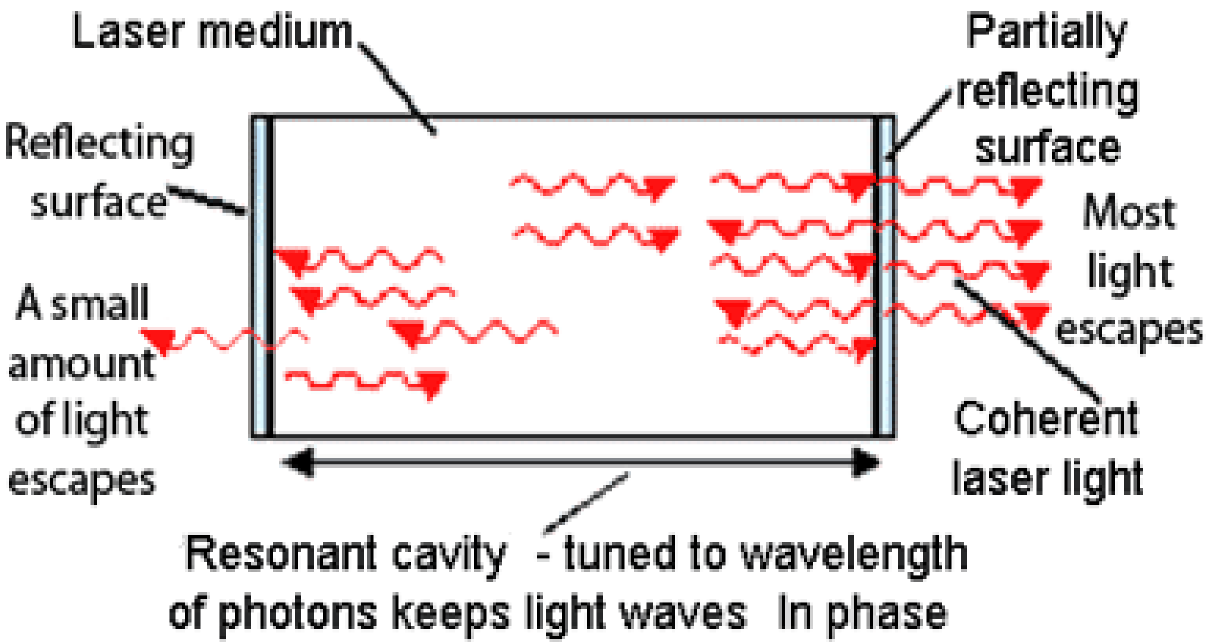
Direct conversion: In this method the electrical energy directly creates the state of population inversion and laser is produced.



To achieve population inversion we must have metastable states. These are excited sates (higher energy levels) where atoms stay for little longer times. These excited states were atom stays longer time is called metastable state

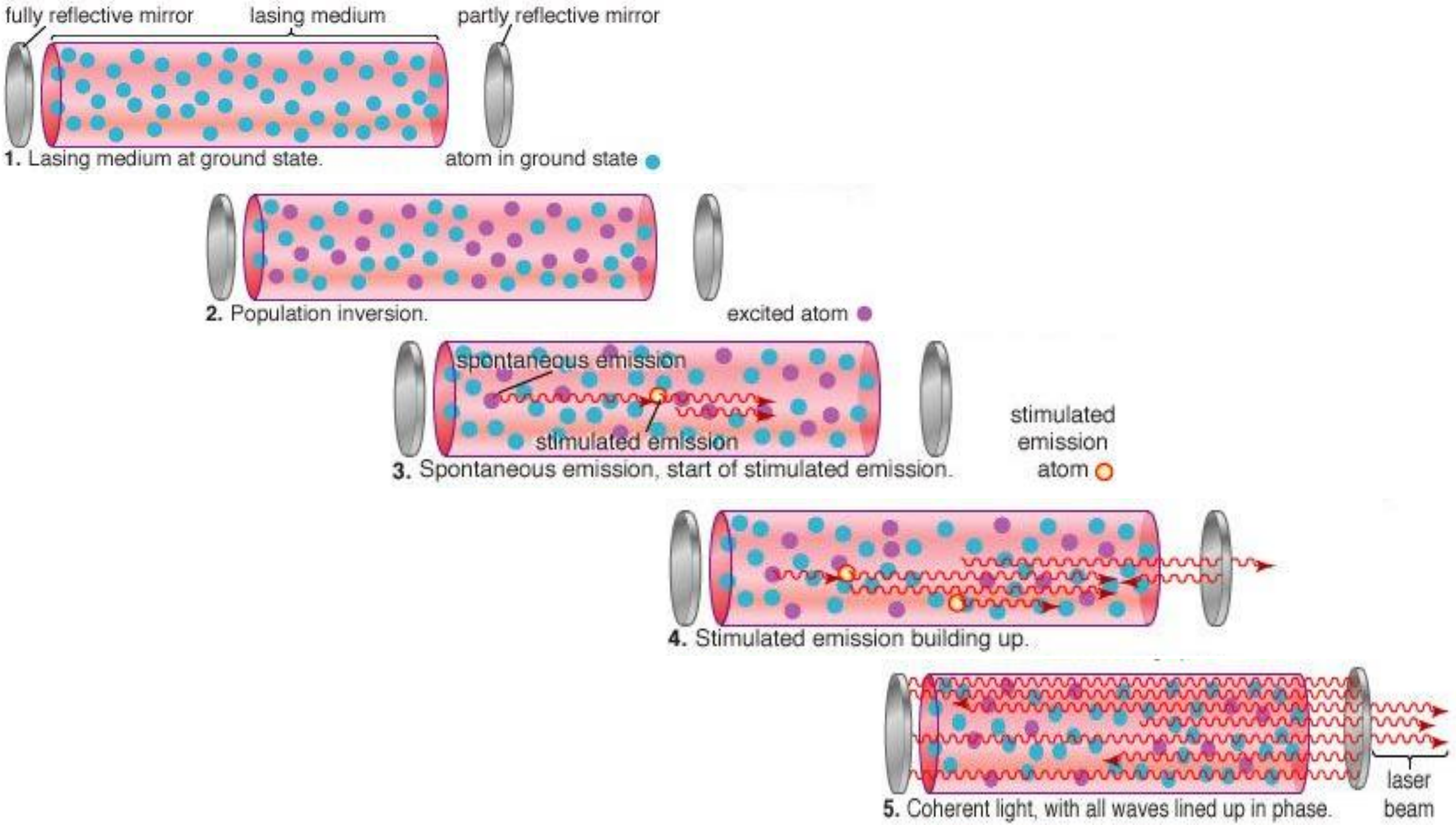


Resonant cavity



- An optical resonating **cavity** or optical resonator is an arrangement of mirrors, in which one is 100% reflecting so that all photons can reflect back and other is partially reflecting from which laser light comes out. Due to optical cavity the density of photons (No. of photons) increases.

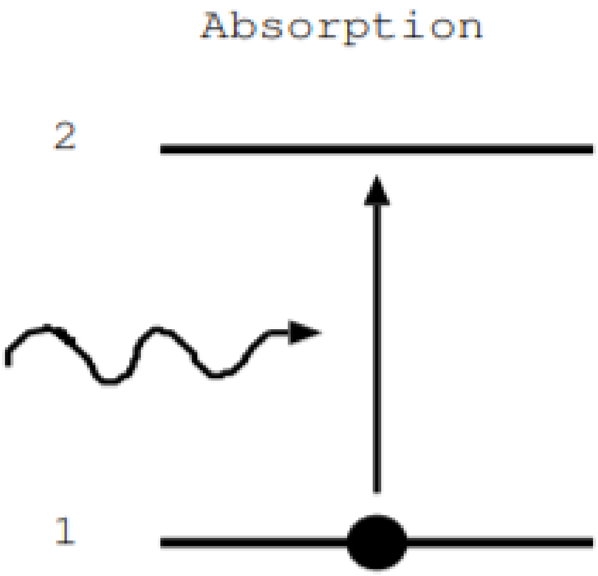
- In optical cavity first spontaneous emission take place, and then stimulated emission take place in which photons moves in particular direction and reflected by resonator mirrors and amplified.



fully reflective mirror
lasing medium
partly reflective mirror
1. Lasing medium at ground state.
atom in ground state
2. Population inversion.
excited atom
spontaneous emission
stimulated emission
3. Spontaneous emission, start of stimulated emission.
stimulated emission atom
4. Stimulated emission building up.
5. Coherent light, with all waves lined up in phase.
laser beam

Einstein's equations

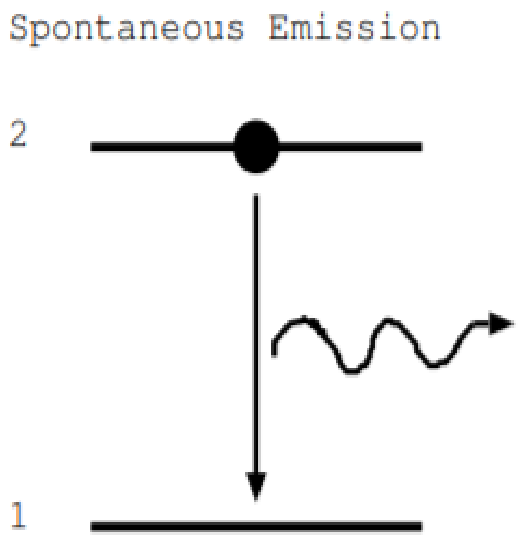
Stimulated absorption



- The rate of stimulated absorption is depends upon no. of atoms (N_1) present in energy level one E_1 and energy density u(v) of incident radiation.
- The rate of stimulated absorption α N_1
  α u(v)
- The rate of stimulated absorption α N_1 u(v)
- The rate of stimulated absorption = B_{12} N_1 u(v)

Where B_{12} is constant of proportionality and it is called Einstein Coefficient for stimulated absorption.

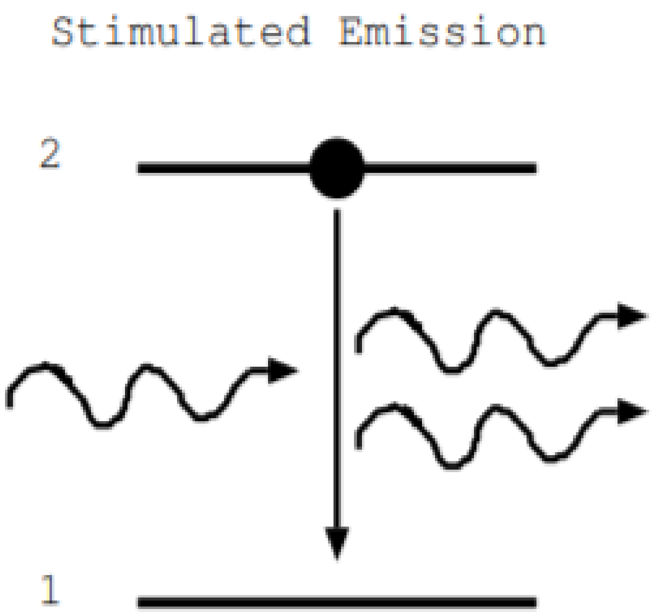
Spontaneous emission



- The rate of **Spontaneous emission** is depends upon no. of atoms (N_2) present in energy level one E_2
- The rate of **Spontaneous emission** α N_2
- The rate of **Spontaneous emission** = A_{21} N_2

Where $\mathbf{A_{21}}$ is constant of proportionality and it is called Einstein Coefficient for spontaneous emission.

Stimulated emission



- The rate of stimulated **emission** is depends upon no. of atoms (N_2) present in energy level two E_2 and energy density u(v) of incident radiation.
- The rate of stimulated **emission** α N_2
  α u(v)
- The rate of stimulated **emission** α N_2 u(v)
- The rate of stimulated **emission** = B_{21} N_2 u(v)

Where $\mathbf{B_{21}}$ is constant of proportionality and it is called Einstein Coefficient for stimulated **emission.**

Relation between Einstein's A and B Coefficient

- In thermal equilibrium at temperature T, with radiation frequency n and energy density u(v).
- Let N_1 and N_2 be the number of atoms in energy states 1and 2 respectively at any instant.
- The number of atoms in state 1 absorb a photon and give rise to absorption per unit time & simultaneously there will be spontaneous emission and stimulated emission.

For equilibrium

The rate of absorption = the rate of emission

the rate of stimulated absorption = the rate of spontaneous + stimulated emission

$$N_1 B_{12} u(v) = N_2 A_{21} + N_2 B_{21} u(v)$$

$$N_1 B_{12} u(v) - N_2 B_{21} u(v) = N_2 A_{21}$$

$$\{N_1 B_{12} - N_2 B_{21}\} u(v) = N_2 A_{21}$$

$$\{N_1 B_{12} - N_2 B_{21}\} u(v) = N_2 A_{21}$$

$$u(v) = \frac{N_2 A_{21}}{N_1 B_{12} - N_2 B_{21}}$$

Let us take $N_2 B_{21}$ term common from denominator

$$= \frac{N_2 A_{21}}{N_2 B_{21}\left(\frac{N_1 B_{12}}{N_2 B_{21}} - 1\right)}$$

$$u(v) = \frac{A_{21}}{B_{21}\left(\frac{N_1 B_{12}}{N_2 B_{21}} - 1\right)}$$

According to Boltzmann distribution law number of atoms N_1 and N_2 in energy states E_1 and E_2 in thermal equilibrium at temperature T are given by

①

$$\frac{N_1}{N_2} = \frac{e^{\frac{-E_1}{KT}}}{e^{\frac{-E_2}{KT}}}$$

$$\frac{N_1}{N_2} = \frac{e^{\frac{E_2-E_1}{KT}}}{1}$$

But $E_2 - E_1$ = hϑ

$$\frac{N_1}{N_2} = e^{\frac{h\vartheta}{KT}} \text{ -------(1)}$$

②

But, from previous equation

$$u(v) = \frac{A_{21}}{B_{21}\left(\frac{N_1 B_{12}}{N_2 B_{21}} - 1\right)} \text{ ------(2)}$$

from equations 1 & 2

$$u(v) = \frac{A_{21}}{B_{21}} \frac{1}{\left(\frac{B_{12}}{B_{21}} e^{\frac{h\vartheta}{KT}} - 1\right)} \text{ ------(3)}$$

But, According to Plank's Radiation law

$$u(\nu) = \frac{8\pi h\nu^3}{c^3} \frac{1}{e^{\frac{h\nu}{KT}} - 1}$$

Comparing equation (3) with Plank's Radiation law

$$u(v) = \frac{A_{21}}{B_{21}} \frac{1}{\left(\frac{B_{12}}{B_{21}} e^{\frac{h\vartheta}{KT}} - 1\right)} \quad \text{------(3)}$$

We get

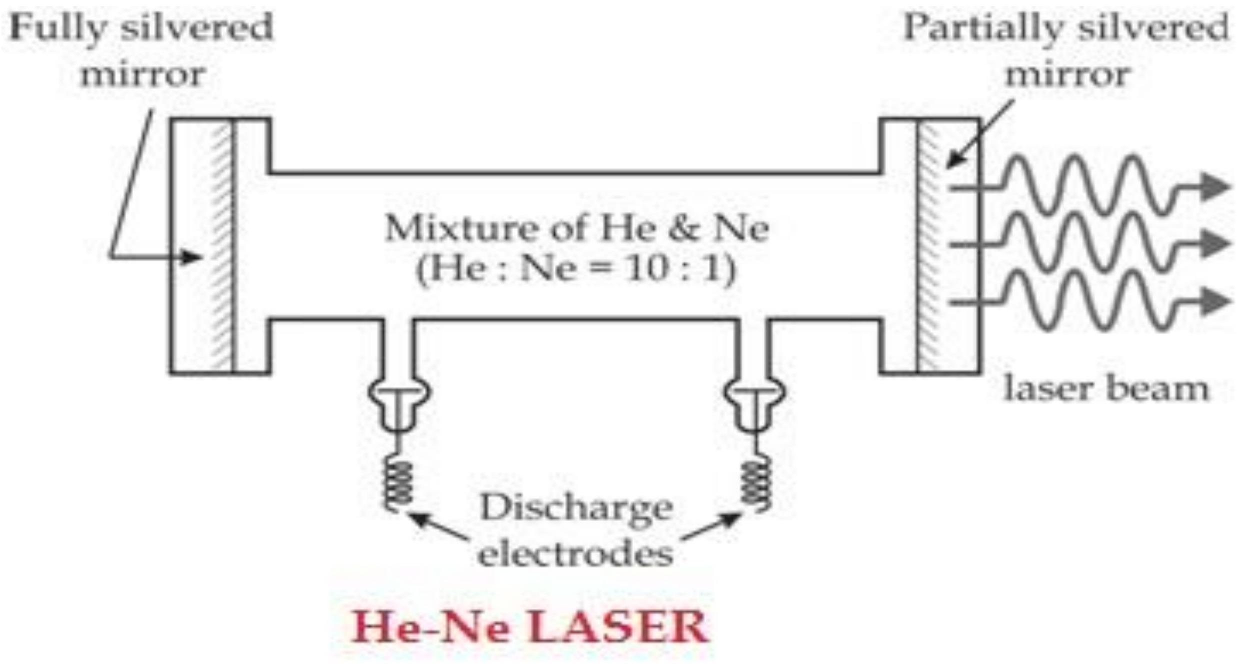
$$\frac{B_{12}}{B_{21}} = 1$$

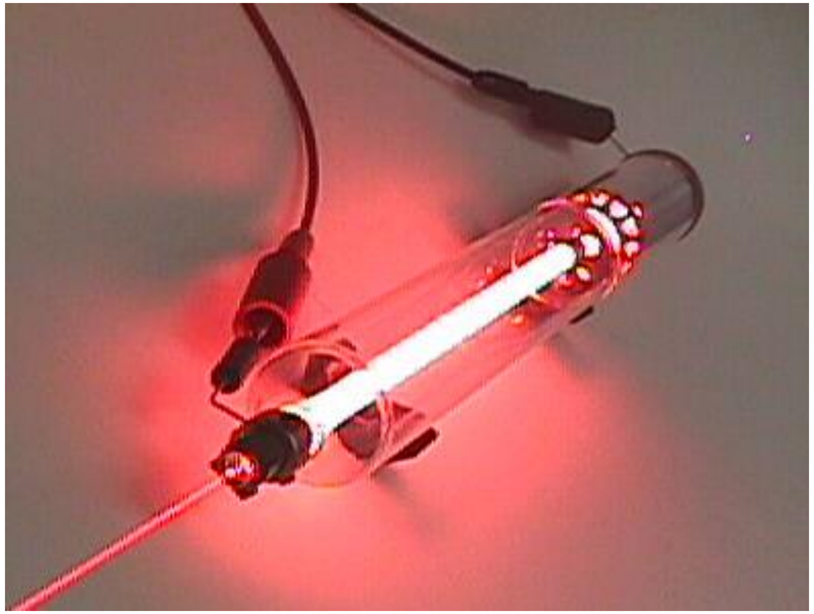
$B_{12} = B_{21,}$ The probability of spontaneous emission is same as that of induced absorption. This means that if these two processes will occur at equal rates, so that no

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$$

The ratio of spontaneous emission and stimulated emission is proportional to ν^3. This implies that the probability of spontaneous emission dominates over induced emission more and more as the energy difference between the two states increases

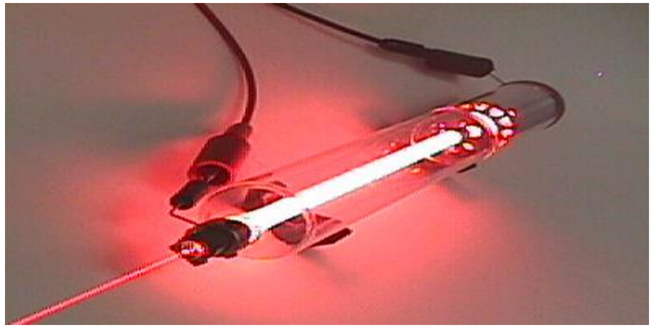
He Ne laser



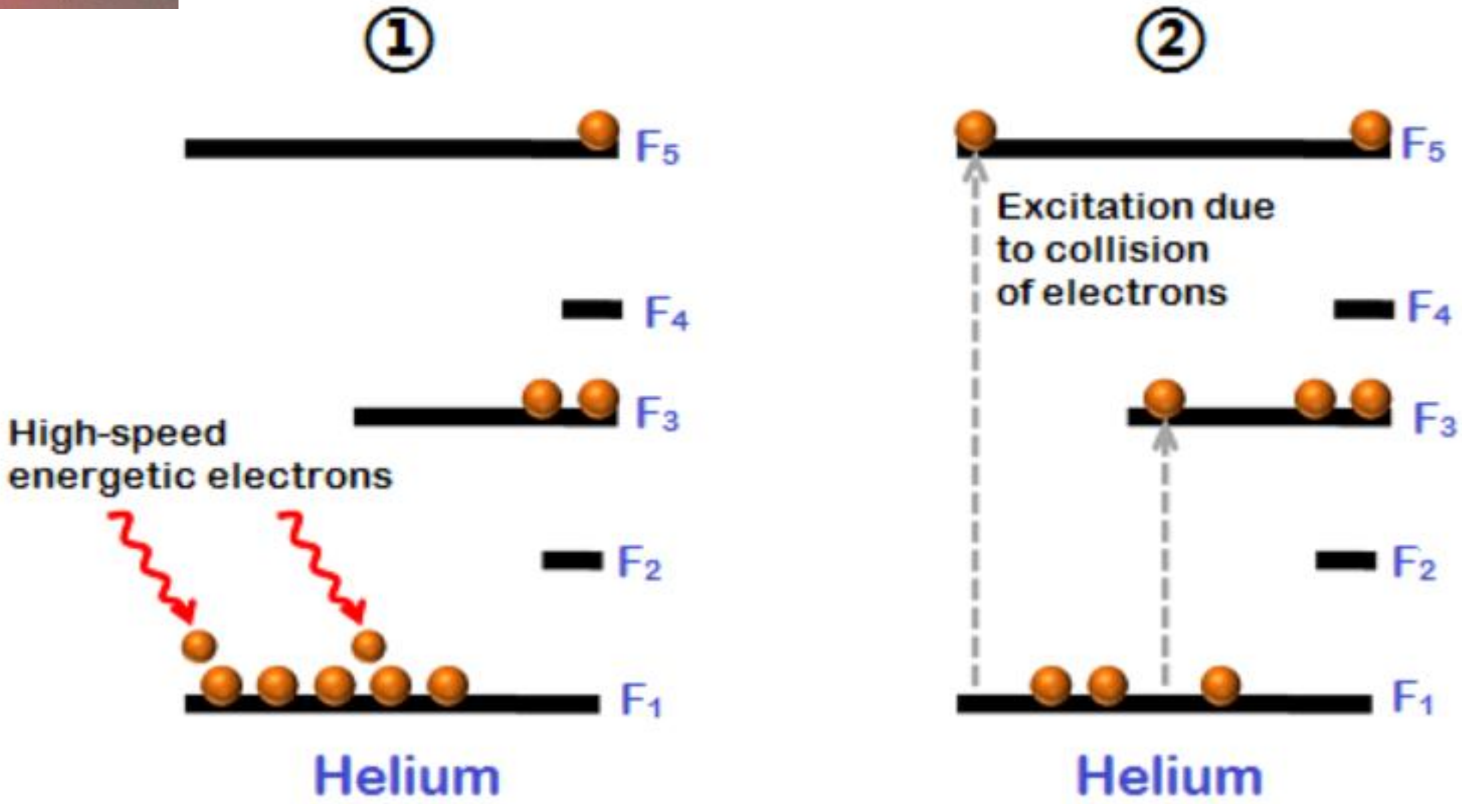


Construction

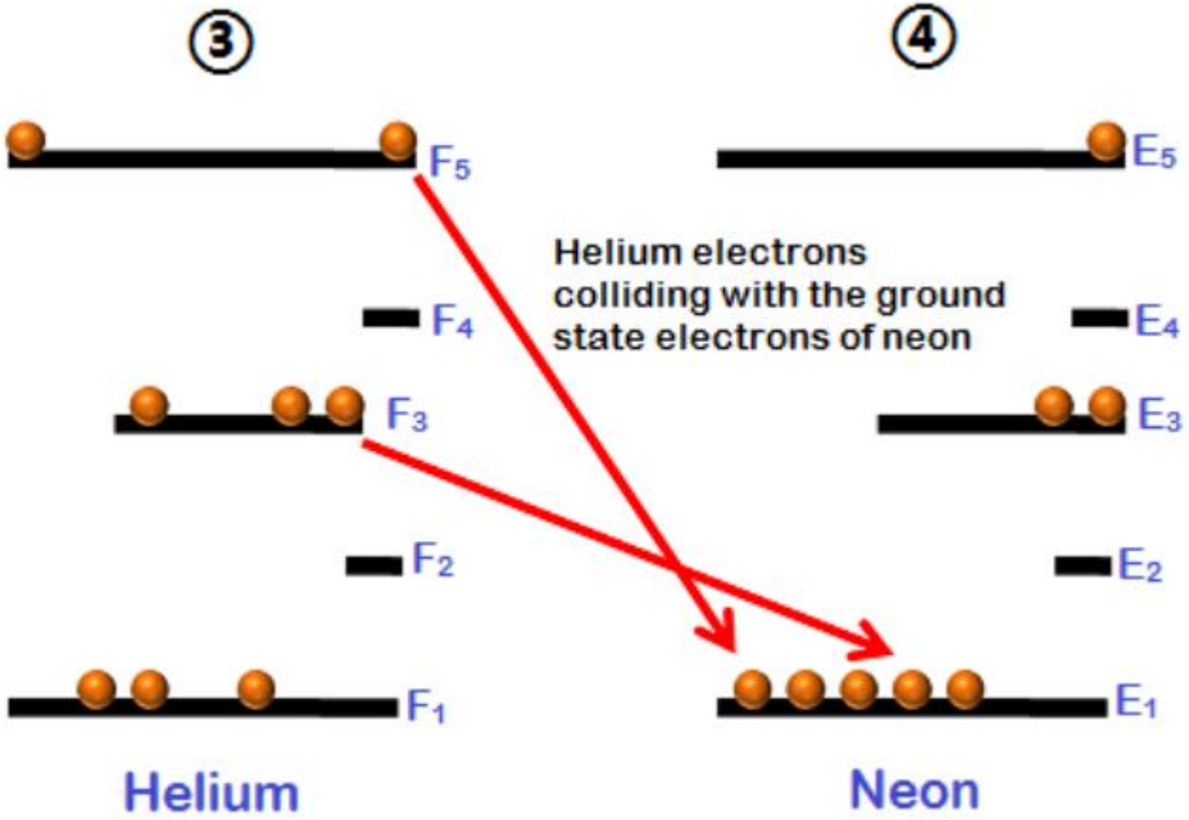
- It consists of long glass tube about 25 cm to 100 cm long and about 1 cm in diameter.
- The ends of tube are closed by two mirrors, in which one mirror is fully silvered and other is partially silvered mirror.
- The tube is filled by mixture of Helium and Neon gases in the ratio of 10:1 at low pressure.
- A high potential difference is set up within the tube by using electrodes.



- A high voltage DC produces energetic electrons that travel through the gas mixture.

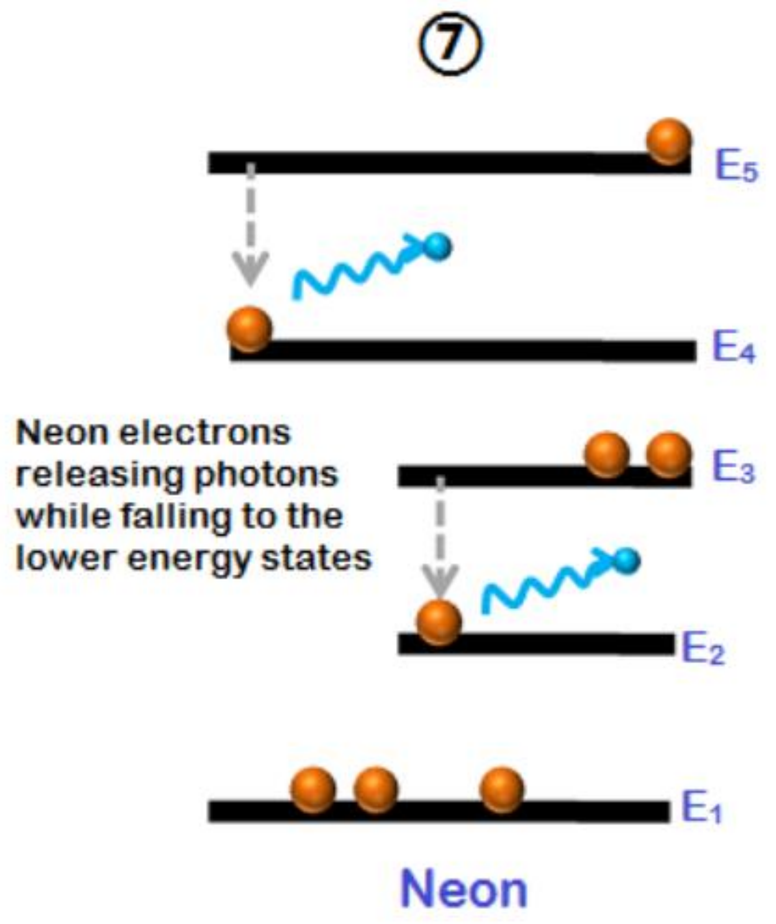


- Helium atoms gain enough energy and jumps into the excited states or metastable states are F_3 and F_5.



- The metastable state electrons of the helium atoms cannot return to ground state by spontaneous emission. However, they can return to ground state by transferring their energy to the lower energy state electrons of the neon atoms.

- Helium atoms collide with the lower energy state electrons of the neon atoms; they transfer their energy to the neon atoms. As a result, the lower energy state electrons of the neon atoms gain enough energy from the helium atoms and jumps into the higher energy states or metastable states (E_3 and E_5). Thus, helium atoms help neon atoms in achieving population inversion.



millions of ground state electrons of neon atoms are excited to the metastable states. The metastable states have the longer lifetime. Therefore, a large number of electrons will remain in the metastable states and hence population inversion is achieved.

After some period, the metastable states electrons (E_3 and E_5) of the neon atoms will spontaneously fall into the next lower energy states (E_2 and E_4) by releasing photons or red light. This is called spontaneous emission.

The light or photons emitted from the neon atoms will moves back and forth between two mirrors until it stimulates other excited electrons of the neon atoms and causes them to emit light. Thus, optical gain is achieved. This process of photon emission is called stimulated emission of radiation.

- **Advantages of helium-neon laser**

➢ Helium-neon laser emits laser light in the visible portion of the spectrum.
➢ High stability
➢ Low cost
➢ Operates without damage at higher temperatures

- **Disadvantages of helium-neon laser**

➢ Low efficiency
➢ Low gain
➢ Helium-neon lasers are limited to low power tasks

- **Applications of helium-neon lasers**

➢ Helium-neon lasers are used in industries.
➢ Helium-neon lasers are used in scientific instruments.
➢ Helium-neon lasers are used in the college laboratories.

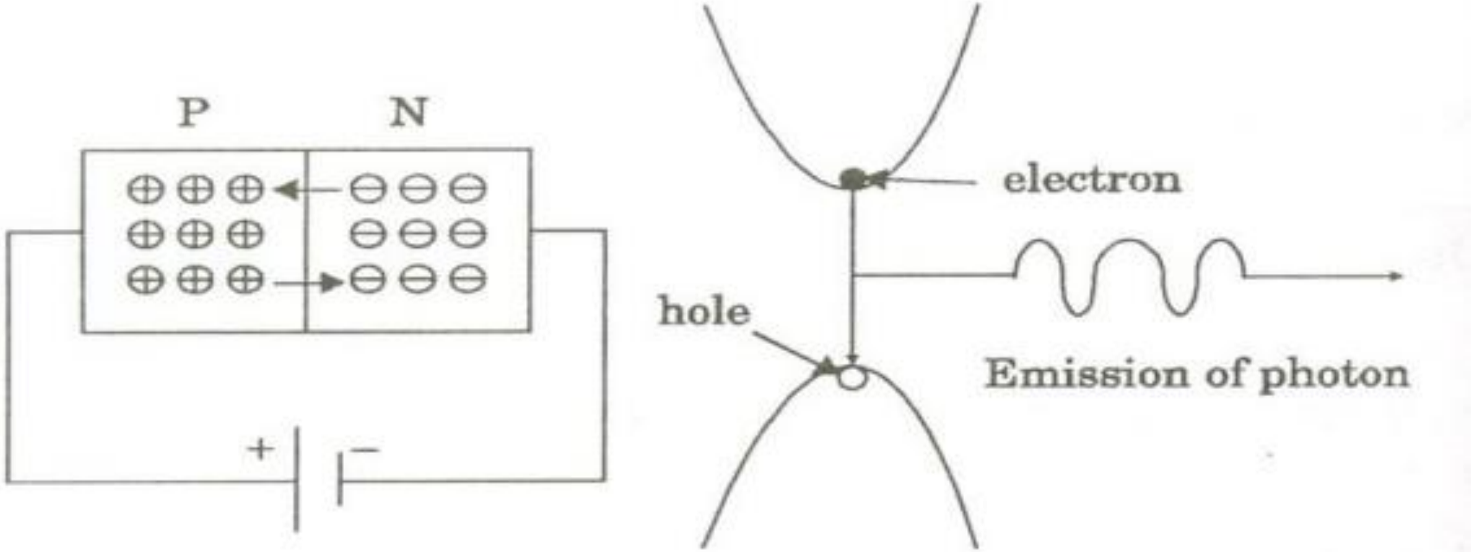
Semiconductor Diode laser:

Principle:

When a p-n junction diode is forward biased, the electrons from n – region and the holes from the p- region cross the junction and recombine with each other. During the recombination process, the light radiation (photons) is released this light radiation is known as recombination radiation.

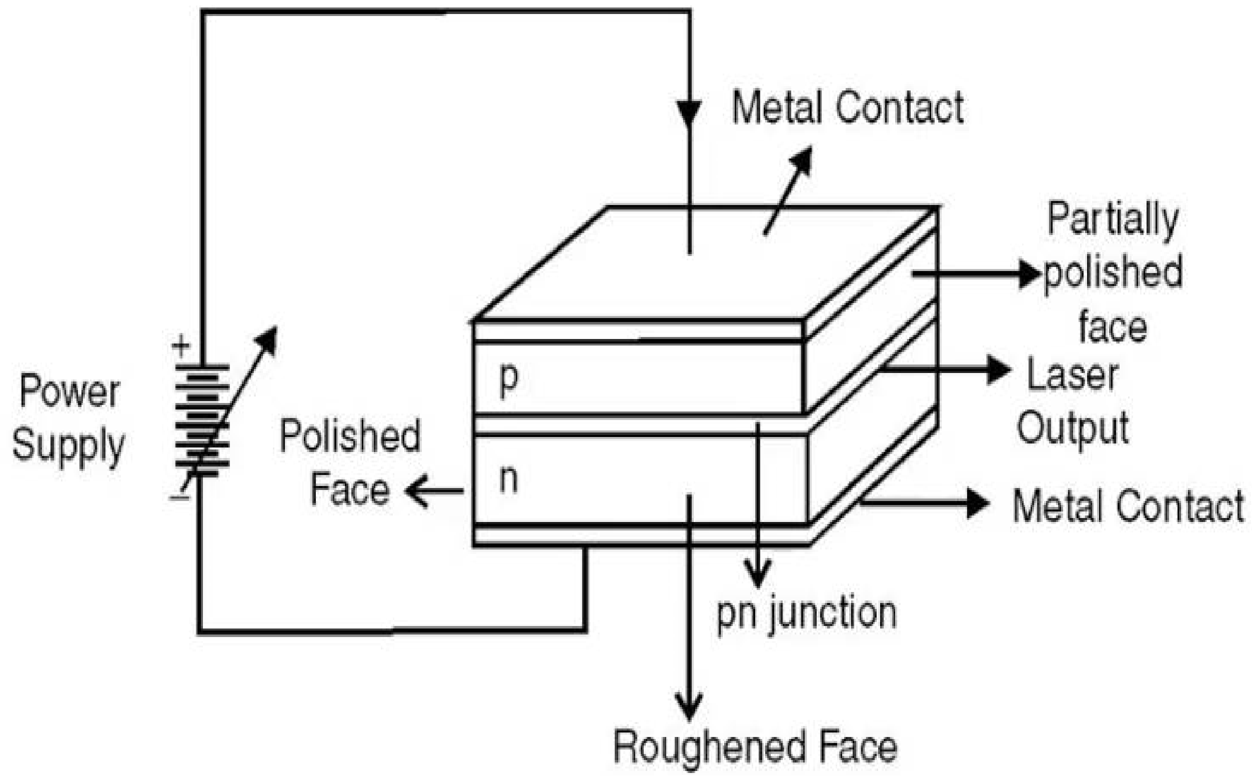
The photon emitted during recombination stimulates other electrons and holes to recombine. As a result, stimulated emission takes place which produces laser.

For production of laser from semiconductor a certain specified direct band gap semiconductors like Ga-As is used.



Construction:

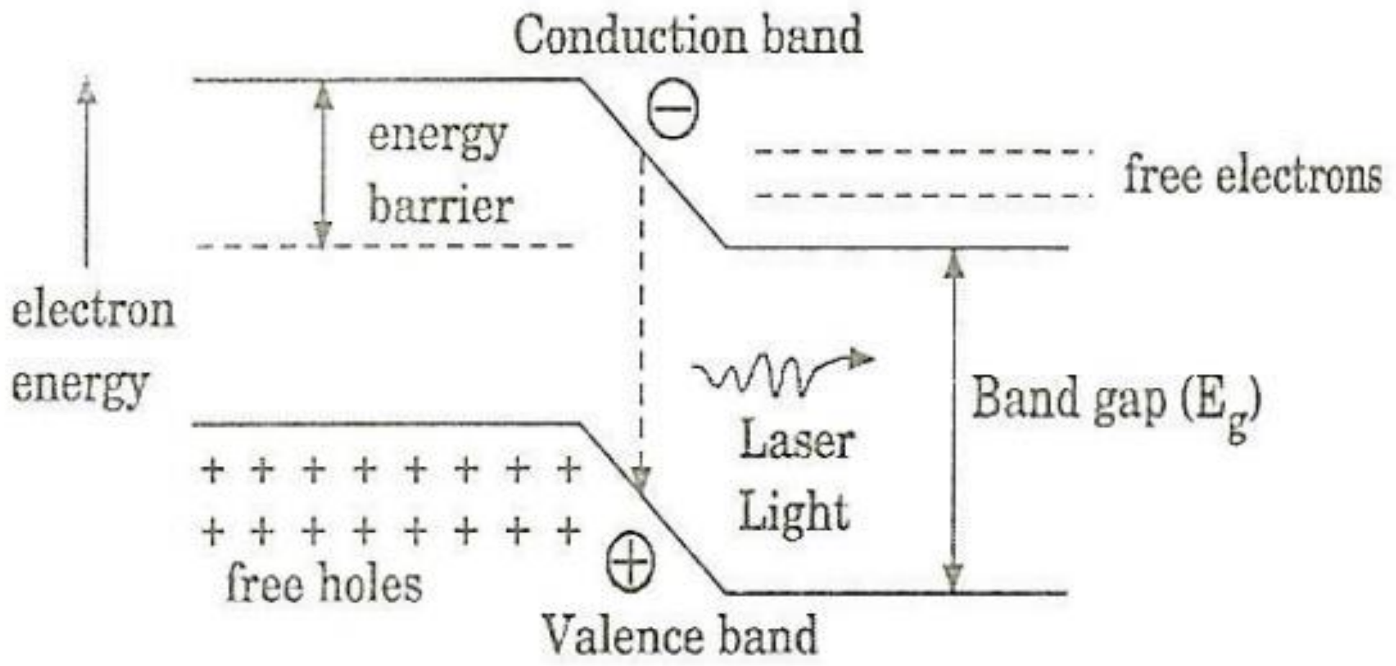
Figure shows the basic construction of semiconductor laser. The active medium is a p-n junction diode made from the single crystal of gallium arsenide having thickness of 0.5μmm.



The top and bottom faces (p and n sides) are connected to the power supply through metal contact. The front and rear faces are polished they act as mirrors to form resonance cavity and others two faces are roughened.

Working:

Figure shows the energy level diagram of semiconductor laser.



When the PN junction is forward biased with large applied voltage, the electrons and holes are injected into junction region.

In the junction contains a large amount of electrons in the conduction band and a large amount of holes in the valence band. The population inversion is achieved. The electrons and holes recombine with each other and this recombination's produce radiation in the form of light.

When the forward – biased voltage is increased, more and more light photons are emitted and the light production instantly becomes stronger. These photons will trigger a chain of stimulated recombination resulting in the release of photons in phase.

The photons moving at the plane of the junction travels back and forth by reflection between two sides placed parallel and opposite to each other and grow in strength.

Semiconductor Diode laser:

Advantages:

1. It is very small in dimension. The arrangement is simple and compact.
2. It exhibits high efficiency.
3. The laser output can be easily increased by controlling the junction current
4. It is operated with lesser power

Application:

1. It is widely used in fibre optic communication
2. It is used to heal the wounds by infrared radiation
3. It is used in laser printers and CD writing and reading.

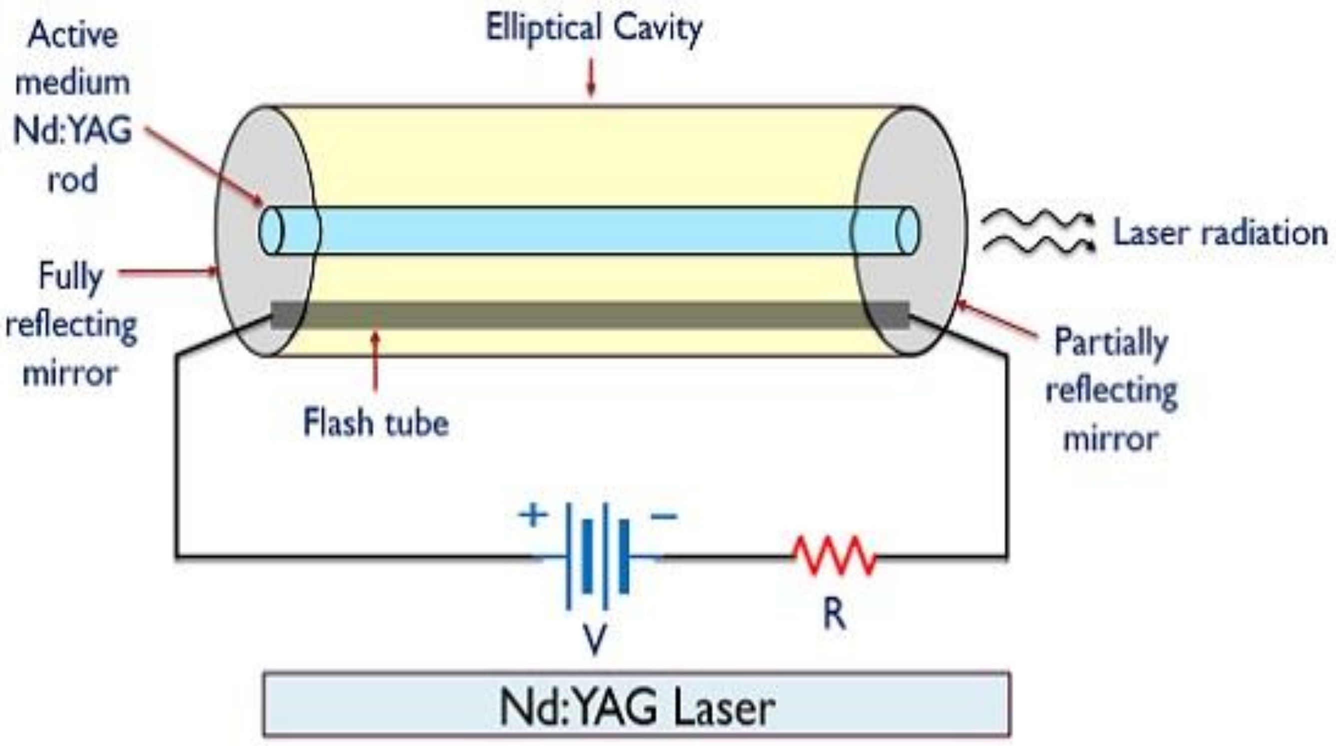
Nd:YAG Laser

Nd: YAG laser is the short form used for **Neodymium-doped Yttrium Aluminium Garnet**. It is a solid state and 4 level laser system.

Principle: when optical pumping is provided to the Nd: YAG rod. Then the ions get raised to higher energy levels and their transition produces a laser beam.

Construction of Nd:YAG laser

The figure below shows the road like the structure of Nd: YAG laser:



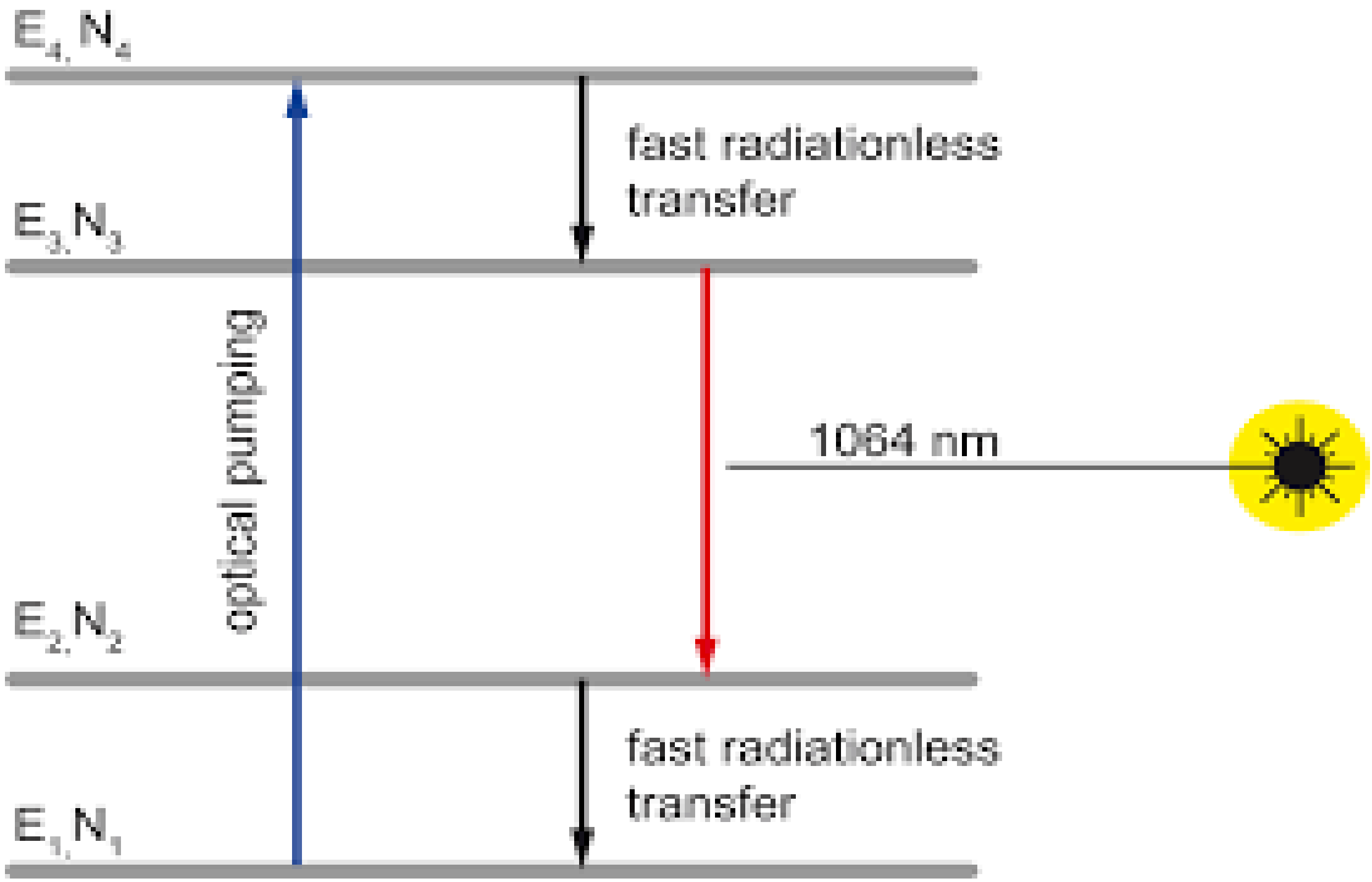
Construction:

It consists of Yttrium aluminium garnet (YAG) in the form of rod of 10 cm long and 1 cm in diameter, doped with Neodymium atoms.

The Nd: YAG rod is fitted in tube along with krypton flash light (as an optical pumping) as shown in the figure. The two ends of tube if closed with fully reflecting and partially reflecting mirrors.

Working of Nd: YAG laser

The figure below shows the 4 state energy level diagram of Nd: YAG laser:



Working of Nd: YAG laser

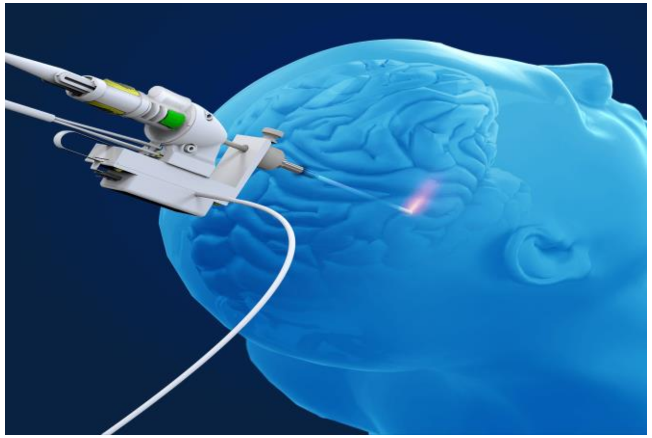
Here, E_1 is the lowest energy state while E_4 is the highest energy level.
So, when external energy is provided in the active medium of the laser. Then the electrons present in the energy state E_1 gains energy and moves to energy state E_4. However, as E_4 is an unstable state and it exhibits short lifespan.
Therefore, electrons that were excited to E_4 state by the application external pumping will not stay at this state for much longer duration and comes to lower energy state E_3 very fastly but without radiating any photon.
The energy state E_3 is the metastable state and exhibits longer lifespan. So, the electrons in this particular state will stay for a longer duration. Due to this more number of electrons will be present at the metastable state E_3. population inversion is build up between E_3 & $E_{4.}$

But once the lifetime of the electrons at the metastable state gets exhausted then these electrons by releasing photons come to lower energy state E_2. This photon will trigger the stimulated emission.

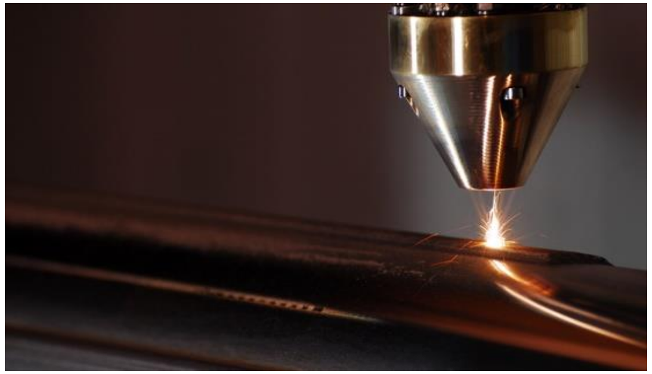
Also, as the system is equipped with optical resonators So, more number of photons will get generated as the pumped energy will get reflected inside the active medium.

Applications of Nd:YAG Laser

- These are used in military applications to find the desired target.



- This type of laser also finds its application in medical field for the surgical purpose.



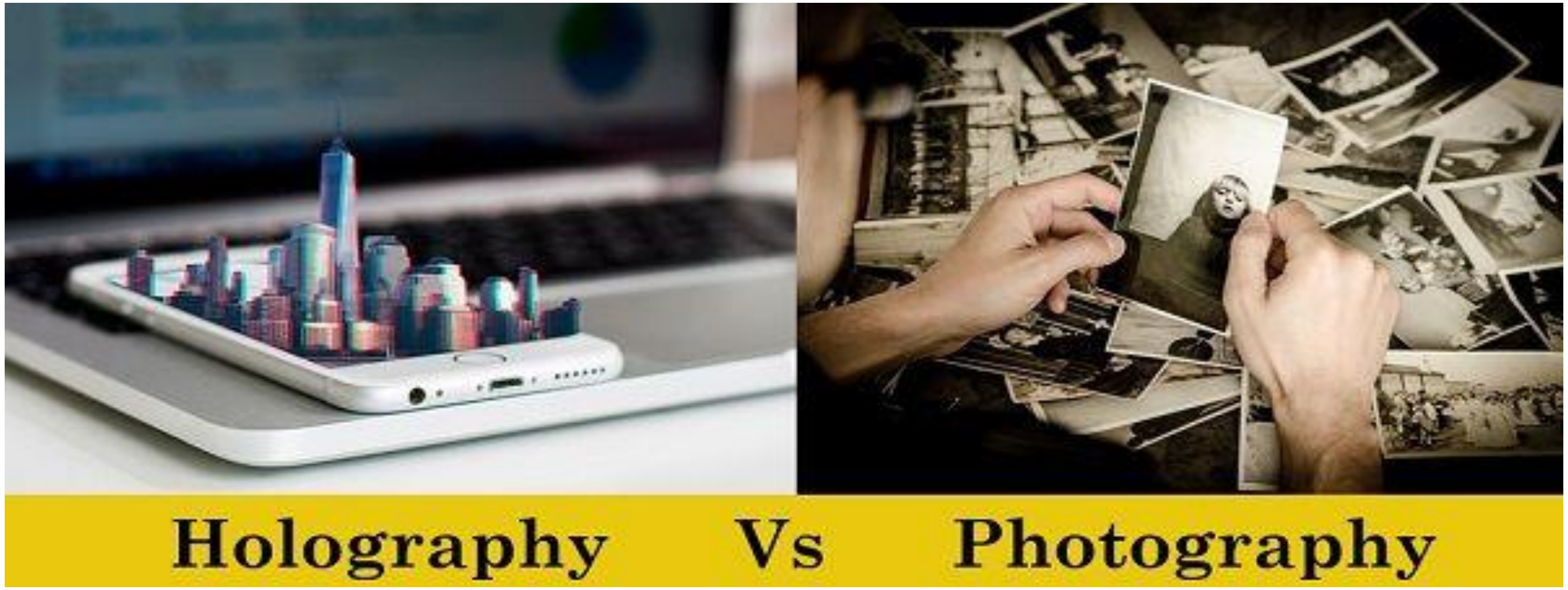
- These are also used in welding and cutting of steel and in communication system also.

Holography

In Greek the meaning of holography is whole information.

In normal photography, it records only two dimensional image of object because it record only intensity variation of received light but the phase difference of light is not recorded.

Holography is the technique in which, both the intensity as well as phase of light waves is recorded. This gives 3 dimensional image of object.



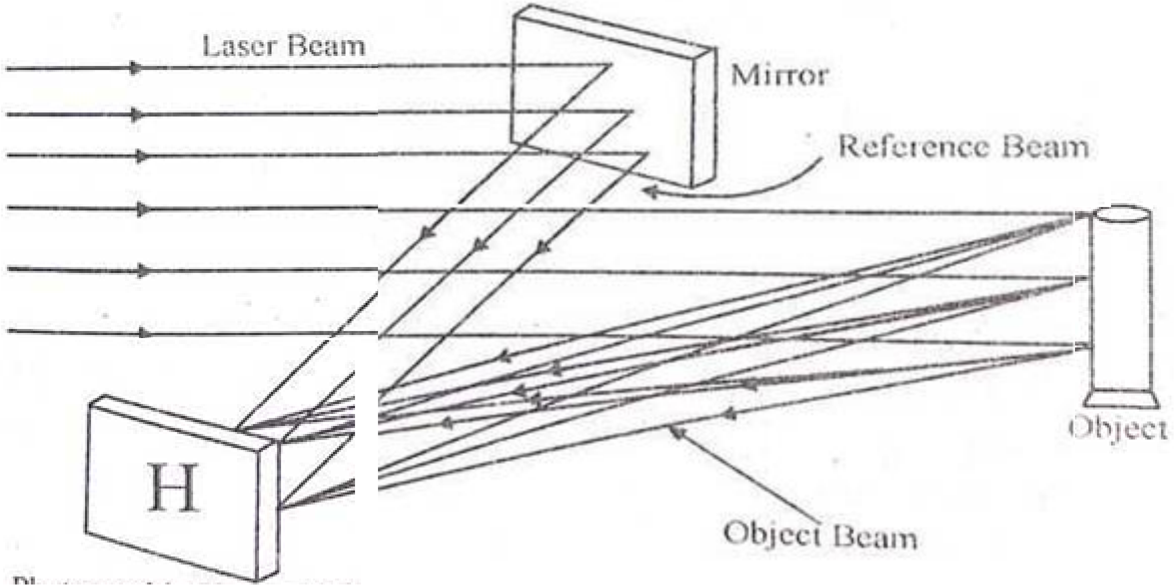
Construction of holography

Laser beam is split into a reference beam which falls on the mirror and an object beam falls on object.

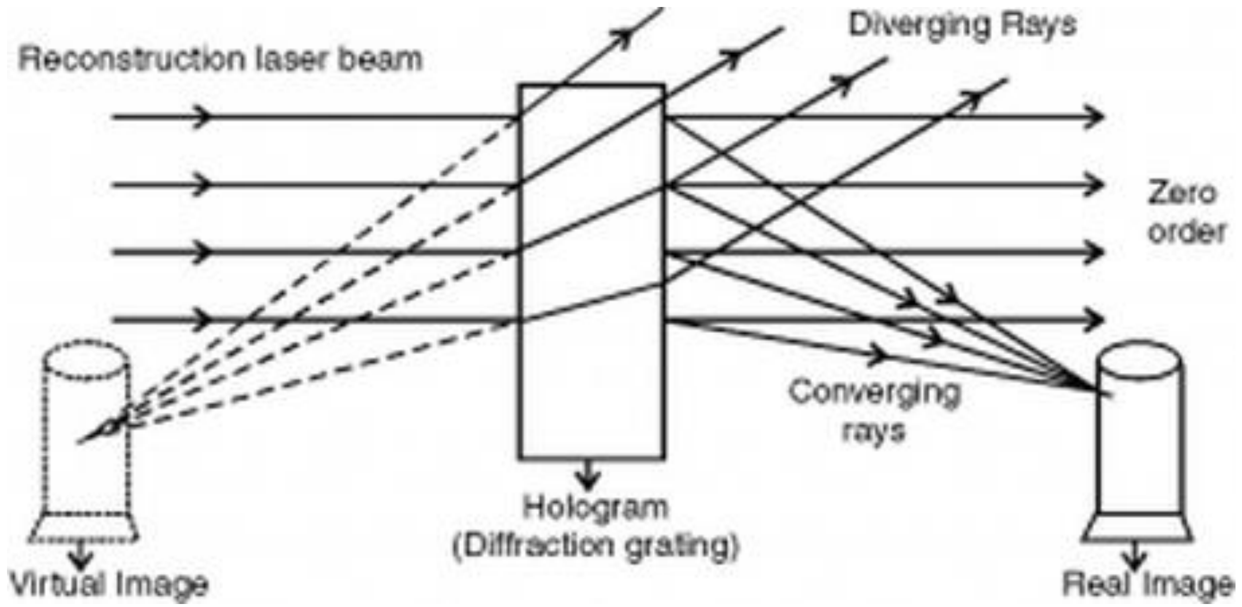
The object beam after reflecting from object and reference beam after reflecting from mirror produces interference pattern on the photographic plate.

This photographic plate with interference pattern is called the hologram.

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



Viewing a Hologram



The **hologram** is illuminated by laser beam and this beam is called **reconstruction** beam. This beam is identical to reference beam used in **construction** of **hologram**

The holography act as diffraction grating producing diffraction pattern. This diffraction pattern is the real image of the object recorded on the hologram. As shown in the figure.

Thus, virtual image is formed behind the **hologram** at the original site of the object and real image in front of the **hologram**.