ELEMENTS OF A LASER

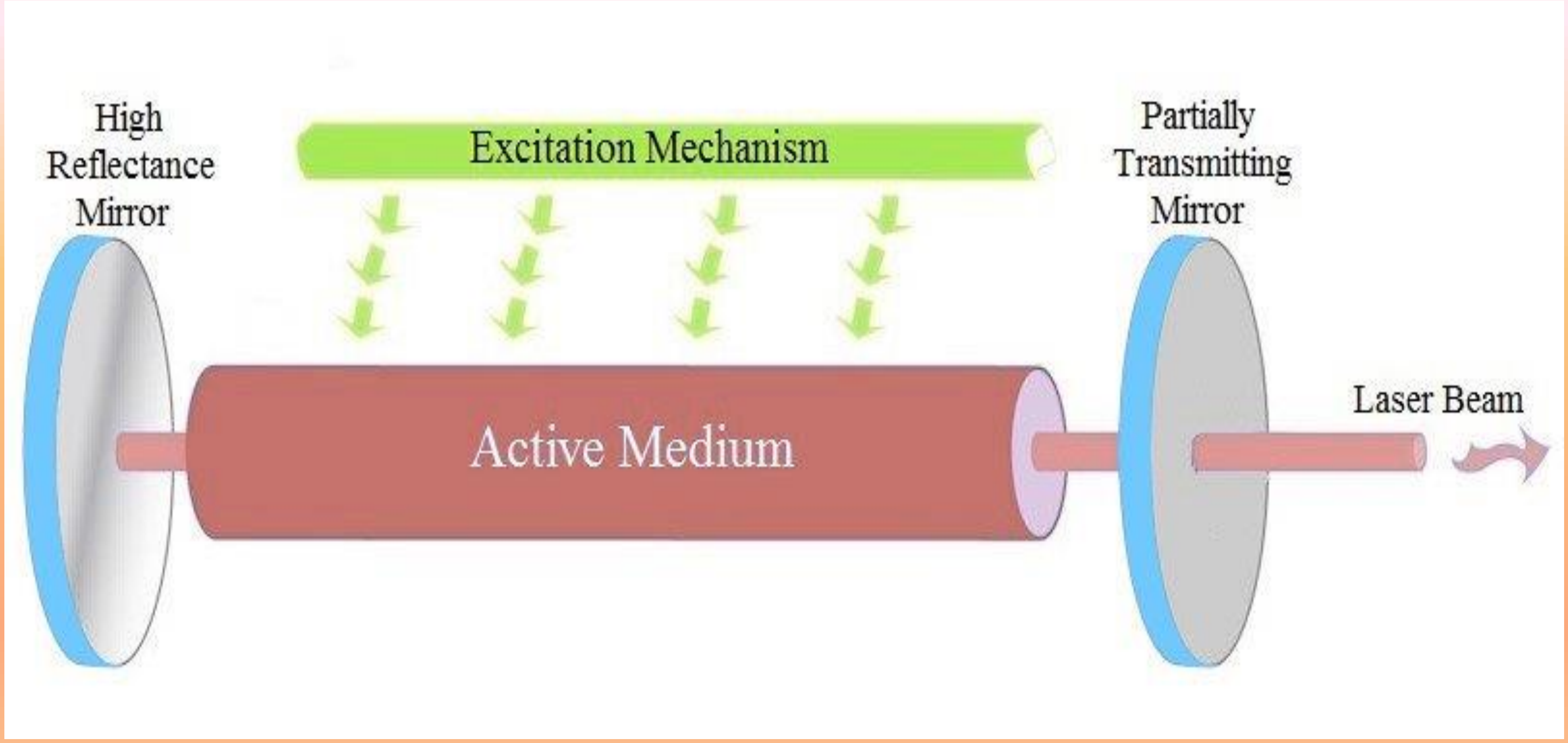
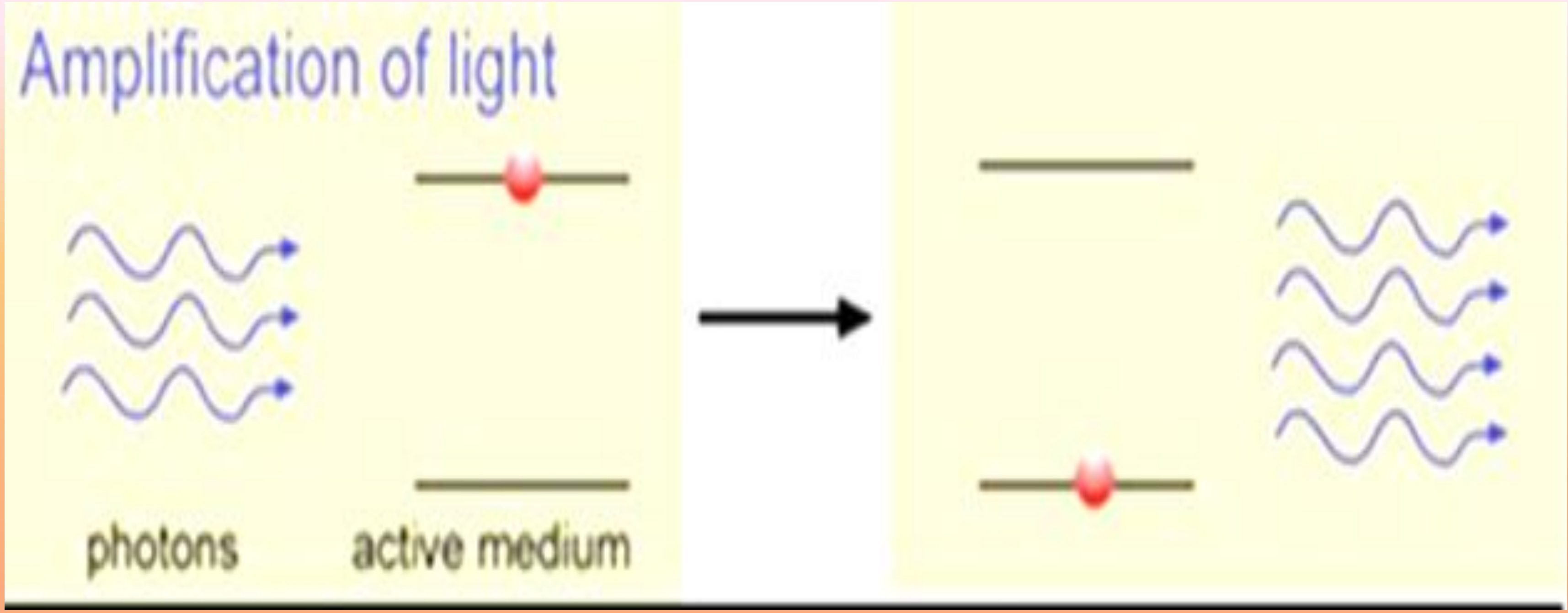


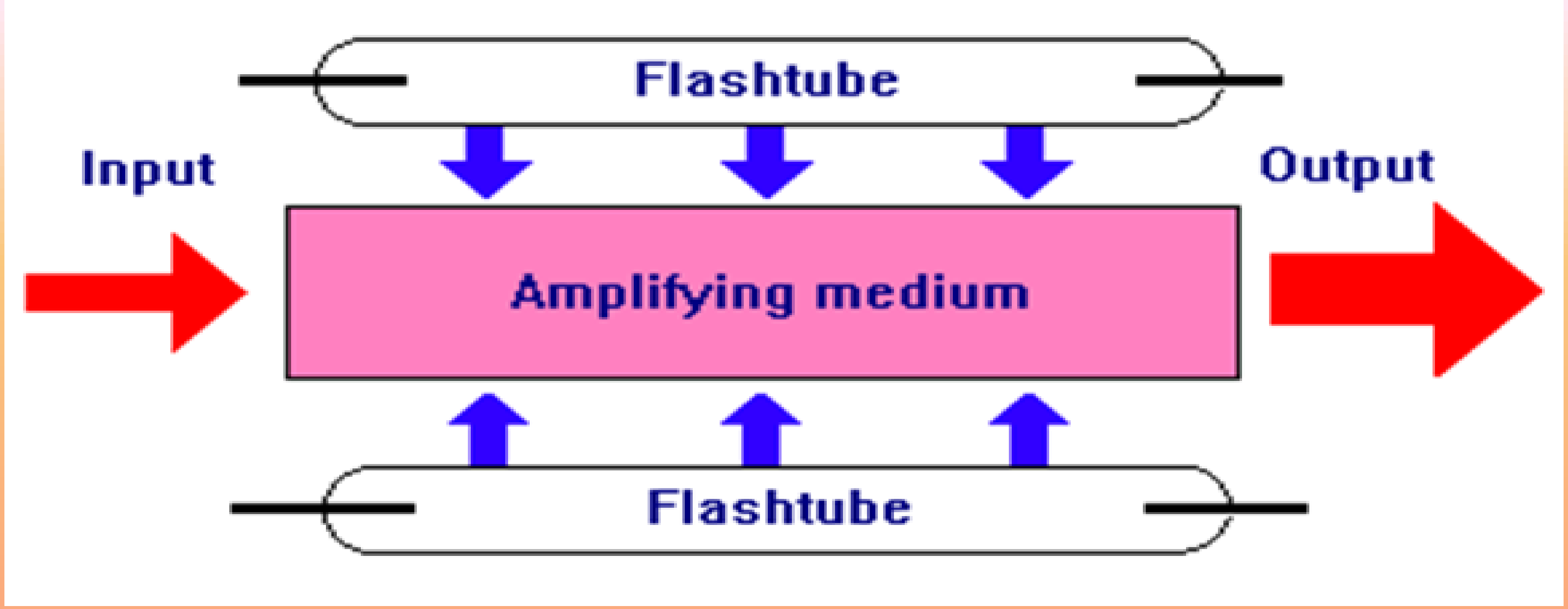
Figure 4-1 illustrates these four functionalities

1 Active Medium

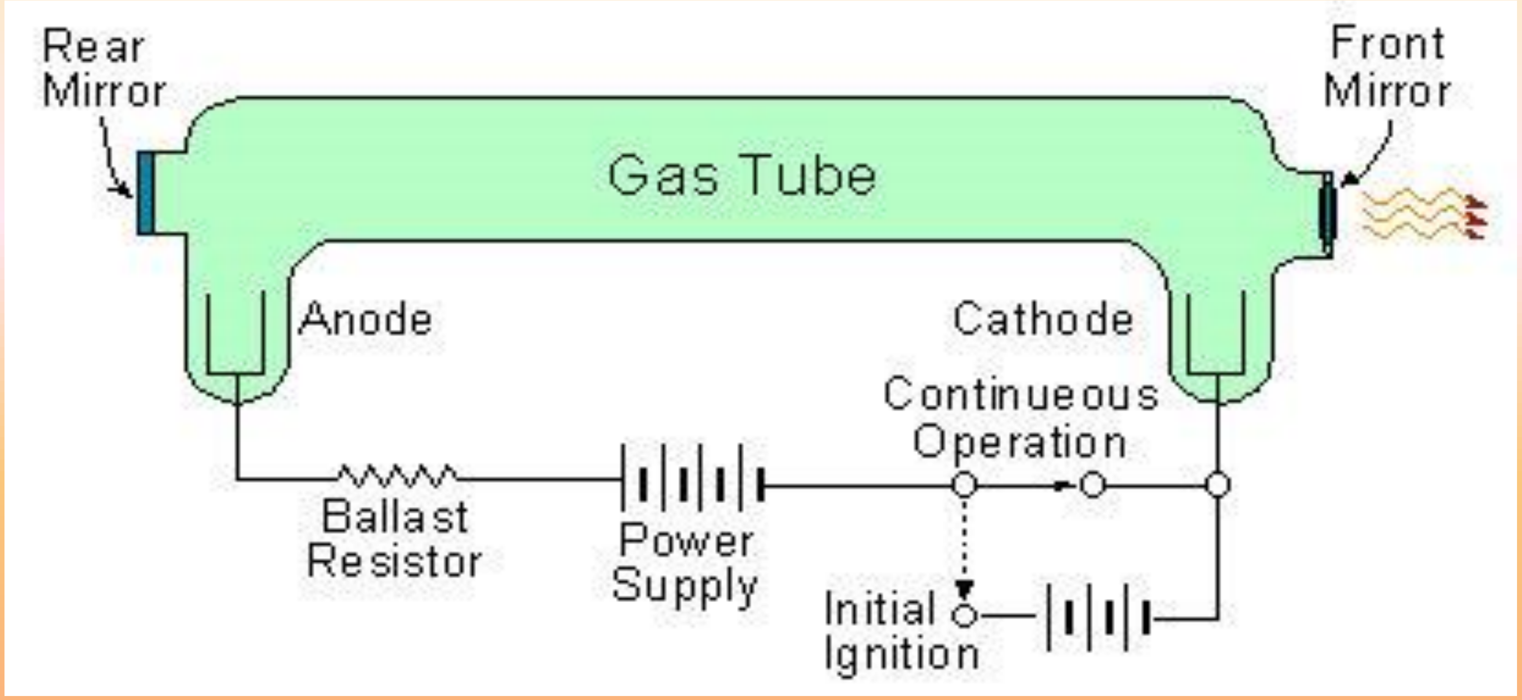


); The laser beam is amplified by stimulation of the excited atoms or molecules to emit photons into the exact same mode as the input light.

Excitation Mechanism



flash lamb (flash tube)



Electrical Excitation of a Gas Laser

highly reflecting mirrors

mirrors of Laser manufacture on the bases of glass substrates (BK7 glass or fused silica glass). The usual glass mirror substrates are cylindrical, with different diameters. For example, the diameter (25 mm) or 12 mm, and the thickness can be 6 mm. For example, for mirrors with high reflectivity, some properties of glass substrates Particularly important, is the low thermal expansion factor, surface quality, and high thermal conductivity to prevent thermal bloating on mirrors surface, especially in high-power laser beams, but also the high hardness of important properties,

The glass substrates on which the mirror is built may be curved, making the laser mirrors focus or defocus the reflected light. The one half mirror diameter of the curvature is equal to the focal length. Good mirrors can have a radius of curvature of 1 mm in diameter and it is made by some specialists.

Output Coupler

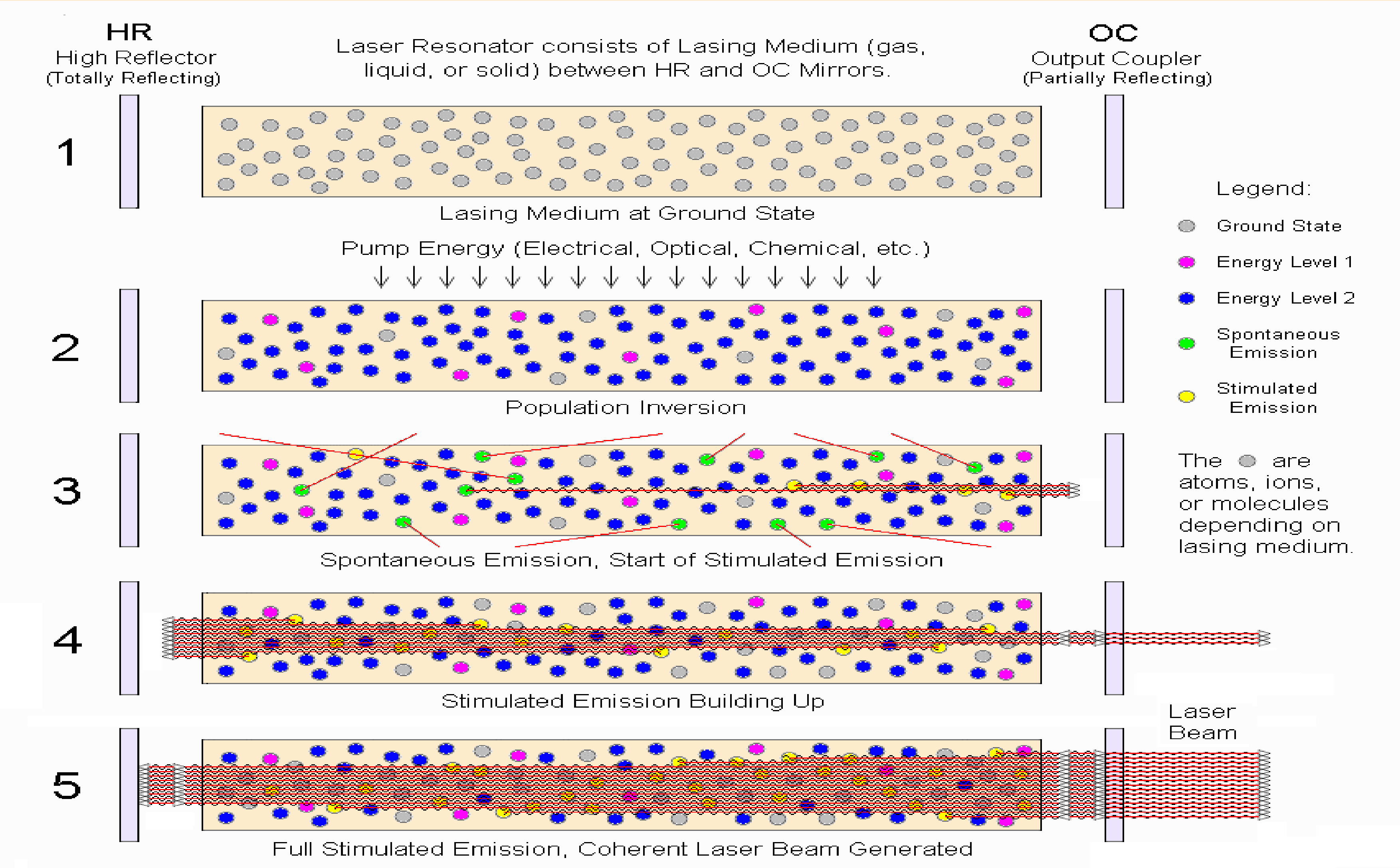
Is a partially reflective mirror that allows for the release of part of the laser light between the two mirrors (in the laser cavity). It has the function to transfer part of the optical power generated inside the cavity in order to obtain the laser, the proportion of the coherent light fraction that allows it to escape dramatically varies for different lasers. Where it has a spatially constant reflection/transmission (R/T) value, which is the main characteristic of the output coupler mirror type. In lasers that emit continuous radiation (continuous wave lasers), most of the radiation is reflected back into the cavity, and only a small percentage is transmit. The selection of an output mirror to fit the design of the laser cavity is important to be taken into account. In pulse-operated lasers, most of the radiation inside the cavity is transmitted out by a short-duration pulse. For example, in continuous wave lasers such as helium-neon, the laser output is less than 1%, whereas in pulse lasers it is more than 80% reflected back, especially for solid state lasers.

Feedback Mechanism

The process of obtaining laser radiation depends on feedback, using mirrors on both ends of the active material. The photons generated from the active material are reflected of these mirrors so that the radiation moves back and forth between them. In this way, an optical cavity is created that satisfies the optical feedback, and finally controls the process of the stimulated emission and obtain the gain of the coherent radiation resulting from the stimulated emission. The optical cavity consists of a mirror that reflects the radiation 100%, so that all the incoming photons of the mirror are reflected to the active material . The other mirror partially reflects (approximately 10% for solid state lasers and about 99% for gaseous lasers),Where the feedback mechanism returns a portion of the coherent light generated by the active medium to the active medium to obtain further amplification by a stimulated emission. The amount of coherent light generated by the stimulated emission depends on both the degree of population inversion and the strength for induced emission. The part of the radiation that is not reflected in the optical cavity, which is the laser beam coming out or so-called (laser output).

Lasing Action

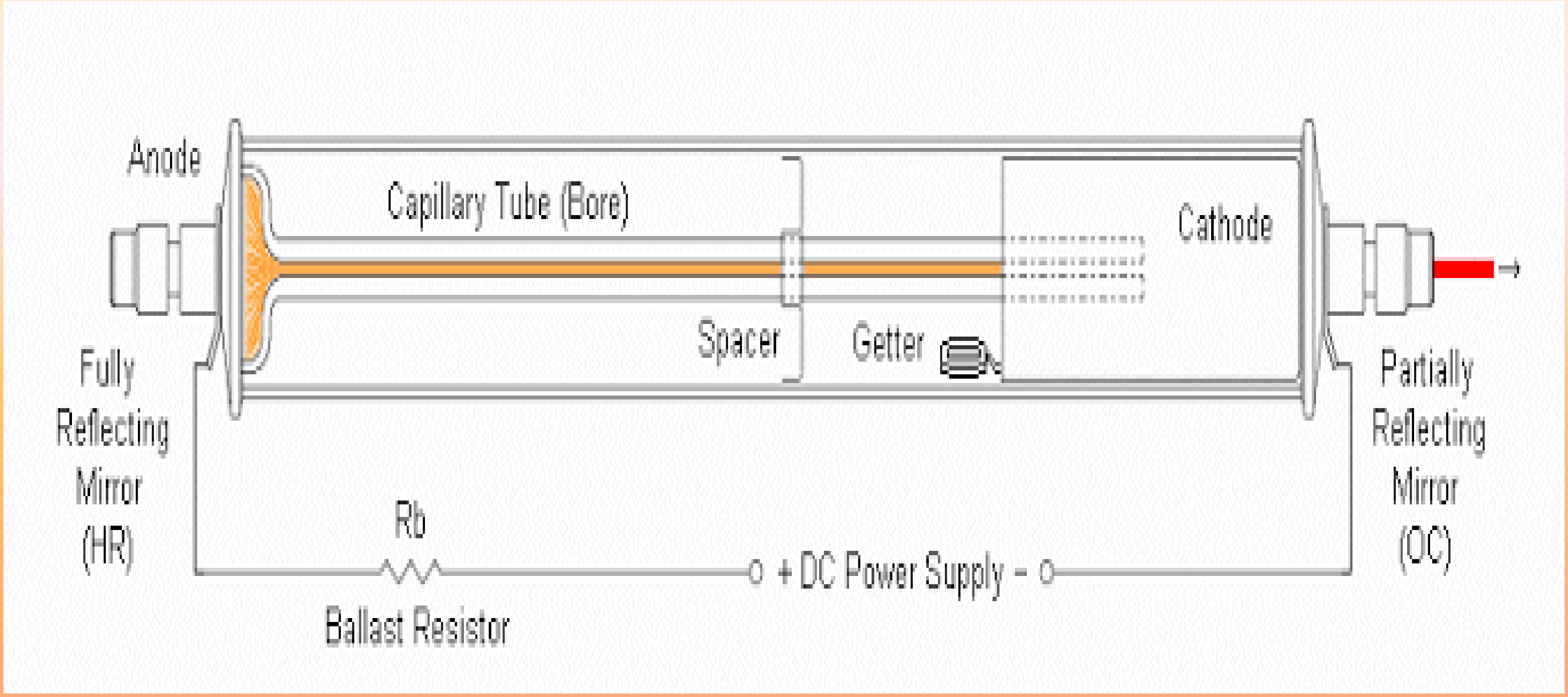
When the energy is injected into the active material of the laser, which may be carried out either by electric charge or light rays or by a chemical reaction between two substances that causes the excitation of the active medium, Causing the atoms to move from ground energy levels to the excited state levels in this way, the population inversion state is configured. Some atoms move from the upper laser level to the lower laser level through the spontaneous emission process. In this case, incoherence photons are emitted at a given laser wavelength and in random directions. Many of these photons come out of the active medium, but those whose direction with the axis of the active medium lead to a stimulated emission, as shown in Figure 4.5. The photons of the beam produced by the active material are reflected back by the mirrors and remain moving between mirrors only and the active material produces sufficient amplification of the number of photons, It also gains high directivity for the outgoing optical beam. the laser output mirror (output coupler) Allow to exit part of the laser light as the output beam.



Laser operation

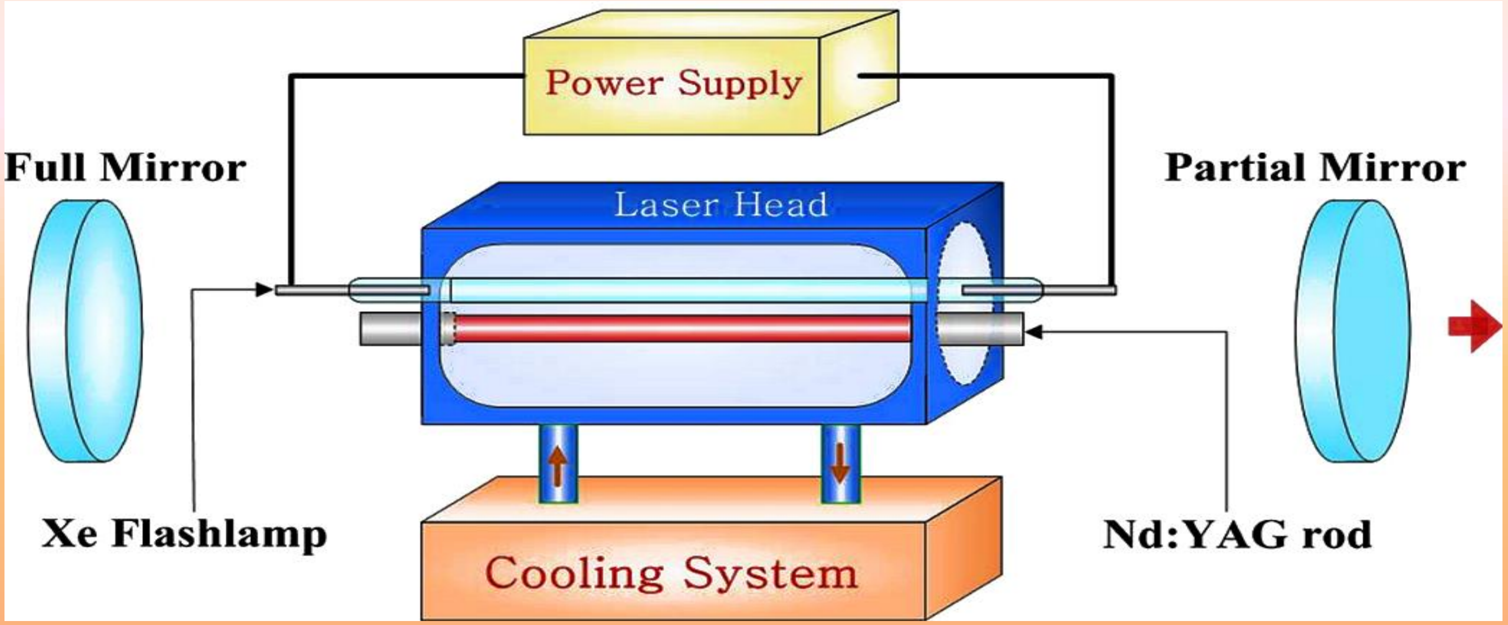
Types of Lasers

Although there are several types of lasers, they all share the same characteristics. The laser may be classified into different types depending on the uses, or according to the type of active medium, the pump mechanism or the duration of the laser output. The type of active medium is the most widely used basis for the distinction between the different laser here. Some types of lasers are characterized by their high power, such as (carbon dioxide laser), which is considered one of the most dangerous Types of lasers, because of its high power of up to tens of kilowatt. Other types of lasers are also very weak, such as those used in daily life in indicators, and these are usually semiconductor laser. Lasers can also be classified according to the duration of the laser output - such as continuous wave laser or pulsed laser. A Q-Switched laser is a pulse laser that contains a shutter that does not allow the laser light to be emitted until it is opened. The following is a detailed study of the most important types of lasers: Here we will explain some examples, which include both pulse and continuous wavelength (CW) with the method of pumping, whether it is electric or optical.



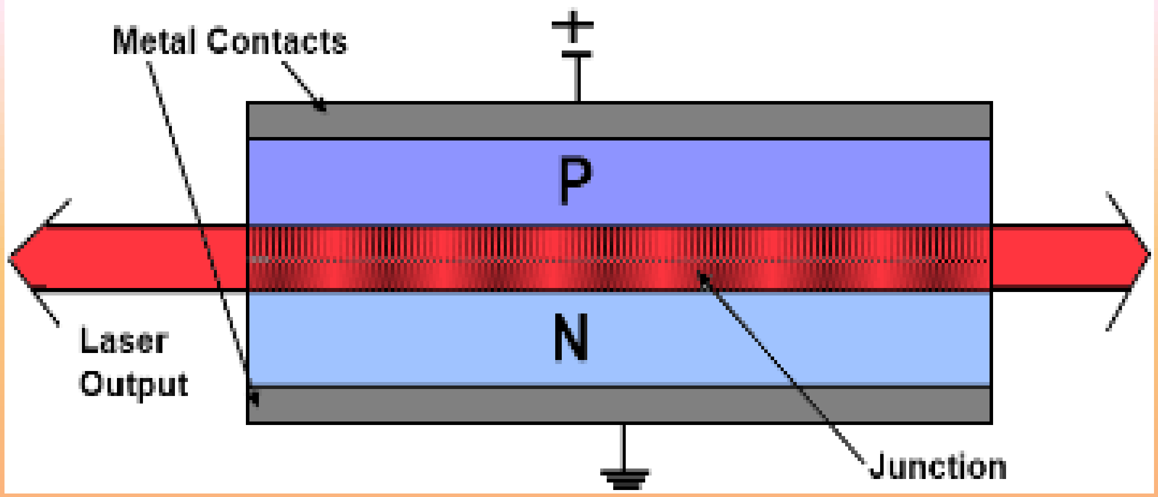
: HeNe laser tube structure and connection

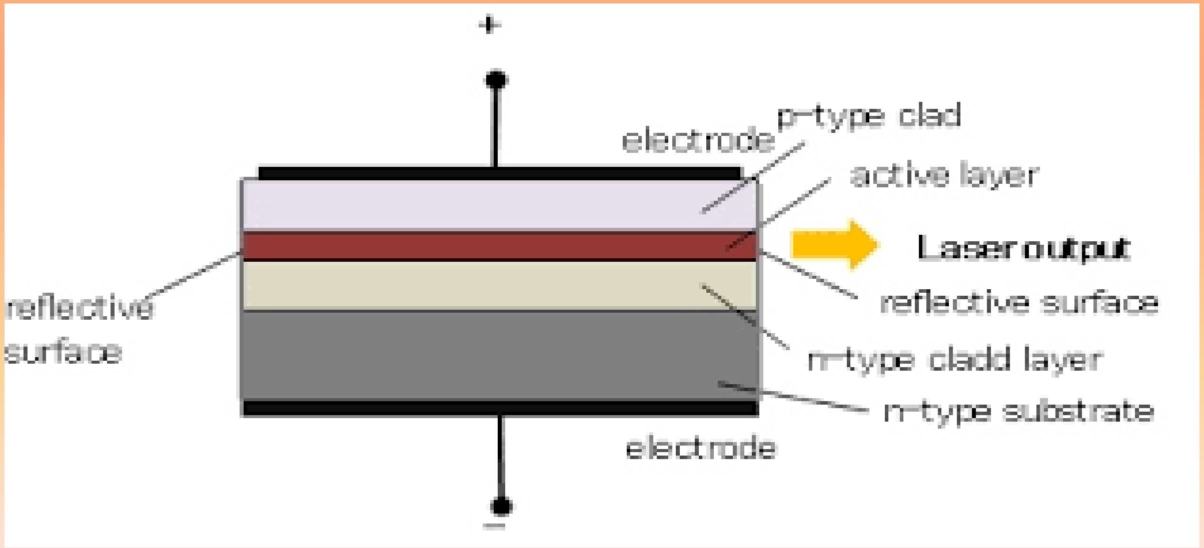
Solid Crystalline and Glass Lasers



CW Nd:YAG laser

Semiconductor Lasers





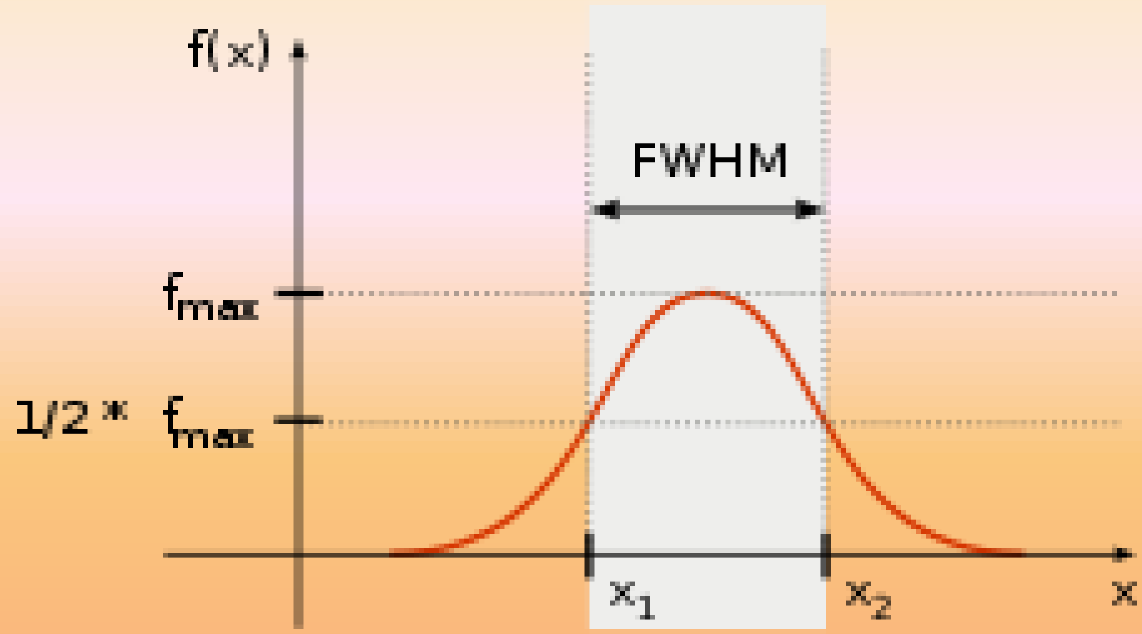
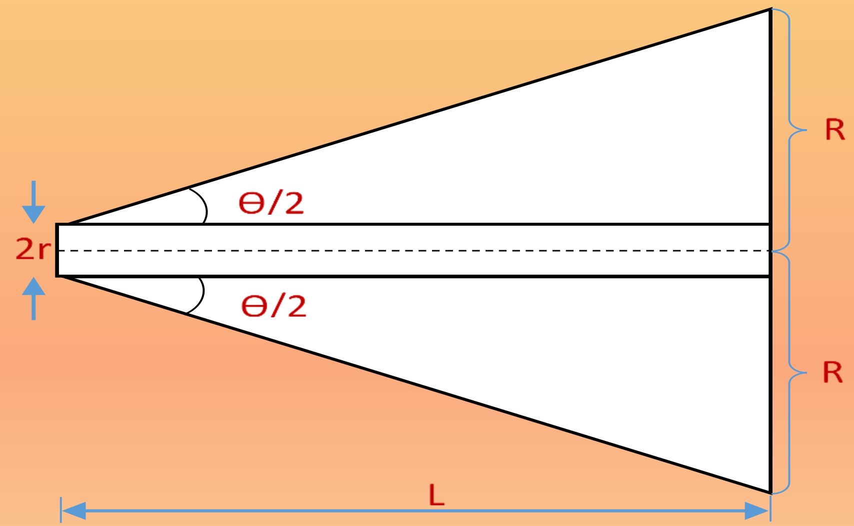


Figure 2.1 (c) full width at half maximum is given by the distance between points on the curve at which the function reaches half its maximum value.

Spot Size Measurement

R = radius of a spot illuminated by the laser beams at distance L from the laser output aperture (as shown in figure below). When measuring the size of the spot near the laser output aperture (the spot is small), then this measurement should be taken into consideration:

$$tan\left(\frac{\theta}{2}\right) = \frac{R - r}{L} \approx \frac{\theta}{2} \qquad \dots 2.2$$



Because the laser beam has a very small diverges angle, then we can use the small angle approximation. Thus, the tangent of the angle can be considered equal to the angle. The laser light produces a spot for its beam on the screen, the diameter of this spot is (2R) which determines the spot size.

EXAMPLE 2.1:

The divergence angle of a laser beams of 1 milli- radian and at a distance of 10 meters great A spot of approximately 10 mm.is. The power density can be defined as the amount of laser power measured over a surface area defined by unit surface. From Figure 2.6, it is possible to obtain a higher power density than conventional or natural sources from a laser beam (see example 2.2). This is why a 5-watt laser is dangerous, and a 100-watt lamp light is not dangerous

EXAMPLE 2.2: NUMERICAL CALCULATION OF POWER DENSITY

Calculate the power density (intensity or power per unit area) at a distance of 2 meters from a 100-watt incandescent lamp, and then compare the result with a 1-megawatt helium-neon laser beam emission. The diameter of the laser beam is at the output aperture is 2 mm and the divergence angle is 1 milliard

Solution:

The incandescent lamp radiate light in all directions, Radiation is distributed over a surface area of a sphere with a radius of 2 meters. Surface area is: πR^2, so the power density at a distance of 2 meters is:

$$\frac{100}{4\pi} = 0.8\, mW/cm^2$$

Compared to the incandescent lamp, at a distance of 2 meters the diameter of the laser beam increases to 4 mm (see diagram below):

$$tan\left(\frac{\theta}{2}\right) = \frac{R - r}{L}$$

$$R = r + L \cdot tan\left(\frac{\theta}{2}\right) = 1 + 2000 \times tan0.5$$

$$R = 2.1\ mm = 0.2\ cm$$

The power density of the laser is:

$$\frac{1}{0.04\pi} = 8\, mW/cm^2$$

There are many different ways to measure the divergence of the laser beam that can be illustrated. Figure 2.6 illustrates the comparison of the outward radiation of a laser and the emission of one of the standard lamps.

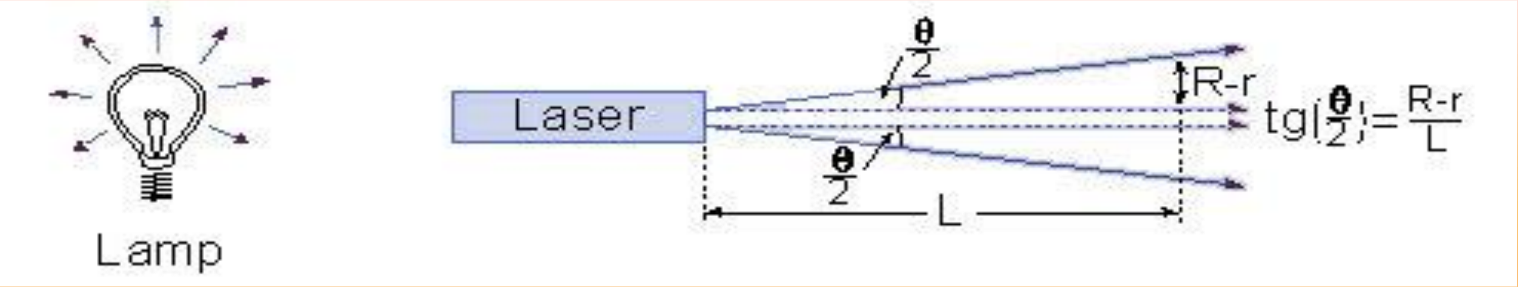
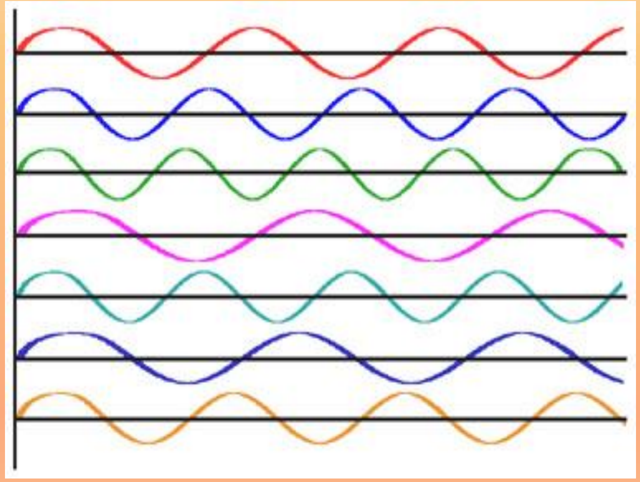


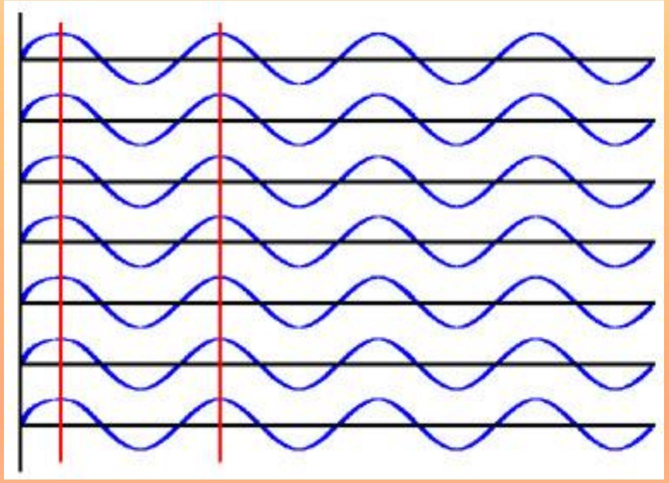
Figure 2.6: comparison between the light out of a laser, and the light out of an incandescent lamp

Again, it is not possible to generate a fully directed light beam, i.e. its parallel light beam is referred to as a directional light (collimated light). All optical beams diverge (spread) as they travel through space. However, the laser light is more directional or more collimated, and has a directional or much higher collimated than any light emitting from a conventional source and thus less divergence. In some applications, certain optical systems are added with laser beams to improve beam directionality.

Coherence

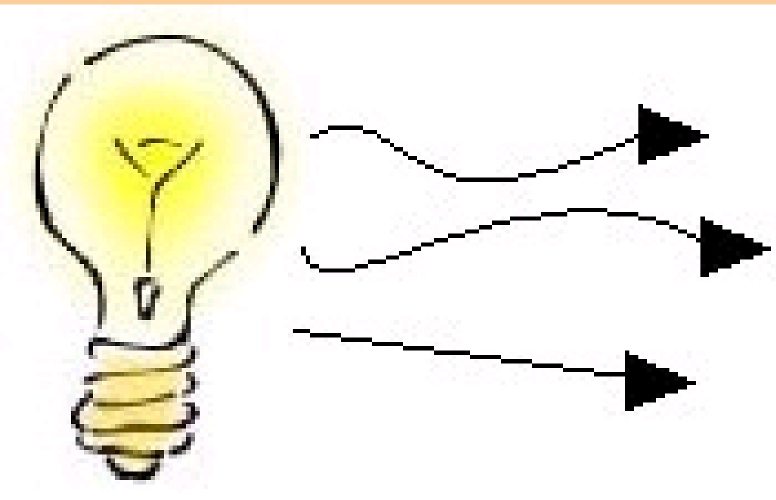


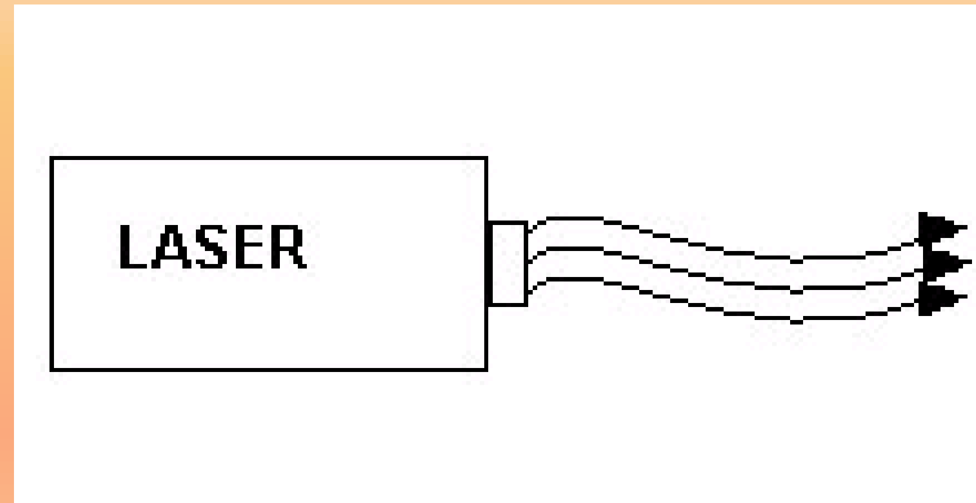
Incoherent light waves



Coherent light waves

Incandescent vs. Laser Light





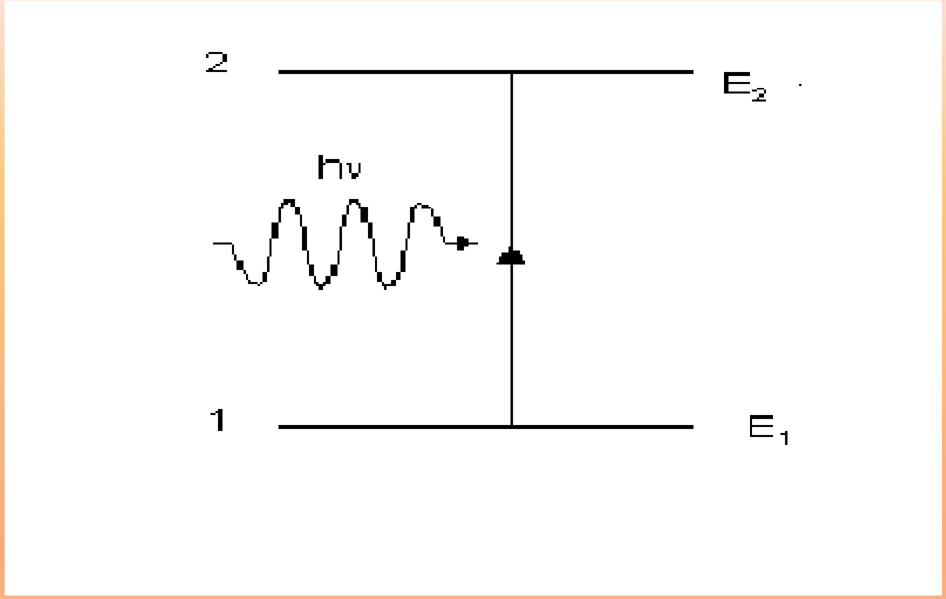
1. Many wavelengths
2. Multidirectional
3. Incoherent

1. Monochromatic
2. Directional
3. Coherent

Basic concepts for a laser

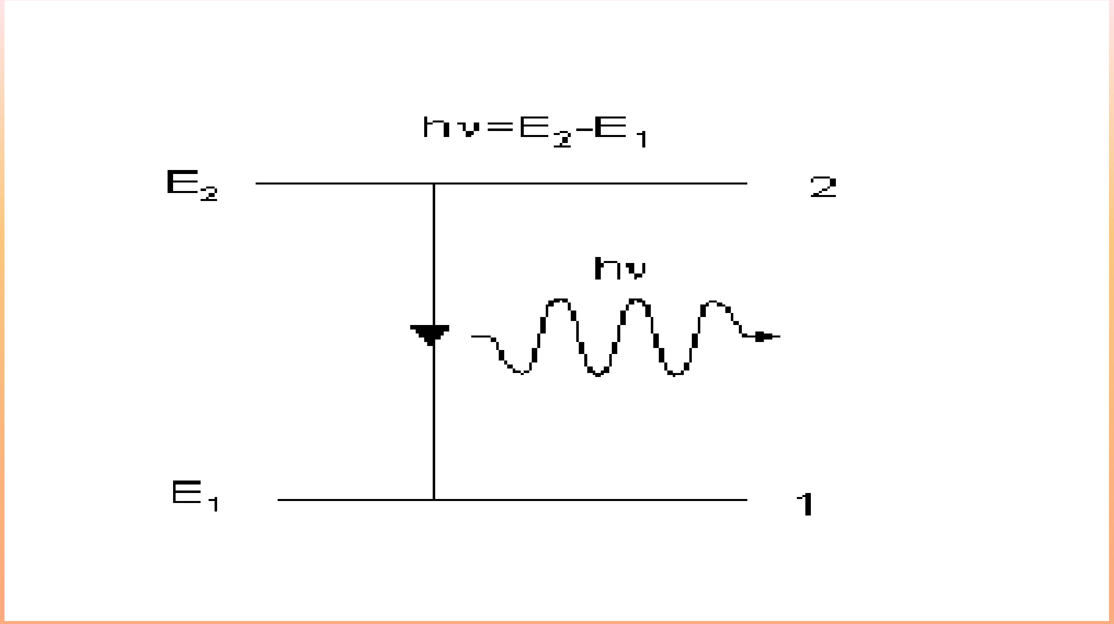
- Absorption
- Spontaneous Emission
- Stimulated Emission
- Population inversion

Absorption



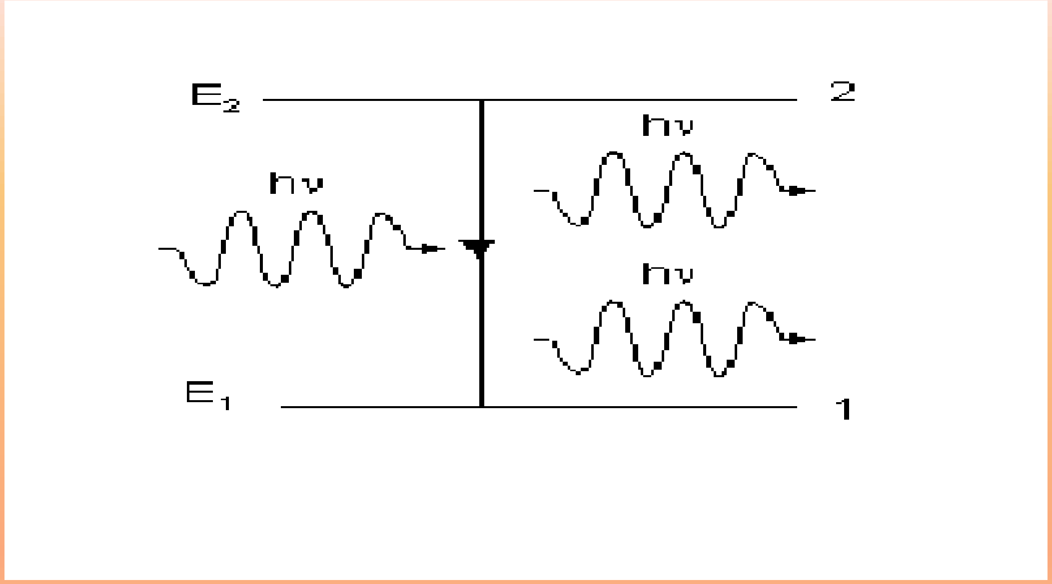
- Energy is absorbed by an atom, the electrons are excited into vacant energy shells.

Spontaneous Emission



- The atom decays from level 2 to level 1 through the emission of a photon with the energy *hv*. It is a completely random process.

Stimulated Emission



atoms in an upper energy level can be triggered or stimulated in phase by an incoming photon of a specific energy.

Stimulated Emission

The stimulated photons have unique properties:

– In phase with the incident photon

– Same wavelength as the incident photon

– Travel in same direction as incident photon

Population Inversion

- A state in which a substance has been energized, or excited to specific energy levels.
- More atoms or molecules are in a higher excited state.
- The process of producing a population inversion is called pumping.
- Examples:

→by lamps of appropriate intensity

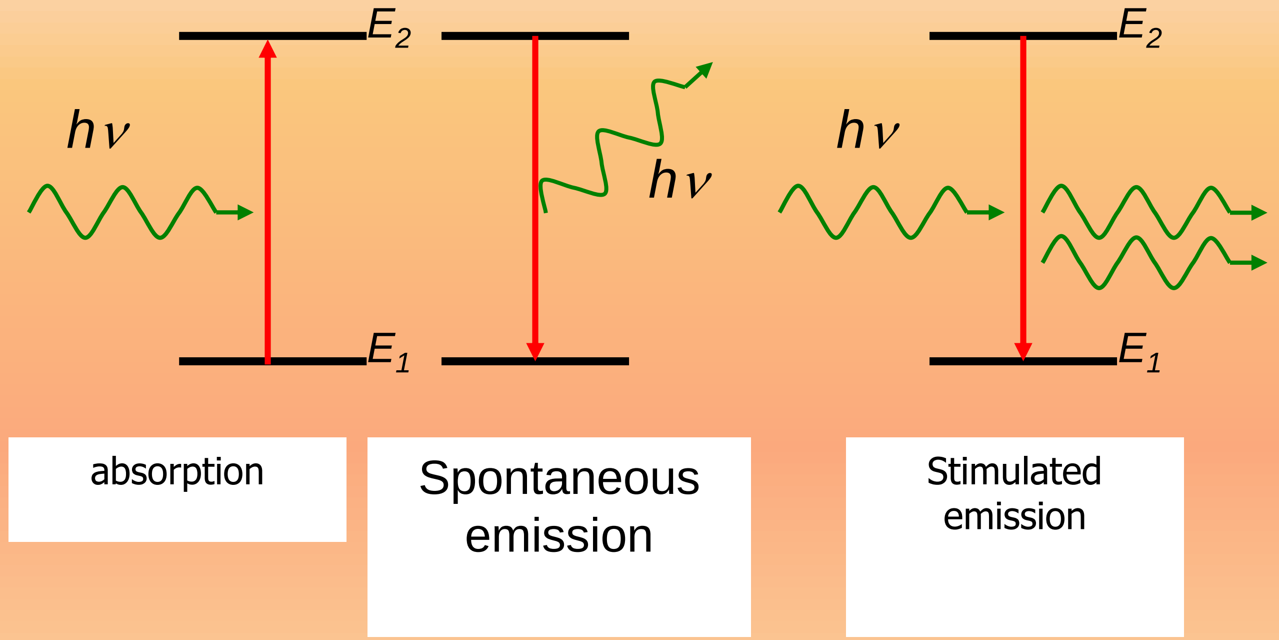
→by electrical discharge

Pumping

- Optical: flashlamps and high-energy light sources
- Electrical: application of a potential difference across the laser medium
- Semiconductor: movement of electrons in "junctions," between "holes"

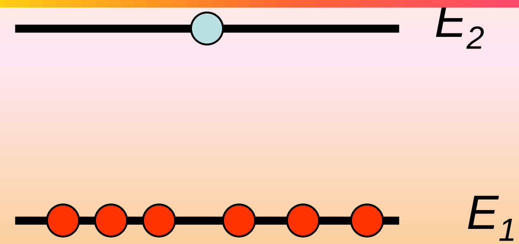
Two level system

$h\nu = E_2 - E_1$



Boltzmann's equation

$$\frac{n_2}{n_1} = \exp\left(\frac{-(E_2 - E_1)}{kT}\right)$$



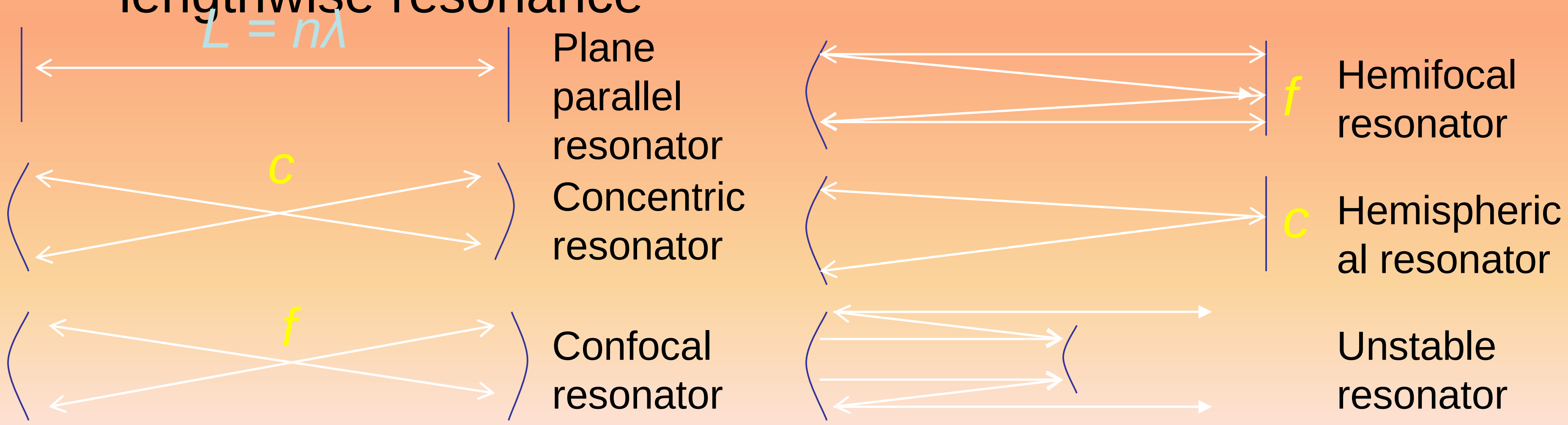
- n_1 - the number of electrons of energy E_1
- n_2 - the number of electrons of energy E_2
- *Population inversion- n2>>n1*

example: T=3000 K E_2-E_1=2.0 eV

$$\frac{n_2}{n_1} = 4.4\times10^{-4}$$

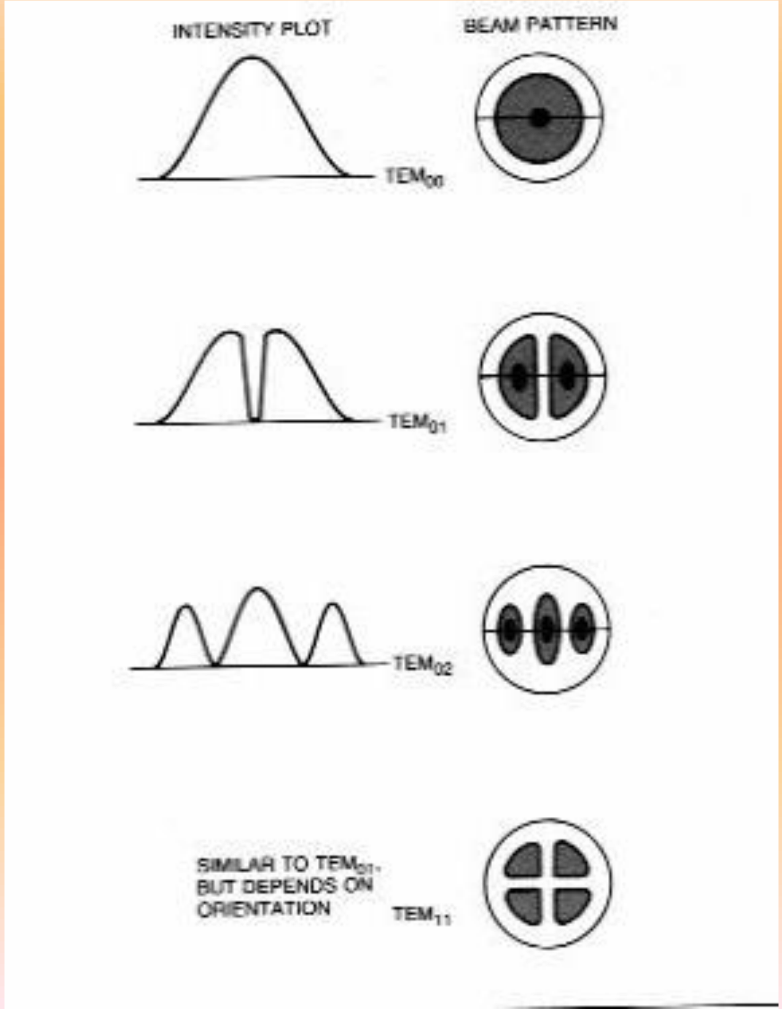
Resonance Cavities and Longitudinal Modes

Since the wavelengths involved with lasers and masers spread over small ranges, and are also absolutely small, most cavities will achieve lengthwise resonance



c: center of curvature, f: focal point

Transverse Modes



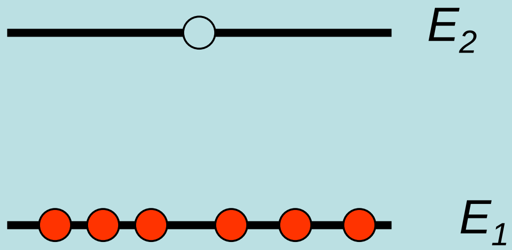
Due to boundary conditions and quantum mechanical wave equations

TEM_{00}:

$I(r) = (2P/\pi d^2)*\exp(-2r^2/d^2)$

(d is spot size measured to the $1/e^2$ points)

Einstein's coefficients



Probability of stimulated absorption R_{1-2}

$$R_{1-2} = \rho(\nu) B_{1-2}$$

Probability of stimulated and spontaneous emission :

$$R_{2-1} = \rho(\nu) B_{2-1} + A_{2-1}$$

assumption: n_1 atoms of energy ε_1 and n_2 atoms of energy ε_2 are in thermal equilibrium at temperature T with the radiation of spectral density $\rho(\nu)$:

$$n_1 R_{1-2} = n_2 R_{2-1} \qquad n_1 \rho(\nu) B_{1-2} = n_2 (\rho(\nu) B_{2-1} + A_{2-1})$$

$\Rightarrow$

$$\rho(\nu) = \frac{A_{2-1}/B_{2-1}}{\frac{n_1}{n_2}\frac{B_{1-2}}{B_{2-1}} - 1}$$

According to Boltzman statistics:

$$\frac{n_1}{n_2} = \exp(E_2 - E_1)/kT = \exp(h\nu/kT)$$

$$\rho(\nu) = \frac{A_{2-1}/B_{2-1}}{\frac{B_{1-2}}{B_{2-1}}\exp(\frac{h\nu}{kT}) - 1} = \frac{8\pi h\nu^3/c^3}{\exp(h\nu/kT) - 1}$$

Planck's law

$B_{1-2}/B_{2-1} = 1$

$$\frac{A_{2-1}}{B_{2-1}} = \frac{8\pi h\nu^3}{c^3}$$

The probability of spontaneous emission A_{2-1} /the probability of stimulated emission $B_{2-1}\rho(\nu)$:

$$\frac{A_{2-1}}{B_{2-1}\rho(\nu)} = \exp(h\nu / kT) - 1$$

1. Visible photons, energy: 1.6eV – 3.1eV.

2. kT at 300K ~ 0.025eV.

3. stimulated emission dominates solely when $h\nu /kT <<1$!
(for microwaves: $h\nu$ <0.0015eV)

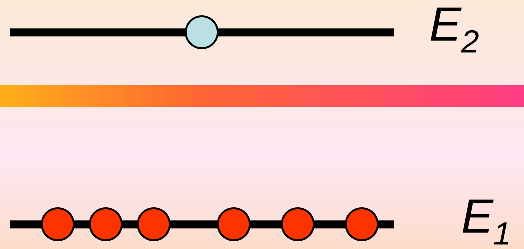
The frequency of emission acts to the absorption:

$$x = \frac{n_2 A_{2-1} + n_2 B_{2-1}\rho(\nu)}{n_1 B_{1-2}\rho(\nu)} = [1 + \frac{A_{2-1}}{B_{2-1}\rho(\nu)}]\frac{n_2}{n_1} \approx \frac{n_2}{n_1}$$

if $h\nu /kT <<1$.

$x \sim n_2/n_1$

Condition for the laser operation



If $n_1 > n_2$

- radiation is mostly absorbed absorbowane
- spontaneous radiation dominates.

if $n_2 >> n_1$ - *population inversion*

- most atoms occupy level E2, weak absorption

- stimulated emission prevails

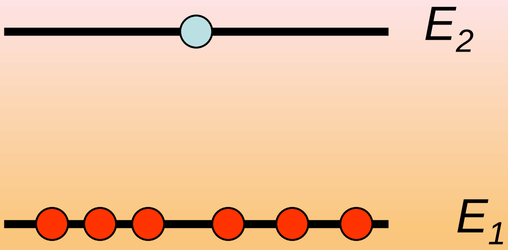
- light is amplified

Necessary condition:
population inversion

How to realize the population inversion?

Thermal excitation:

$$\frac{n_2}{n_1} = \exp\left(\frac{-\Delta E}{kT}\right)$$



impossible.

The system has to be „pumped”

Optically,
electrically.