LASER

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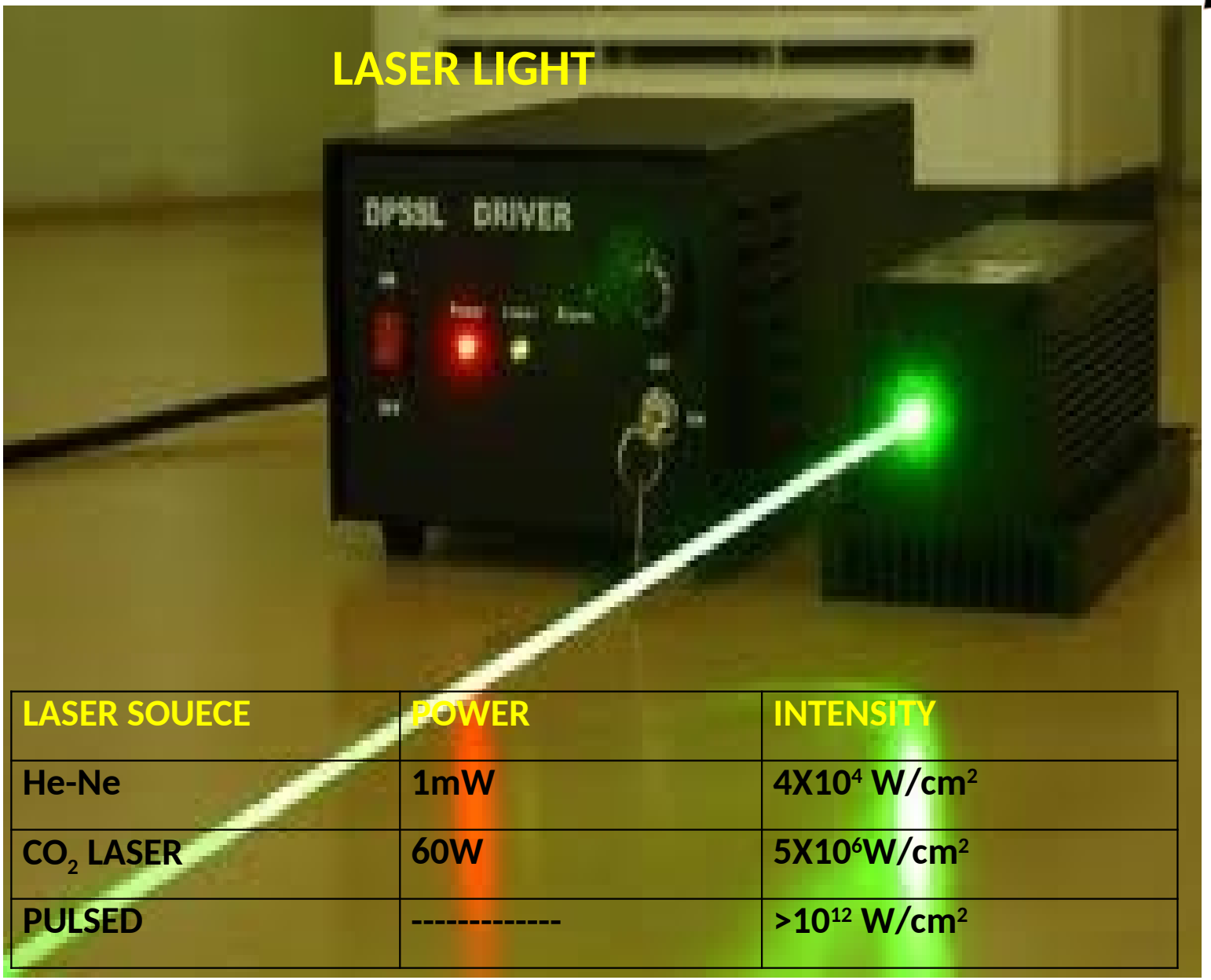
- Introduction,
- Importance of Lasers - Engineering & Technology
- What is laser?
- Characteristics of lasers
- Basic physics behind laser
- He-Ne Laser and Semiconductor laser
- Applications of laser

LIGHT SOURCES

FLASH LIGHT

LASER LIGHT



LASER SOUECE	POWER	INTENSITY
He-Ne	1mW	$4X10^4$ W/cm^2
CO_2 LASER	60W	$5X10^6$W/cm^2
PULSED	----------	$>10^{12}$ W/cm^2

WHAT IS LASER ?

Laser is a device, which emits amplified, monochromatic, electromagnetic radiation ,using the process stimulated emission of atoms and molecules

Acronym

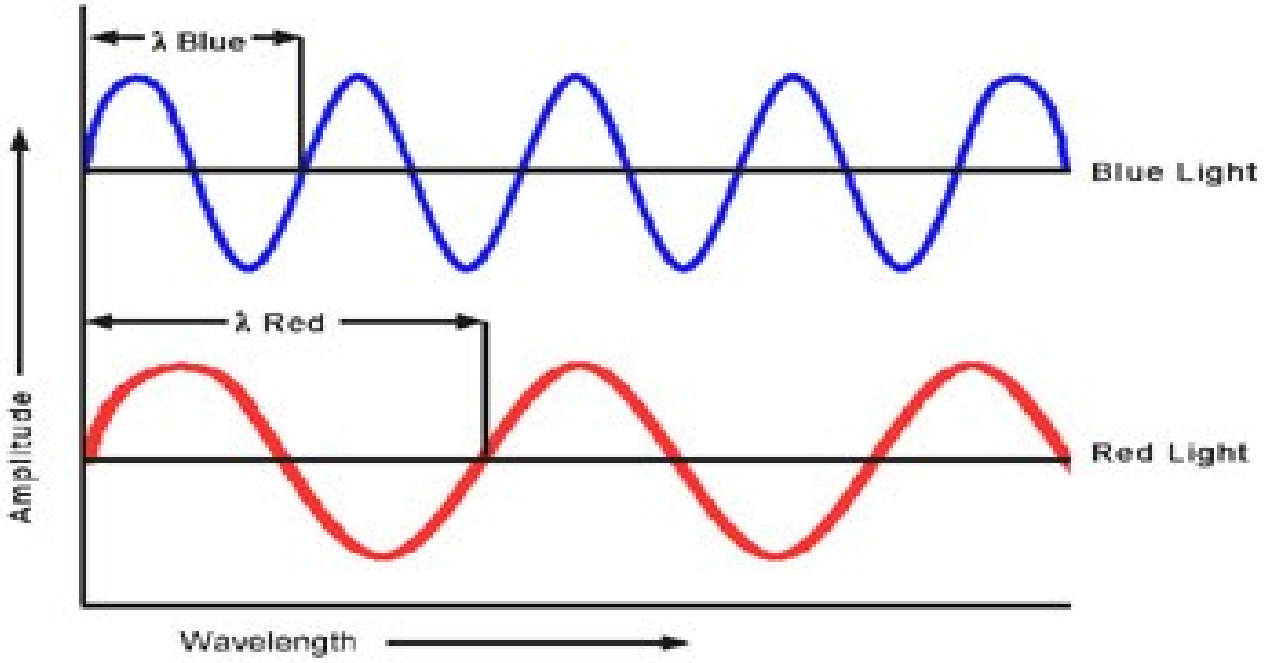
LIGHT AMPLIFICATION BY STIMULATED EMISSION AND RADIATION

laser light is just light

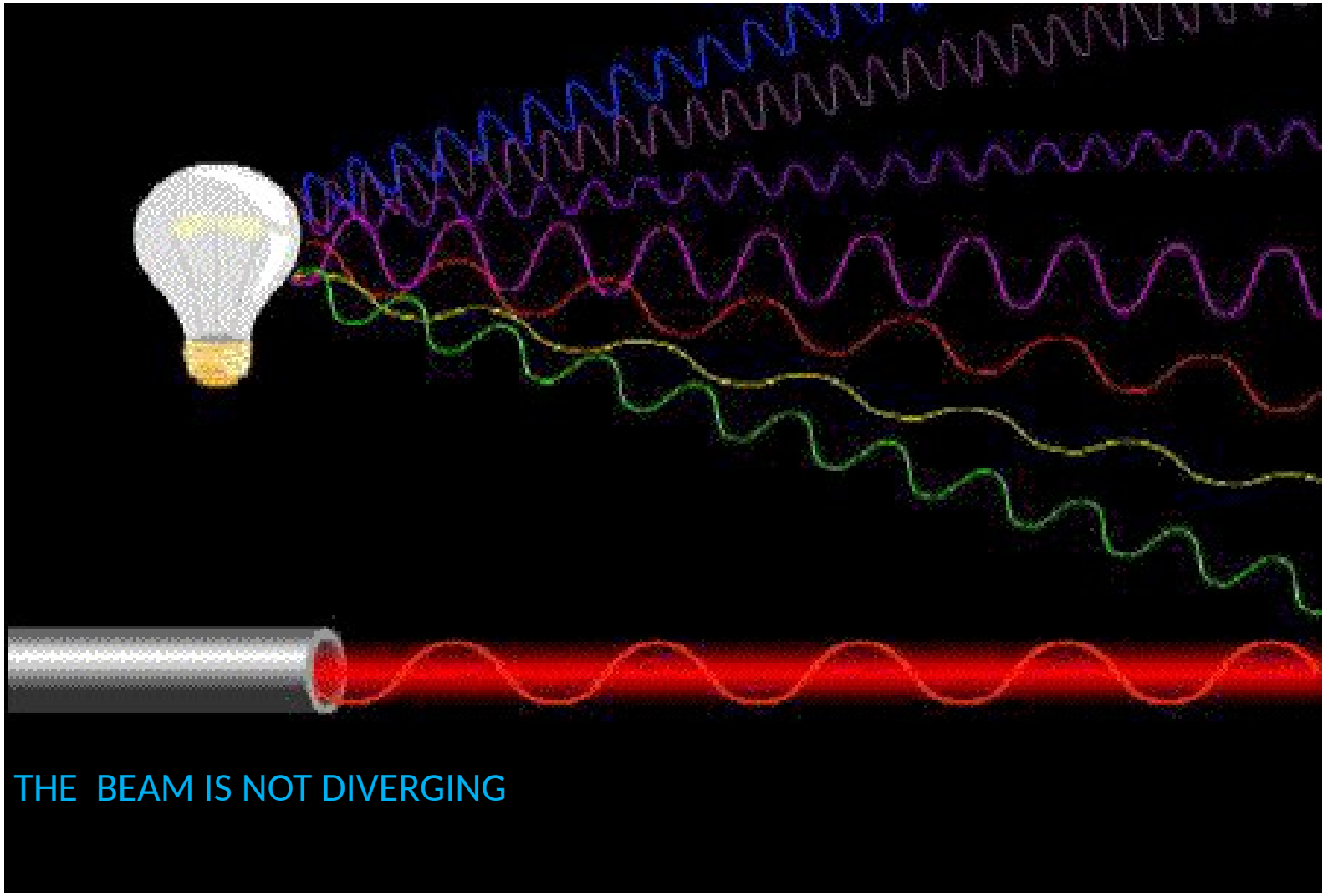
- **Highly monochromatic**

Example:

He-Ne Laser	Diode Laser
λ_0= 632.5 nm	λ_0= 900 nm
$\Delta\lambda$= 0.2 nm	$\Delta\lambda$= 10 nm



- **Highly Directional**
- Controllable spatial structure – narrow beams



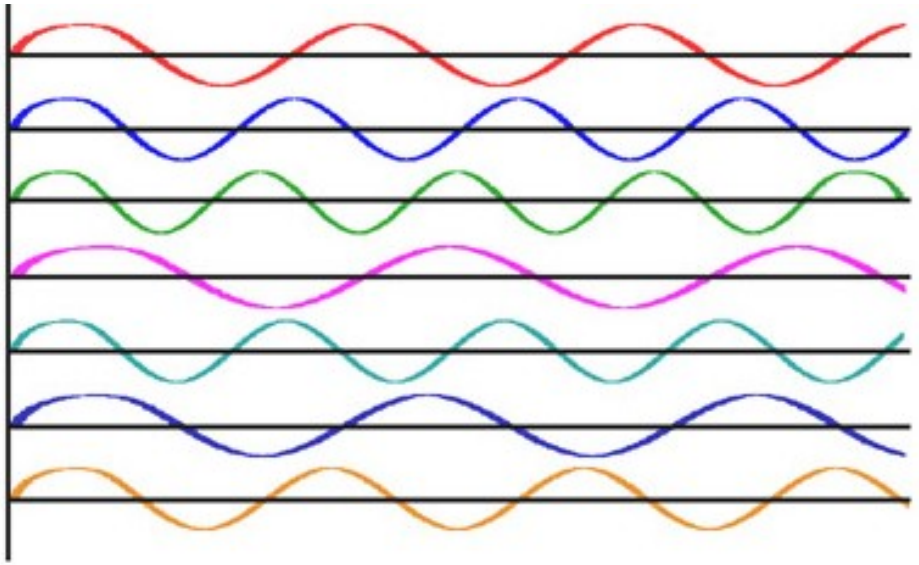
Used to measure distance between Earth and Moon-3,84,400km

HIGHLY COHERENT

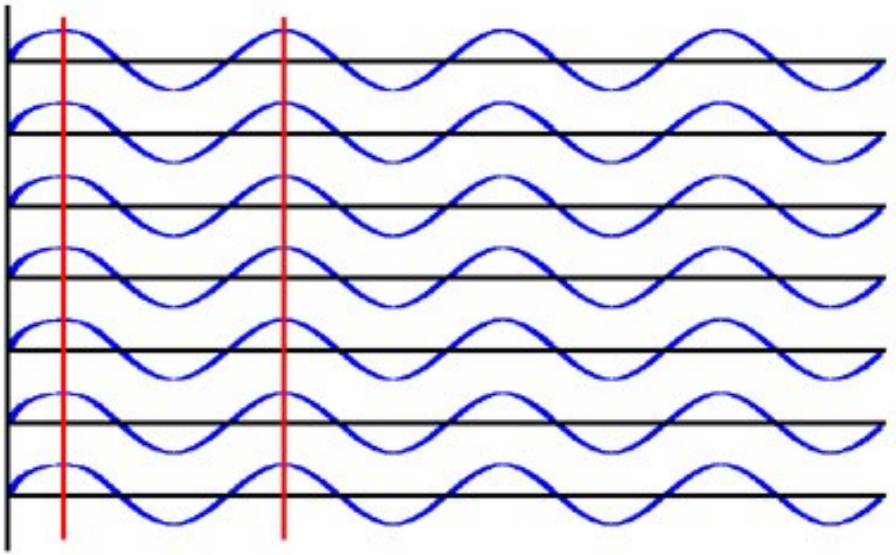
All waves exactly in phase with one another

Two waves have zero or constant phase diffrence between them

IDENTICAL PHOTONS



In coherent light waves

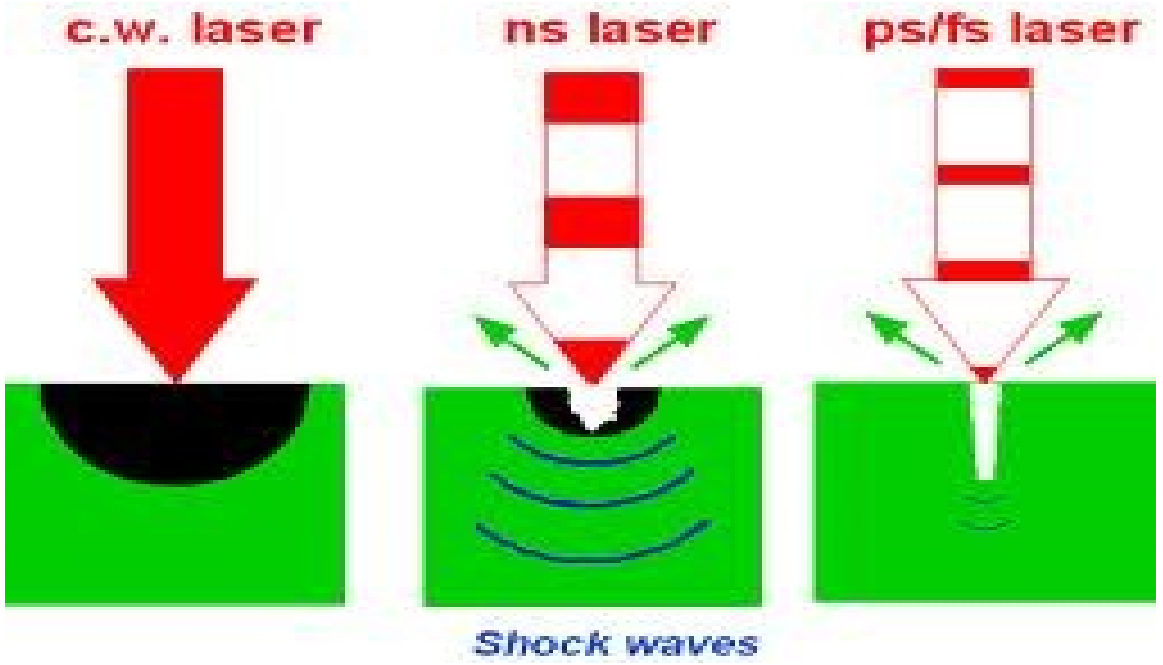


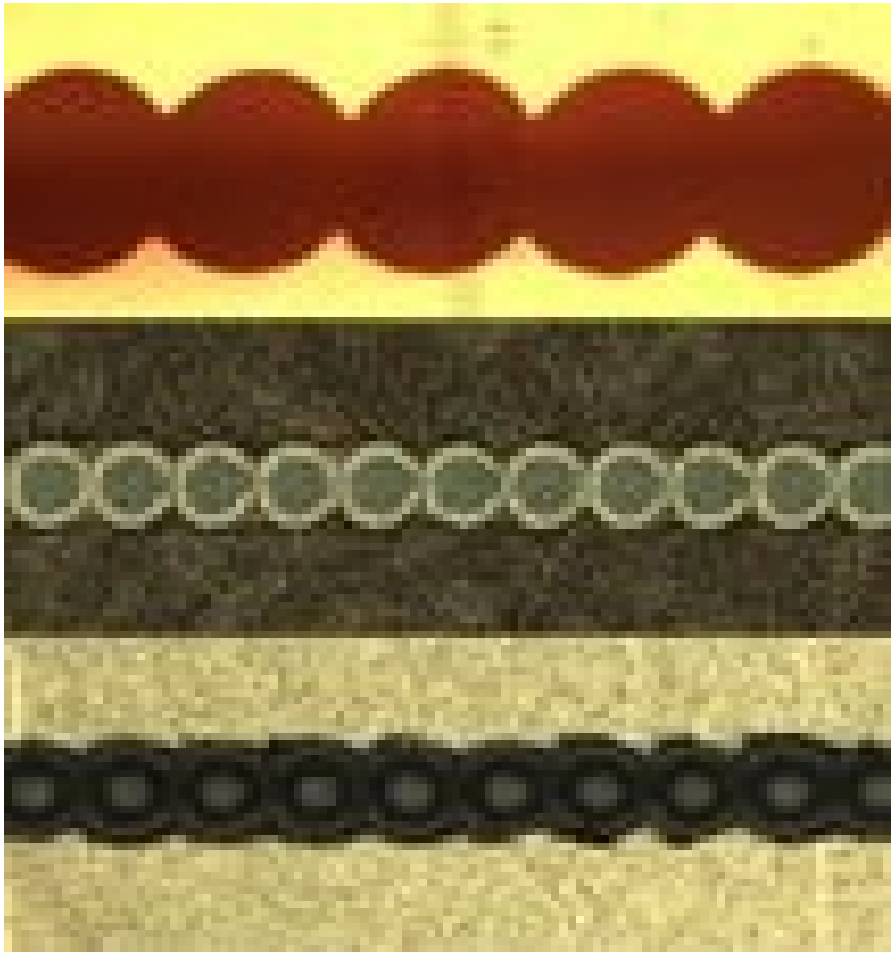
Coherent light waves

Highly powerful & Intensed

Extremely high compared to other conventional sources

Intensity of the laser can draw this

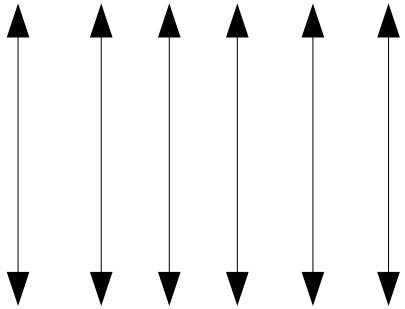


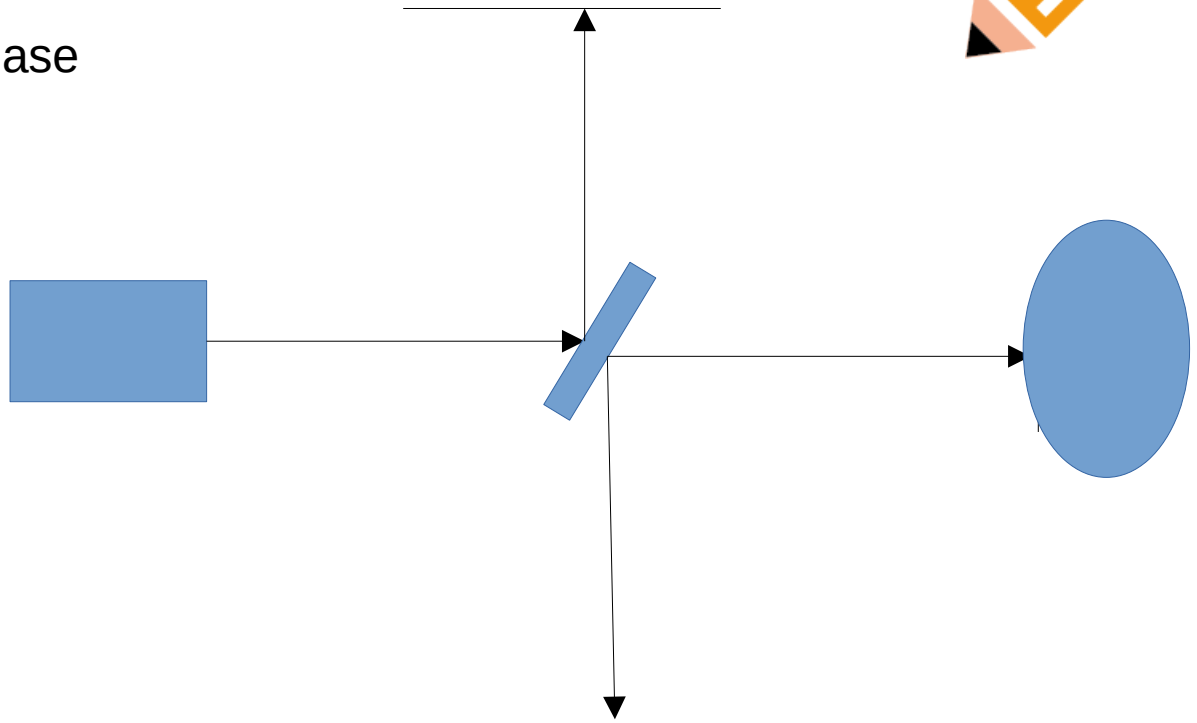


Cutting, welding, drilling, military weapons

Laser is Polarised

Stimulated Photons vibrate in same phase

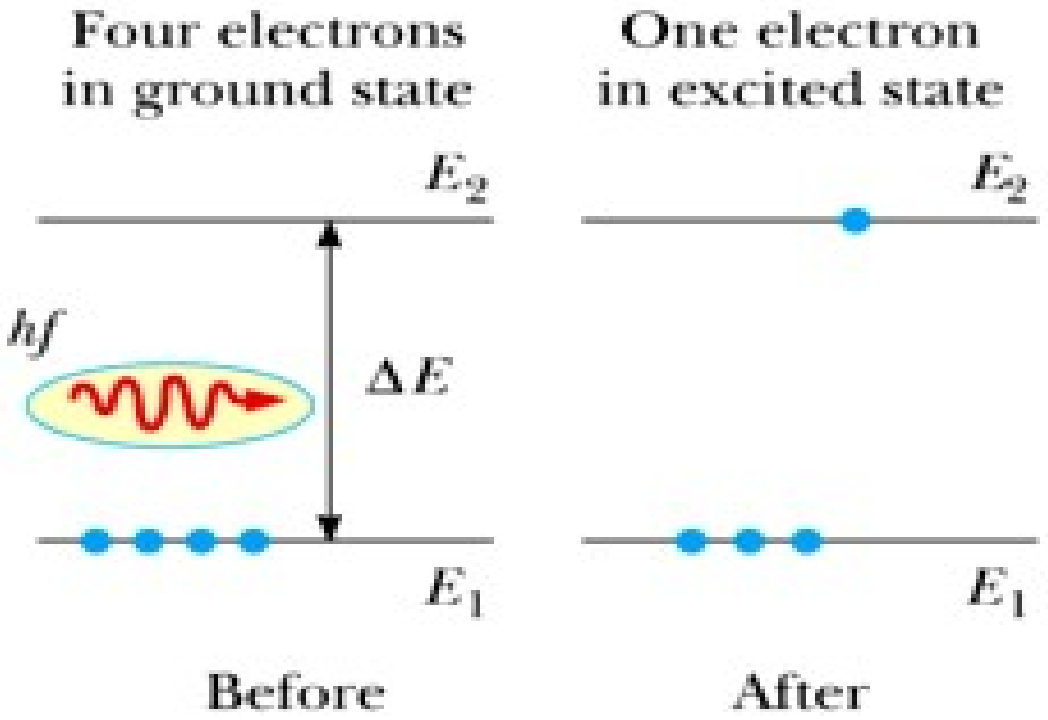




Basic Physics Behind Laser (PRINCIPLE)

Before that we have to know 3 TYPES OF TRANSITIONS
i.e. Quantum process that takes place between the energy (Photon)& matter (atom)

STIMULATED ABSORPTION



- When an atom is in ground state , it will jump to excited state by absorbing photon energy

Energy of the absorbed photon
= $\Delta E = E_2 - E_1 = hf = h\nu$

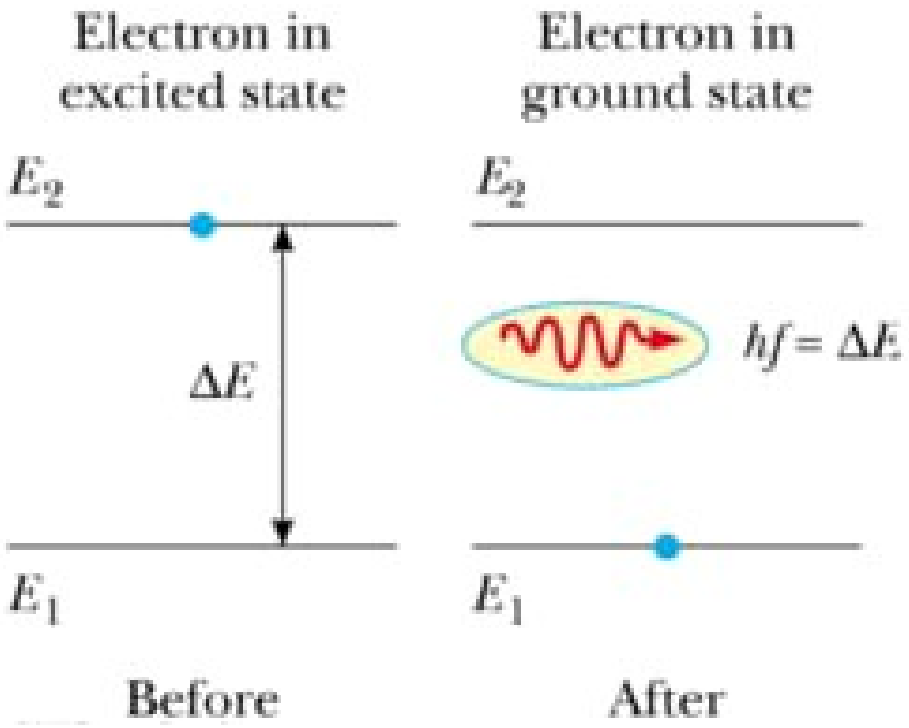
When a photon of energy hν hits an atom

$$A + h\nu = A^*$$

A-- atom in E_1 A*--- atom in E_2

SPONTANEOUS EMISSION

Life time of an exicited state= 10^{-8}s
After 10^{-8}s , atom deexcites by its own without taking any external energy

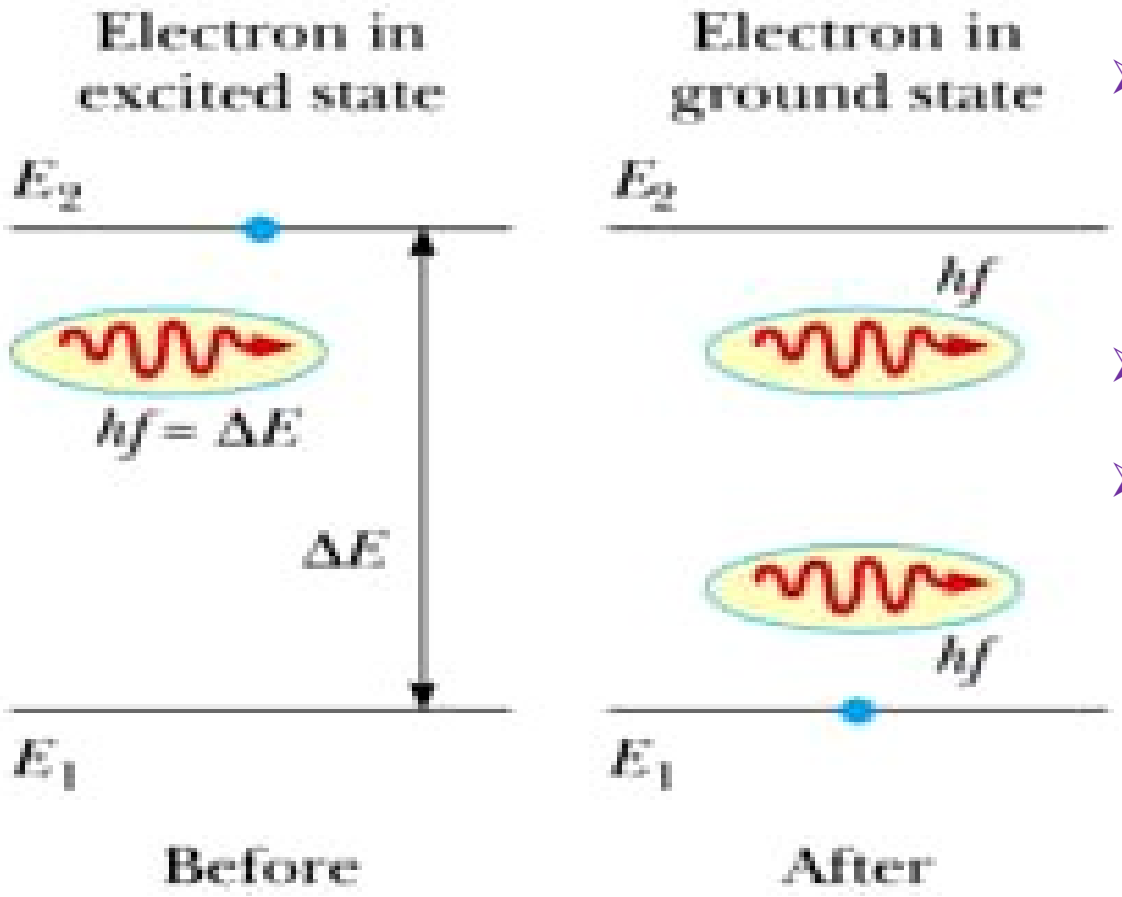


- When an atom is in excited energy state, it decay to a lower level emitting a photon of radiation
- Emitted photon is random in direction and in phase

Energy of the emitted photon
= ΔE= E_2-E_1=hf=hν

$$A^* = A + h\nu$$

STIMULATED EMISSION



- When an atom is in excited energy state, by passing a photon energy will cause the atom, decay to a lower level emitting a photon of radiation
- 1 Photon produces 2 photons
- Emitted, amplified photons is at same wavelength, same direction and in same phase, this process is called as Laser

$$h\nu + A^* = A + 2h\nu$$

Conditions for LASER action

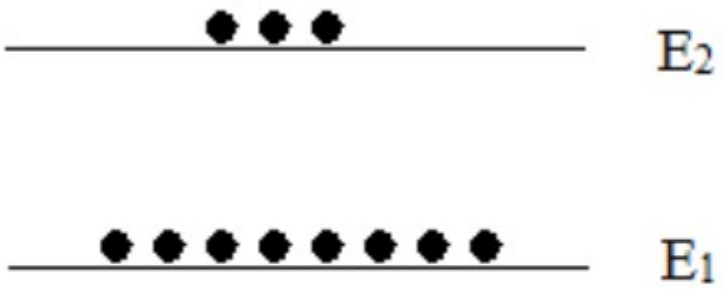
- **Stimulated emission**
- **Meta stable levels**
- **Population inversion**
- **Enough Number of Photons in the System**

- **META STABLE LEVEL : Excited energy level having lifetime 10^{-3} s**

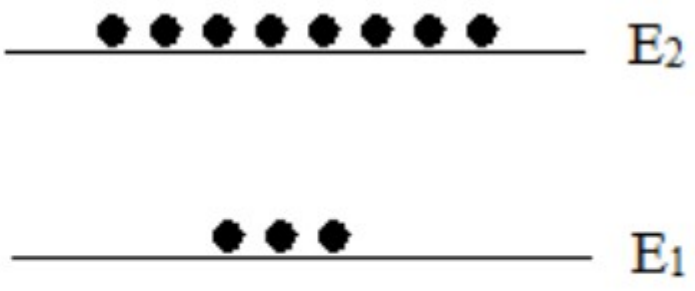
- **life time of such states is one lakh times greater than ordinary excited states**

POPULATION INVERSION

Number of atoms in the excited state is greater than the ground state



Normal population



Population inversion

N_1- number of atoms in the ground state

N_2-number of atoms in the Excited state

$N_2 > N_1$-- condition of population inversion

If $N_2 < N_1$ -stimulated absorption will dominate over stimulated emission

As a result light is attenuated rather than getting amplified

According to Boltzman,
the number of atoms (N) per unit volume in an energy level E,

$$N = N_o e^{-\frac{E}{kT}}$$

N_o --- Constant, k--- Boltzman constant, T--- Temperature

Meaning of Equation:
At any temperature, the number of atoms in higher energy level is lesser than that in the lower energy level.

E_1 and E_2 --- Two energy levels with number of atoms in these levels be N_1 and N_2

$$N_1 = N_o e^{-\frac{E_1}{kT}} \qquad N_2 = N_o e^{-\frac{E_2}{kT}}$$

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

at any finite and positive temperature, As $E_2 > E_1$, we have $N_1 > N_2$

This is equilibrium condition (stimulated absorption dominate)

for stimulated emission to dominate over stimulated absorption,

we require $N_2 > N_1$ (population inversion)

From the above equation it is possible only when the temperature is negative.

So the state of population inversion is called as negative temperature state

The word negative temperature state indicates a non-equilibrium situation

PUMPING Method of producing population inversion

The process of provision of energy to achieve population inversion

Types:

Optical Pumping → flooding a powerful light → solid state lasers

Electrical Pumping → by electrical discharge → gas lasers

Forward biasing the PN junction (diode laser)

Chemical pumping

Nuclear pumping

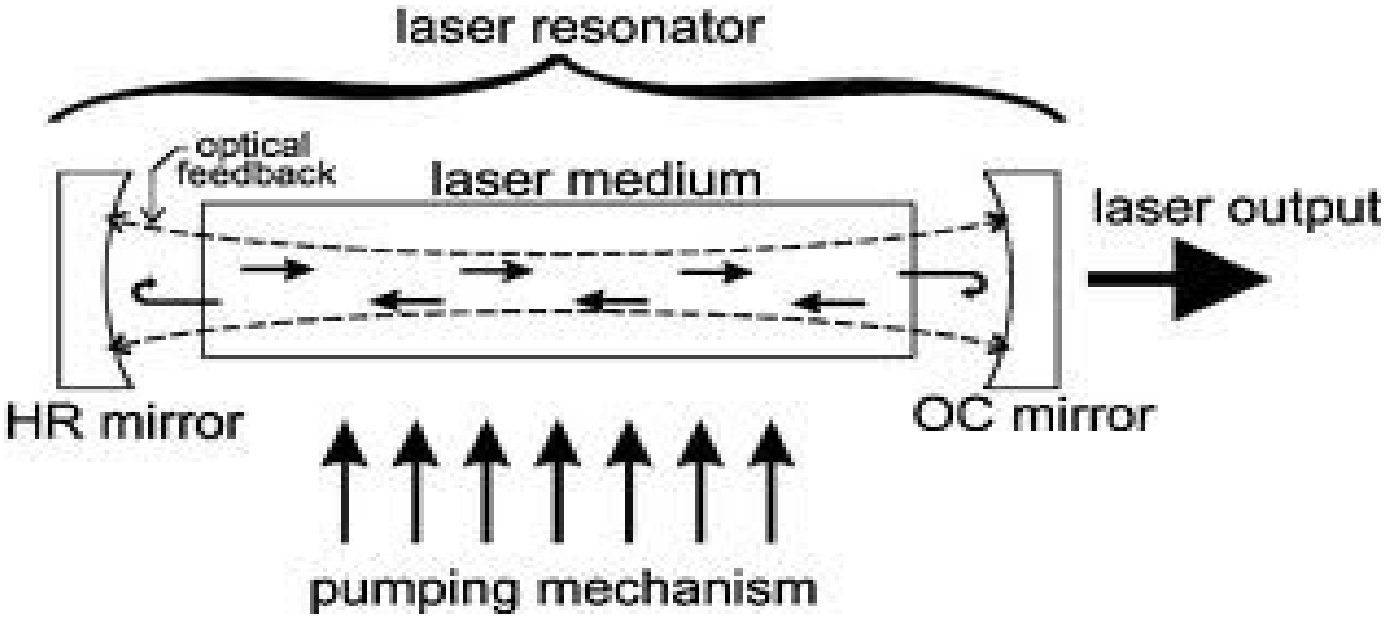
X ray pumping

Active system

An atomic or molecular system with metastable state and having population inversion

Active system is characterized by optical gain (amplification).

The active system can be in solid, liquid or gas.

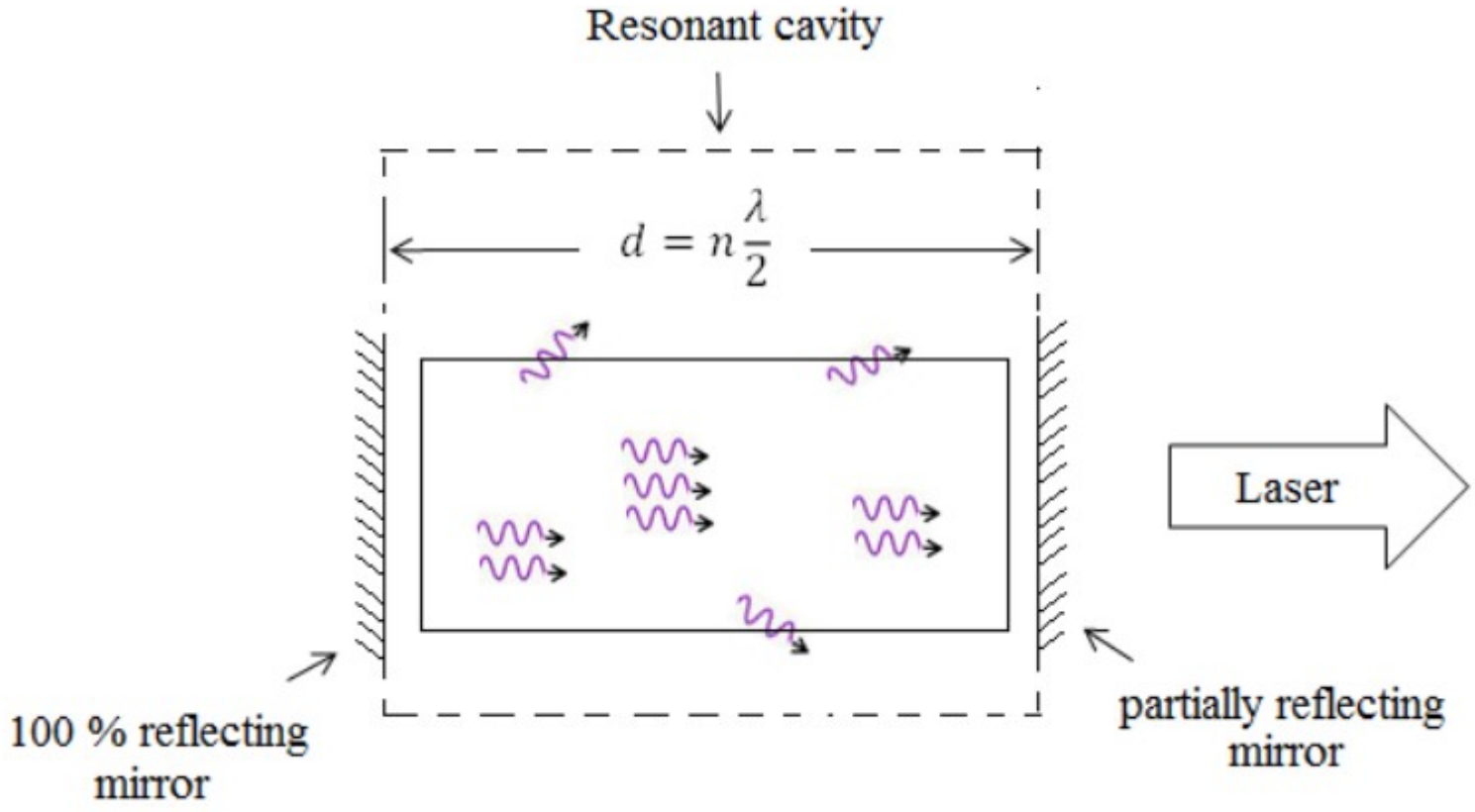


Resonant Cavity

for lasing action, enough number of stimulating photons in the system is required

This can be achieved by placing the active medium in between 100 % reflecting and another is partially reflecting mirrors at a distance d=nλ/2.

Due to such distance, the laser cavity resonates at λ, due to which the laser having wavelength λ is enhanced



Role of Resonant cavity

1. Enhances the photons in laser having wavelength λ, due to distance d=nλ/2
   Wavelength other than λ, where supressed due to non resonance
   Thus laser becomes pefectly monochromatic.

2. The resonant cavity supports positive feedback. first emission is always a spontaneous emission. photons produced due to first few spontaneous emissions trigger the stimulated emissions of remaining atoms. The mirrors used across the resonant cavity reflect back the photons, and these photons hits atoms present in the laser cavity producing another two photons. And also Due to this mirrors, photons oscillate in the laser cavity. When it acquires sufficient intensity it will come out from semitransparent mirror

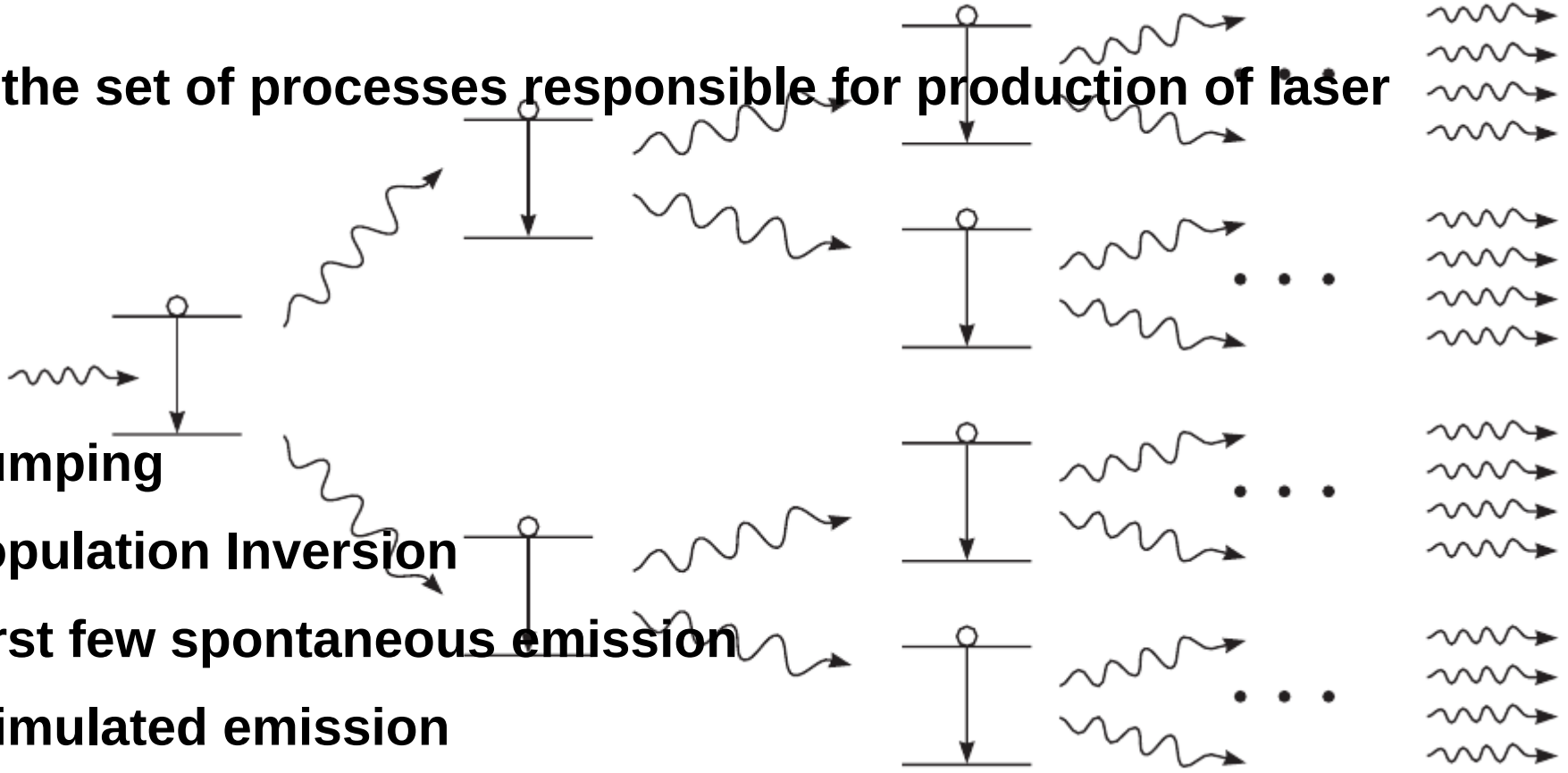
3. It provides directionality to the laser, due to presence of mirror, the photons travelling off axis escape from the cavity. Thus laser along the axis is built up and becomes more directional

Cavity Oscillations

The oscillation of the photons between mirrors (inside laser cavity)
It supports the positive feed back and provide the directional and monochromatic properties to the laser

Lasing

It is the set of processes responsible for production of laser



1.Pumping

2.Population Inversion

3.First few spontaneous emission

4.Stimulated emission

5.Absorption of the off axis photons

6.Back and forth oscillations of the photons in the laser cavity

7.The chain reaction of stimulated emission

8.Avalache multiplication of the photon

9.Outbrust of the laser through the partially reflecting mirror

Principal laser schemes

Even though atoms/molecules have several discrete energy levels but selected levels only utilised for laser action

3 Types

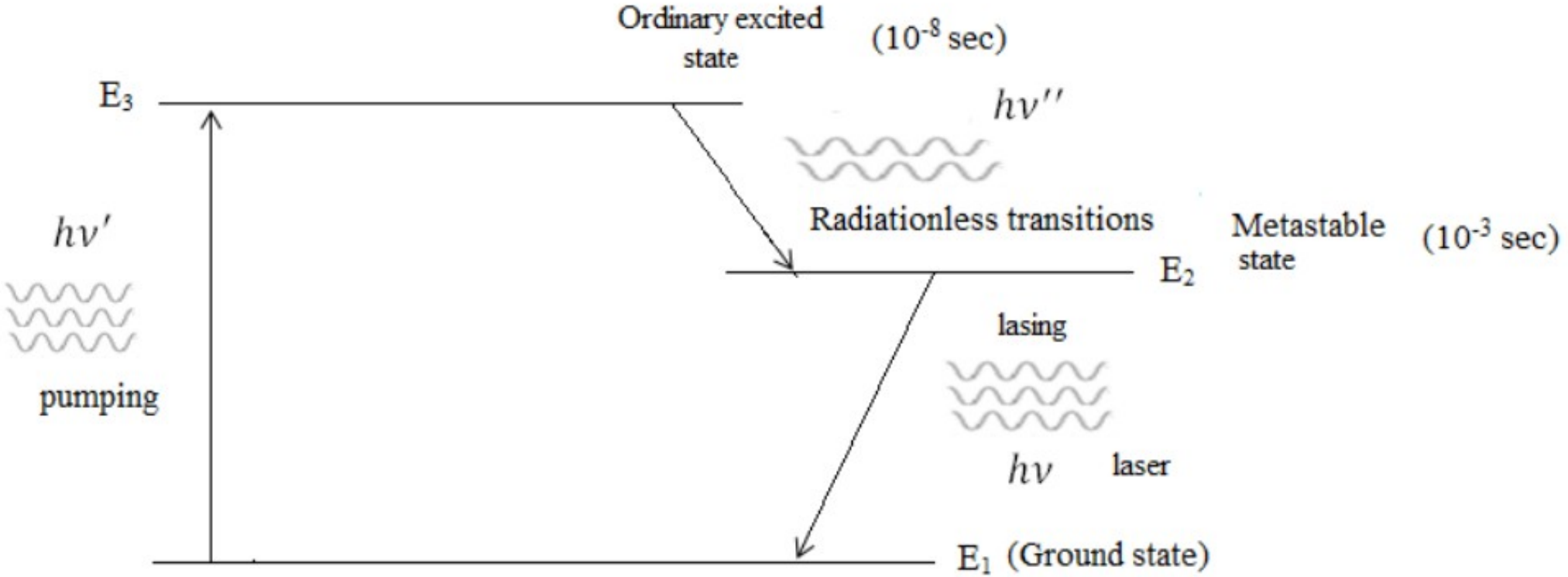
1. **Two level scheme**
2. **Three level sceme**
3. **Four level scheme**

Two Level Scheme

Only two energy levels are used for lasing
The atoms are pumped from E_1 to E_2
Stimulated emission takes place from E_2 to E_1
Thus energy levels used for pumping and stimulated emission are same

Ex: Diode Laser
Draw back:
Same enrgy levels used for pumping and lasing
Since number of atoms in E_1 and E_2 may be same
Therefor achieving population inversion is difficult,
hence lasing becomes difficult

Three Level System



This scheme involves three energy levels, one of which is metastable

E_1 (ground state),
E_2 (metastable state/upper lasing level)
E_3 (ordinary state: pump state)

Flash a lamp:
Pumping radiation having photon energy ($h\nu'$) falls on the active system

The atoms are excited from E_1 to E_3
the atoms stay there only for a short time.

Then they de-excite to E_2 by emitting a photon energy ($h\nu''$).
Weak and rapid transitions- Non-radiative transitions

E_2 state is a metastable state and therefore the atoms stay there for longer time.

Thus the number of atoms in E_2 state builds up and population inversion is achieved.

The first transition from E_2 to E_1 produces a spontaneously emitted chance photon.

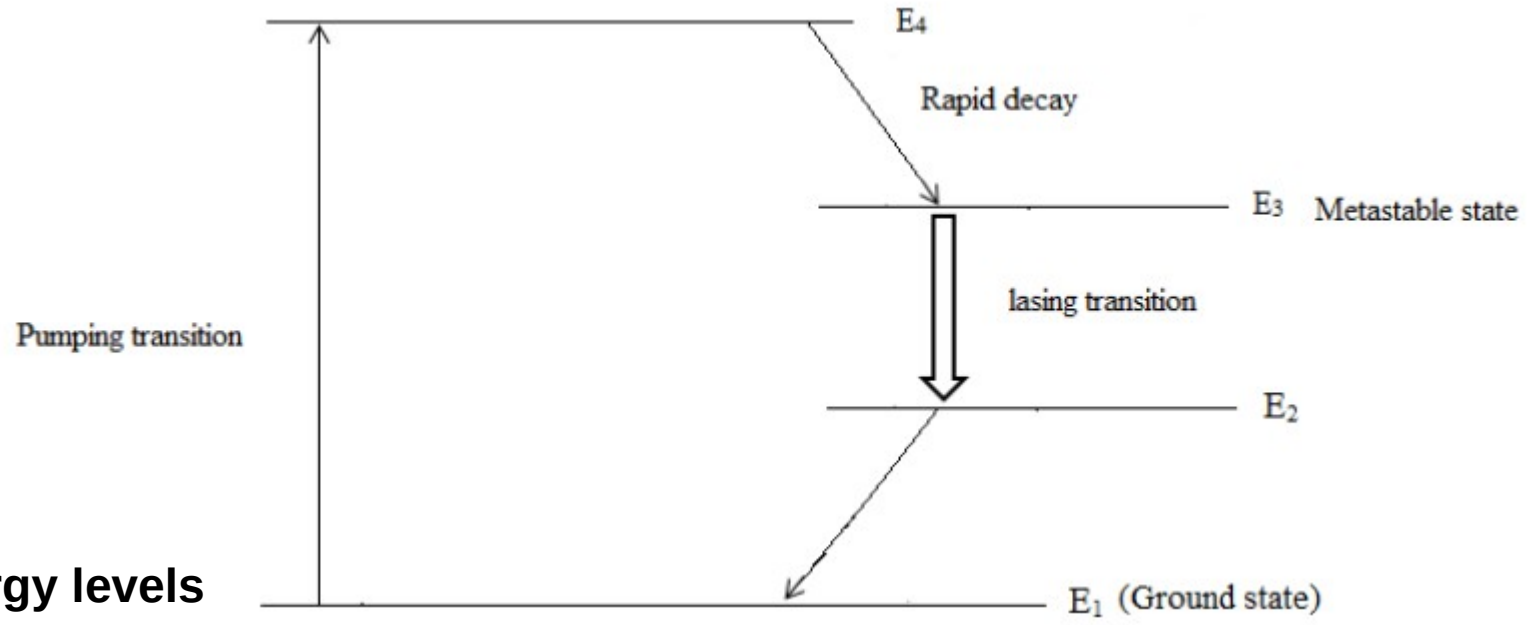
This photon triggers a chain of stimulated emissions ($h\nu$)and thus laser is produced.

This scheme requires large pumping power.

Further when all the atoms lase from E_2 to E_1, E_2 depopulates and E_1 populates. Thus the lasing temporarily ceases.

It is necessary to pump the atoms once again from E_1 to E_2.
Therefore all lasers which result from three level scheme - Pulsed laser
Ex: Ruby laser

Four Level System



Four energy levels

E1 is ground state --- E_3 is metastable --- E_2 and E_4 are ordinary excited states.

Pumped --- E_1 to E_4

E_4 to E_3 --- de-excite spontaneously--- Non radiative transitions.

The atoms thus stay in E_3 for longer time and therefore population inversion is achieved

E_3 to E_2---Lasing

E_2 to E_1 --- Spontaneous---Non radiative transitions

E_1 always contains enough number of atoms for pumping

Pumping requires less power.

The lasing and pumping take place simultaneously---- Continuous Wave Laser

Ex: He Ne laser, Nd-YAG laser, CO_2 laser

He-Ne Laser

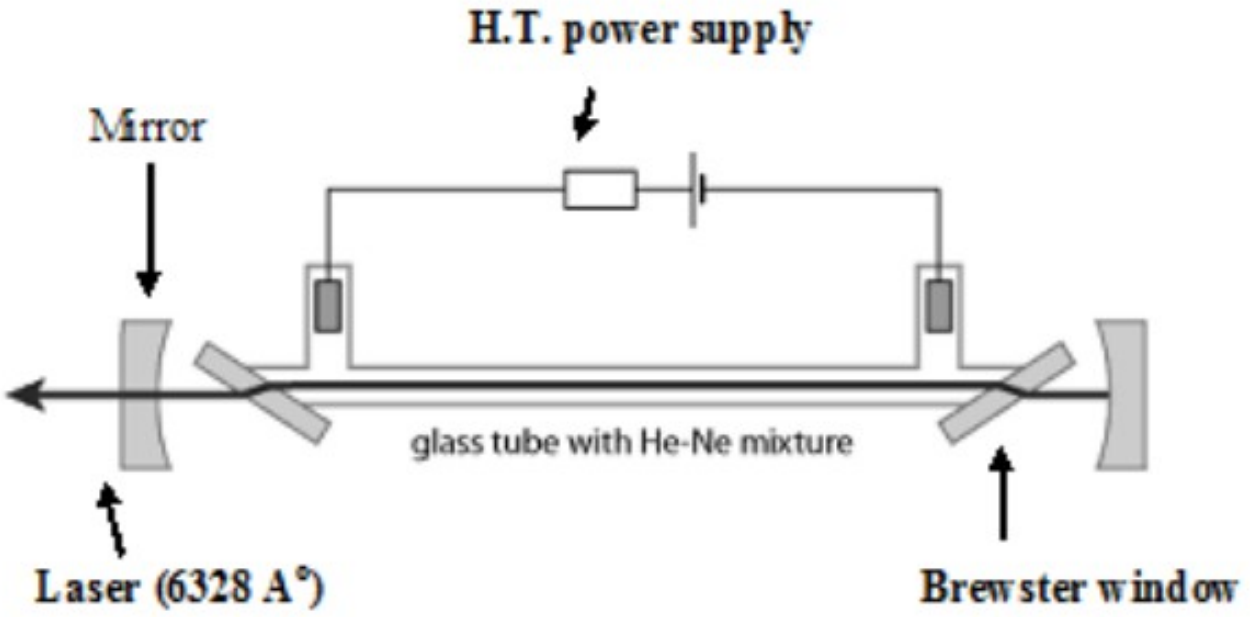
Low power Continous Laser

Gas Laser

The energy levels are more precisely defined and transition from higher to lower levels are sharper

Electrical Pumping: Electric discharge using high tension power supply

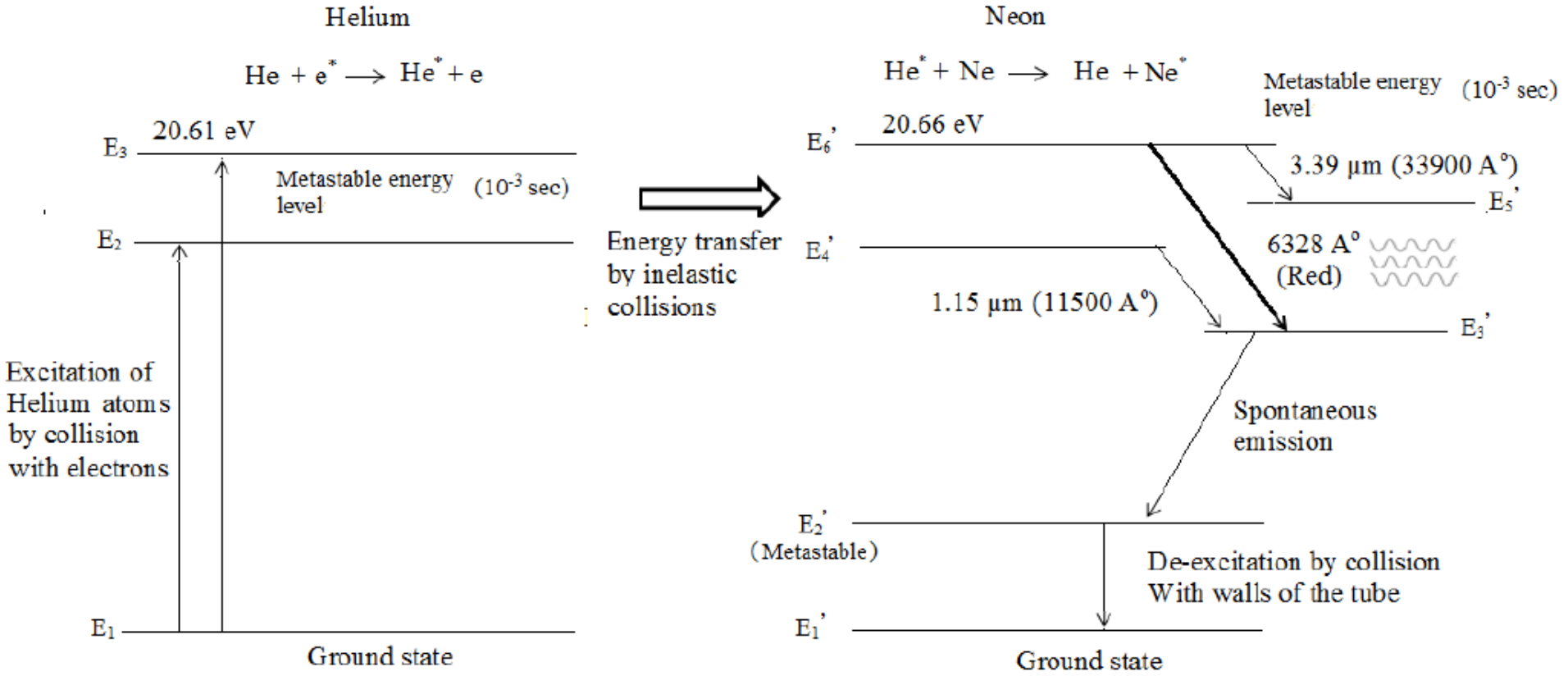
Construction



Glass tube of length 10-100cm and diameter of 2-8mm
Filled with the mixture of 85% helium and 15% Neon gas
Laser Active system --- Neon
Pumping System --- Helium
Pressure He --- 1mm of Hg
Pressure Ne --- 0.1mm of Hg
Electrode --- connected to High tension power supply (10kV) --- Produce electric discharge
Brewester's Window --- At the ends of the active medium, silica windows were fixed at Brewester's angle --- Produces polarised light
At the ends two mirrors were fixed
One is fully reflecting another is partially reflecting
Separated by distance $n\lambda/2$

Working

Energy Level Diagram



He + e* ----- He*+ e

Ne + He* ----- Ne* + He

When discharge begins, high energy electrons are produced in the tube

These electrons collide with the aroms of of He and Ne and excite them to high energy states

Probability of collision between He and electorn is more due to their higher concerntration
Hence He excites to variety of states

E_1--- Ground State E_2 and E_3 --- Metastable states

He + e* ----- He*+ e

Excited He atom collides with Ne atom

This elastic collision excites Ne from E_1' to E_4' and E_6'

Energy levels E_4' and E_6' of Ne atoms are close to each other with E_2 and E_3 of He atom

Ne + He* ----- Ne* + He

The percentage and pressure of Ne atom is less compared to He atom
The probability of reverse de-excitation of he atom due to He and Ne collision is very less

Due to continous de-excitations, the Ne meta stable E_4' and E_6' energy levels Populated more than lower levels
Therfore below de-excitations occurs

E_6' ---→ E_3' ---- 6328 Å Red Color
E_6' ---→ E_5' ---- 33900 Å (3.39μm) Infra red
E_4' ---→ E_3' ---- 11500 Å (1.15μm) Infra red

The transitions from **E_6' ---► E_5' and E_4' ---► E_3'** is supressed by

1. By using highly reflective coatings at 6328Å, that absorb all other wavelengths
2. By selecting laser cavity of suitable length **(D=nλ/2)** such that the wavelength 6328Å resonates and hence dominates over the other wavelengths

The **first Photon is spontaneously emitted**
This photon initiates the **chain of stimulated emissions**
These stimulated photons **move back and forth** between the mirrors and **amplify** the laser
When the laser acquires **sufficient intensity**, it comes out from the semi reflecting mirror

After lasing transition, there occur spontaneous de-excitation from E_3' to E_2'

Thus the **population of E_2'** level increase, E_2' is **undesirable metastable level**
If the atom stay in E_2' level for longer time, there is a **possibility of re-excitation** of ne atoms from E_2' to E_3' due to photons emitted from E_3' to E_2'
So population of E_1' level decreases
This prevents pumping of Ne atoms from E_1' to E_4'and E_6' due to which lasing may stop

To depopulate E_2' level **diameter of the glass tube made narrow**.
Due to this Ne atom de-excites from E_2' to E_1' due to collision of Ne atom with the wall of the tube

So that Ne atoms were continously pumped from E_1' to E_4' and E_6'
Hence He-Ne Laser is continous Laser

Applications of He-Ne Laser

1. Used in Laboratories
2. Super market Scanners
3. Scanners for bar code reading, printers, image and pattern recognition set ups
4. Range finders
5. FT Spectrometers
6. Holography
7. Non Destructive testing-- surface flaw and roughness measurements
8. To align other lasers

SEMICONDUCTOR LASER

Principle:

Heavily doped P & N regions is forward biased

Electrons and Holes recombine across depletion region to produce radiation

Photons thus produced may interact with

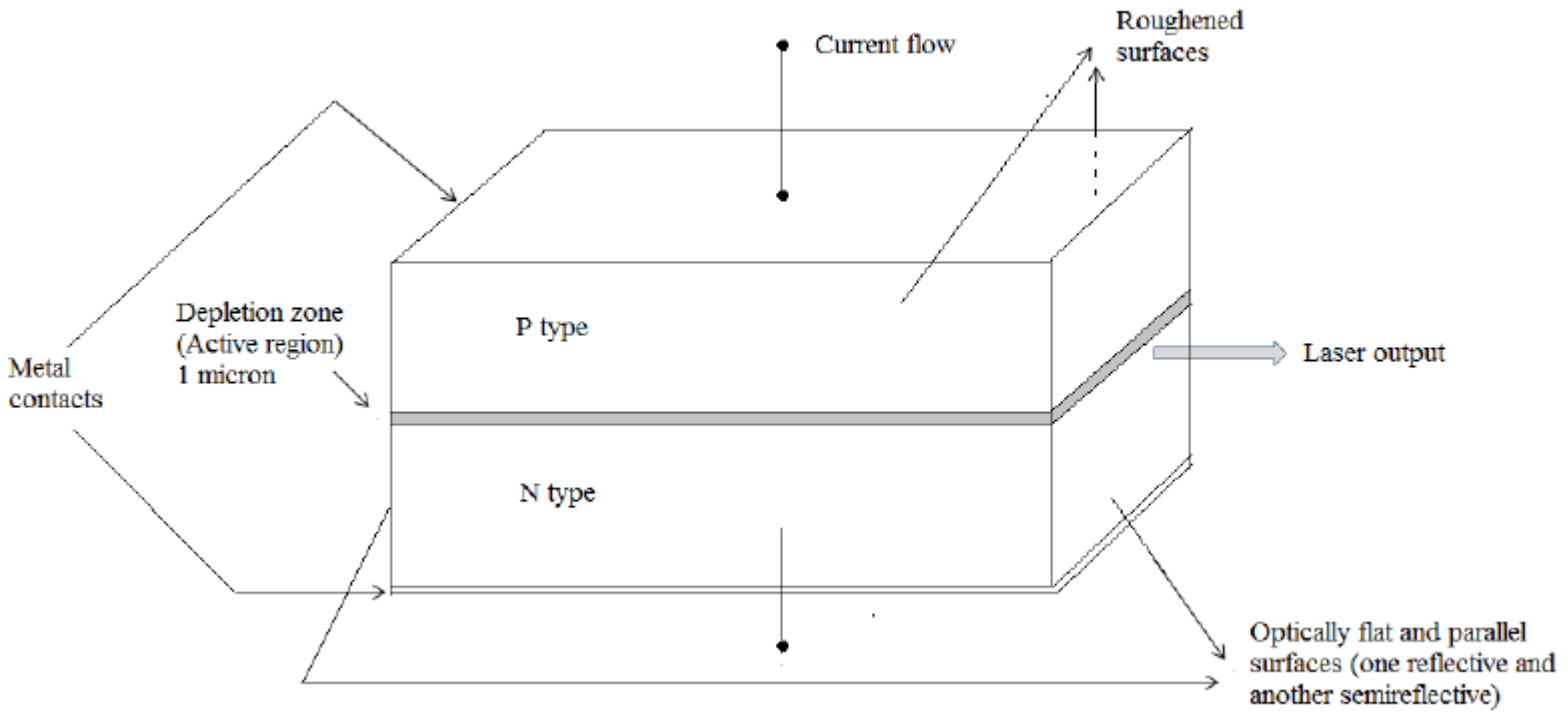
1. **Either with conduction band electrons stimulating radiative recombination (stimulated emission)**
2. **With valance band electrons to get absorbed (Stimulated absorption)**

If the voltage across the PN junction is large,

the injected carrier concerntration would be large

In such cases the stimulated emission can exceed the absorption, producing amplification in the active region which results in a good light output

Construction



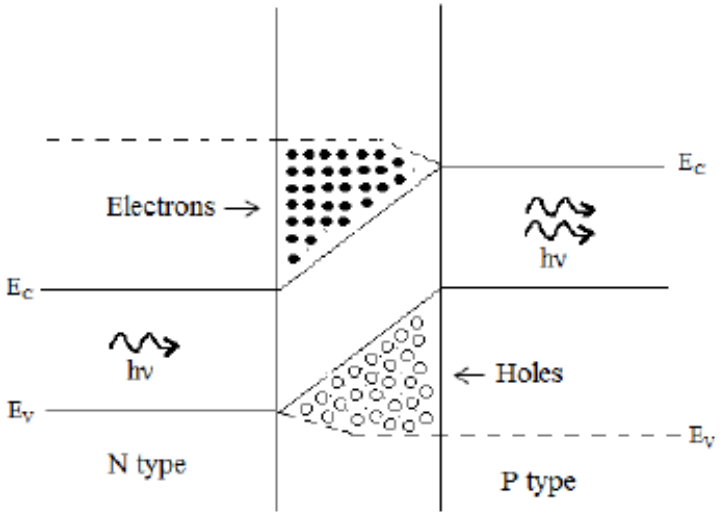
Sandwiched heavily doped P and N type Semiconductors
Two side surfaces opposite to each other made flat and polished
One out of these surfaces is fully reflecting while another is semi reflecting

The region inbetween these two mirrors work as Fabry-Perot resonator

The other two side surfaces are roughned to avoid lasing action in that direction.

Due to heavy doping there is a large concerntration of electrons in N-Region (Conduction Band) and large concerntration of holes in P-Region (Valance band)

Working



If **high forward current** (Above Thresh hold) is injected, then Heavy concerntration of electrons and holes quickly approach towards depletion zone

This results in to **large concerntration of filled levels of electrons in the conduction band** near the junction and **large concerntration of vacant levels of holes in the valance band** near the junction
This results in **Population Inversion**
Thus **high forward current acts as pumping agent**
The electrons and holes **recombine at fast rate** and results in to sudden production of large number of photons
These **photons work as a stimulating photons for subsequent deexcitations**
This proces is supported by the **fully reflecting and semireflecting mirrors**
In this manner an **avalanche of photons constitue a laser production**

Ex: GaAs --- 9000 Å
GaAsP --- 6500Å

Advantages

Simple

Low cost

Compact

Highly Efficient

low power consuming

requires less equipment

Disadvantages

More Divergence (5^o to 15^o)

Applications

Read and write CD, DVD

In Laser Printers, Copiers

Fiber optic communications

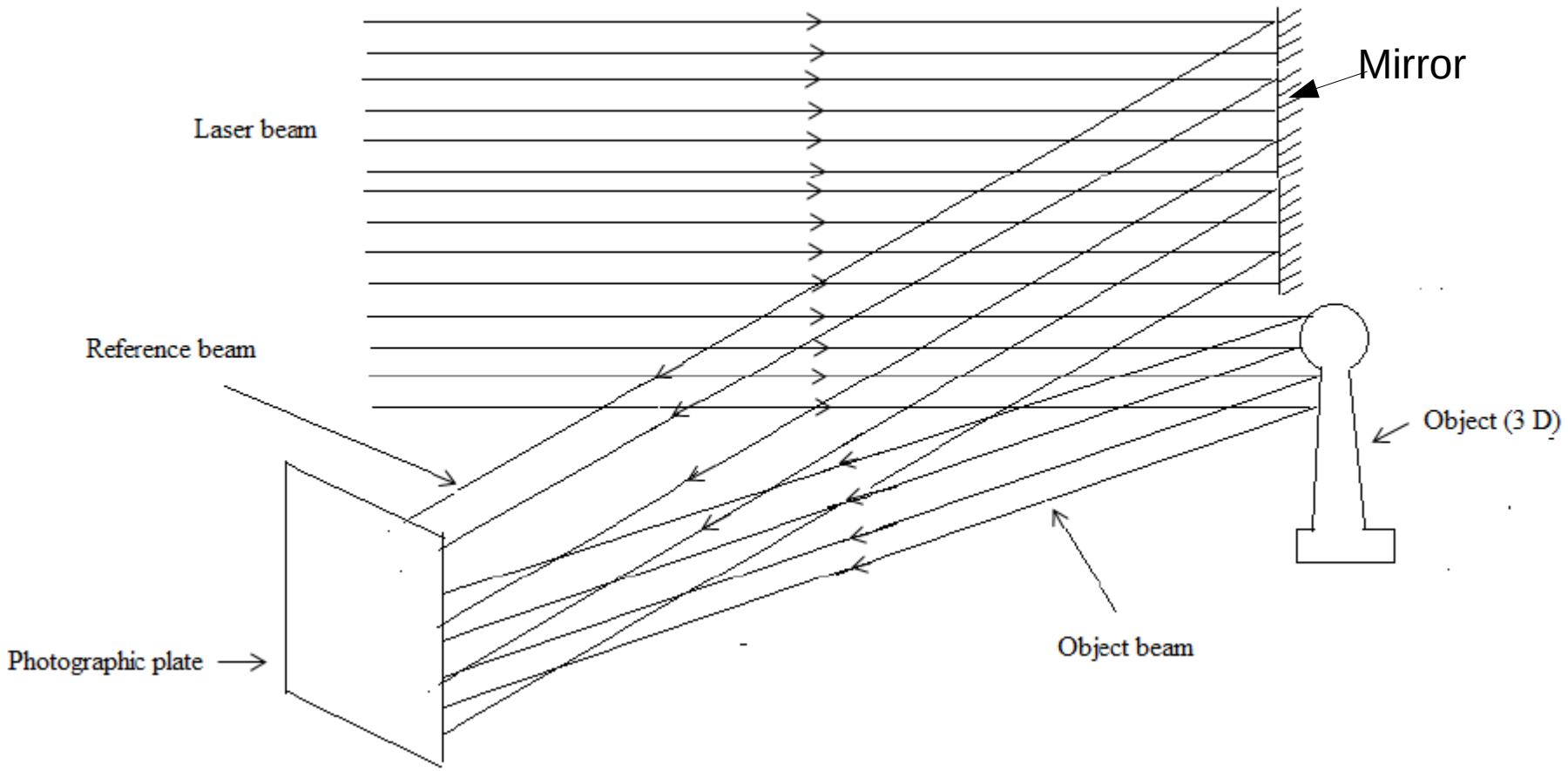
Holography

- Lense less Photography
- Technique of producing 3-dimensional images
- 3-D Photography
- It records information about the amplitude as well as Phase of the object
- It is based on the concept of interference

- **Two step process**

  1. Construction of hologram (Recording)
- 2. Reconstruction of hologram

Construction of Hologram



Reference Beam: Some part of laser beam is made to fall on a mirror. The mirror reflects the beam towards a photographic plate

Object Beam:

Another part of the same laser beam is incident on the object and is reflected (scattered) towards a photographic plate

Contains information about amplitude and phase of the object

Amplitude and Phase variation in the object beam depends on structure of the object

Object beam and reference beam both are coherent as they are derrived from same source

On photographic plate both the rays undergo interference

Interference – Phase dependent phenomenon

It records the phase variation of the object

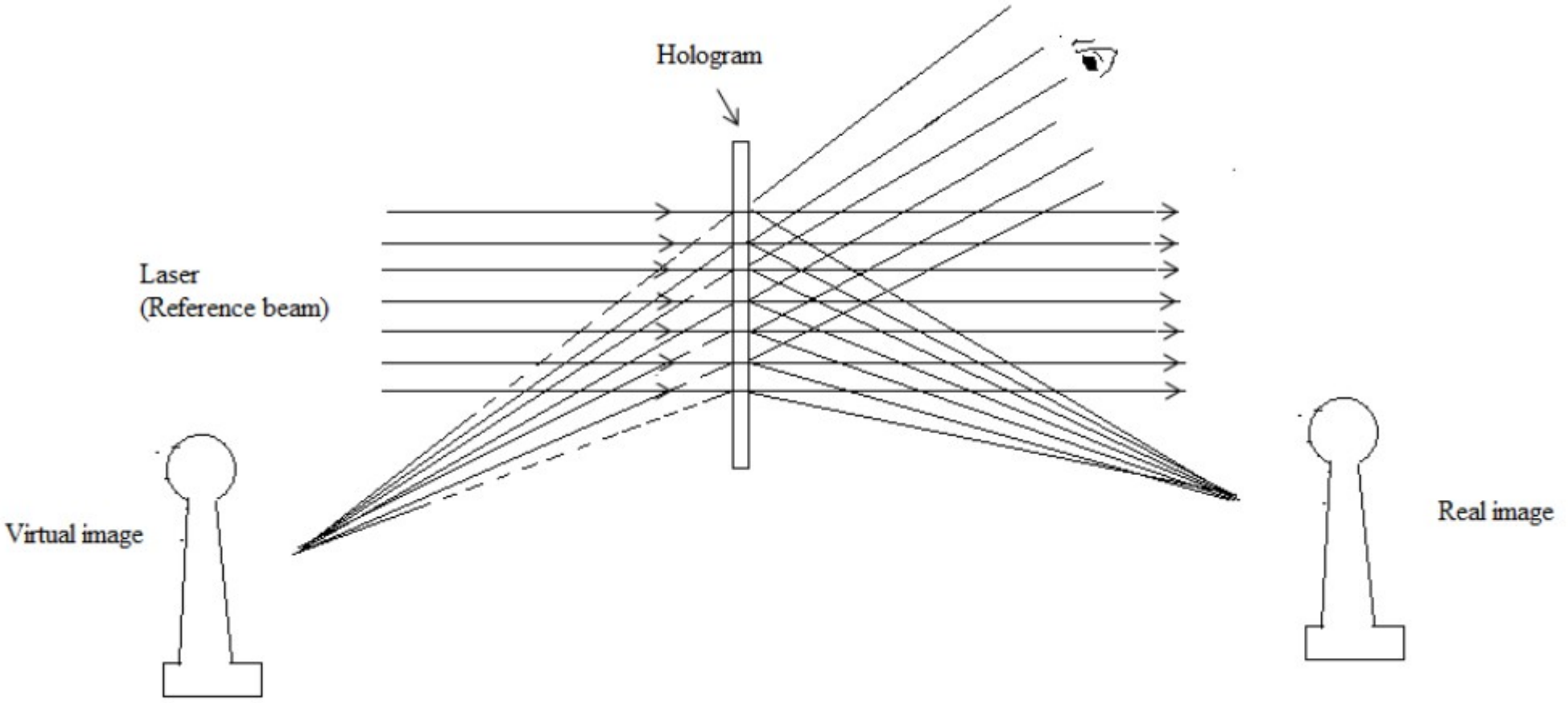
Intensity at any point depends upon phase diffrence between the object beam and referance beam

On photographic plate we get complex pattern of maxima and minima

It serves as a diffraction grating

This complex interference pattern viwed directly, it doesn't look like an object. Such photographic plate is called as **Hologram**

Reconstruction of Hologram



It involves Difraction

For viewing object Hologram need to be illuminated with same wavelength laser used for construction

Hologram is a complex difraction grating

When illuminated with laser is difracted from the hologram

This produces Two images:Virtual and Real

Vitual Image

It appears at same position as it was occupied by the object, opposite to observer called as True image

It is only viewed not possible to take photograph of it

Real Image

It produced infront of the hologram (opposite side of the referance beam or same side of the observer

It can be Photgraphed

Advantages

Holographic image is Parallax

it appears difrent as viewing direction is changed like 3-D image

Hologram is cut in to pieces, each piece of image produces complete image

Very sensitive to vibrations

Photography	Holography
There is no parallax	There is parallax
Ordinary Light is sufficient	Laser is necessory
No interference	There is a interference between Object beam and referance beam
It stores one image on one photographic plate	It can be stored several diffrent images images on a single holographic plate
If photograph is broken in to pieces the information is lost	Each broken piece retrieves entire information stored in whole hologram
This is not secure	Highly secure,in order to retrieve data stored in hologram requires exactly same wavelength laser used for construction

Applications of Holography

1. Data storage

In conventional storage information stored in one angle, it is called as Surface Data Storage

In Holographic data storage, the data stored in each possible angle, it is called Volume data storage

Storage capacity is very high

2. Holographic trademarks- secret maintain

3. Acoustic holography – combining holography and ultrsonography to view 3D image of an internal oragans

4. Holographic microscopy

5. holographic pattern recognition used to identify fingerprints

6. To study air pollution

7. holographic Interferometry- minute deformation in object

8. holographic optical elements- splitters, grating

Other Applications of Laser

1. **Read and write CD**
2. **Laser Printer**
3. **Opthomology-Eye/ cataract surgery**
4. **Plastic surgery**
5. **Bloodless cancer surgery**
6. **Painless dental surgery**
7. **Laser Welding-intens heat generated**
8. **Laser Cutting-focussed**
9. **Laser Drilling-micromachining**
10. **LIDAR- for surveying and ranging**
11. **Inspect pollution level**
12. **Barcode scanning**

Reference : Concepts of Engineering Physics, Dr. N. L.Mathakari , MIT WPU

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Dhanyavada