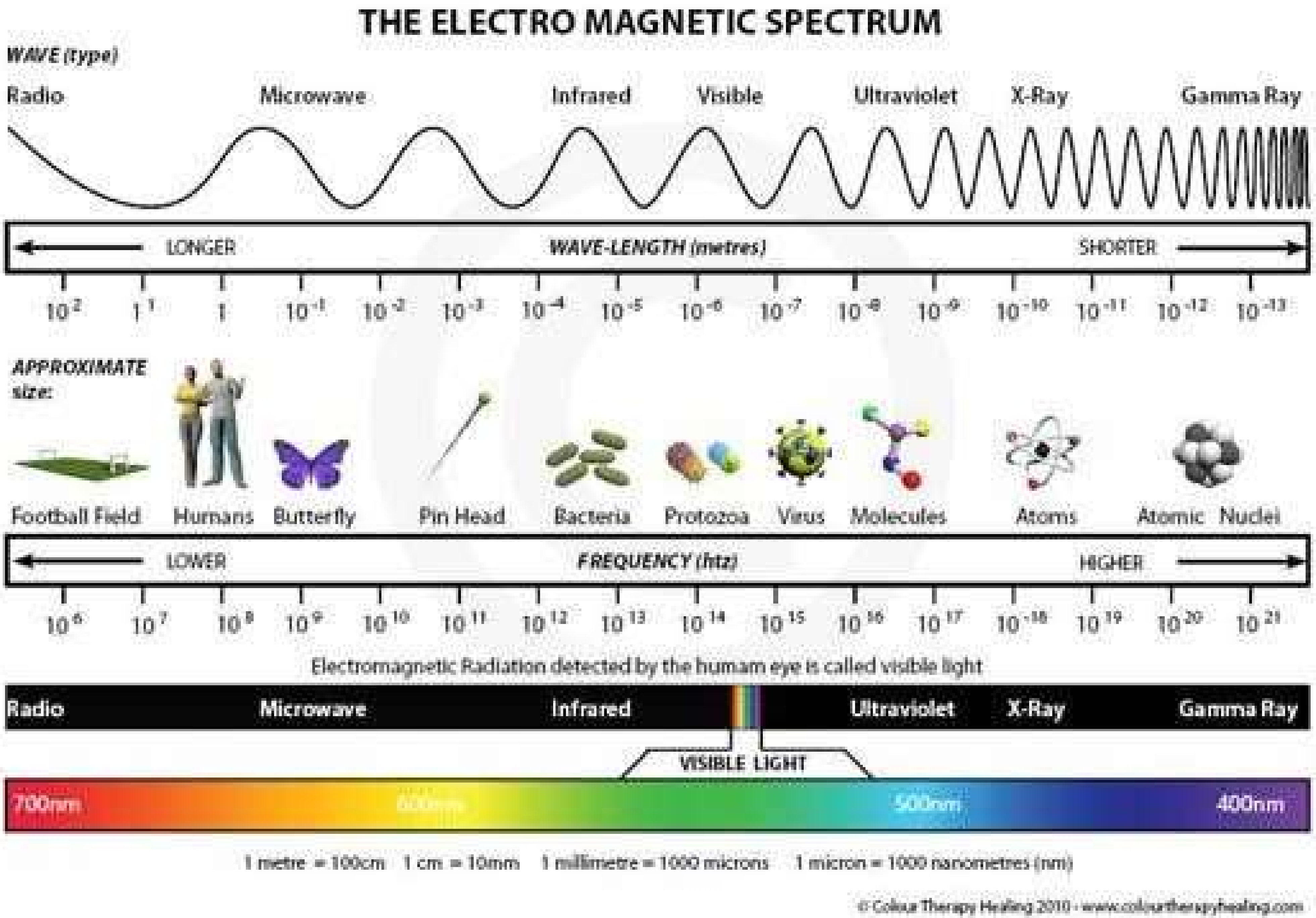
UNIT 2- LASER Physics
PHY125

Unit 2:- Laser Physics and optoelectronic Sources
Coherent sources, interaction of radiation with matter (spontaneous and stimulated emission), Einstein's relation, population inversion and pumping, active components of laser, optical amplification or gain, threshold condition for laser action, Ruby and He-Ne lasers. Optoelectronic sources: Light emitting diode (construction, basic working principle), semiconductor laser (construction, basic working principle)



THE ELECTRO MAGNETIC SPECTRUM
WAVE (type)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-Ray
Gamma Ray
LONGER
WAVE-LENGTH (metres)
SHORTER
10^{2} 1^{1} 1 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7} 10^{-8} 10^{-9} 10^{-10} 10^{-11} 10^{-12} 10^{-13}
APPROXIMATE size:
Football Field
Humans
Butterfly
Pin Head
Bacteria
Protozoa
Virus
Molecules
Atoms
Atomic Nuclei
LOWER
FREQUENCY (htz)
HIGHER
10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{-18} 10^{19} 10^{20} 10^{21}
Electromagnetic Radiation detected by the humam eye is called visible light
Radio
Microwave
Infrared
Ultraviolet
X-Ray
Gamma Ray
VISIBLE LIGHT
700nm
600nm
500nm
400nm
1 metre = 100cm 1 cm = 10mm 1 millimetre = 1000 microns 1 micron = 1000 nanometres (nm)
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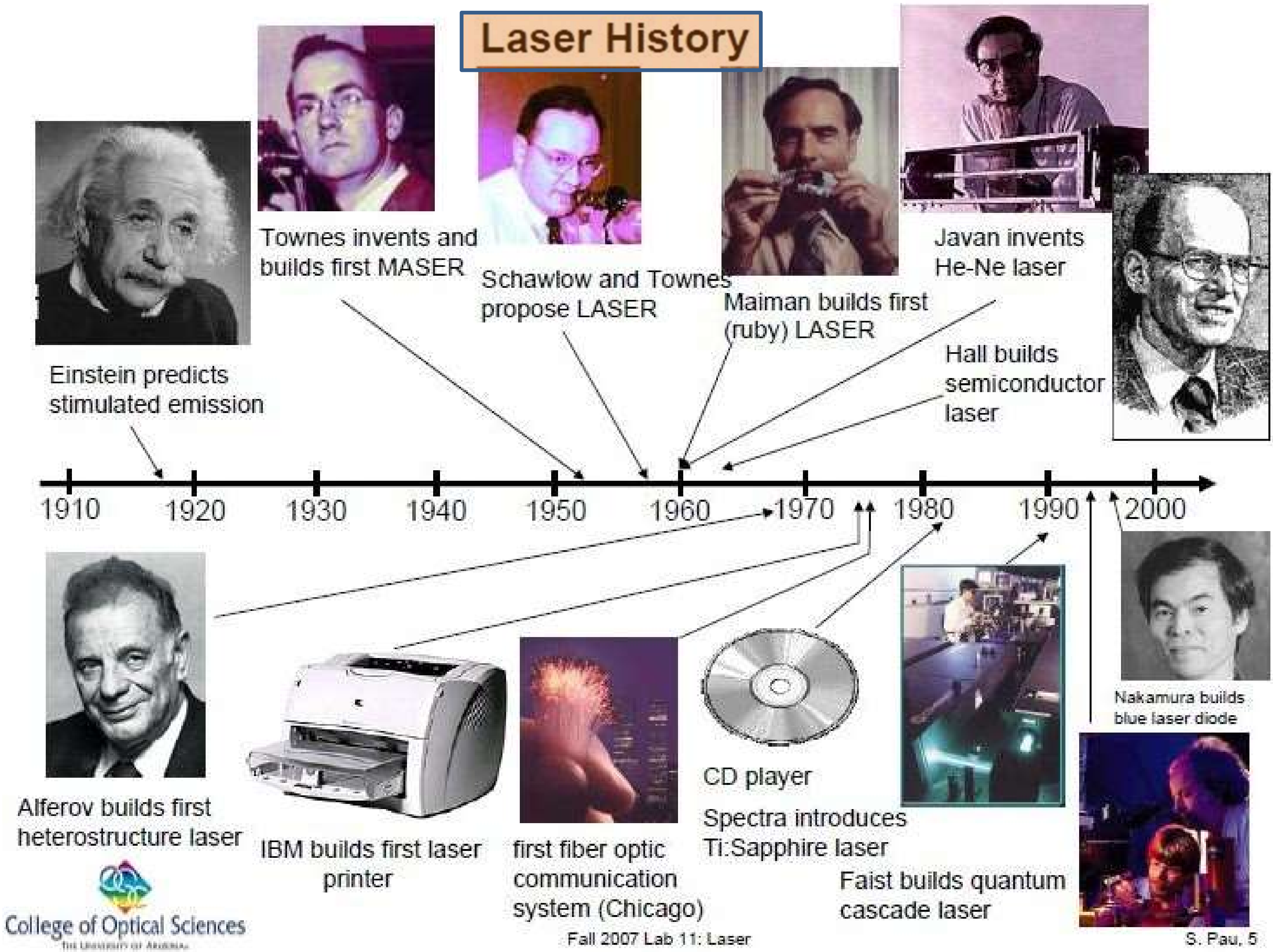
LASER

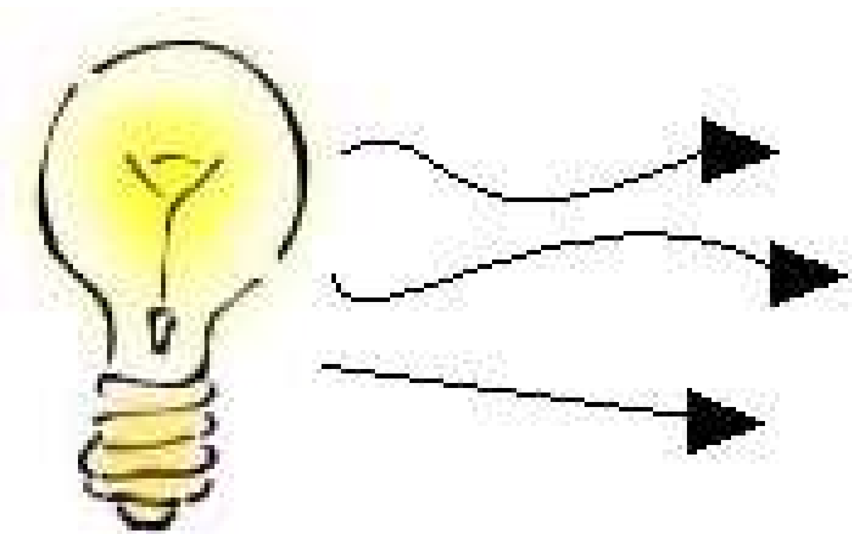
(acronym)

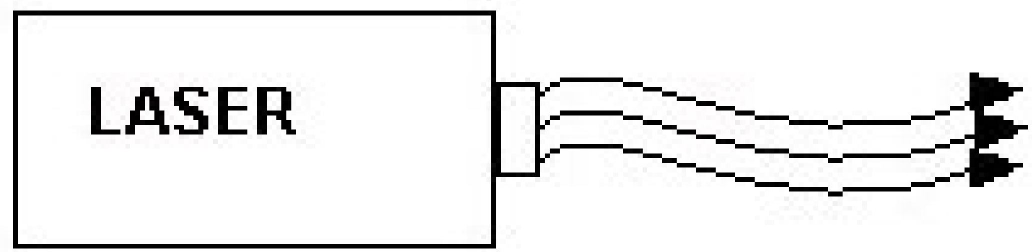
Light Amplification by Stimulated Emission of Radiation

•The laser is a device that produces coherent (All waves are exactly in phase with one another) nearly monochromatic, Less diverging and extremely intense light beam.


Laser History
Einstein predicts stimulated emission
Townes invents and builds first MASER
Schawlow and Townes propose LASER
Maiman builds first (ruby) LASER
Javan invents He-Ne laser
Hall builds semiconductor laser
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Alferov builds first heterostructure laser
IBM builds first laser printer
first fiber optic communication system (Chicago)
CD player
Spectra introduces Ti:Sapphire laser
Faist builds quantum cascade laser
Nakamura builds blue laser diode
College of Optical Sciences
Fall 2007 Lab 11: Laser
S. Pau, 5

Incandescent vs. Laser Light





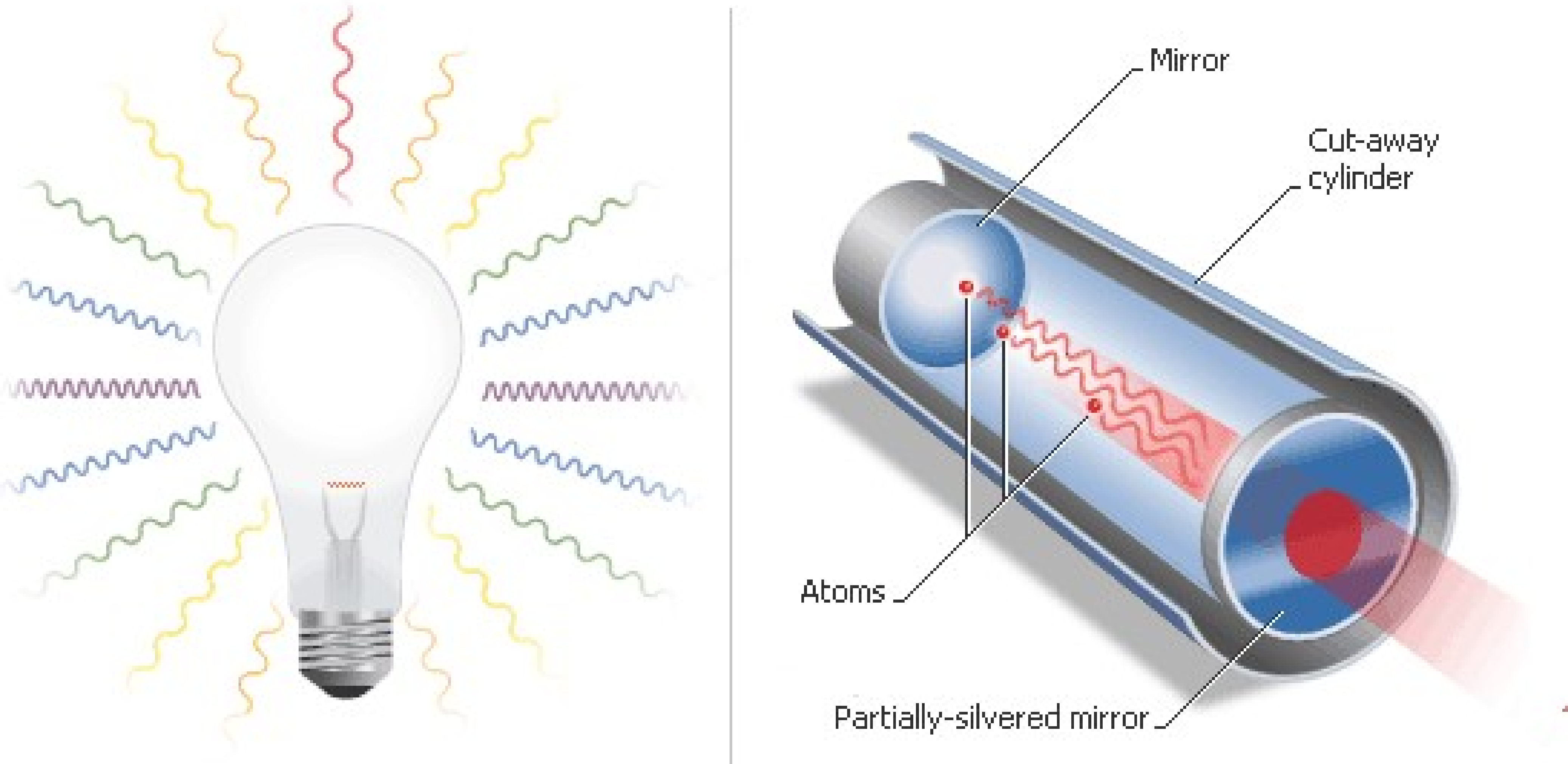
1. Many wavelengths
2. Multidirectional
3. Incoherent

1. Monochromatic
2. Directional
3. Coherent

Laser Fundamentals

- The light emitted from a laser is **monochromatic**, that is, it is of one color/wavelength. In contrast, ordinary white light is a combination of many colors (or wavelengths) of light.
- Lasers emit light that is highly **directional**, that is, laser light is emitted as a relatively narrow beam in a specific direction. Ordinary light, such as from a light bulb, is emitted in many directions away from the source.
- The light from a laser is said to be **coherent**, which means that the wavelengths of the laser light are in phase in space and time. Ordinary light can be a mixture of many wavelengths.

These three properties of laser light are what can make it more hazardous than ordinary light. Laser light can deposit a lot of energy within a small area.



Incandescent bulb

Laser

Light sources

Light sources of two types

1. Incoherent Sources

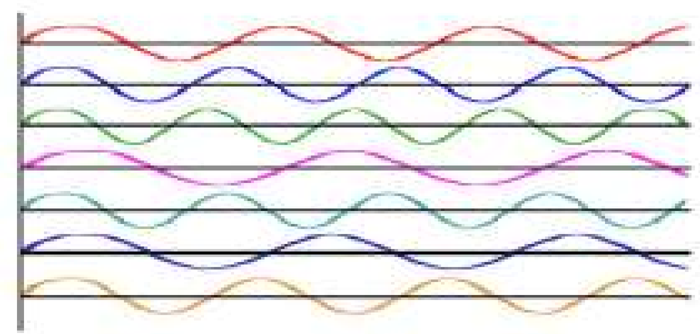
2. Coherent Sources

Incoherent Sources : Those sources in which the phase difference of the waves is a function of time or dependence on time are called the incoherent sources of light

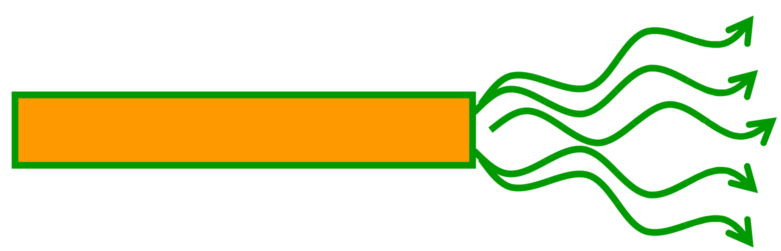
For example:

The light emitted from the Sun or other ordinary light sources such as tungsten filament, neon and fluorescent tube lights is spread over a wide range of frequencies.

- **Such light is irregular and mixed of different frequencies, directions and durations, and is incoherent.**
- **Incoherent light is due to spontaneous and random emission of photons by the atoms in excited state. These photons will not be in phase with each other.**



Incoherent light waves



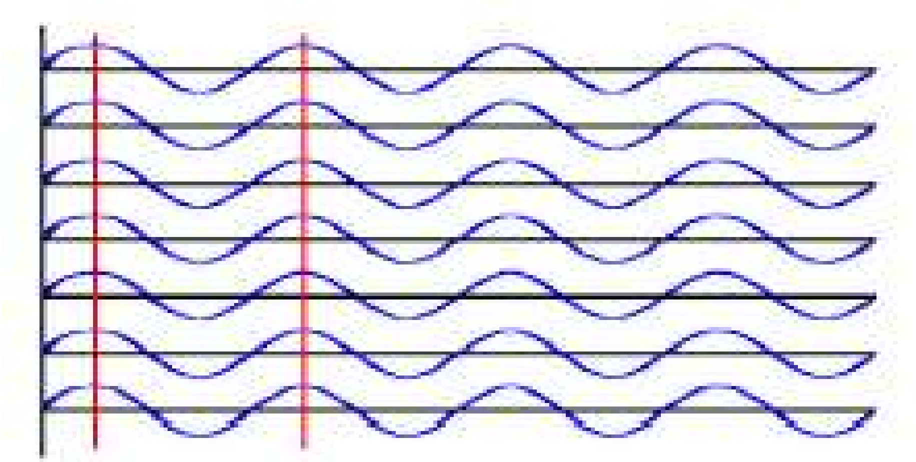
Incoherent Light

Light sources (Cont….)

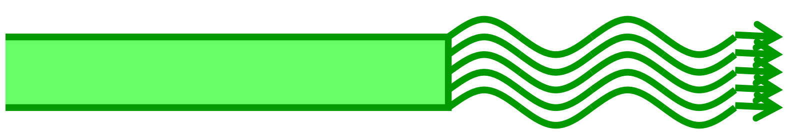
Coherent Sources : Those sources in which the phase difference of the waves is not a function of time or independent of time are called the coherent sources of light.

For example: From Laser device

- **Coherent light is uniform in frequency, amplitude, continuity and constant initial phase difference.**
- **Coherent beam of light is obtained due to stimulated emission of photons from the atoms jumping from meta-stable state to lower energy state.**



Coherent light waves



Coherent Light

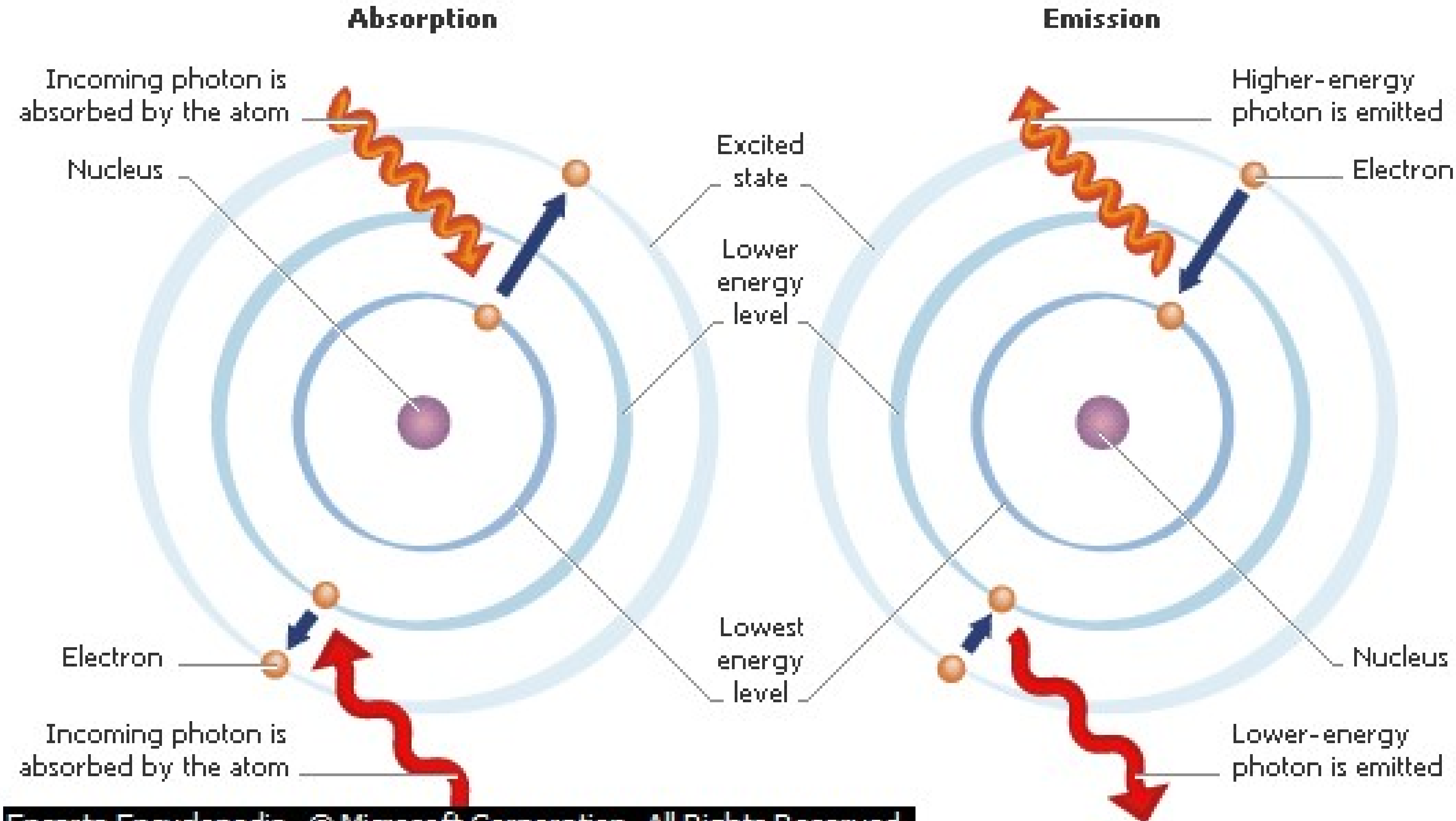
LASER DEFINITION

LASER stands ***for Light Amplification by Stimulated Emission of Radiation.***

It is a device for producing very intense ,almost unidirectional ,monochromatic and highly coherent visible light beams. The basic principle involved in the lasing action is the phenomenon of stimulated emission.

Atomic Interactions Related to LASER

1. **Stimulated Absorption**
2. **Spontaneous Emission**
3. **Stimulated Emission**

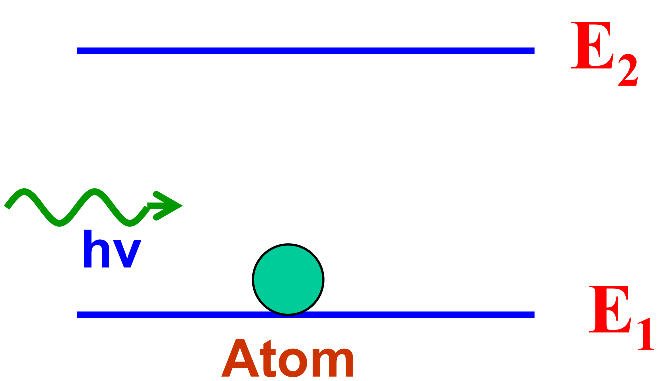

Absorption
Emission
Incoming photon is absorbed by the atom
Nucleus
Excited state
Lower energy level
Electron
Lowest energy level
Incoming photon is absorbed by the atom
Higher-energy photon is emitted
Electron
Nucleus
Lower-energy photon is emitted

Atomic Interactions related to LASER

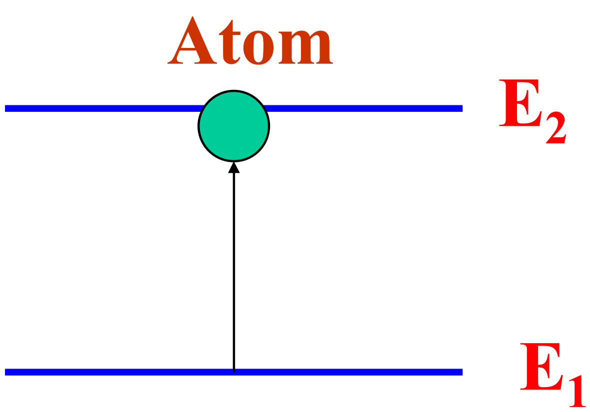
1. Stimulated Absorption **: Photons of suitable energy are supplied to the atoms in the ground state. These atoms absorb the supplied energy and go to the excited or higher energy state . IF E_1 and E_2 are energies of ground state (lower energy) and excited state (higher energy).**

the frequency of required photon for absorption is

- $$\boxed{\nu = \frac{E_2 - E_1}{h}}$$ **where 'h' is Planck's constant**



Before absorption



After absorption

The probability of absorption transition is given by P_{12}

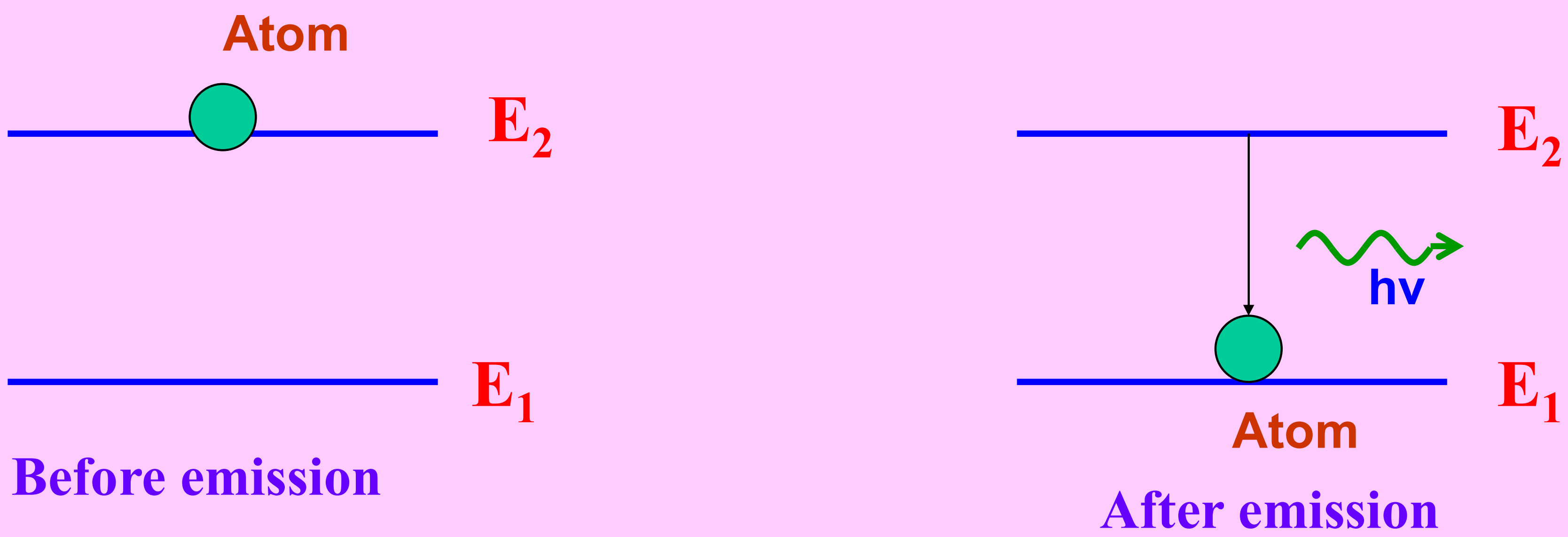
$P_{12} \alpha N_1$
$P_{12} \alpha u(\nu)$
$P_{12} \alpha N_1.u(\nu)$

$P_{12} = B_{12} N_1 u(\nu)$……………….(1)
Where, B12 is known as Einstein's coefficient of stimulated absorption

Atomic Interactions related to LASER (Cont……)

2. ***Spontaneous Emission :*** An excited atom can stay in the higher energy state only for the time of 10^{-8} s. After this time, it returns back to the lower energy state by emitting a photon of energy $h\nu = E_2 - E_1$. This emission is called 'spontaneous emission'.

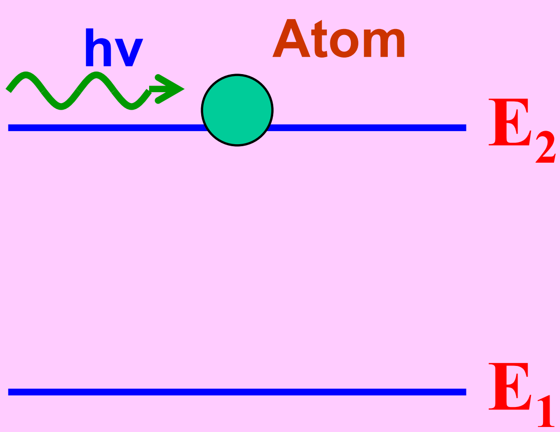
During spontaneous emission, photons are emitted randomly and hence they will not be in phase with each other. Therefore, the beam of light emitted is incoherent.



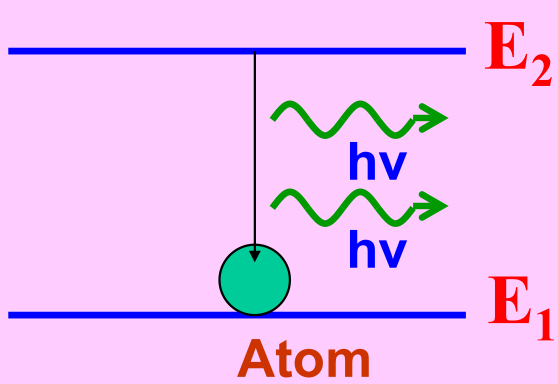
The probability of spontaneous transition is given by $P_{21} = A_{21}N_2$……………(2)

Atomic Interactions related to LASER (Cont……)

3. ***Stimulated Emission*** **: When photon of suitable energy is made to fall on an excited atom in the higher energy state, then this atom transits back to the ground state by emitting a photon of energy $h\nu = E_2 - E_1$ .Thus there is two photon of same energy and same phase. Hence this process is called 'stimulated emission'**



Before emission



After emission

The probability of stimulated transition is given by $P_{21} = B_{21} N_2 u(\nu)$……………(3)

Einstein's Relation

Consider an assembly of atoms in thermal equilibrium at temp. T with radiation of frequency ν and energy density u (ν).

Let N_1 and N_2 be the number of atoms in energy state 1 and energy state 2 respectively at any instant.

At thermal equilibrium, the absorption and emission rates must be equal.

Hence, $$P_{12} = P_{21} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Putting the value of P_{12} and P_{21} , we get

$$N_1 B_{12}\, u(\nu) = N_2 A_{21} + N_2 B_{21}\, u(\nu) \quad \ldots\ldots\ldots\ldots(2)$$

$$u(\nu)\,[N_1 B_{12} - N_2 B_{21}] = N_2 A_{21} \quad \text{..}(3)$$

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

$$u(\nu) = \frac{N_2 A_{21}}{B_{21}\,[N_1 B_{12} / B_{21} - N_2]}$$

$$u(\nu) = \frac{A_{21}}{B_{21}} \times \frac{1}{[\,N_1 / \; N_2\,(B_{12} / B_{21}) - 1\,]} \quad \text{..................}(4)$$

But according to Boltzman's distribution law, the number of atoms N_1 and N_2 in energy state E_1 and E_2 in thermal equilibrium at temp. T are given by

$$N_1 = N_0\, e^{-E_1/KT} \text{ and } N_2 = N_0\, e^{-E_2/KT}$$

Where, N_0 = the total number of atoms present in assembly

K = the Boltzman's constant.

Then

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

$$\frac{N_2}{N_1} = e^{-(E_2 - E_1)/KT} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

we know that $E_2 - E_1 = h\nu$

Putting this value in equation (5), we have

$$\frac{N_2}{N_1} = e^{-h\nu/KT} \quad \text{or} \quad \frac{N_1}{N_2} = e^{h\nu/KT} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

From equation (4) & (6), we get

$$u(\nu) = \frac{A_{21}}{B_{21}} \times \frac{1}{e^{h\nu/KT}(B_{12}/B_{21}) - 1} \quad \ldots\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

But according to **Plank's theory**, the energy density corresponding to the frequency ν is given by

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

Comparing of equation (7) & (8), we get

$$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3} \quad \text{And} \quad \frac{B_{12}}{B_{21}} = 1$$

Hence

$$B_{12} = B_{21}$$

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

Hence ratio of spontaneous emission and stimulated emission is proportional to ν^3.

Common Components of all Lasers

1. **Active Medium**

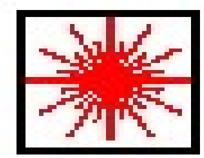
   The active medium may be solid crystals such as ruby or Nd:YAG, liquid dyes, gases like CO2 or Helium/Neon, or semiconductors such as GaAs. Active mediums contain atoms whose electrons may be excited to a metastable energy level by an energy source.

2. **Excitation Mechanism**

   Excitation mechanisms pump energy into the active medium by one or more of three basic methods; optical, electrical or chemical.

3. **High Reflectance Mirror**

   A mirror which reflects essentially 100% of the laser light.



4. **Partially Transmissive Mirror**

   A mirror which reflects less than 100% of the laser light and transmits the remainder.

Common Components of all Lasers

1. **Active System and Cavity Resonator**

   Active mediums contain atoms whose electrons may be excited to a metastable energy level by an energy source. This system is placed in a cylindrical tube, called resonance cavity. Cavity consists of a pair of mirrors, facing each other.

2. **Population Inversion**

   The situation in which the number of atoms in the higher energy state is greater than that in the lower energy state.

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

$N_2 > N_1$ while $E_2 > E_1$!

Common Components of all Lasers

3. Pumping

The process by which atoms are brought from lower energy states to higher energy states and maintained is called pumping.

Various Pumping Methods:

3.1 Optical pumping: for transparent media, most suitable, e.g. Ruby laser.

3.2 Electrical pumping: for gaseous media, accelerated cathode electrons transfer energy to gas atoms, e.g. Argon ion laser.

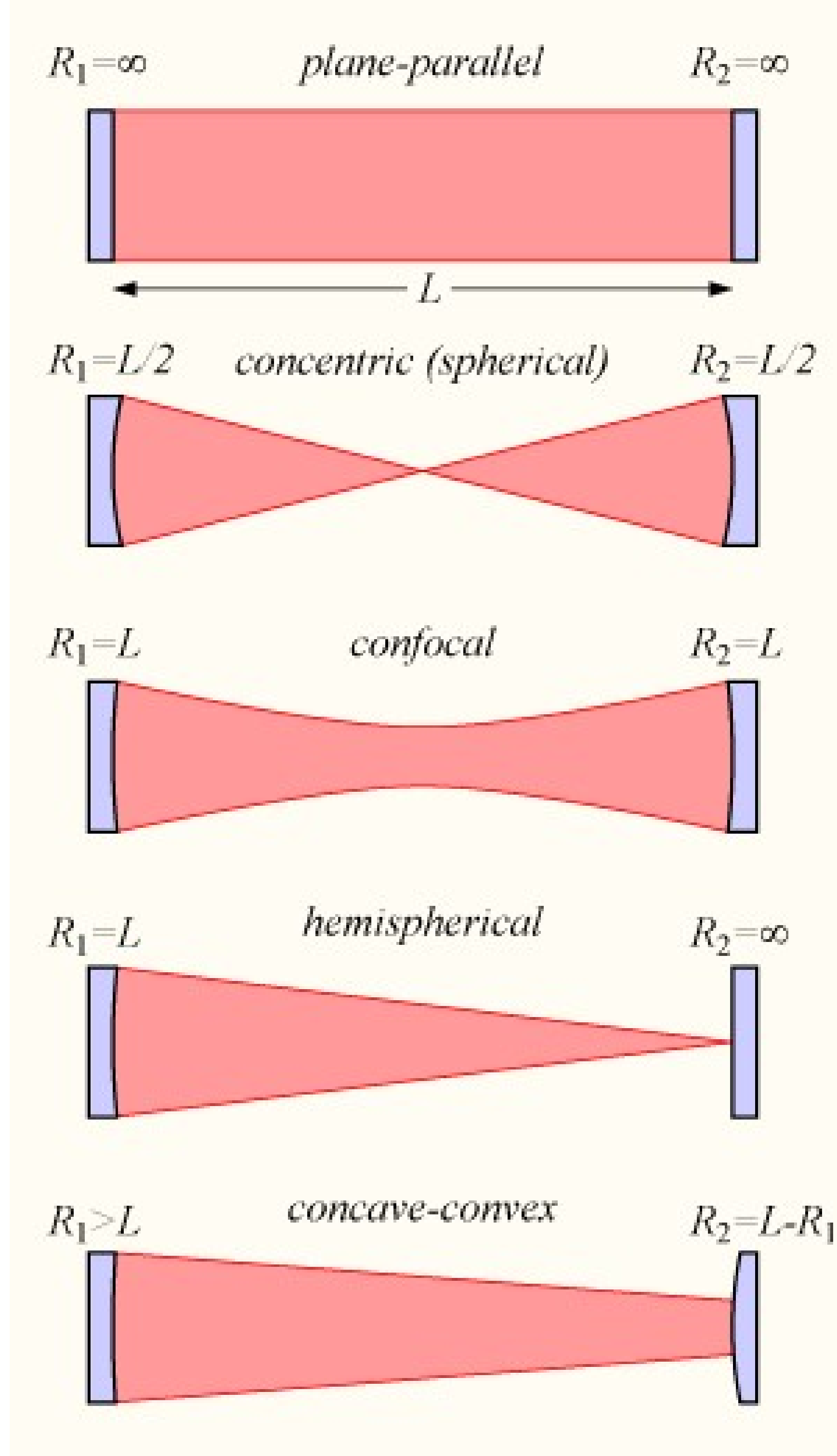
3.3 Inelastic atom-atom collisions: for mixture of gases, electric discharge of one gas, collision with other, e.g. He-Ne laser.

3.4 Chemical pumping: energy generated by chemical reactions. e.g. in CO2 laser, Hydrogen and Fluorine are combined to form hydrogen fluoride and heat energy.

OPTICAL CAVITY/RESONATOR

An optical cavity or optical resonator is an arrangement of mirrors that forms a standing wave cavity resonator for light waves. Optical cavities are a major component of lasers, surrounding the gain medium and providing feedback of the laser light. Light confined in the cavity reflect multiple times producing standing waves for certain resonance frequencies.

Various types of Optical cavity



Stable and unstable resonators:

Only certain ranges of values for $R1$, $R2$, and L produce stable resonators in which periodic refocussing of the intracavity beam is produced. If the cavity is unstable, the beam size will grow without limit, eventually growing larger than the size of the cavity mirrors and being lost. It is possible to calculate a stability criterion:

$$0 \leq \left(1 - \frac{L}{R_1}\right)\left(1 - \frac{L}{R_2}\right) \leq 1.$$

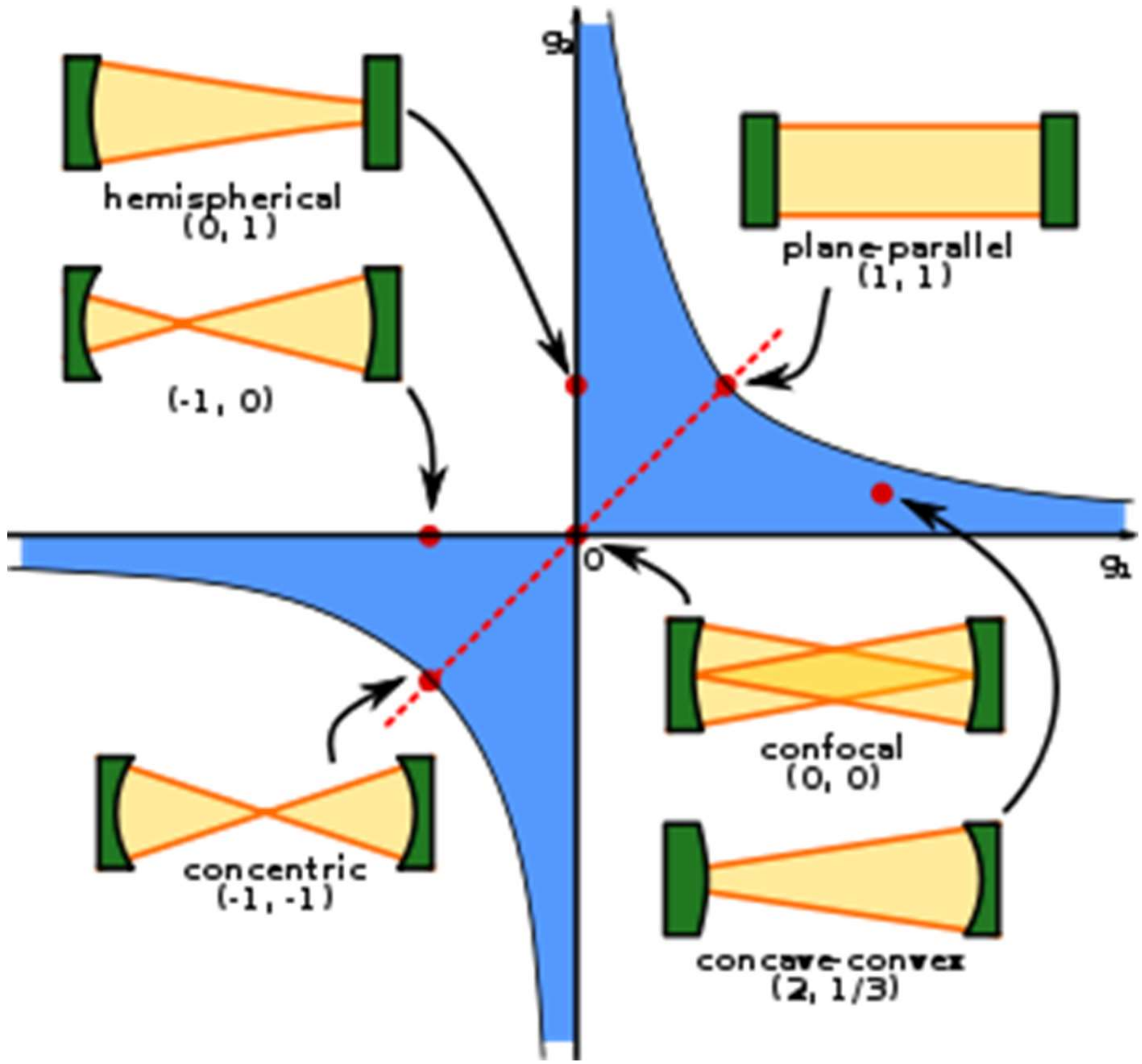
Values which satisfy the inequality correspond to stable resonators. The stability can be shown graphically by defining a stability parameter, g for each mirror:

$$g_1 = 1 - \frac{L}{R_1}, \qquad g_2 = 1 - \frac{L}{R_2}$$

and plotting $g1$ against $g2$ as shown.

Areas bounded by the line $g1\ g2 = 1$ and the axes are stable. Cavities at points exactly on the line are marginally stable; small variations in cavity length can cause the resonator to become unstable, and so lasers using these cavities are in practice often operated just inside the stability line.

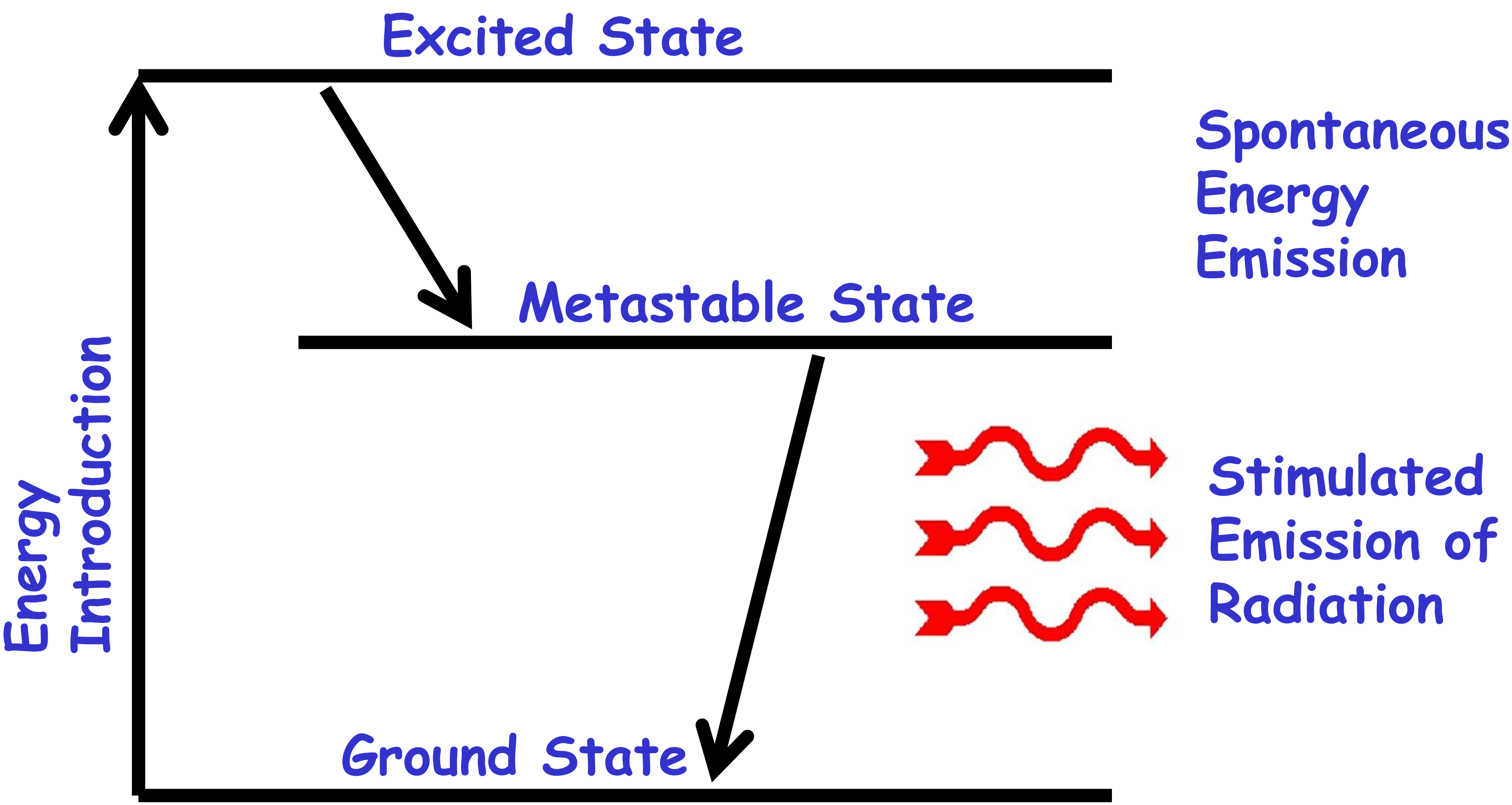
Stable and unstable resonators

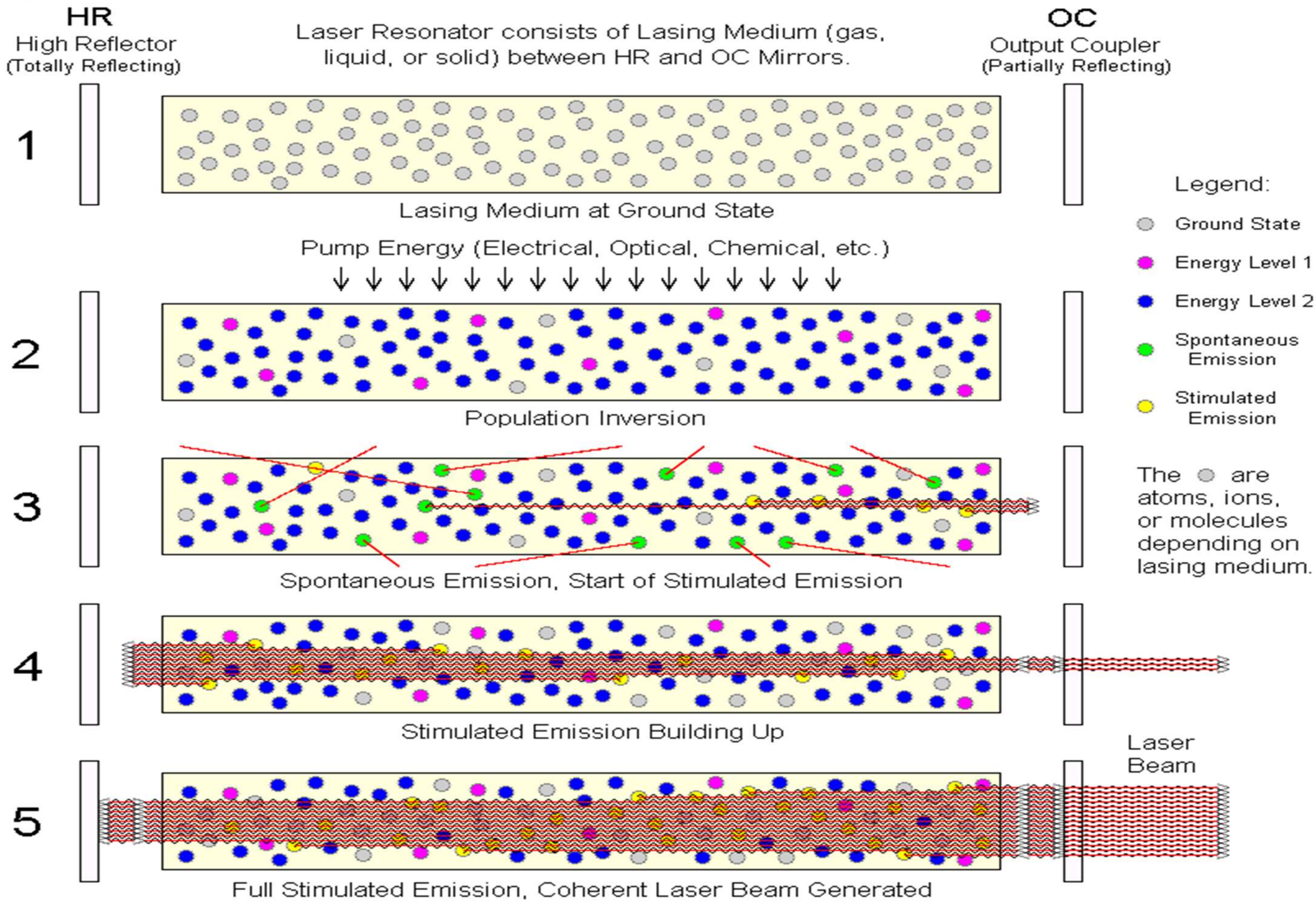


Lasing Action

1. Energy is applied to a medium raising electrons to an unstable energy level.
2. These atoms spontaneously decay to a relatively long-lived, lower energy, metastable state.
3. A population inversion is achieved when the majority of atoms have reached this metastable state.
4. Lasing action occurs when an electron spontaneously returns to its ground state and produces a photon.
5. If the energy from this photon is of the precise wavelength, it will stimulate the production of another photon of the same wavelength and resulting in a cascading effect.
6. The highly reflective mirror and partially reflective mirror continue the reaction by directing photons back through the medium along the long axis of the laser.
7. The partially reflective mirror allows the transmission of a small amount of coherent radiation that we observe as the “beam”.
8. Laser radiation will continue as long as energy is applied to the lasing medium.

Lasing Action Diagram





Basic Laser Operation

Threshold condition for laser action

The steady condition for laser oscillation/action is that the gain in active Medium must be equal or more than the total losses.
For oscillations, the two conditions must be satisfied:

1. There must be population inversion between energy states providing the laser transition.
2. There must be a threshold (minimum) gain within the active medium to initiate and sustain the laser oscillation.

Gain per unit length is given by: $$g = \alpha + \frac{1}{2L}\ln\left(\frac{1}{K_1 K_2}\right)$$

(Where, α is the total loss coefficient for unit length in the active medium of length L and doesn't include the transmission loss through the two mirrors of reflectance K_1 and K_2)

WAVELENGTHS OF MOST COMMON LASERS

Laser Type	Wavelength (μm)	Laser Type	Wavelength (μm)
Argon fluoride (Excimer-UV)	0.193	Helium neon (yellow)	0.594
Krypton chloride (Excimer-UV)	0.222	Helium neon (orange)	0.610
Krypton fluoride (Excimer-UV)	0.248	Gold vapor (red)	0.627
Xenon chloride (Excimer-UV)	0.308	Helium neon (red)	0.633
Xenon fluoride (Excimer-UV)	0.351	Krypton (red)	0.647
Helium cadmium (UV)	0.325	Rohodamine 6G dye (tunable)	0.570-0.650
Nitrogen (UV)	0.337	Ruby ($CrAlO_3$) (red)	0.694
Helium cadmium (violet)	0.441	Gallium arsenide (diode-NIR)	0.840
Krypton (blue)	0.476	Nd:YAG (NIR)	1.064
Argon (blue)	0.488	Helium neon (NIR)	1.15
Copper vapor (green)	0.510	Erbium (NIR)	1.504
Argon (green)	0.514	Helium neon (NIR)	3.39
Krypton (green)	0.528	Hydrogen fluoride (NIR)	2.70
Frequency doubled Nd YAG (green)	0.532	Carbon dioxide (FIR)	9.6
		Carbon dioxide (FIR)	10.6
Helium neon (green)	0.543		
Krypton (yellow)	0.568		
Copper vapor (yellow)	0.570		

Key: UV = ultraviolet (0.200-0.400 μm)
VIS = visible (0.400-0.700 μm)
NIR = near infrared (0.700-1.400 μm)
Nd3+: YAG = Neodymium Yttrium Aluminium Garnet laser

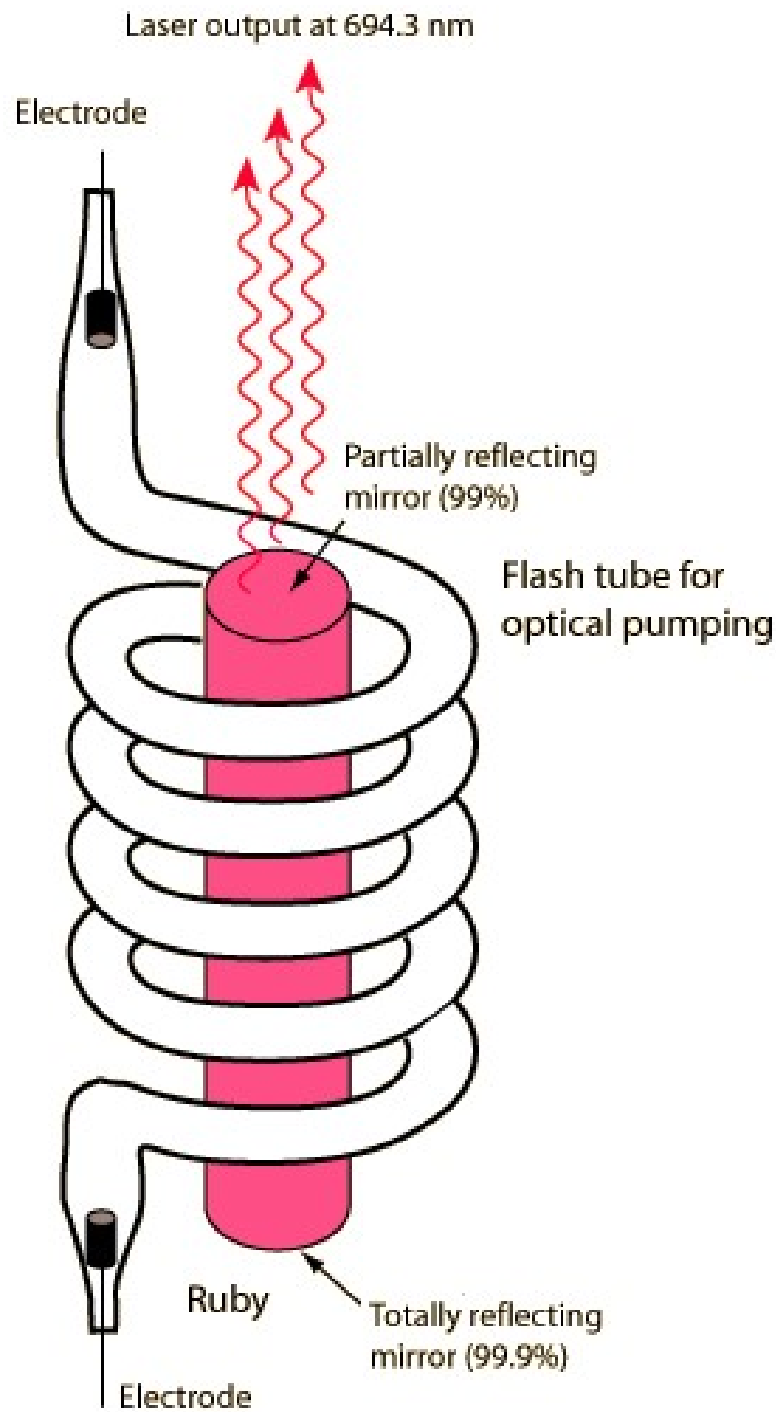
RUBY LASER

Introduction

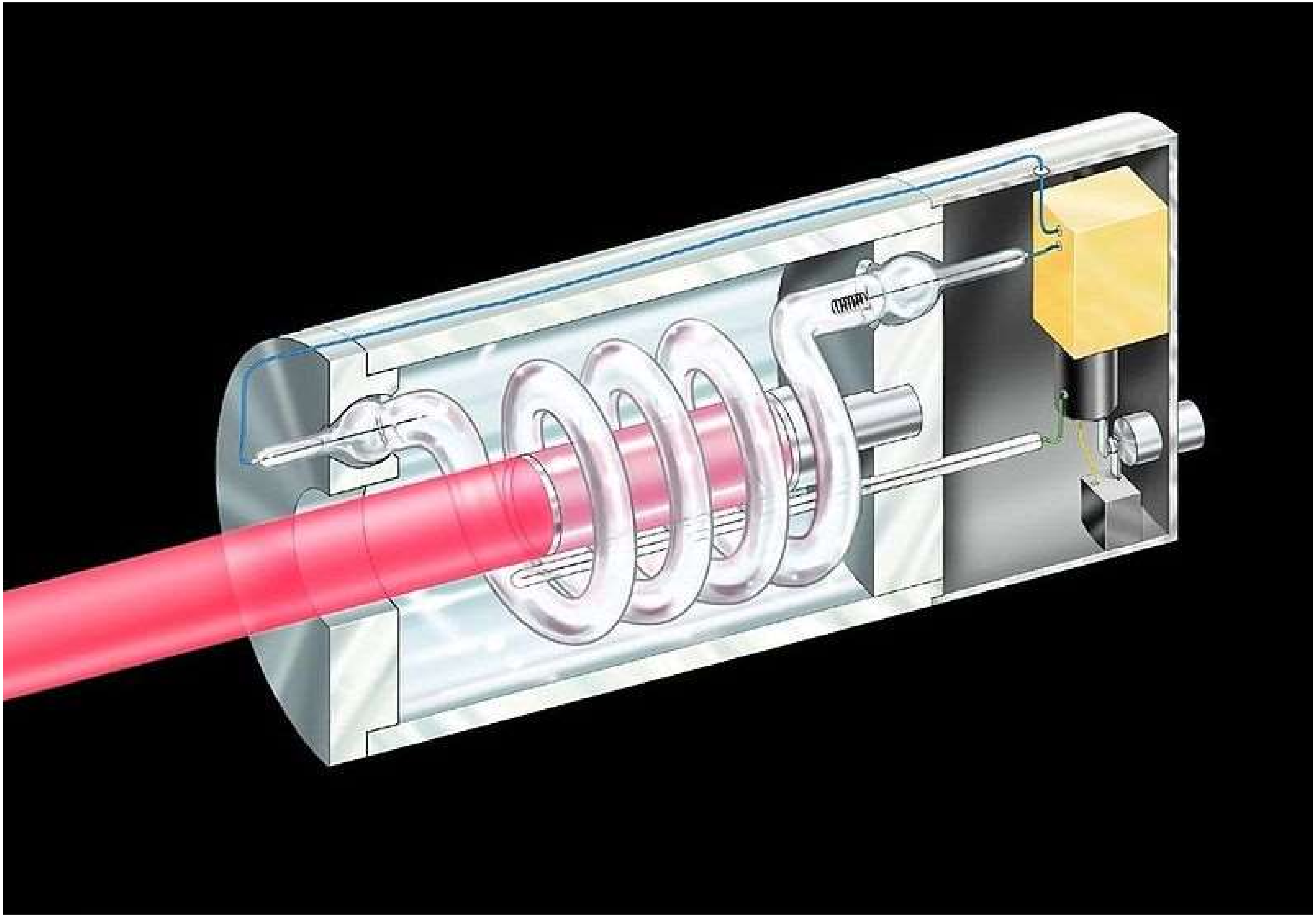
- A ruby laser is a solid-state laser that uses a synthetic ruby crystal as its gain medium.
- It was the first type of laser invented, and was first operated by Theodore H. "Ted" Maiman at Hughes Research Laboratories on 1960-05-16 .
- The ruby mineral (corundum) is aluminum oxide with a small amount(about 0.05%) of chromium which gives it its characteristic pink or red color by absorbing green and blue light. The ruby laser is The ruby laser is used as a pulsed laser, producing red light at 694.3 nm. After receiving a pumping flash from the flash tube, the laser light emerges for as long as the excited atoms persist in the ruby rod, which is typically about a millisecond.

Historical importance

- A pulsed ruby laser was used for the famous laser ranging experiment which was conducted with a corner reflector placed on the Moon by the Apollo astronauts. This determined the distance to the Moon with an accuracy of about 15 cm.



Laser output at 694.3 nm
Electrode
Partially reflecting mirror (99%)
Flash tube for optical pumping
Ruby
Totally reflecting mirror (99.9%)
Electrode

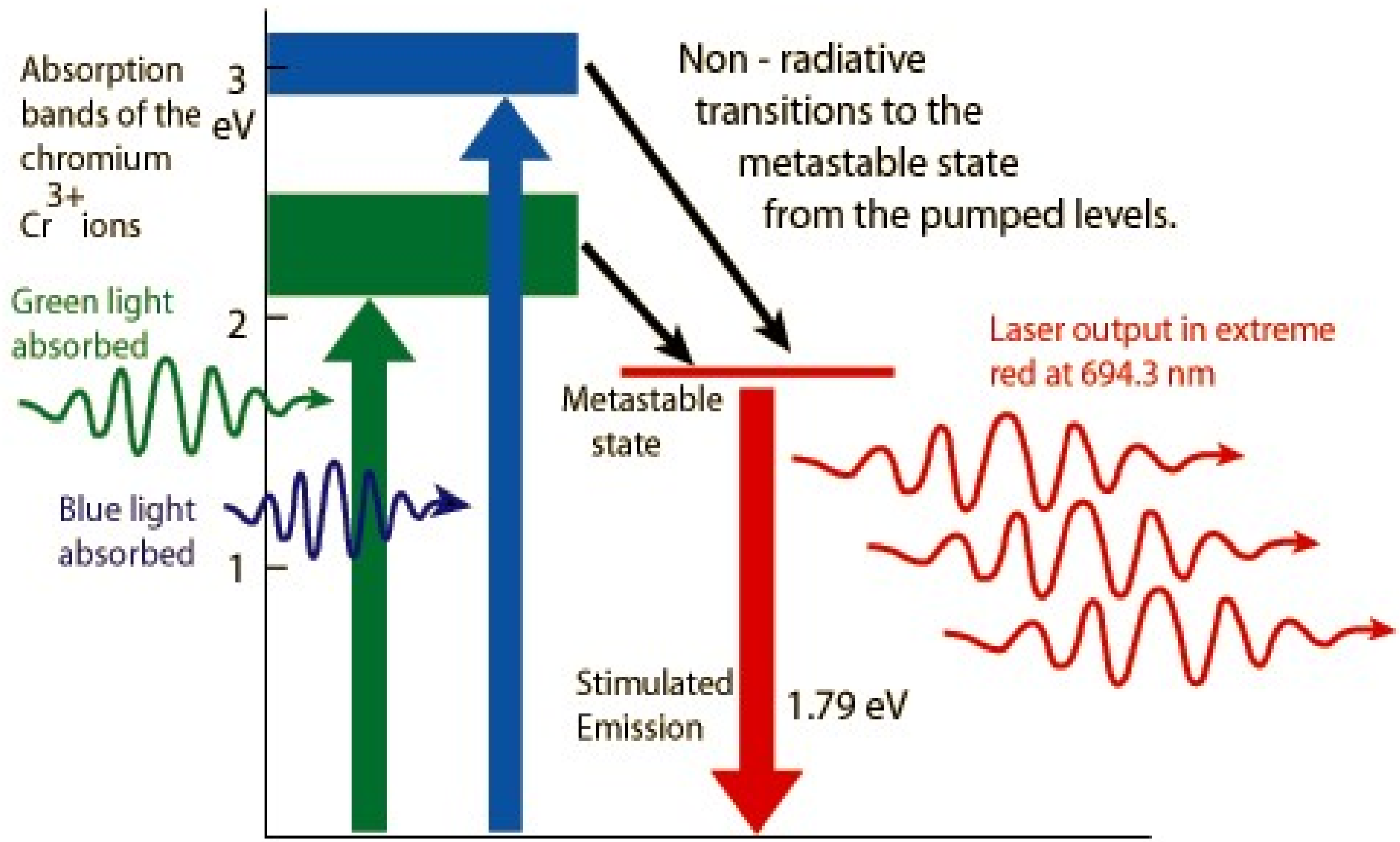


Laser construction

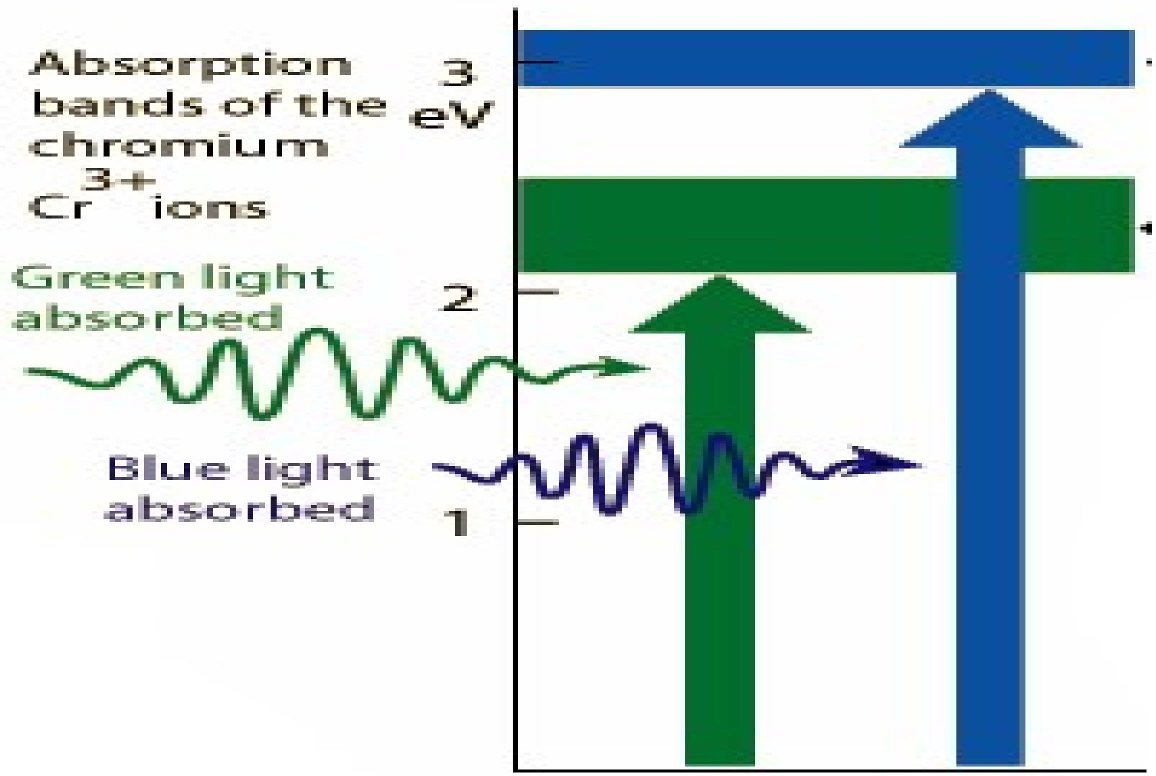
- The active laser medium is a synthetic ruby rod (4 cm long, 0.5 cm in diameter). Chromium gives ruby its characteristic red color and is responsible for the lasing behavior of the crystal. Chromium atoms absorb green and blue light and emit or reflect only red light.
- The rod's ends had to be polished with great precision, such that the ends of the rod were flat to within a quarter of a wavelength of the output light, and parallel to each other within a few seconds of arc. The finely polished ends of the rod were silvered: one end completely, the other only partially. The rod with its reflective ends then acts as a cavity.
- A xenon lamp is rolled over ruby rod and is used for pumping ions to excited state.

Working of ruby laser

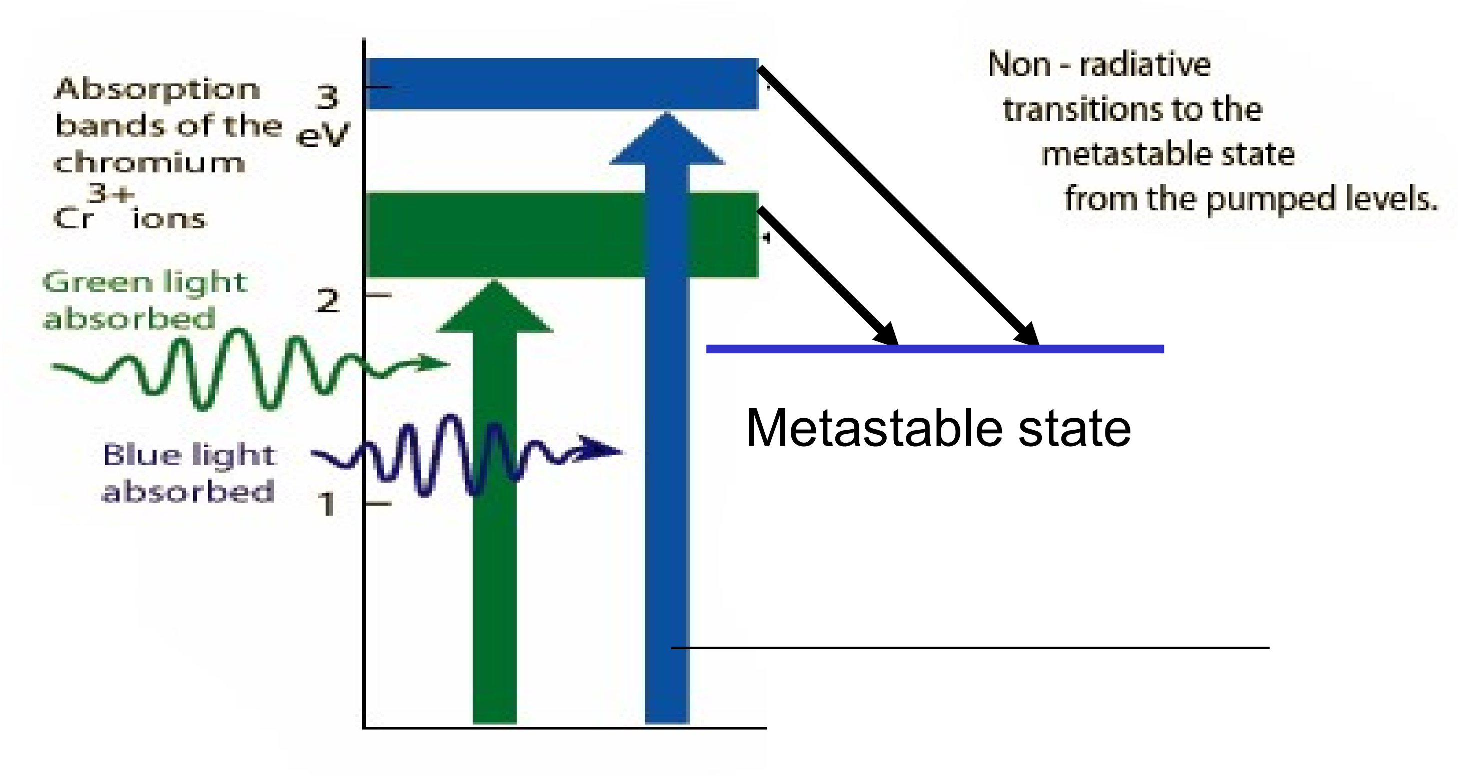
- Ruby laser is based on three energy levels. The upper energy level E3 I short-lived, E1 is ground state, E2 is metastable state with lifetime of 0.003 sec.



- When a flash of light falls on ruby rod, radiations of wavelength 5500 A (green) and 4200 A (blue) are absorbed by Cr3+ which are pumped to E3.

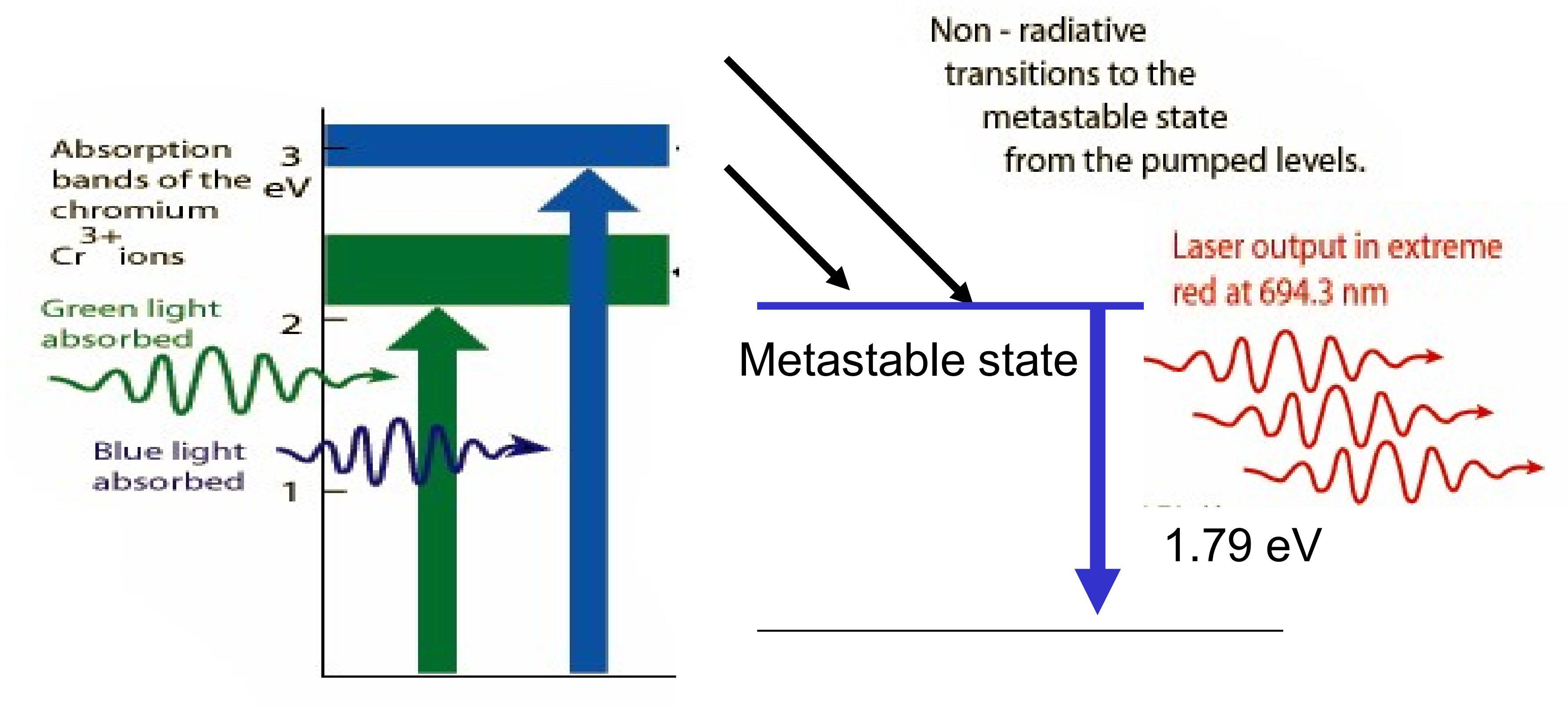


The ions after giving a part of their energy to crystal lattice decay to E2 state undergoing radiation less transition.



In metastable state , the concentration of ions increases while that of E1 decreases. Hence,population inversion is achieved.

A spontaneous emission photon by Cr3+ ion at E2 level initiates the stimulated emission by other Cr3+ ions in metastable state



Application

- Ruby lasers have declined in use with the discovery of better lasing media. They are still used in a number of applications where short pulses of red light are required. Holographers around the world produce holographic portraits with ruby lasers, in sizes up to a metre squared.
- Many non-destructive testing labs use ruby lasers to create holograms of large objects such as aircraft tires to look for weaknesses in the lining.

Drawbacks of Ruby laser

- The laser requires high pumping power because the laser transition terminates at the ground state and more than half of ground state atoms must be pumped to higher state to achieve population inversion.
- The efficiency of ruby laser is very low because only green component of the pumping light is used while the rest of components are left unused.
- The laser output is not continuous but occurs in the form of pulses of microseconds duration.
- The defects due to crystalline imperfection are also present in this laser.
- Heating of the rod limits its application time.

Helium-Neon Laser

Historical facts

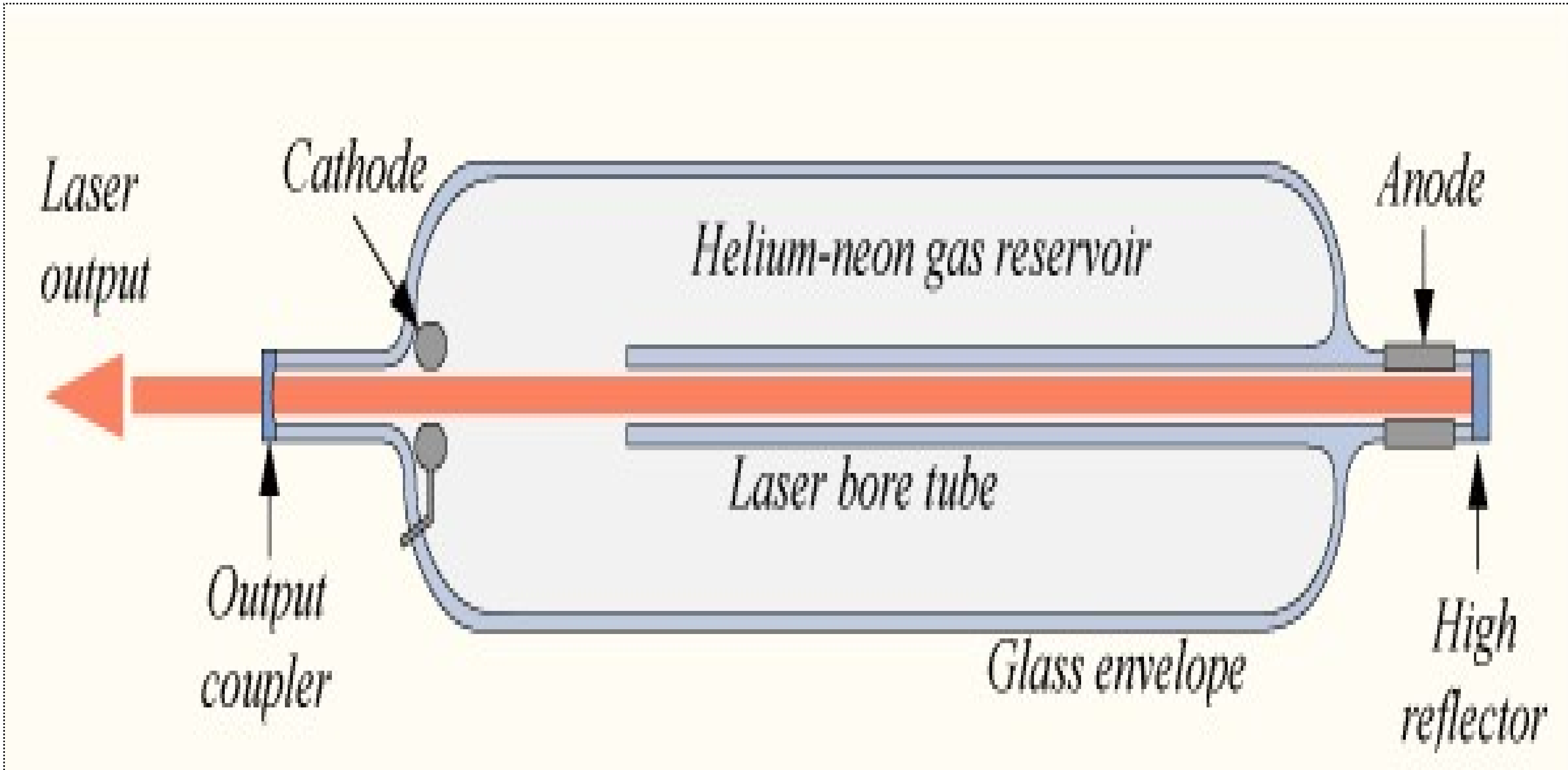
- The Helium-Neon laser was the first continuous laser.
- It was invented by Javan et. al. in 1961.
- The similarity between the manufacturing techniques of He-Ne lasers and electron valves helped in the mass production and distribution of He-Ne lasers.
- It is now clear that He-Ne lasers will have to increasingly compete with laser diodes in the future. But He-Ne lasers are still unequalled as far as beam geometry and the purity of the modes are concerned. Laser diodes will have to be improve to a great extent before they pose a serious threat to helium-neon laser

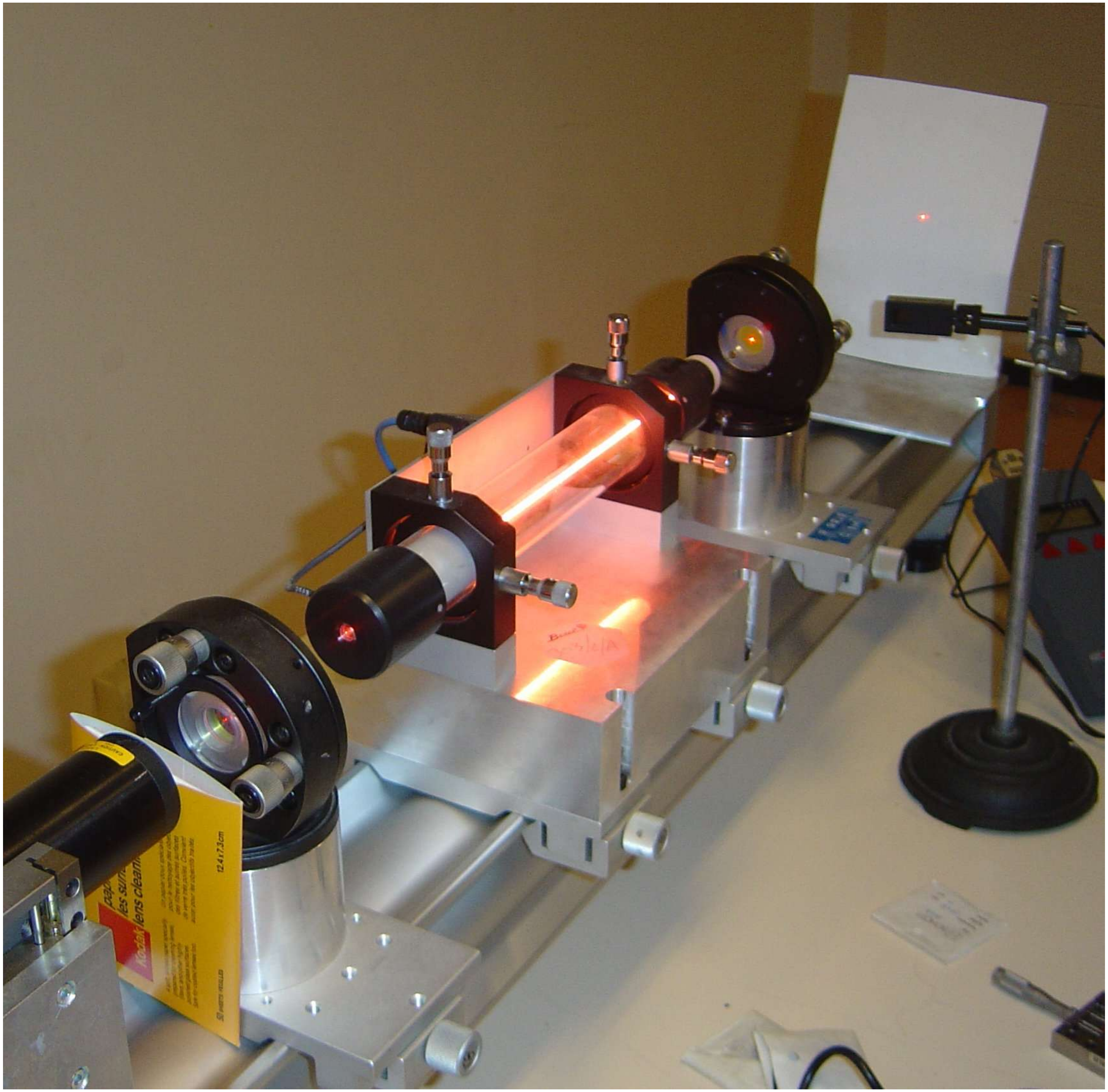
Introduction

- A helium-neon laser, usually called a He-Ne laser, is a type of small gas laser. He Ne lasers have many industrial and scientific uses, and are often used in laboratory demonstrations of optics.
- He-Ne laser is a four-level laser.
- Its usual operation wavelength is 632.8 nm, in the red portion of the visible spectrum.
- It operates in Continuous Working (CW) mode.

Construction of He-Ne laser

- The setup consists of a discharge tube of length 80 cm and bore diameter of 1.5cm.
- The gain medium of the laser, as suggested by its name, is a mixture of helium and neon gases, in a 5:1 to 20:1 ratio, contained at low pressure (1 mm of Hg) in a glass envelope.
- The energy or pump source of the laser is provided by an electrical discharge of around 1000 volts through an anode and cathode at each end of the glass tube. A current of 5 to 100 mA is typical for CW operation.
- The optical cavity of the laser typically consists of a plane, high-reflecting mirror at one end of the laser tube, and a concave output coupler mirror of approximately 1% transmission at the other end.
- HeNe lasers are normally small, with optical output powers ranging from 1 mW to 100 mW.


Laser output
Cathode
Helium-neon gas reservoir
Anode
Laser bore tube
Output coupler
Glass envelope
High reflector


Kodak
12.4x7.3cm

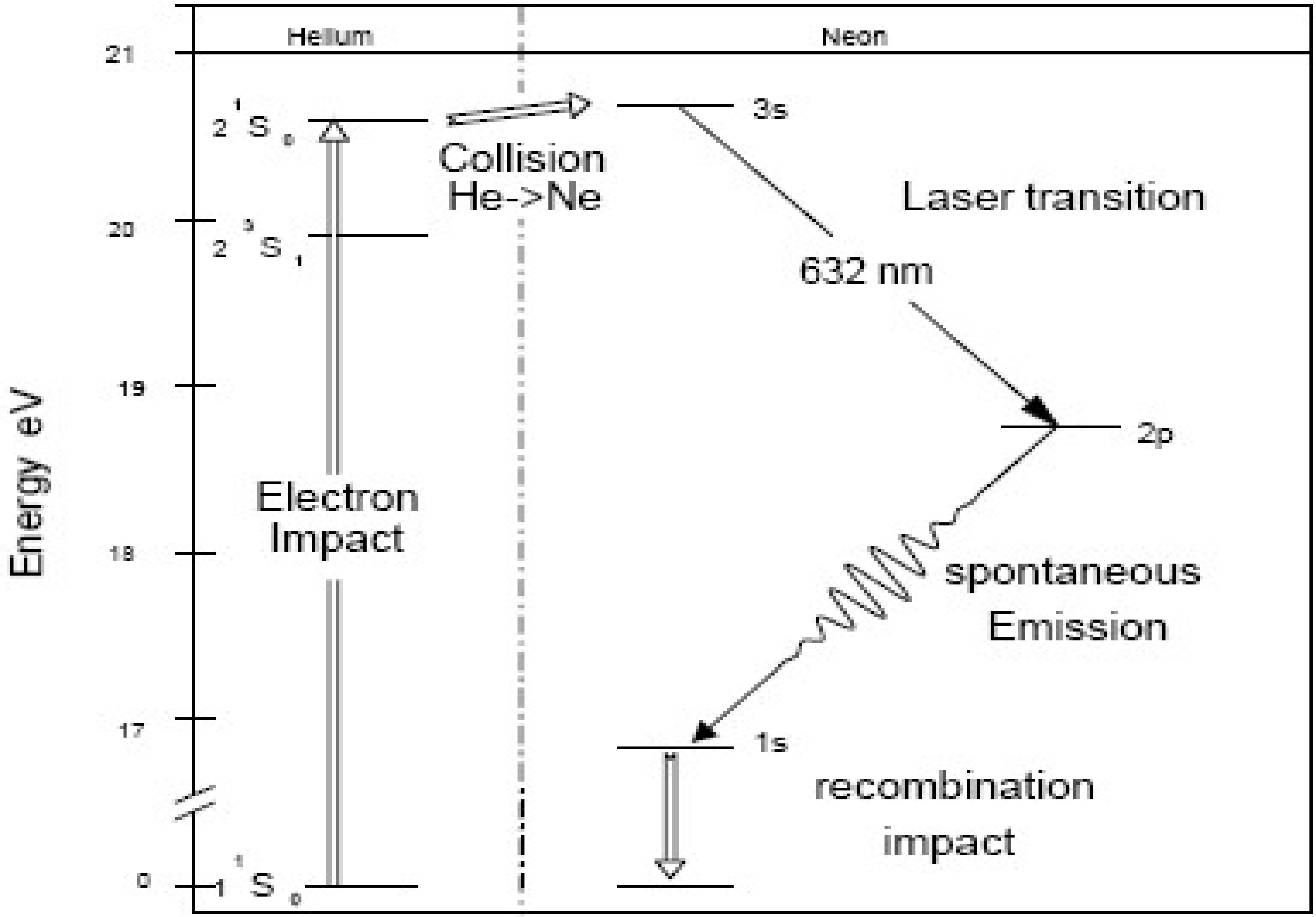


Fig. 1: Excitation and Laser process for the visible Laser emission

Working of He-Ne laser

(a)When the power is switched on, An energetic electron collisionally excites a He atom to the state labeled 21So . A He atom in this excited state is often written He*(21So), where the asterisk means that the He atom is in an excited state.

(b) The excited He*(21So) atom collides with an unexcited Ne atom and the atoms exchange internal energy, with an unexcited He atom and excited Ne atom, written Ne*(3s2), resulting. This energy exchange process occurs with high probability only because of the accidental near equality of the two excitation energies of the two levels in these atoms. Thus, the purpose of population inversion is fulfilled.

(c) When the excited Ne atom passes from metastable state(3s) to lower level(2p), it emits photon of wavelength 632 nm.

(d) When the excited Ne atom passes from metastable state(3s) to lower level(2p), it emits photon of wavelength 632 nm.

(e)This photon travels through the gas mixture parallel to the axis of tube, it is reflected back and forth by the mirror ends until it stimulates an excited Ne atom and causes it to emit a photon of 632nm with the stimulating photon.

(f) The stimulated transition from (3s) level to (2p) level is laser transition.

(g) This process is continued and when a beam of coherent radiation becomes sufficiently strong, a portion of it escape through partially silvered end.

(h) The Ne atom passes to lower level 1s emitting spontaneous emission. and finally the Ne atom comes to ground state through collision with tube wall and undergoes radiationless transition.

Properties

- It is simple in design and easy to operate so is widely used even after its low power.
- Most lasers have an efficiency of about 1 percent, about ten times the efficiency of the typical helium-neon laser.
- Helium-neon lasers do not require any consumables (sapphire rods or cryogenic gases for example), nor do they generate enough heat to require special cooling devices.
- They also have good beam quality, that is, their beams stay tightly focused even over long distances.

Applications of He-Ne laser

- The Narrow red beam of He-Ne laser is used in supermarkets to read bar codes.
- The He- Ne Laser is used in Holography in producing the 3D images of objects.
- He-Ne lasers have many industrial and scientific uses, and are often used in laboratory demonstrations of optics.
- Surveyors take advantage of the helium-neon laser's good beam quality to take precise measurements over long distances or across inaccessible terrain.

Optoelectronic Sources

Almost all light sources used in communications today are made from semiconductors. Commonly used devices are Light Emitting Diodes (LEDs) for local networks and Laser Injection diodes (Semiconductor laser diodes) (LID) for longer transmissions. LEDs are simpler than lasers but have a lot in common with them.

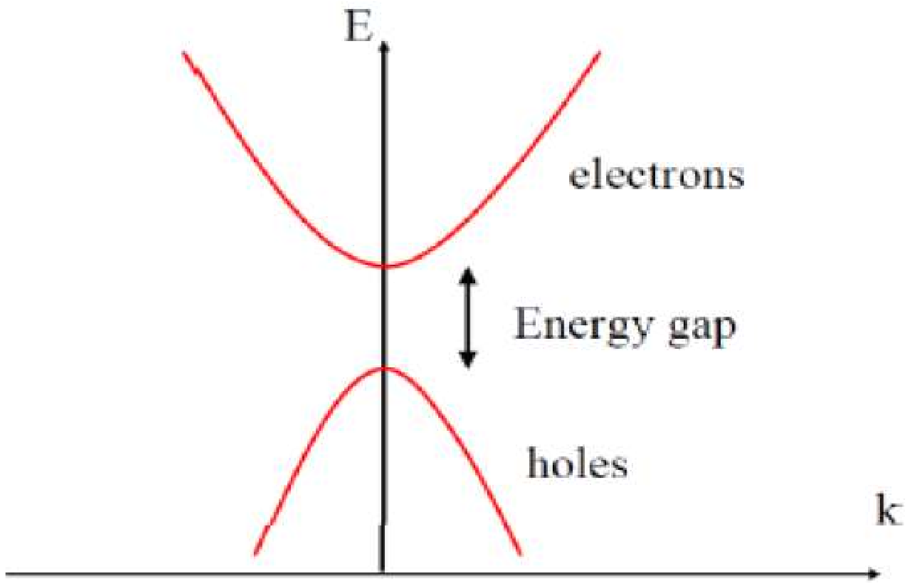
LID against LED

- 👍 Coherent light
- 👍 Higher radiant output power
- 👍 Monochromatic light: less wavelength dispersion

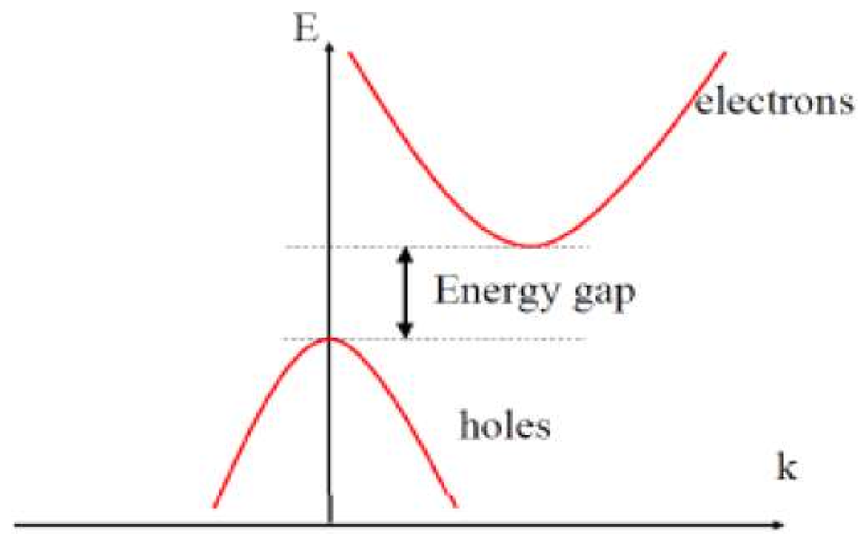
- 👎 10 times more expensive than LEDs
- 👎 shorter lifetime
- 👎 more temperature dependent

Semiconductor laser
Diode laser
Injection laser
and
Light Emitting Diodes (LED)

Direct and Indirect bandgap semiconductors:



Direct bandgap semiconductors



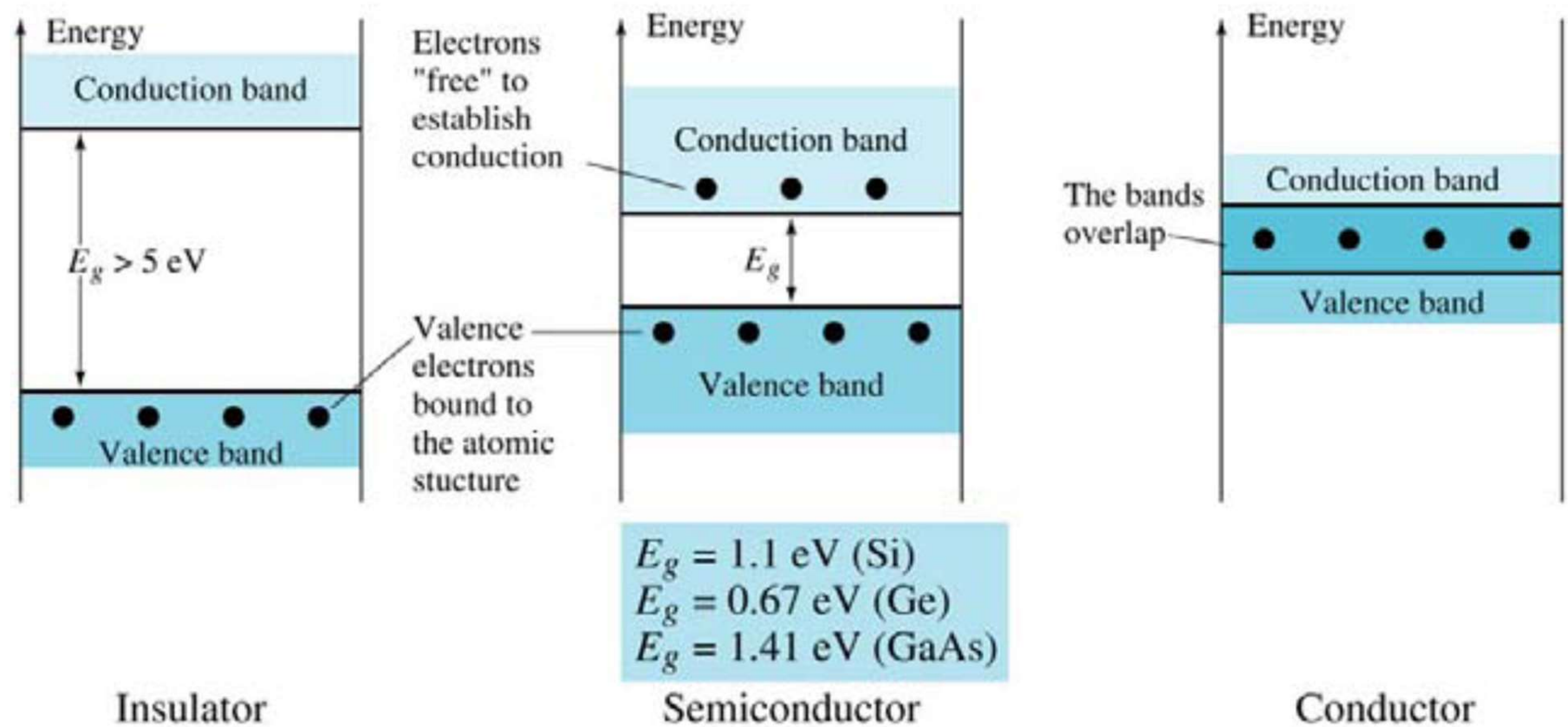
Indirect bandgap semiconductors

- Those materials for which maximum of valence band and minimum of conduction band lie for same value of k, called direct bandgap materials (i.e. satisfies the condition of energy and momentum conservation). For example: GaAs, InP, CdS..etc

- Those materials for which maximum of valence band and minimum of conduction band do not occur at same value of k, called indirect bandgap materials. For example: Si and Ge

- Indirect bandgap materials are not suitable for optical devices (LEDs and Laser diodes)

Conductors, semiconductors and insulators



(b)

General facts

- GaAs (Eg = 1.4 eV) is widely used for this purpose.
- 1mm x 1mm diode can be used with active medium consisting of a layer of thickness ~ 1 μm.
- These are called injection lasers since the laser action is created by charge carriers injected into a semiconductor diode.
- It is quite similar to LED. Two sides are polished.
- At room temperature, the wavelength is ~ 9000A. Mixed semiconductor alloy of GaAs and GaP gives 6500A.
- Main advantages are compactness, simplicity and efficiency. Used widely in communication and IT equipments.
- Disadvantages include difficulty in mode control due to tiny size. Also, as the laser action originates not between two sharp levels but between the edges of two broad bands, the spectral purity is much poorer.

Active medium: The active medium in semiconductor laser is GaAs or GaN or $GaAs_{1-x}P_x$, but it is commonly said that depletion region is the active medium in semiconductor laser. The thickness of the depletion region is usually very small (1 micrometer) because of Heavy Doping.

Pumping Source: The pn junction is made forward biased, that is , the p-side is connected to positive terminal of the battery and n-side to negative.

Under the influence of forward biased electric field, conduction electron will be injected from n-side .

Thus there will again recombination of holes and electrons in depletion region.

Achievement of population inversion:

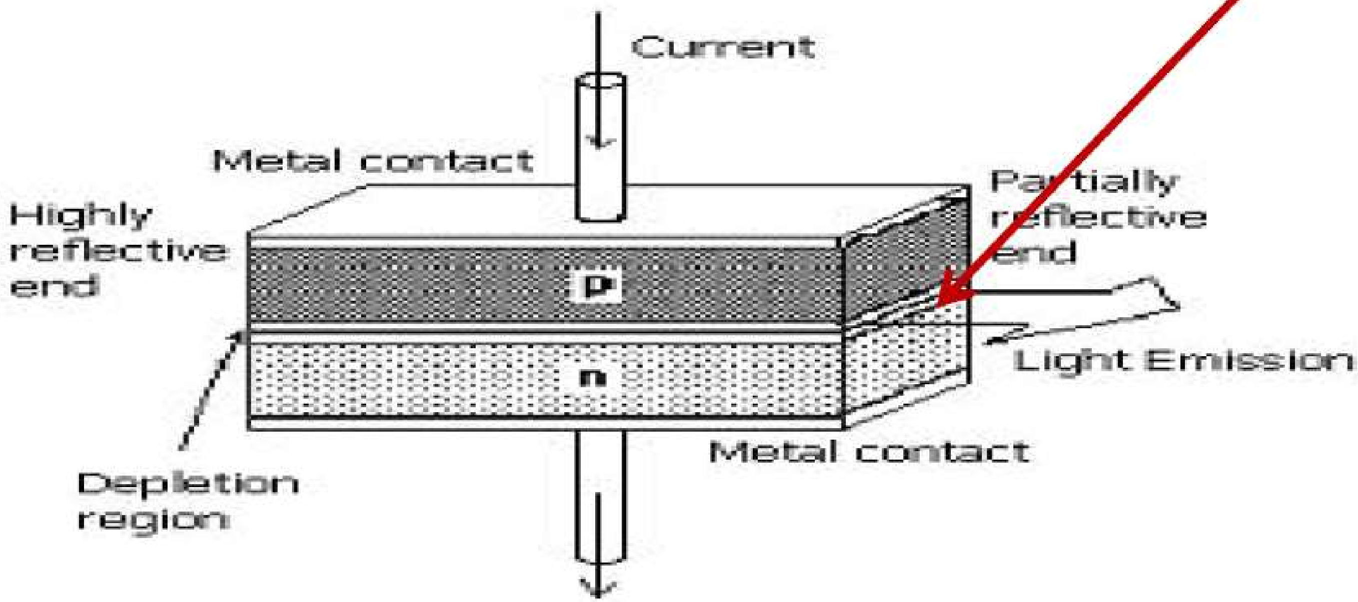
When the forward voltage reaches at a *threshold value* the carrier concentration rises to very high value.

As a result the depletion region "d" contains large number of electrons in the conduction band and at the same time large number of holes in the valence band.

Thus the upper energy level has large number of electrons and the lower energy level has large number of vacancy, thus population inversion is achieved.

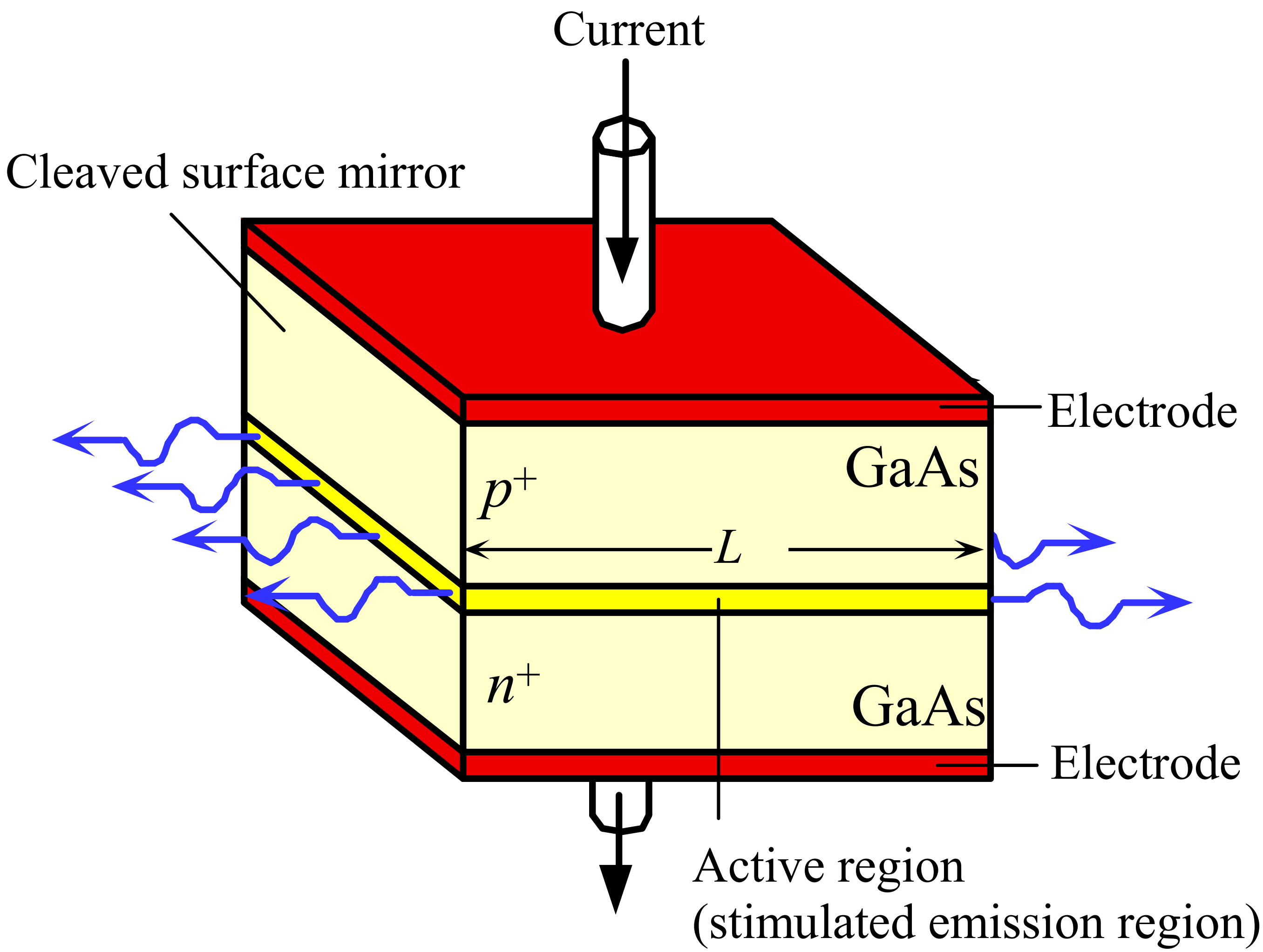
Optical resonator system

The two faces of semiconductor which are perpendicular to junction plane make a resonant cavity.



The top and bottom faces of diode, which are parallel to junction, are metalized so as to make external connections.

The front and back faces are roughened to suppress the oscillations in unwanted direction.



A schematic illustration of a GaAs homojunction laser diode. The cleaved surfaces act as reflecting mirrors.

Application / Uses of Semiconductor Lasers

The semiconductor laser can be pulsed at varying rate and pulse widths. Therefore this laser is a natural transmitter of digital data. Semiconductor laser is well suited for interface with fiber optic cables used in communication.

Advantages of Semiconductor Lasers

Smaller size and appearance make them good choice for many applications.

From cost point of view the semiconductor lasers are economical.

Semiconductor lasers construction is very simple.

No need of mirrors is in semiconductor lasers.

Semiconductor lasers have high efficiency.

The low power consumption is also its great advantage

Disadvantages of Semiconductor Lasers

Due to relatively low power production, these lasers are not suited to many typical laser applications.

Semiconductor laser is greatly dependent on temperature. The temperature affects greatly the output of the laser.

The lasing medium of semiconductor lasers is too short and rectangular so the output beam profile has an unusual shape.

Beam divergence is much greater from 125 to 400 milli radians as compared to all other lasers.

The cooling system requirement in some cases may be considered its disadvantage.

General applications of lasers

- In communication, holography.
- In information technology and data storage.
- In medical.
- In industry for cutting and welding.
- In Military.
- In scientific research.