LECTURE PLAN

ENGINEERING PHYSICS

BECF181T30/CBSPH18T30

B.E. / B. Tech.

(ECE, EIE, Mechatronics, EEE, CSE&IT)

(2020 -21 / I SEMESTER)

UNIT III – PHOTONICS

- Properties of laser- spontaneous and stimulated emission, amplification of light by population inversion

Delivery mode	• Black board/ PPT
Key lecture points	• Absorption, spontaneous and stimulated emission processes with EL diagrams due to radiation –matter interaction • Ground, excited and metastable states • Introduction to laser with its characteristic properties • Stimulated emission as principle of lasing action • Pumping process and creation of population of inversion • Components of lasers – active medium, pumping source, reflecting mirrors and power supply for pumping • Types of lasers based on nature of active medium
Conclusions	• Atoms and molecules can be excited by supplying external energy • Active medium is the source of atoms or molecules • Pumping process is essential for creating population inversion • Metastable states are useful for creating population inversion • Stimulated emission supplies coherent photons • Electronic transitions are responsible for lasing in solid state laser
Questions	• Differentiate between spontaneous and stimulated emissions • Give the significance of meta-stable states • Why population inversion is necessary? • Essential components of laser set up

Credits	Exam	Marks		Total
		UI	UE	
4	3Hrs	40	60	100

Objectives

- To understand energy absorption and emission mechanisms
- To understand the principle of laser, its characteristics and its components

Outcomes

Student will be able to explain

- Absorption, spontaneous and stimulated emission processes
- Meta stable states and population inversion
- Principle of lasing and components for laser set up

Pre requisites

Basic knowledge on

- Concept of photons, ground state and excited states of atoms

Terms used

- Spontaneous emission
- Relaxation time
- Stimulated emission
- Coherent photons & Laser characteristics
- Active medium
- Optical and electrical Pumping and sources
- Reflective mirrors

INTRODUCTION TO LASER

[LASER stands for Light Amplification by Stimulated Emission of Radiation]

Laser is a special light compare to normal light with the following characteristics

- **High intensity**
- **Monochromaticity (Single wavelength)**
- **Unidirectionality (Lesser divergence)**
- **Coherence (Same wavelength, phase and frequency)**

PRINCIPLE OF LASER

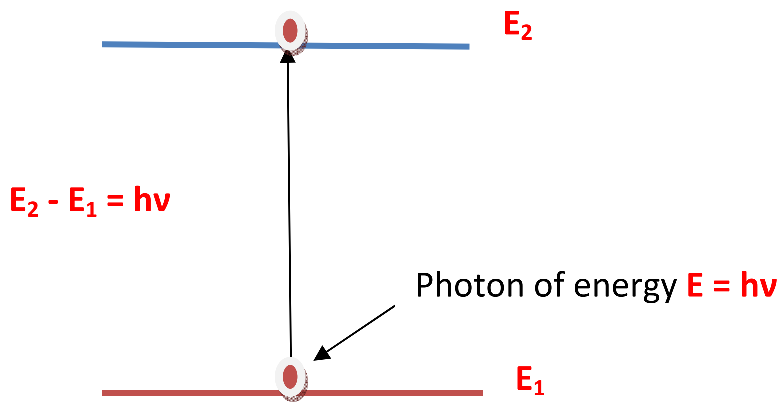
To know the principle, let us try to understand the interaction of radiation with matter.

- Matter refers to collection of atoms or molecules in solid, liquid and gaseous phase
- Radiation refers to electromagnetic radiation and composed of photons (energy $E = h\nu$)

When photons in radiation excite the atoms in a matter, following processes occur;

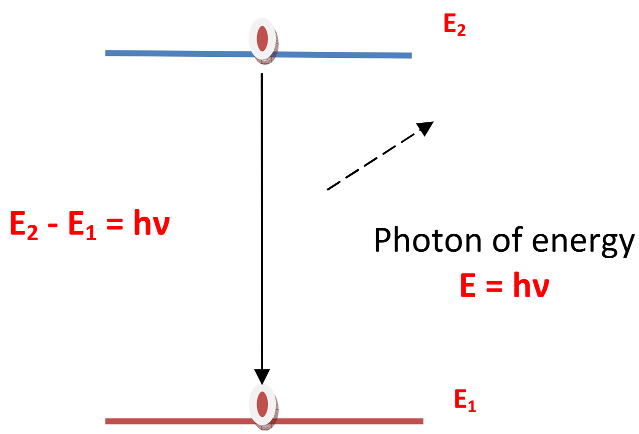
- Absorption
- Emission
  - **Spontaneous emission**
  - **Stimulated emission**

Absorption



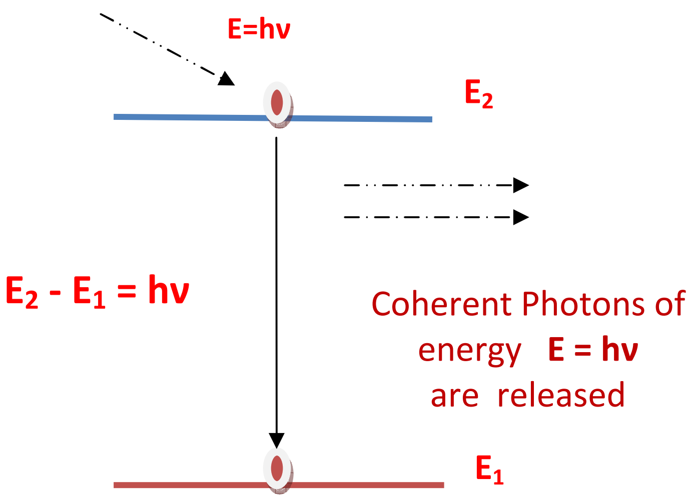
- In absorption, photons of energy **$E = h\nu$** incident on atoms.
- The atoms consists of central nucleus and surrounding electrons. The electron inside the atom absorbs energy and excited to permitted higher energy levels.

Spontaneous emission



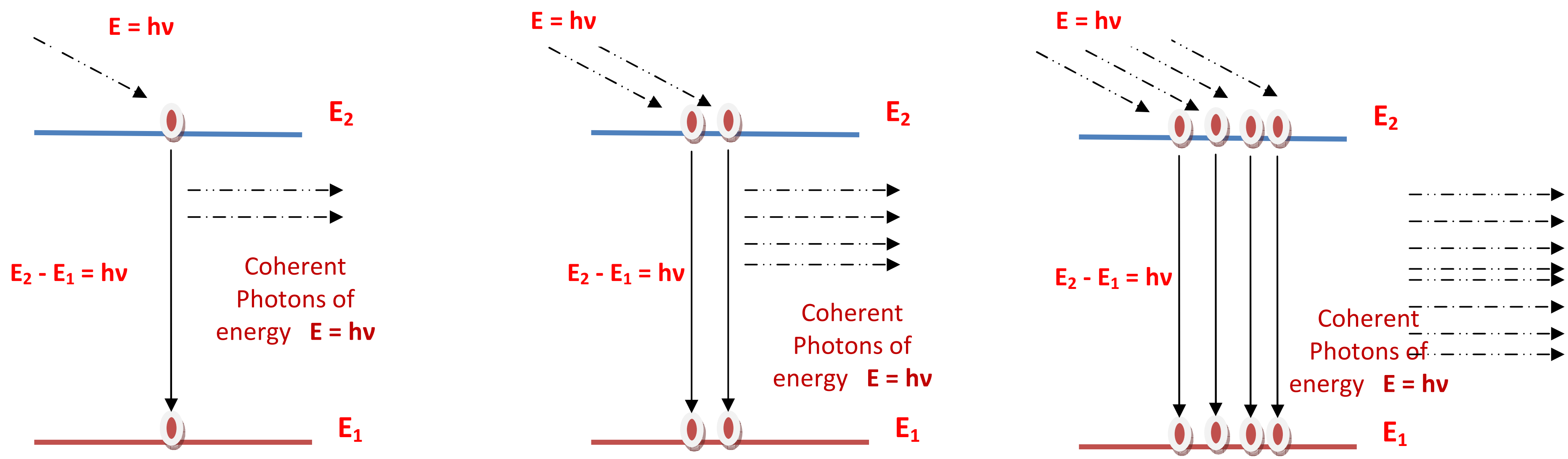
- The excited atom resides in excited level for a certain period of time (micro seconds) called relaxation time
- After completing the relaxation time, due to normal tendency to occupy ground state, the atoms spontaneously come to ground state
- During this downward transition, the difference in energy **$E = h\nu$ is released in the form of photon.**
- **Since this is taking place spontaneously, we call it as spontaneous emission**

Stimulated emission



- The excited atom resides in excited level for a certain period of time (micro seconds) called relaxation time
- But before completing this time, some of the photons with energy **E = hν stimulate the atoms at energy E = hν in the excited state and induce them to go to ground state, as both of them in same frequencies (ν).**
- This emission is stimulated by external photons and is called stimulated emission.
- In this emission, since the atom is going to the ground state, the difference in energy is released in the form of photon along with the stimulating photon .
- Therefore 2 photons of frequency **ν is emitted in the stimulated emission**
- These photons **have same frequency, phase and wavelength and are called as Coherent photons**

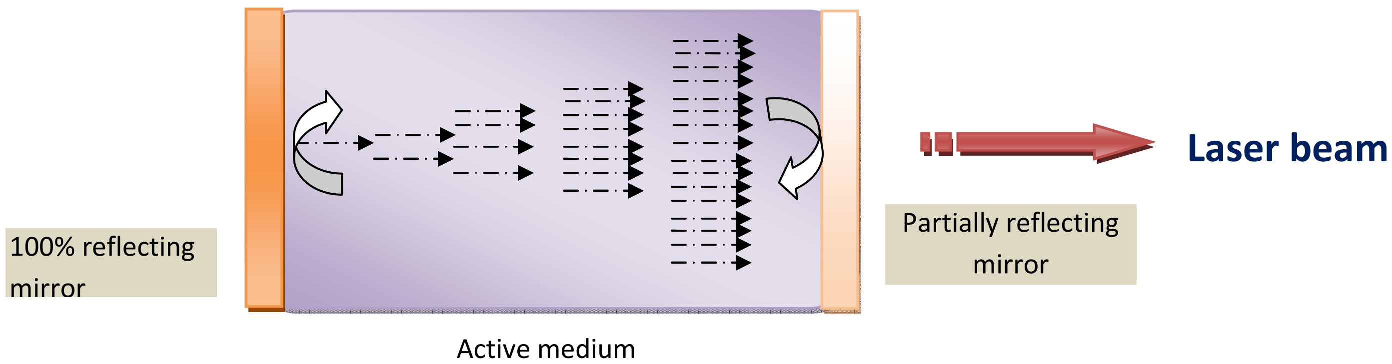
FORMATION OF LASER



- In the first diagram, two coherent photons are released
- These two photons again induce emission in two atoms and four photons are released
- These four photons again induce four atoms at excited state and eight coherent photons are released
- This 8 becomes 16 and 16 becomes 32 and goes on….
- When the atoms or molecules terminate in the journey path of photons, this multiplication stops and lesser photons may come out and this will not a laser beam

FORMATION OF LASER

- Since laser beam forms due to a huge number of photon in small cross sectional area, photon number should be increased to an optimum level and then should be released as a laser



- In the above diagram, the photons are increasing in number and reache the end of the active medium (source of atoms or molecules) and they are turned back using a mirror and again reflected on the other side by another mirror.

- Among two mirrors one is fully reflecting and another is partially reflecting

- This is because, after developing optimum number of photons, the high dense of photons are released through partially reflecting window and coming out laser

COMPONENTS OF LASER

ACTIVE MEDIUM

- **Solid, liquid or gaseous matter whose atoms or molecules act as active centers for laser emission. [active centres are atoms or molecules which involve in absorption and emission]**

    - **Solid – Solid state laser**
    - **Liquid – Liquid lasers**
    - **Gas – Gas lasers**

REFLECTING MIRRORS

- **100% reflecting and partially reflecting mirrors**
- **To build up number of photons through forward and backward journey through active medium**
- **Partially reflecting mirror is to release the laser beam out from active medium**

PUMPING SOURCE

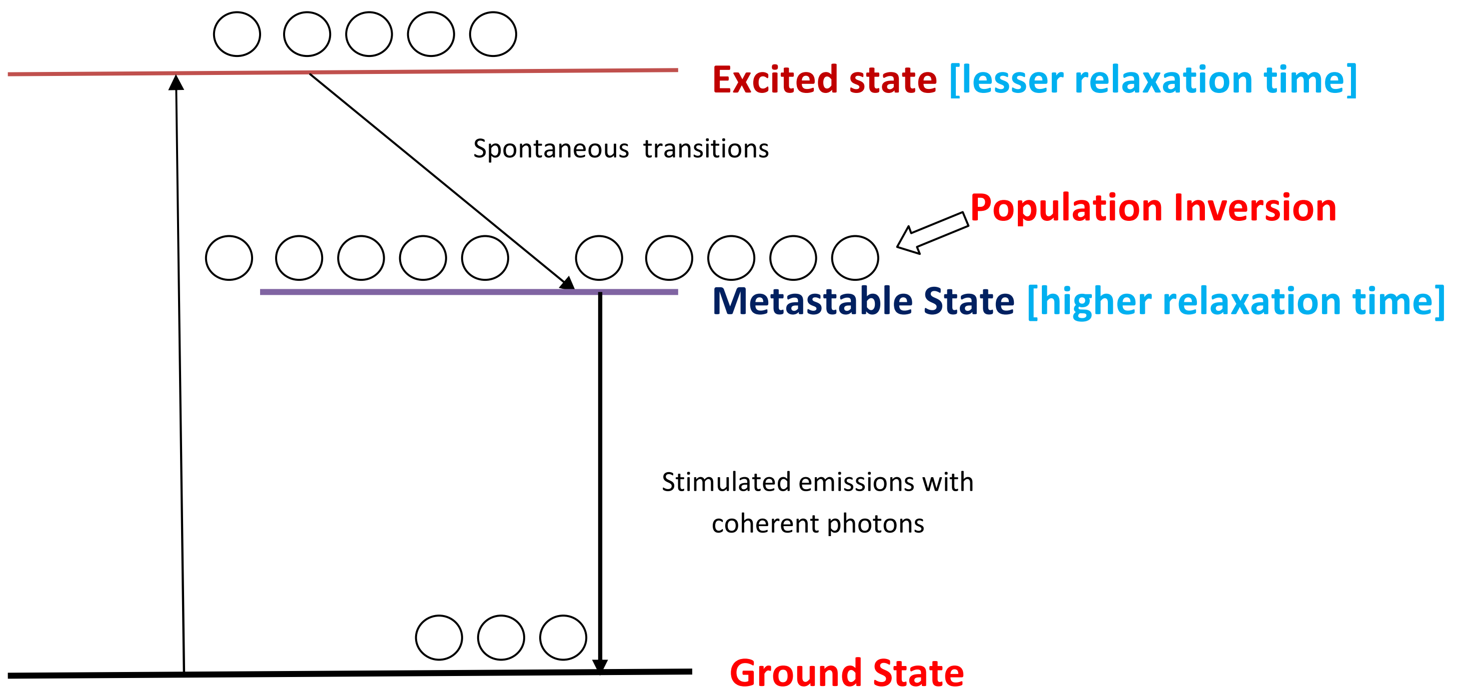
- **Pumping is the process of supplying energy to atoms so that they can be raised to excitation levels**

- **Various types of Pumping**
  - **Optical Pumping by Optical pumping source – Xenon, Crypton Flash Lamps**
  - **Electrical Pumping by Electrical discharge tubes**
  - **Chemical Pumping by the usage of thermal energy released by chemical reactions [exothermic]**
  - **Thermal pumping by supplying heat energy**

POWER SUPPLY

- **Power supply is given for pumping mechanism to achieve pumping**

ENERGY LEVEL SCHEME



- Metastable states are highly useful in creating population inversion [$N_2 > N_1$]
- In population inversion , no. of atoms in excited state (N_2) is greater than that of ground level (N_1)
- In normal population [$N_1 > N_2$]

BASICS ON WORKING OF LASER

- Efficient Pumping brings more atoms to excited levels at once
- This results in population inversion at metastable states
- From meta-stable states, atoms come to lower states through stimulated emissions giving coherent photons
- Coherent photons are suitably multiplied and laser is produced

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UNIT III – PHOTONICS

- solid-state laser (Nd-YAG laser)

Delivery mode	• Black board/ PPT
Key lecture points	• Nature of components of Nd:YAG laser • Characteristics of Nd:YAG laser • Description on working set up (with diagram) • Explanation on working with energy level diagrams • Applications.
Conclusions	• Nd-YAG laser uses a solid Nd-YAG rod as active medium • Laser transition occurs between electronic levels in solid state lasers • Four level solid state laser • Optical pumping is employed for solid state lasers
Questions	• Differentiate between various pumping systems • Give the significance of meta-stable states • Essential components of Nd-YAG laser set up

Credits	Exam	Marks		Total
		UI	UE	
4	3Hrs	40	60	100

Objectives

- To understand the components of Nd-YAG laser
- To understand the working of Nd-YAG laser

Outcomes

Student will be able to explain

- Solid state Four level lasers
- Optical pumping
- Meta stable states and population inversion
- Electronic transitions

Pre requisites

Basic knowledge on

- Spontaneous and stimulated emissions
- Laser components

Terms used

- Nd-YAG rod
- Xenon flash lamp
- Elliptical cavity
- Four level laser
- Reflective mirrors

Nd-YAG L A S E R

[Neodymium doped Yittrium Aluminium Garnet Laser]

Why Y A G?

YITTRIUM ALUMINIUM GARNET [YAG]

- Garnets [$X_3Y_2(SiO_4)_3$] are group of silicate minerals [gem stones and abrasives]

  X sites - Divalent cation $(Ca, Mg, Fe, Mn)^{2+}$

  Y sites - Trivalent cation $(Al, Fe, Cr)^{3+}$

- YAG is a synthetic garnet made using aluminium in the place of Si
- High optical quality
- YAG can be polished to a good optical finish
- High thermal conductivity for easy extraction of the heat generated

Lab created YAG Gem
https://www.jtv.com/library/gemopedia/yag

CHARACTERISTICS

❖ **ACTIVE MEDIUM : Neodymium [Nd $^{3+}$ ions] doped YAG**

- **Size of Nd^{3+} ions are almost same as Y^{3+} ions**
- **Some of the Y^{3+} ions (1%) are replaced by Nd^{3+} ions on doping**
- **Nd^{3+} ions act as active centers in the active medium**
- **Active centers are those atoms or molecules which involve in absorption and emission transitions during pumping processes.**

Nd:YAG laser rod 0.5 cm in diameter

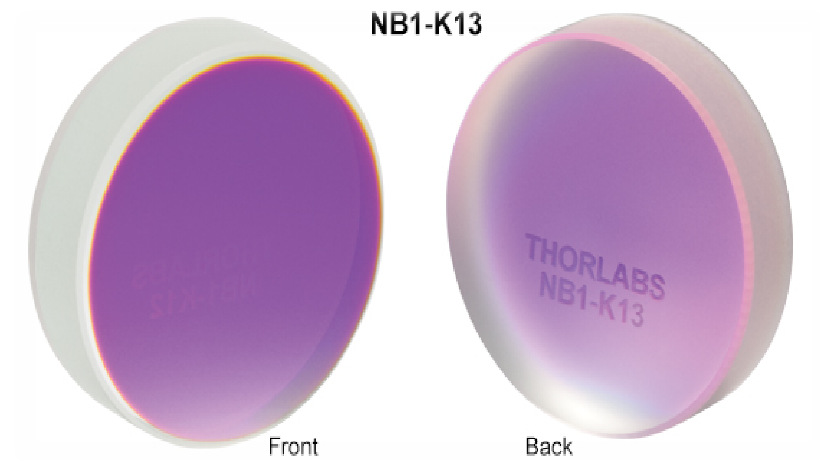
❖PUMPING MECHANISM : Optical Pumping

- Pumping Source : Xenon Flash Lamp
- Photons from the flash of flash lamp excite Nd^{3+} ions to higher excited levels
- Population inversion is created

Customized Xenon flash lamps
https://gbondtech.com/product-categories/laser-crystal-xenon-lamps/

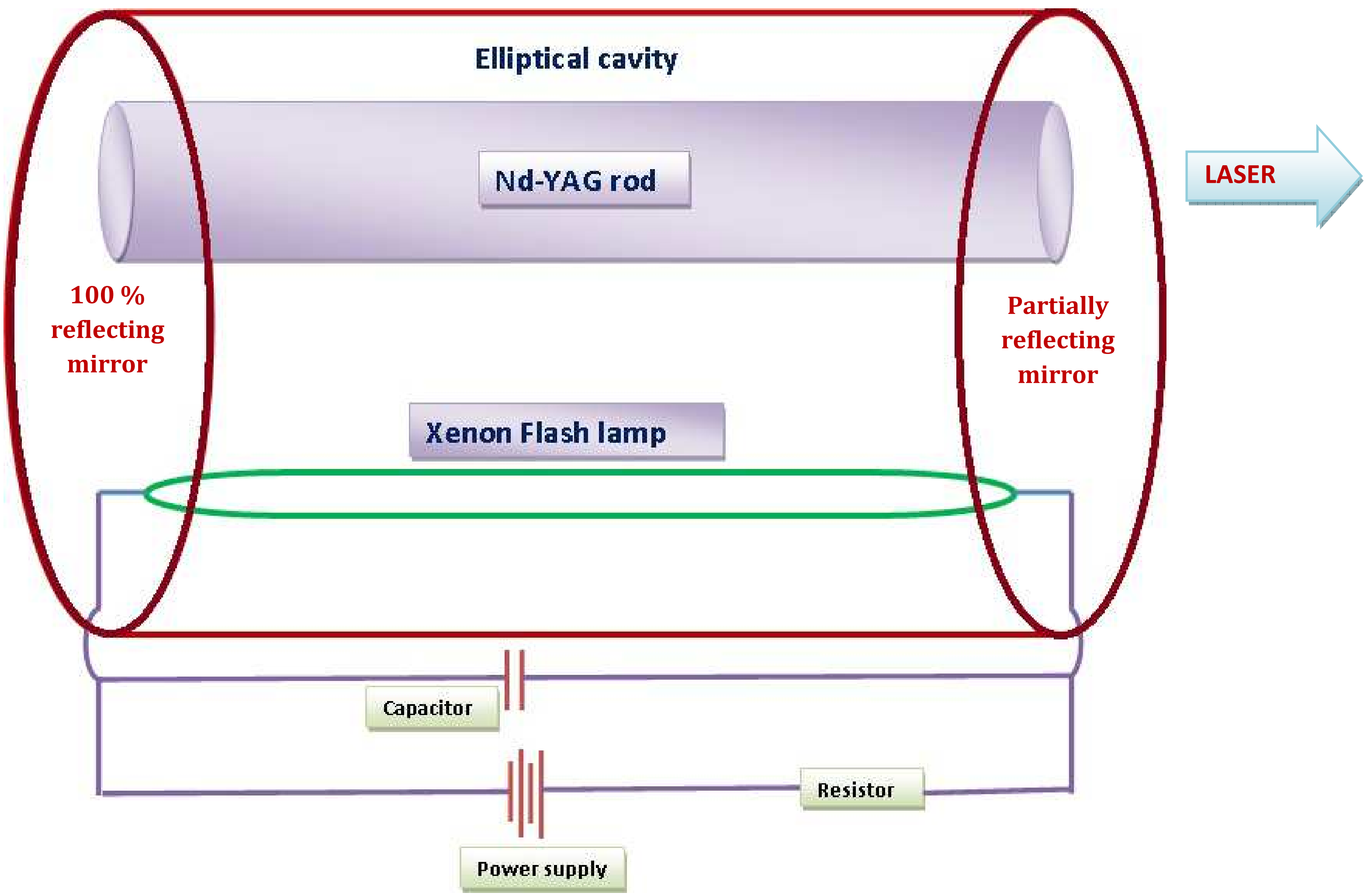
❖REFLECTIVE MIRROR SET UP

- The ends of Nd-YAG rod are fitted with suitable reflective mirrors
- One mirror gives 100% reflection
- The other mirror gives partial reflection



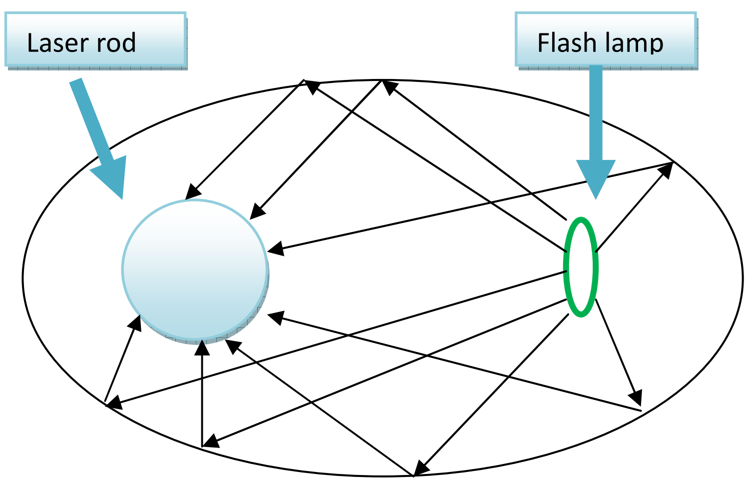
Mirrors for Nd-YAG lasers
https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=3793

SCHEMATIC SET UP



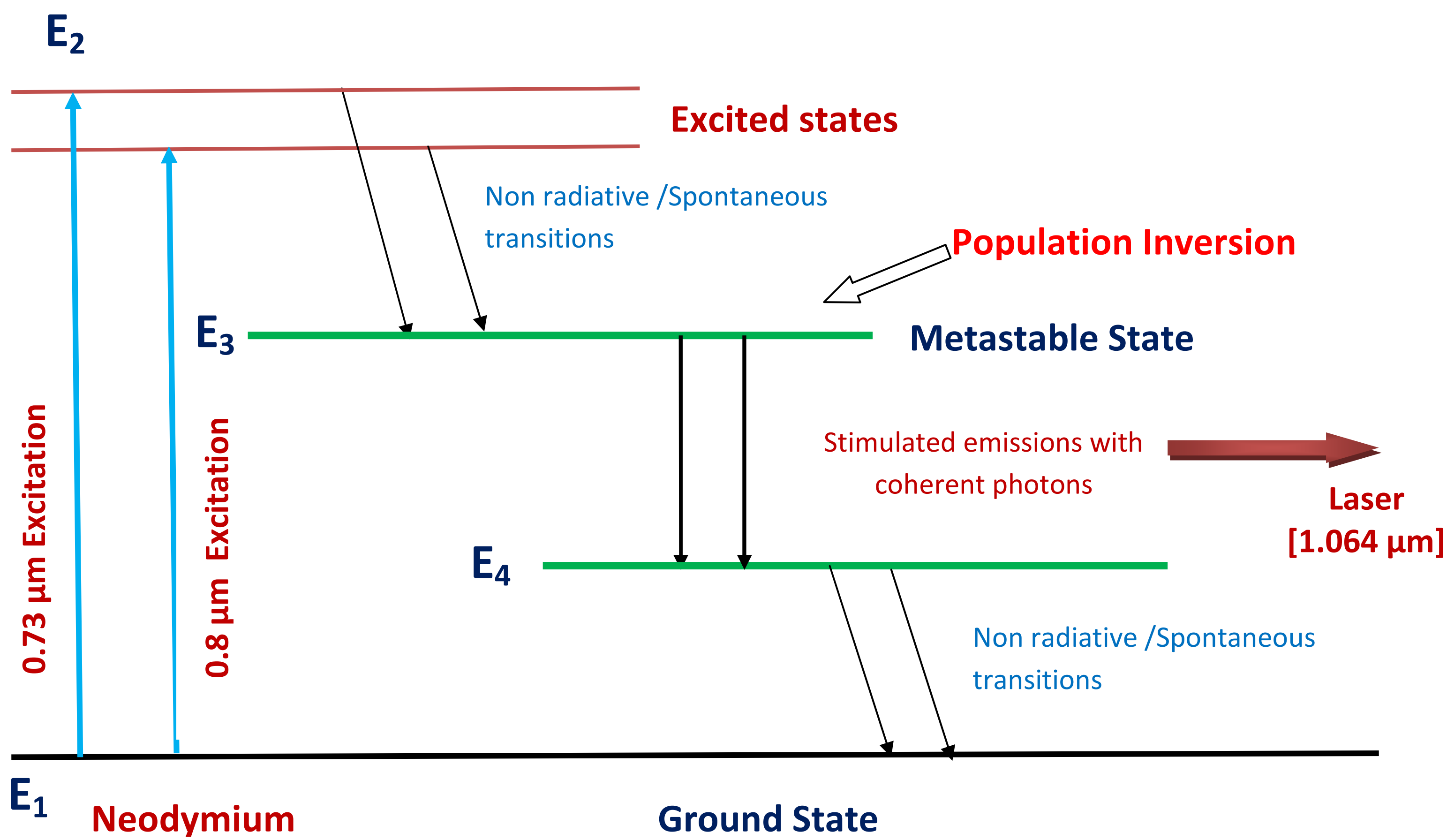
ELLIPTICAL CAVITY

- The elliptical cavity is a hollow casing and whose inner surface is coated with reflective coating
- At one of the focal point of elliptical cavity, Nd-YAG rod [active medium] is placed
- At another focal point a Xenon flash lamp is fixed
- This arrangement focus all the light on the laser rod [Nd-YAG rod]



WORKING OF LASER

ENERGY LEVEL SCHEME



WORKING OF LASER

- When the flash lamp gives flash, the Nd^{3+} ions are excited to higher levels
- These levels are highly unstable and the excited ions make a non-radiative transition to meta stable states
- Population inversion takes place in meta stable levels
- Stimulated emission is induced in the meta stable levels by spontaneously emitted photons
- Coherent photons are released in stimulated emission
- These photons are suitably multiplied by resonant cavity [laser rod attached with mirrors] and finally released as laser beam at 1.064 μm [IR region] through partial windows.

APPLICATIONS

- Nd:YAG lasers are used in ophthalmology
- In oncology, Nd:YAG lasers can be used to remove skin cancers
- Nd:YAG dental lasers are used for soft tissue surgeries in the oral cavity,
- Nd:YAG lasers are used in manufacturing for engraving, etching and metal surface enhancement processes.
- The Nd:YAG laser is the most common laser used in military as laser rangefinders.

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UNIT III – PHOTONICS • Gas laser (CO_2 laser)	
Delivery mode	• Black board/ PPT
Key lecture points	• Transition mechanism in atoms and molecules between various energy levels • Rotational, vibrational and electronic energy levels • Nature of transitions in CO_2 molecules for laser emission • Nature of components of CO_2 laser • Characteristics of CO_2 laser • Description on working set up (with diagram) • Explanation on working with energy level diagrams • Applications.
Conclusions	• CO_2 laser uses a mixture of He, N_2 and CO_2 as active medium • Electrical discharge pumping is employed for gas lasers • Laser transition occurs between vibrational levels in molecular gas lasers • Four level gas laser
Questions	• Differentiate between various pumping systems • Give the significance of meta-stable states • Essential components of CO_2 laser set up • Differentiate between rotational, vibrational and electronic energy levels

Credits	Exam	Marks		Total
		UI	UE	
4	3Hrs	40	60	100

Objectives

- To understand rotational, vibrational and electronic energy levels
- To understand electrical discharge pumping
- To understand inelastic atom-atom collision
- To understand the lasing through vibrational transitions
- To understand the working of CO_2 laser

Outcomes

Student will be able to explain

- rotational, vibrational and electronic energy levels
- Electrical discharge pumping
- Inelastic atom-atom collision
- Lasing due to vibrational transitions

Pre requisites

Basic knowledge on

- Spontaneous and stimulated emissions
- Basic laser components

Terms used

- He, N_2 and CO_2
- Electrical discharge tube
- Rotational, vibrational and electronic energy levels

CO_2 L A S E R

[Carbon Dioxide Laser]

Type

Molecular Gas Laser

Active Medium

He, N_2 and CO_2 gases
[Enclosed in a quartz tube with closing windows held at Brewster angle]

Pumping

Electrical discharge
[Inelastic atom-atom collision]

Active centers

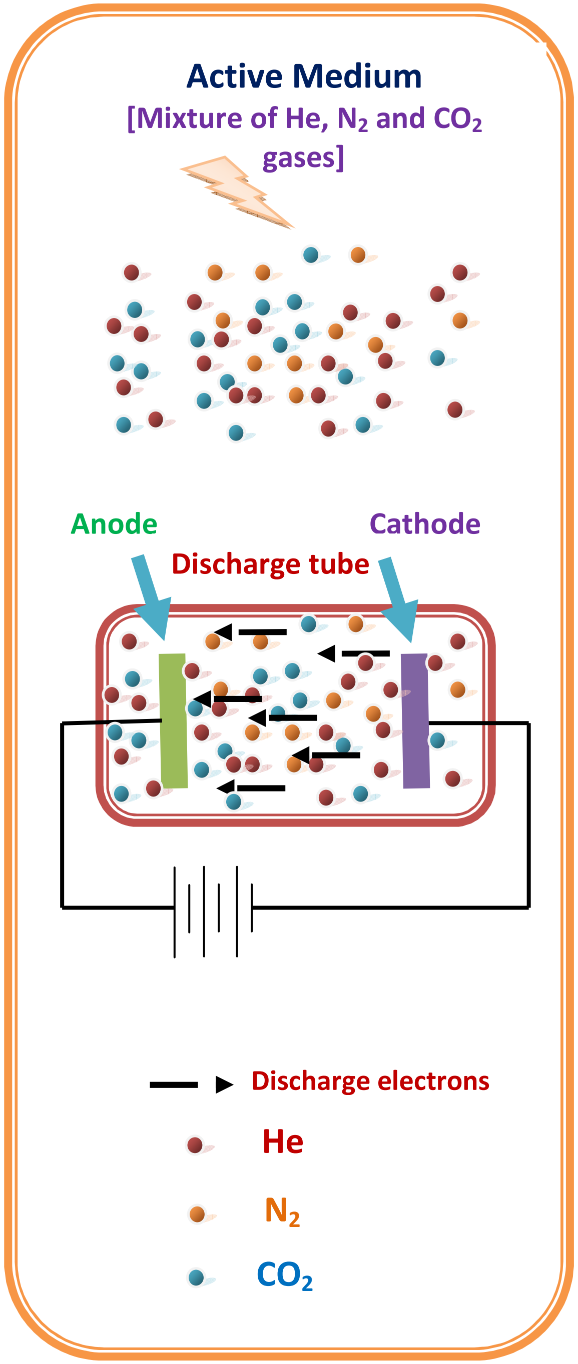
CO_2 molecules

CO_2 L A S E R

[Carbon Dioxide Laser]

ACTIVE MEDIUM

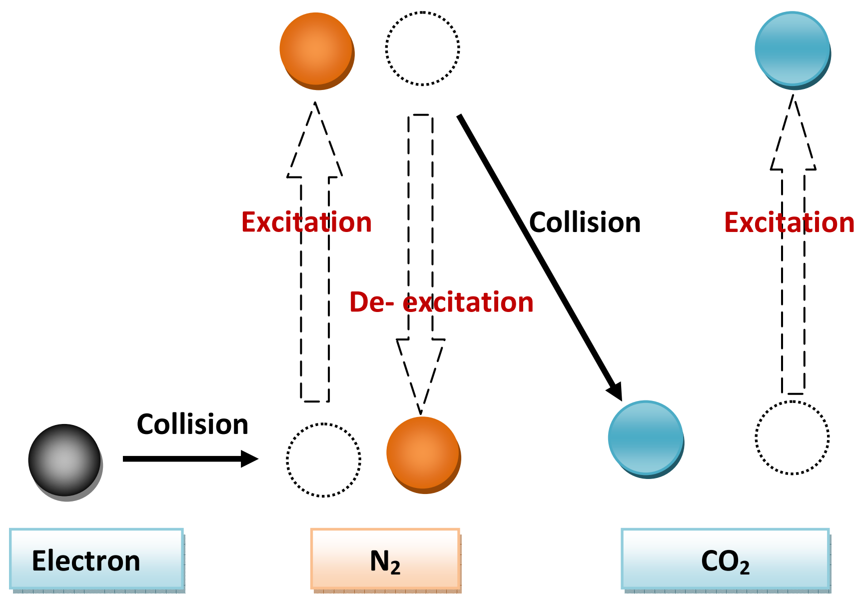
- Mixture of Helium [He], Nitrogen [N_2] and Carbon Dioxide [CO_2]
- N_2 and CO_2 have almost same vibrational excitation levels
- Initially N_2 is excited by discharge electrons in discharge tube
- N_2 excite CO_2 molecules to higher vibrational levels through resonant energy transfer
- CO_2 molecules make transitions to lower vibrational levels and emit coherent photons
- Laser beam is released after suitable multiplication



PUMPING MECHANISM

Inelastic atom- atom Collision

- **Pumping is achieved by electrons from electrical discharge in a discharge tube**
- **Discharge tube is filled with the mixture of gases He, N_2 and CO_2 [Active medium] in a proper ratio**
- **During the discharge, electrons first collide with Nitrogen atoms and excite them to higher vibrational levels**
- **Since N_2 and CO_2 have almost similar vibrational excitation levels, N_2 readily transfer energy to CO_2 molecules by collision**
- **The probability of collisions with N_2, CO_2 and He is decided by the ratio at which these gases are filled in discharge tube**



$$e^* + N_2 \Rightarrow e + N_2^*$$

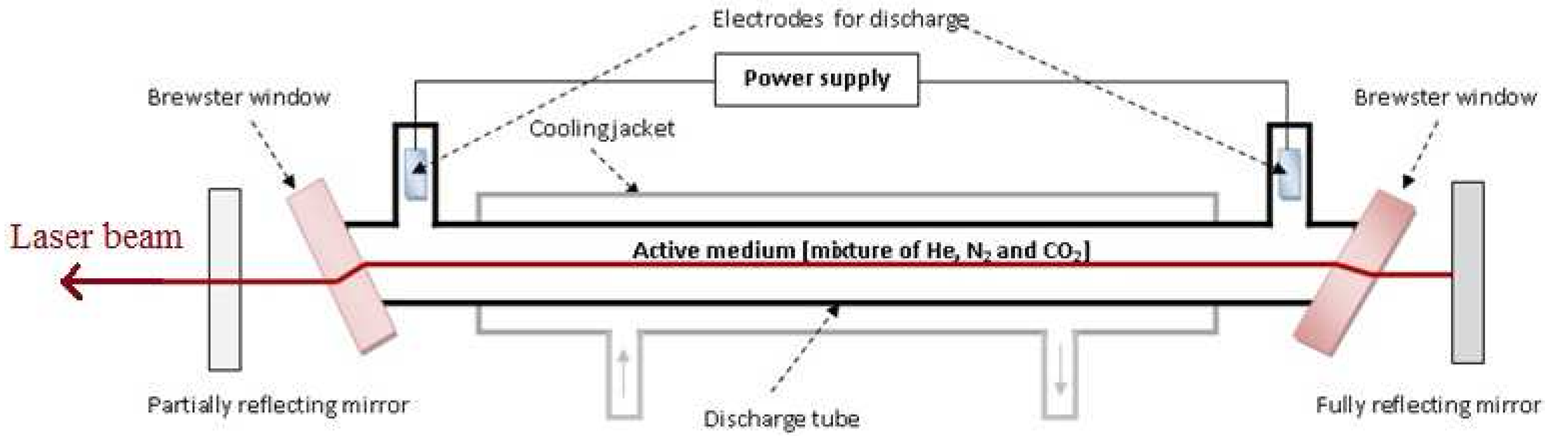
[Electron collides with N_2, N_2 is excited]

$$N_2^* + CO_2 \Rightarrow CO_2^* + N_2$$

[N_2 collides with CO_2, CO_2 is excited]

* denotes excited state

SCHEMATIC SET UP



Schematic setup of a sealed-tube carbon dioxide laser

LASER SET UP

Contains

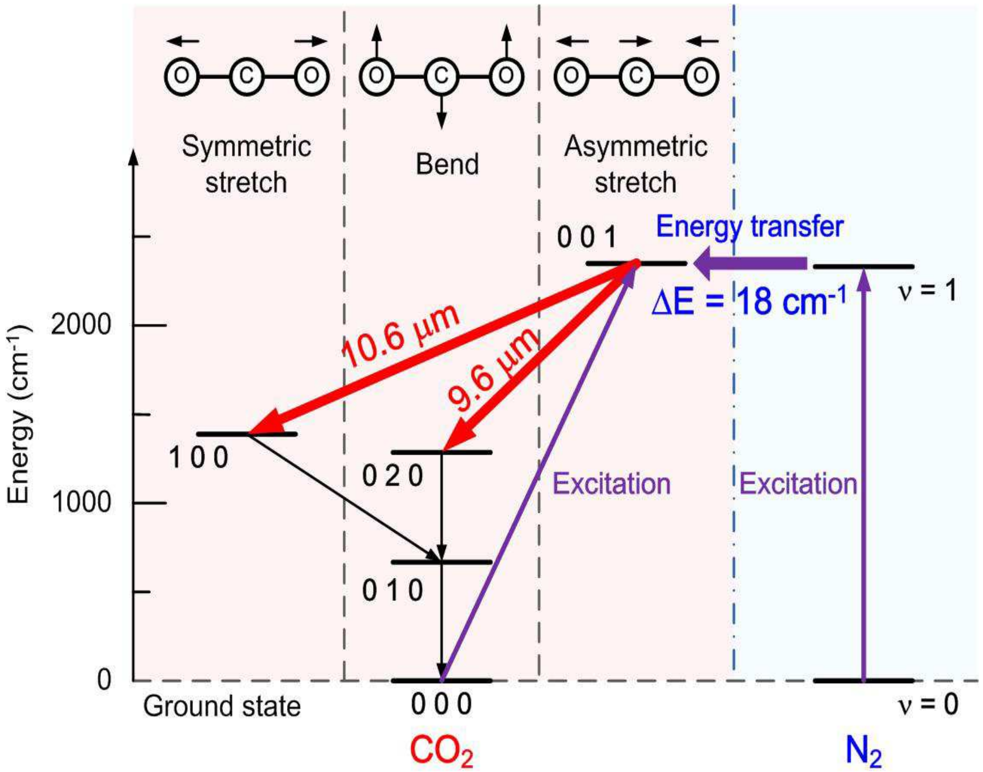
- **Discharge tube filled with active medium [He, N_2 and CO_2]**
- **Cooling jacket**
- **Electrodes for discharge**
- **Power supply for discharge**
- **Brewster windows for closing discharge tube**
- **Reflecting mirrors mixture of gases**

Breswter windows

- *Photons are multiplied by reflecting mirrors*
- *Photons meet the mirror after coming out from discharge tube*
- *In this process optical losses occur due to reflection at discharge tube itself*
- *To minimize this loss, transparent optical windows are used at Brewster angle at the tube ends*
- *At Brewster angle, the light suffers no reflection for a particular plane of vibration.*
- *The output light become polarized and loss also minimized*

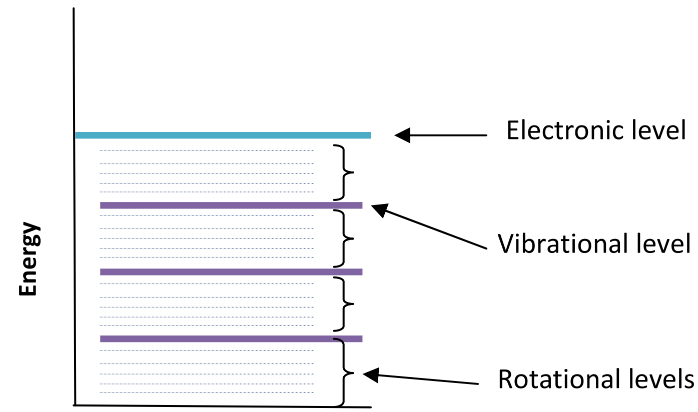
WORKING OF LASER

ENERGY LEVEL SCHEME



Energy level diagram of CO_2 laser
(https://www.intechopen.com/books/laser-pulses-theory-technology-and-applications/longitudinally-excited-co2-laser)

Electronic, vibrational and rotational levels in molecules



Vibrational modes of CO_2 molecule

On excitation CO_2 starts to vibrate in following modes

Symmetric stretching

- Carbon is at rest
- Both oxygen atoms move outwards and inwards symmetrically about central carbon

Aymmetric stretching

- Carbon is moving in one direction
- Both oxygen atoms move in opposite direction and vice versa

Bending Vibration

- Carbon is moving in upward and downward directions
- Both oxygen atoms move in opposite direction to carbon atom

WORKING

- Discharge electrons collide with N_2 atoms and excite them to their first vibrational level
- Excited N_2 molecules remain in excited state for a longer duration compared to CO_2 molecules
- Hence to increase pumping efficiency N_2 molecules are used in active medium
- N_2 molecules and CO_2 molecules both have almost same excited vibrational levels
- Excited N_2 molecules readily transfer their energy to CO_2 molecules on collision and excite them higher metastable vibrational level
- Population inversion takes place and CO_2 molecules make laser transitions to lower vibrational states [which have other mode of vibration]
- Laser beam at wavelengths 9.6 µm and 10.6 µm are emitted
- In most cases, average output powers are between some tens of watts and many kilowatts

APPLICATIONS

CO2 lasers are widely used for laser material processing, in particular for

- cutting plastic materials, wood, die boards, etc.,
- cutting and welding metals such as stainless steel, aluminum or copper, applying multi-kilowatt powers
- laser marking of various materials
- other applications include laser surgery (including ophthalmology) and range finding

COURSE TEACHER

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