Lasers

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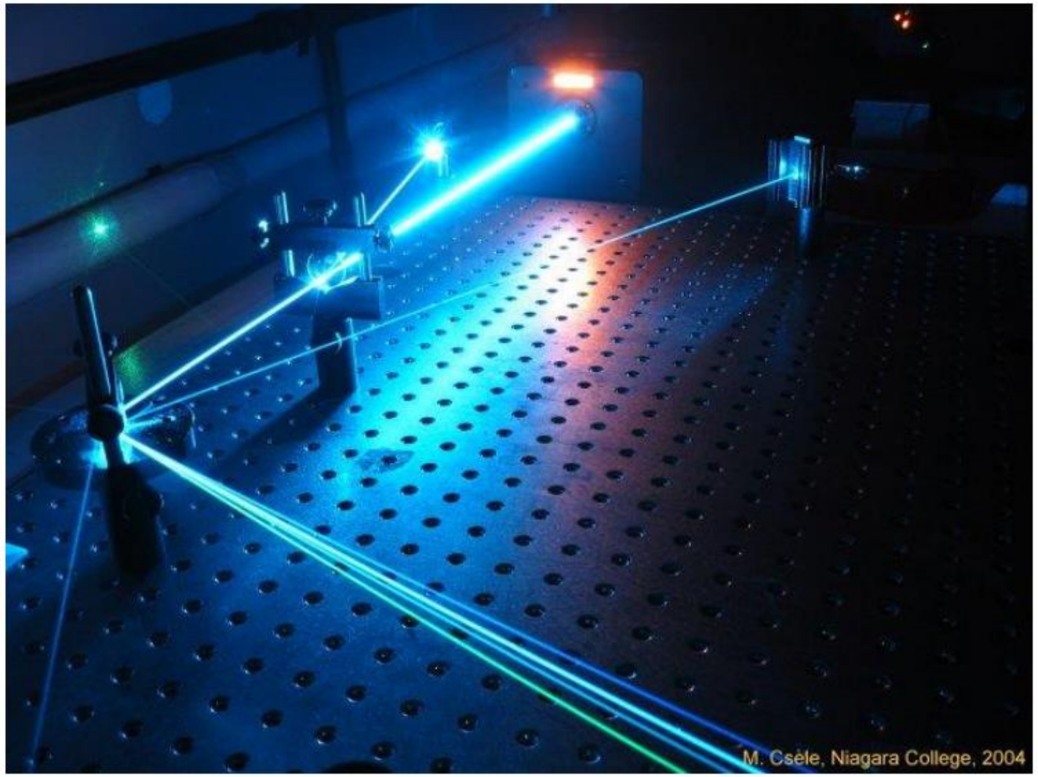
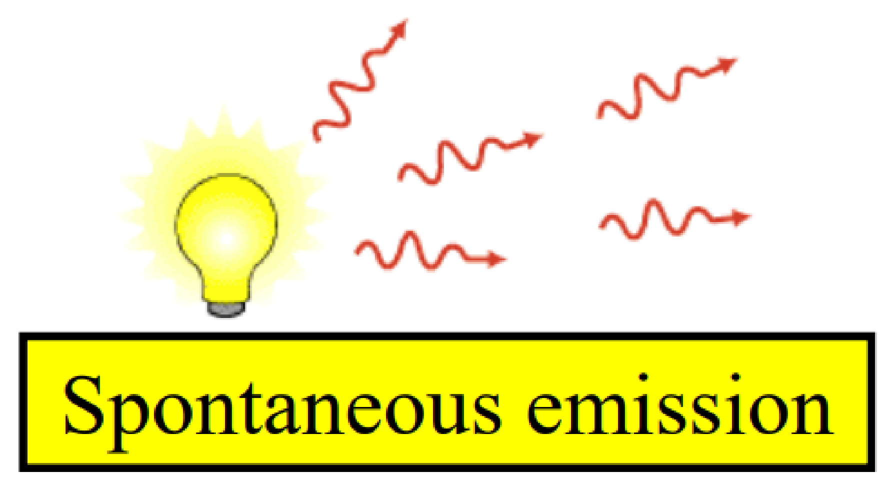
Introduction

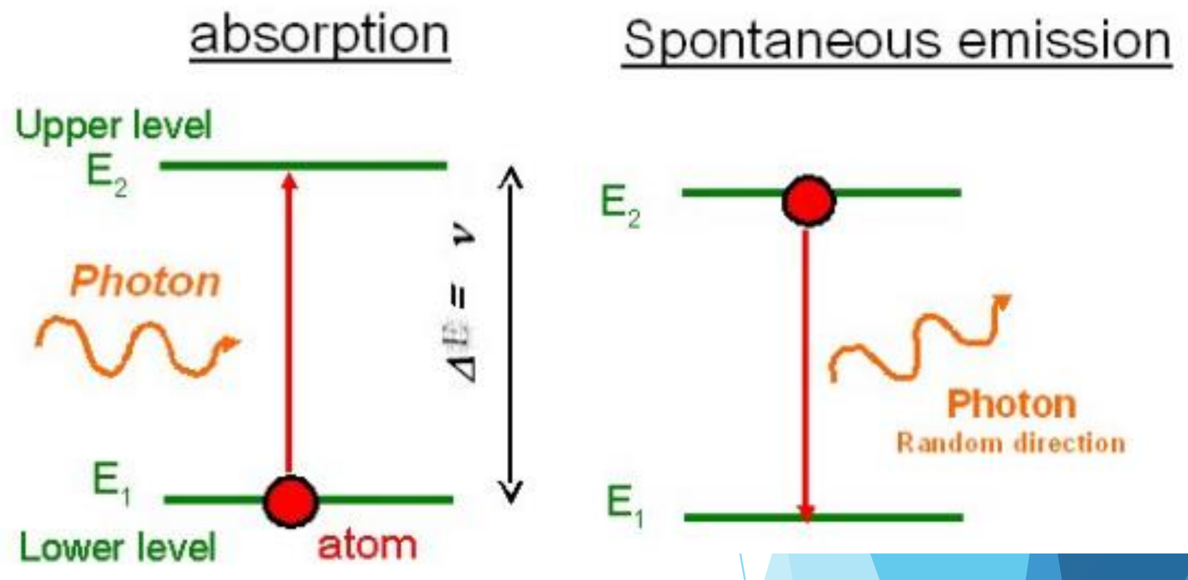
- **Light Amplification by Stimulated Emission of Radiation**
- Lasers are devices that produce intense beams of light which are monochromatic, coherent, and highly collimated.
- The wavelength (color) of laser light is extremely pure (monochromatic) when compared to other sources of light, and all of the photons (energy) that make up the laser beam have a fixed phase relationship (coherence) with respect to one another. Light from a laser typically has very low divergence.
- It can travel over great distances or can be focused to a very small spot with a brightness which exceeds that of the sun.



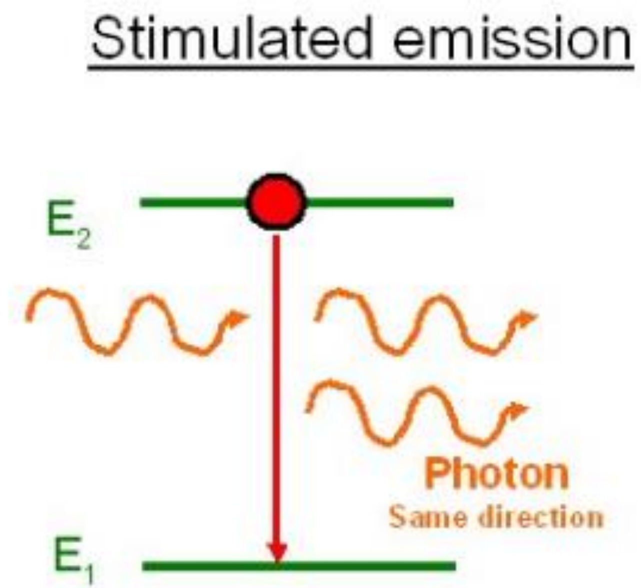


Basic mechanisms: emission, absorption and pumping

- The three different mechanisms are shown below (Figure):
- 1. Absorption: An atom in a lower level absorbs a photon of frequency hv and moves to an upper level.
- 2. **Spontaneous emission**: An atom in an upper level can decay spontaneously to the lower level and emit a photon of frequency hv if the transition between E2 and E1 is radiative. This photon has a random direction and phase.
- 3. **Stimulated emission:** An incident photon causes an upper level atom to decay, emitting a "stimulated" photon whose properties are identical to those of the incident photon. The term "stimulated" underlines the fact that this kind of radiation only occurs if an incident photon is present. The amplification arises due to the similarities between the incident and emitted photons



$$h\nu = E_2 - E_1$$



Differences between Stimulated and spontaneous emission of radiation

S. No.	Stimulated Emission	Spontaneous emission
1.	An atom in the excited state is induced to return to the ground state , thereby resulting in two photons of same frequency and energy is called Stimulated emission	The atom in the excited state returns to the ground state thereby emitting a photon, without any external inducement is called Spontaneous emission.
2	The emitted photons move in the same direction and is highly directional	The emitted photons move in all directions and are random
3	The radiation is highly intense, monochromatic and coherent	The radiation is less intense and is incoherent
4	The photons are in phase, there is a constant phase difference	The photons are not in phase (i.e.) there is no phase relationship between them.
5	The rate of transition is given by $R_{12}(Sp) = A_{21}\ N_2$	The rate of transition is given by $R_{12}(Sp) = A_{21}\ N_2$

Population inversion and pumping

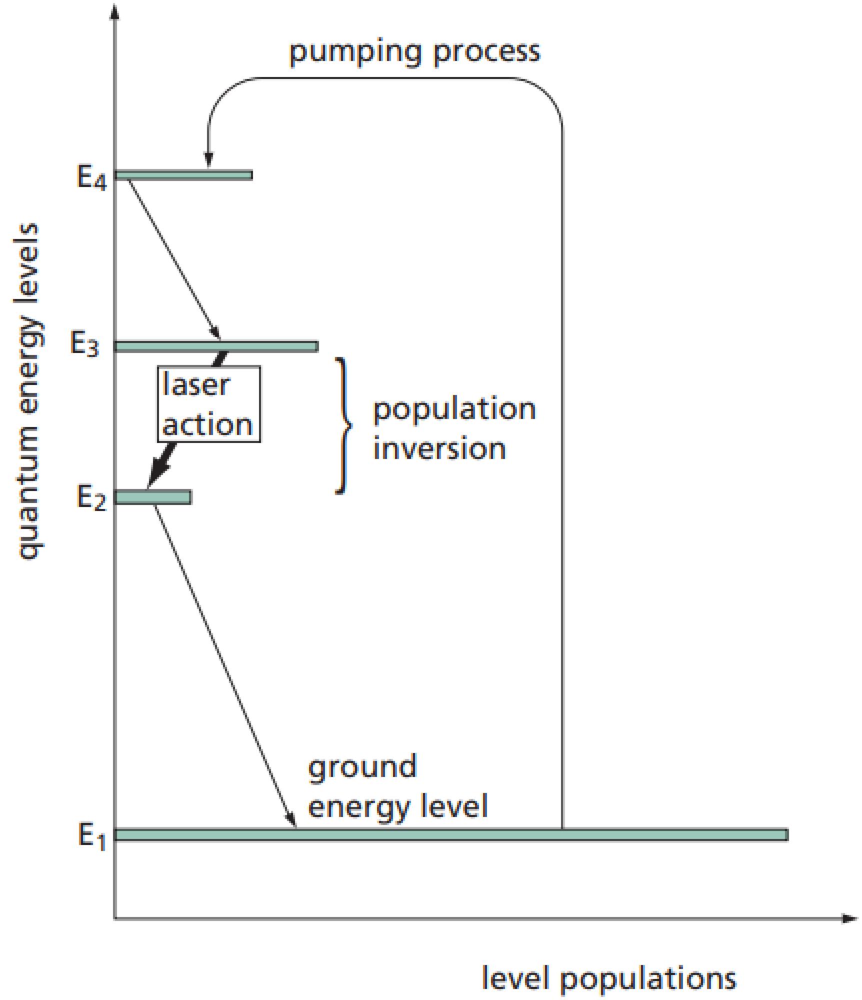
- If there are more atoms in the upper level (N2) than in the lower level (N1), the system is not at equilibrium. In fact, at thermodynamic equilibrium, the distribution of the atoms between the levels is given by Boltzmann's Law:

$$N_2 = N_1 x \exp -((E_2 - E_1)/kT)$$

- In this case, N2 is always less than N1. A situation not at equilibrium must be created by adding energy via a process known as “pumping” in order to raise enough atoms to the upper level.
- This is known as population inversion and is given by ∇=N2−N1 . Light is amplified when the population inversion is positive. Pumping may be electrical, optical or chemical.

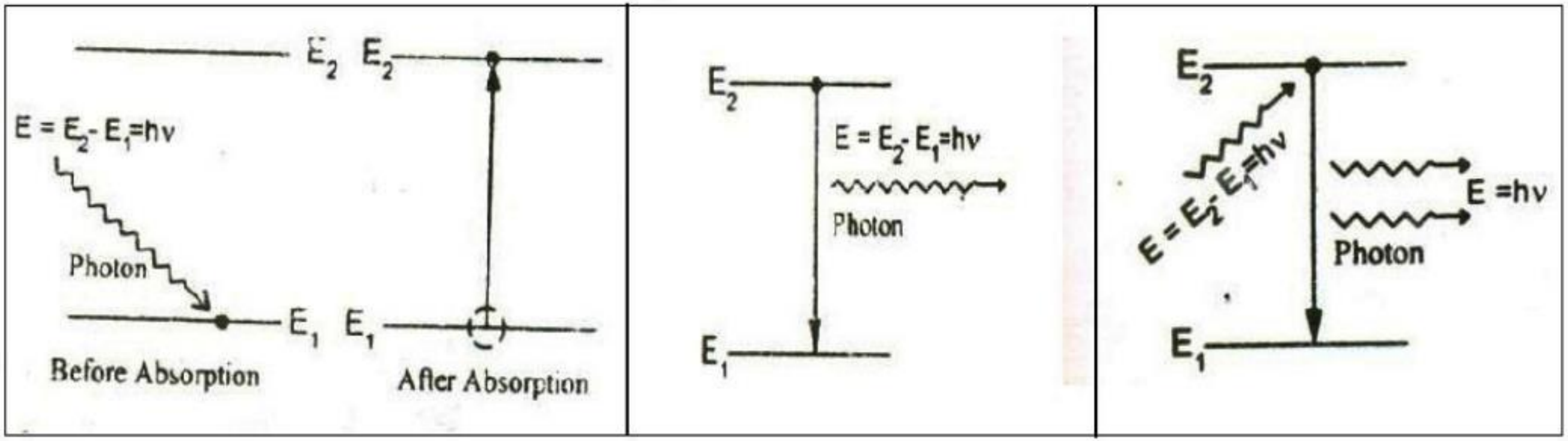
META STABLE STATES

- An atom can be excited to a higher level by supplying energy to it. Normally, excited atoms have short life times and release their energy in a matter of nano seconds (10^{-9}) through spontaneous emission.
- It means atoms do not stay long to be stimulated. As a result, they undergo spontaneous emission and rapidly return to the ground level; thereby population inversion could not be established. In order to do so, the excited atoms are required to 'wait' at the upper energy level till a large number of atoms accumulate at that level.
- It is necessary that excited state have a longer lifetime.
- A Meta stable state is such a state. Metastable can be readily obtained in a crystal system containing impurity atoms.
- These levels lie in the forbidden gap of the host crystal. There could be no population inversion and hence no laser action, if metastable states don't exist



EINSTEIN'S "A & B" COEFFICIENTS - DERIVATION

- We know that, when light is absorbed by the atoms or molecules, then it goes from the lower energy level (E1) to the higher energy level (E2) and during the transition from higher energy level (E2) to lower energy level (E1) the light is emitted from the atoms or molecules. Fig., process involved in Laser



Absorption

- An atom in the lower energy level or ground state energy level E1 absorbs the incident photon radiation of energy $h\gamma$ and goes to the higher energy level or excited level E2 as shown in figure. This process is called absorption.
- If there are many numbers of atoms in the ground state then each atom will absorb the energy from the incident photon and goes to the excited state

$$R_{12} \propto \rho_v N_1 \qquad ---\rightarrow (1)$$

$$R_{12} = B_{12}\rho_v N_1 \qquad ---\rightarrow (2)$$

Where ρ_v = Energy density of incident radiation, N_1 = no. of atoms in the ground state and B_{12}- is a constant which gives the probability of absorption transition per unit time.

Normally, the atoms in the excited state will not stay there for a long period of time, rather it comes to ground state by emitting a photon of energy . Such an emission takes place by one of the following two methods.

Spontaneous emission

- The atom in the excited state returns to the ground state by emitting a photon of energy E = (E2 – E1) = spontaneously without any external triggering as shown in the figure. This process is known as spontaneous emission. Such an emission is random and is independent of incident radiation. If N1 and N2 are the numbers of atoms in the ground state (E1) and excited state (E2) respectively, then The rate of spontaneous emission is

$$R_{21}(Sp) \propto N_2 \qquad \dashrightarrow (3)$$

$$R_{21}(Sp) = A_{21}\, N_2 \quad \dashrightarrow (4)$$

- Where A21- is a constant which gives the probability of spontaneous emission transitions per unit time.

Stimulated Emission

- The atom in the excited state can also return to the ground state by external triggering or inducement of photon thereby emitting a photon of energy equal to the energy of the incident photon, known as stimulated emission. Thus results in two photons of same energy, phase difference and of same directionality as shown. Therefore, the rate of stimulated emission is given by

$$R_{21}(St) \propto \rho_\nu N_2 \qquad --\rightarrow (5)$$

$$R_{21}(St) = B_{21}\rho_\nu N_2 \qquad --\rightarrow (6)$$

- Where B21- is a constant which gives the probability of stimulated emission transitions per unit time.

Einstein's theory

- Einstein's theory of absorption and emission of light by an atom is based on Planck's theory of radiation. Also under thermal equilibrium, the population of energy levels obeys the Maxwell Boltzmann distribution law
- Under thermal equilibrium

$$\textit{The rate of Absorption} = \textit{The rate of Emission}$$

$$B_{12}\rho_v N_1 = A_{21} N_2 + B_{21}\rho_v N_2$$

$$B_{12}\rho_v N_1 - B_{21}\rho_v N_2 = A_{21} N_2 \text{ (or) } \rho_v(B_{12}N_1 - B_{21}N_2) = A_{21} N_2$$

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

$$\rho_v = \frac{A_{21}}{\left(B_{12}\frac{N_1}{N_2} - B_{21}\right)} \quad --\rightarrow (7)$$

Cont.

- We know from the Boltzmann distribution law

$$N_1 = N_0 e^{-E_1/K_B T}$$

$$N_2 = N_0 e^{-E_2/K_B T}$$

- Where KB is the Boltzmann Constant, T is the absolute temperature and N0 is the number of atoms at absolute zero. At equilibrium, we can write the ratio of population levels as follows

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

$$\frac{N_1}{N_2} = e^{\frac{hv}{K_B T}} \quad \dashrightarrow (8)$$

- Substituting equation (8) in equation (9)

$$\rho_v = \frac{A_{21}}{\left(B_{12}\left(e^{\frac{hv}{K_B T}}\right) - B_{21}\right)}$$

$$\rho_v = \frac{A_{21}}{B_{21}} \frac{1}{\left(\frac{B_{12}}{B_{21}}\left(e^{\frac{hv}{K_B T}}\right) - 1\right)} \quad --\rightarrow (10)$$

This equation has a very good agreement with Planck's energy distribution radiation law.

$$\rho_v = \frac{8\pi h v^3}{C^3} \frac{1}{e^{\frac{hv}{K_B T}} - 1} \quad --\rightarrow (11)$$

Therefore comparing equations (6) and (7) , we can write

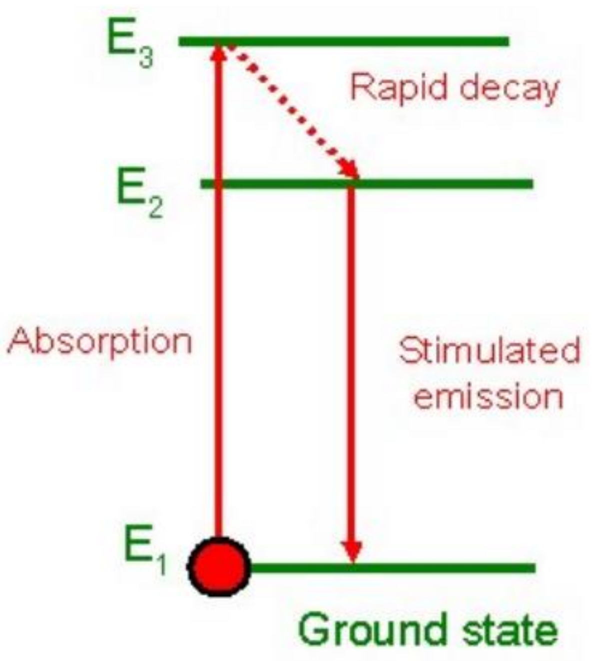
$$B_{12} = B_{21} = \mathrm{B} \quad \text{and} \quad \frac{A_{21}}{B_{21}} = \frac{8\pi h v^3}{C^3} \quad --\rightarrow (12)$$

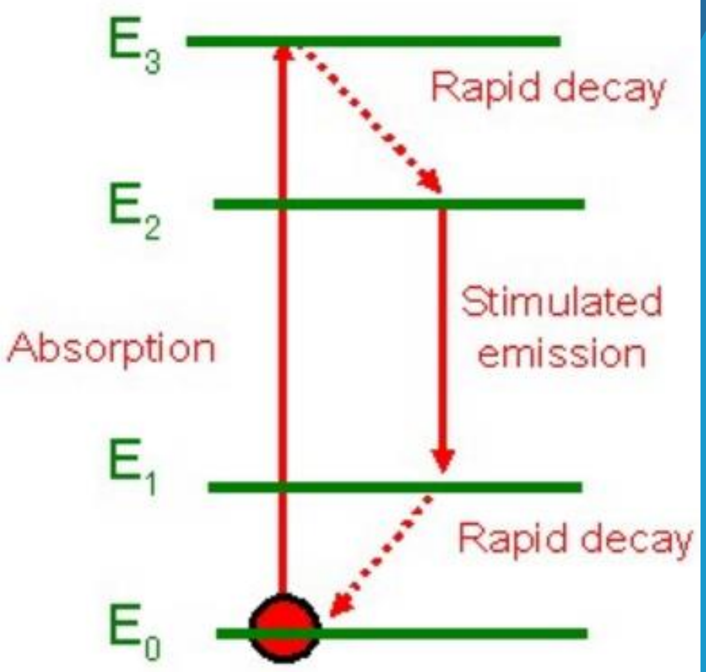
Taking $A_{21} = A$

The constants A and B are called as Einstein Coefficients, which accounts for spontaneous and stimulated emission probabilities.

3 level and 4 level laser

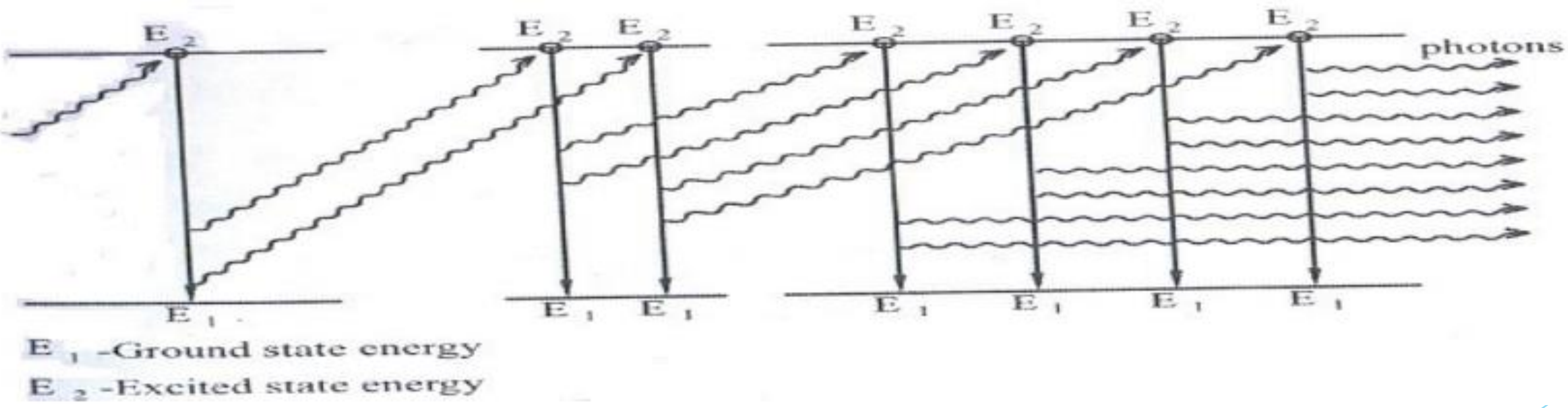
- In a three-level laser, the material is first excited to a short-lived high-energy state that spontaneously drops to a somewhat lower-energy state with an unusually long lifetime, called a metastable state.
- The metastable state is important because it traps and holds the excitation energy, building up a population inversion that can be further stimulated to emit radiation, dropping the species back to the ground state.
- the three-level laser works only if the ground state is depopulated.
- As atoms or molecules emit light, they accumulate in the ground state, where they can absorb the stimulated emission and shut down laser action, so most three-level lasers can only generate pulses.
- This difficulty is overcome in the four-level laser, where an extra transition state is located between metastable and ground states.
- This allows many four-level lasers to emit a steady beam for days on end.





Amplification in Laser process

- Let as consider many number atoms in the excited state. We know the photons emitted during stimulated emission have same frequency, energy and are in phase as the incident photon. Thus result in 2 photons of similar properties.



Due to stimulated emission the photons multiply in each step-giving rise to an intense beam of photons that are coherent and moving in the same direction. Hence the light is amplified by Stimulated Emission of the Radiation termed LASER

Schematic diagram of a basic laser

The three main components of a laser are:

Lasing medium

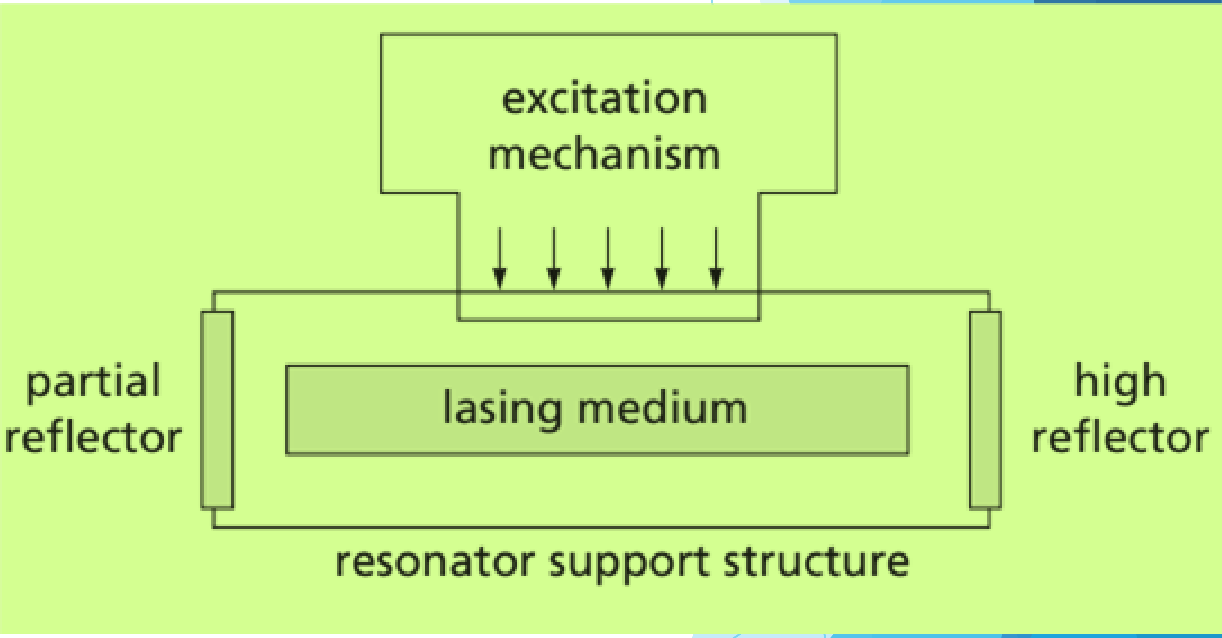
A material that amplifies light through stimulated emission. It can be a solid, liquid, or gas, and is made up of atoms, molecules, or ions. The type of lasing material determines the wavelength of light emitted.

Pump

An energy source that supplies the lasing medium with the energy it needs to amplify light. The pump can be an electric current or light of a different wavelength.

Optical resonator

A pair of mirrors that form a cavity around the lasing medium. Light bounces back and forth between the mirrors, passing through the lasing medium and being amplified each time. One of the mirrors, called the output coupler, is partially transparent, allowing some light to escape



PUMPING ACTION

- The process to achieve the population inversion in the medium is called Pumping action. It is essential requirement for producing a laser beam.
- Methods of pumping action The methods commonly used for pumping action are:
- 1. Optical pumping (Excitation by Photons)
- 2. Electrical discharge method (Excitation by electrons)
- 3. Direct conversion
- 4. In elastic atom – atom collision between atoms
- **1. Optical pumping**
- When the atoms are exposed to light radiations energy, atoms in the lower energy state absorb these radiations and they go to the excited state. This method is called Optical pumping. It is used in solid state lasers like ruby laser and Nd-YAG laser. In ruby laser, xenon flash lamp is used as pumping source.

Electrical discharge method (Excitation by electrons)

- In this method, the electrons are produced in **an electrical discharge tube**. These electrons are accelerated to high velocities by a strong electrical field. These accelerated electrons collide with the gas atoms.
- By the process, energy from the electrons is transferred to gas atoms. Some atoms gain energy and they go to the excited state.
- This results in population inversion. This method is called Electrical discharge method. It is represented by the equation

$$A + e^* = A^* + e$$

Where A – gas atom in the ground state A^* = same gas atom in the excited state

e^* = Electrons with higher Kinetic energy e – Same electron with lesser energy.

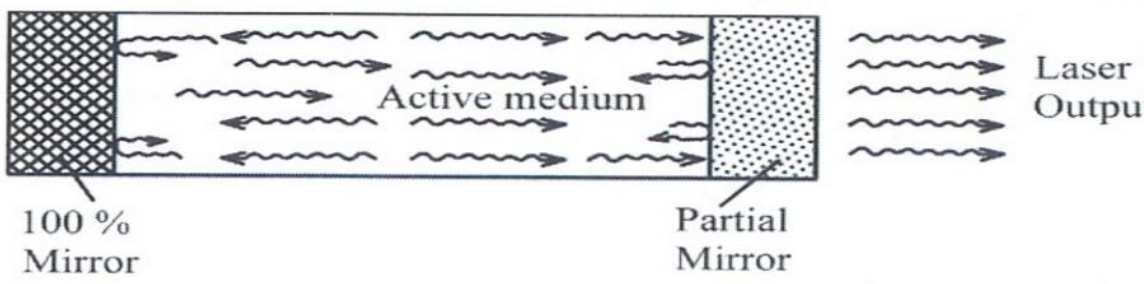
This method of pumping is used in gas lasers like argon and CO_2 Laser.

Direct Conversion

- In this method, due to electrical energy applied in direct band gap semiconductor like Ga As, recombination of electrons and holes takes place. During the recombination process, the electrical energy is directly is converted into light energy.
- **In elastic atom – atom collision**
- In this method, a combination of two gases (Say A and B are used). The excited states of A and B nearly coincides in energy. In the first step during the electrical discharge atoms of gas A are excited to their higher energy state A* (metastable state) due to collision with the electrons . $A + e^* = A^* + e$ Now A* atoms at higher energy state collide with b atoms in the lower state. Due to inelastic atom - atom collision B atoms gain energy and they are excited to a higher state B*. Hence, A atoms lose energy and return to lower state. $A^* + B = A + B^*$

OPTICAL RESONATOR

- An optical resonator consists of a pair of reflecting surfaces in which one is fully reflecting (R1) and the other is partially reflecting (R2). The active material is placed in between these two reflecting surfaces
- The photons generated due to transitions between the energy states of active material are bounced back and forth between two reflecting surfaces. This will induce more and more stimulated transition leading to laser action.
- A laser generally requires a laser resonator (or laser cavity), in which the laser radiation can circulate and pass a gain medium which compensates the optical power losses. Exceptions are a few cases (e.g. some free electron lasers) where a medium with very high gain is used, so that amplified spontaneous emission extracts significant power in a single pass through the gain medium.
- A laser resonator typically contains multiple laser mirrors, one of them being an output coupler, a laser gain medium, and possibly additional optical elements e.g. for wavelength tuning, Q switching or mode locking. It can be a linear resonator, having two end mirrors, or a ring resonator.



The role of the optical cavity

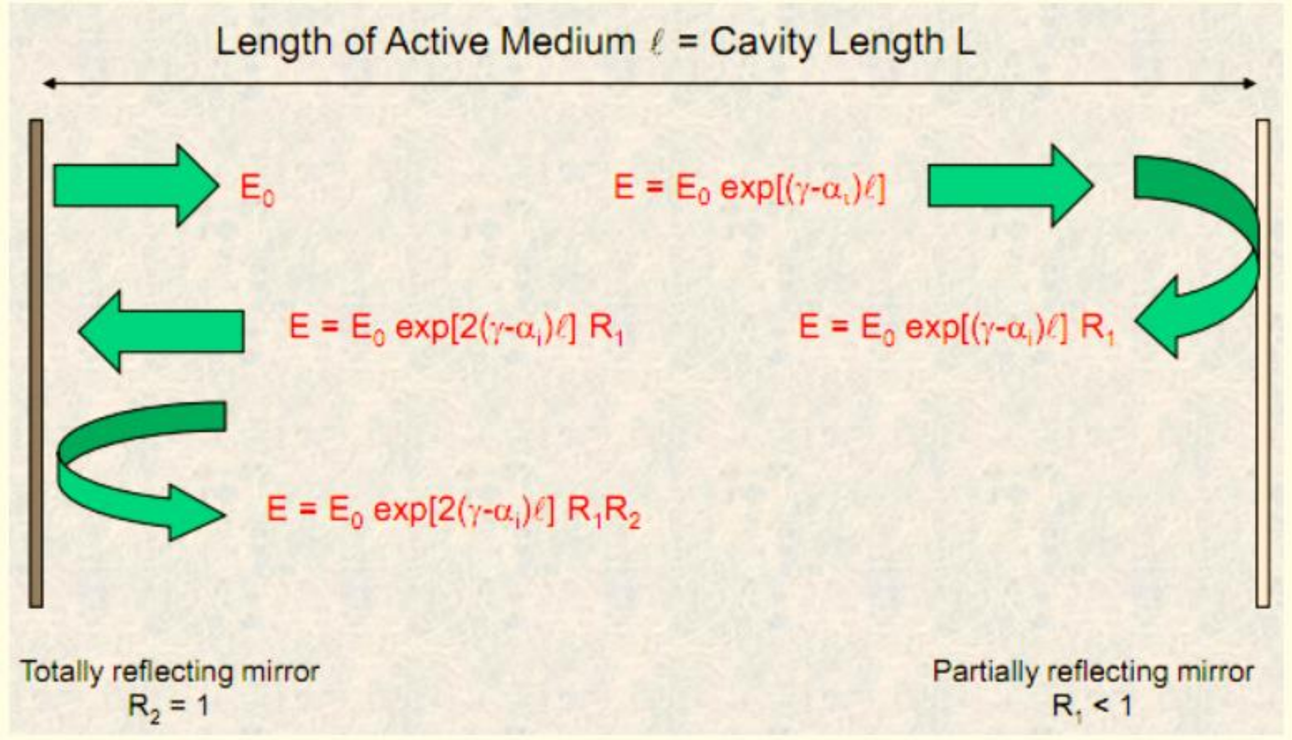
- The previous section showed how to favour population inversion by choosing the right spectroscopic system and energy levels.
- However, population inversion is not enough to generate a laser effect. As stated previously, stimulated and spontaneous emissions are competing with each other.
- Thus, before becoming an amplifying medium, a laser medium pumped by an external energy source is first a “lamp” (spontaneous emission).
- It is the optical cavity that creates the conditions necessary for stimulated emission to become predominant over spontaneous emission.
- The cavity or resonator is composed of several mirrors that bounce the beam back and forth through the amplifying medium.
- There are two different types : linear cavities (light is reflected back and forth) and ring cavities (light circulates round and round).
- The first type will be studied here.

Cont.

- When the laser starts up, the “lamp-amplifying medium” emits spontaneously in all directions. However, a small part of the emission occurs along the axis of the laser cavity.
- These spontaneous photons can travel backwards and forwards. Thus, over time, thanks to the amplifying medium, the amount of light in the cavity increases considerably.
- The confinement of the light increases the probability of stimulated emission rather than spontaneous emission occurring.
- At the same time, the cavity acts as a filter due to the numerous round trips: only the wave perfectly perpendicular to the axis of the cavity will be propagated and certain frequencies will be favoured (the resonance frequencies of the cavity).
- In this way, the cavity produces a specific radiation.

THRESHOLD CONDITION

- Light bouncing back and forth in the optical resonator
- Undergoes amplification as well as suffers various losses
- Losses occur mainly due to
- (i) Transmission at the output mirror
- (ii) Scattering & Diffraction of light within the active medium.
- For the proper build up of oscillations Essential is that the amplification between two consecutive reflections of light from reflecting end mirror can balance losses.
- Determination of threshold gain by considering the change in intensity of a beam of light undergoing a round trip within the resonator



After a complete round trip (Reflection from M1), the final Intensity will be

$$I(2L) = R_1 R_2 I_0 e^{(\gamma-\alpha_s)2L}$$

The condition is used to determine the threshold value of pumping energy necessary for lasing action.

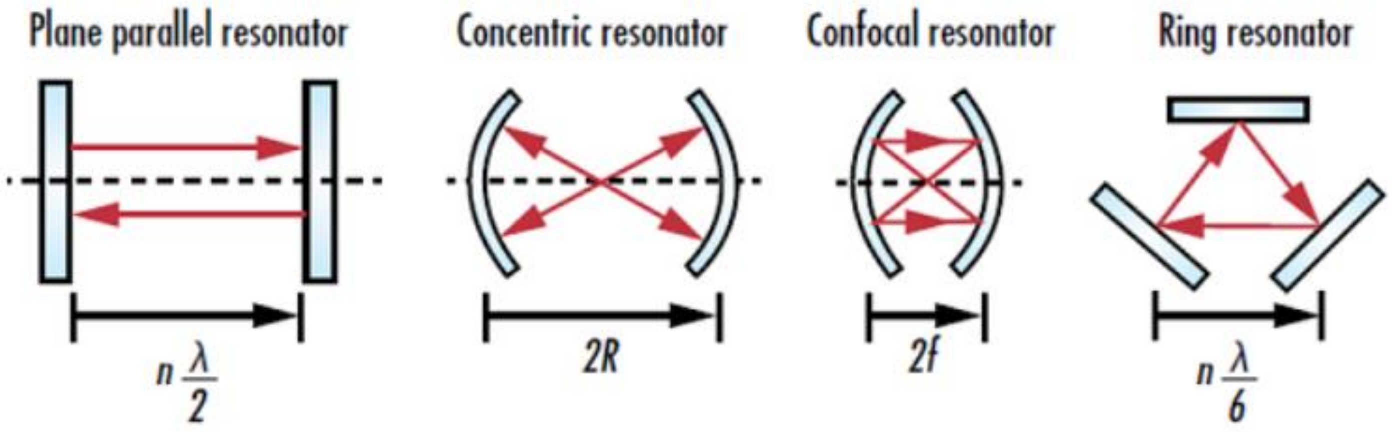
$$\gamma_{th} = \alpha_s + \frac{1}{2L}\ln\left(\frac{1}{R_1 R_2}\right)$$

α_s includes all the distributed losses such as scattering, diffraction and absorption occurring in the medium

Types of resonators

- The shape of a laser beam is determined by the resonator cavity, a laser optical mirror, in which the laser light is amplified in a gain medium. Laser resonators are typically formed by using highly reflective dielectric mirrors or a monolithic crystal that utilizes total internal reflection to keep light from escaping (Figure 1). Below is a list of common laser resonator geometries1:

- Plane parallel resonator: two flat mirrors separated by a distance equal to an integral multiple of one half of the lasing wavelength
- Concentric resonator: two spherical mirrors with the same radius of curvature and coincident centers of curvature
- Confocal resonator: two spherical mirrors with the same radius of curvature and coincident focal points
- Ring resonator: ring of more than two reflectors where the total closed loop path of the reflected light is equal to an integral multiple of one half of the lasing wavelength



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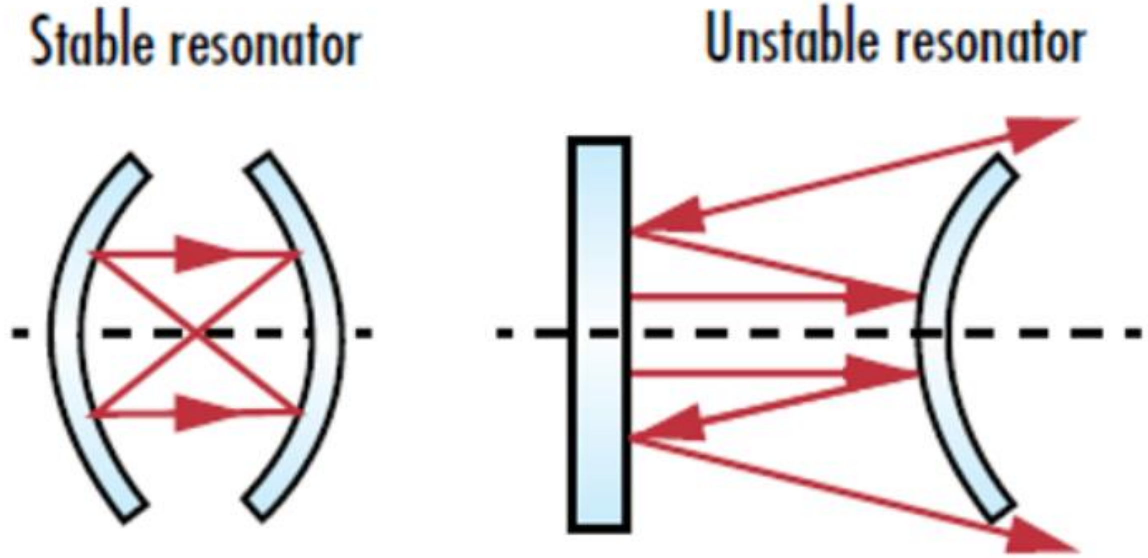
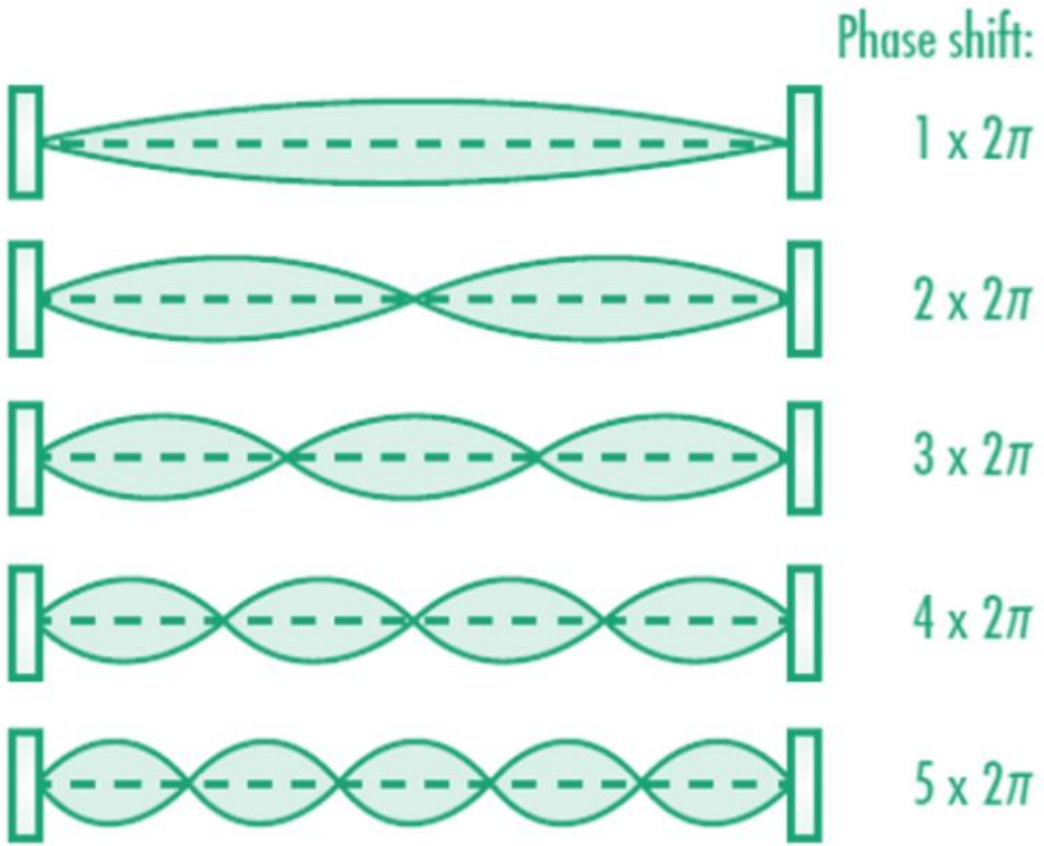
- Resonator cavities are “stable” if the reflected light stays inside the cavity, even as the number of reflections approaches infinity.
- In this instance, the only way for light to leave the cavity is through a partially reflective mirror.
- On the other hand, resonator cavities are considered “unstable” if the reflected light continuously diverges as the number of reflections approaches infinity.
- When this occurs, the beam size will grow until it is larger than the reflectors and then escape the system.
- Stable resonators are often used with lasers that have powers up to 2kW to achieve high gain and improve directionality.
- Unstable resonators are typically used with higher power lasers to reduce the chance of damaging the reflectors



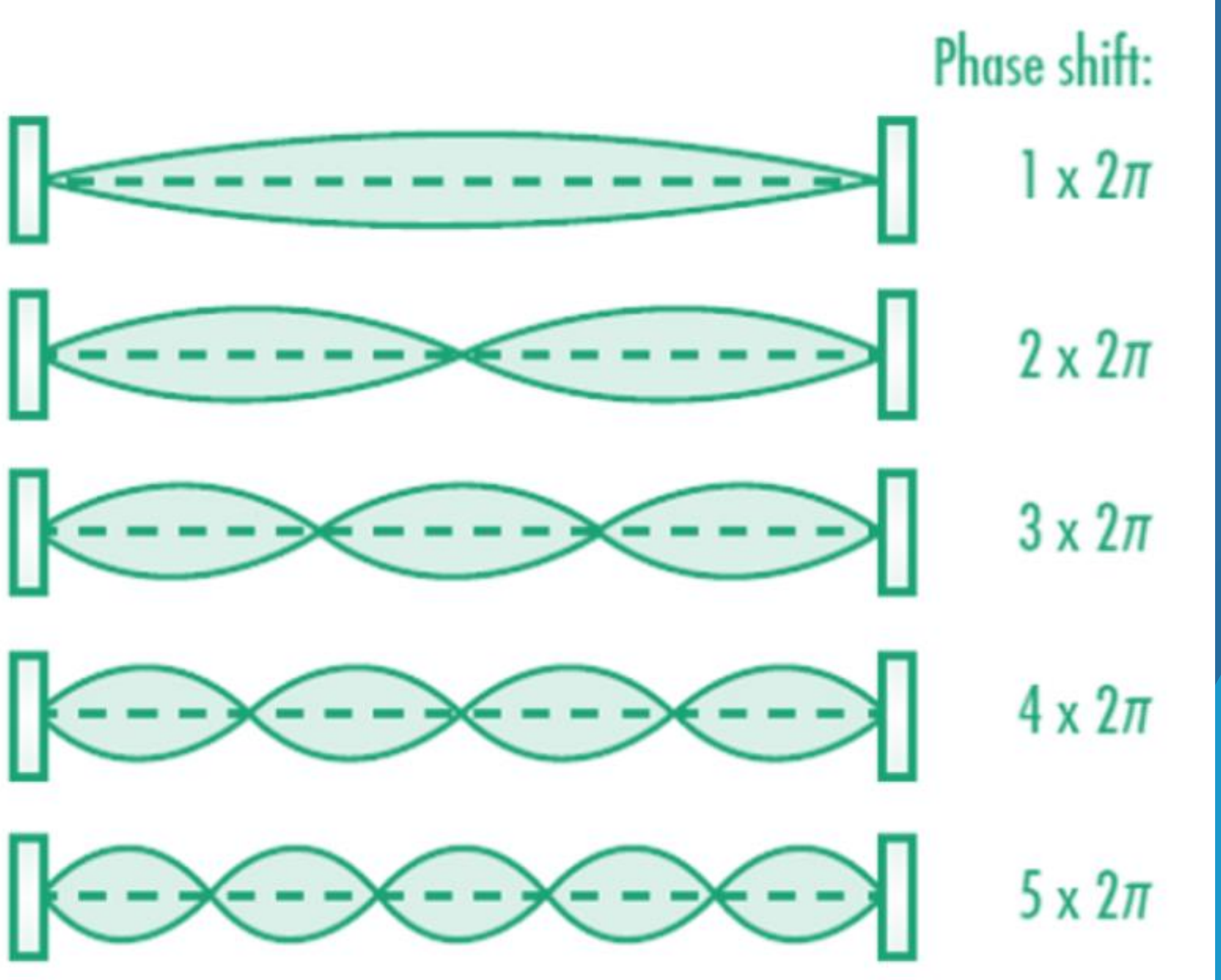
Laser modes

- Resonator modes are the modes of an optical resonator (cavity), i.e. electromagnetic field distributions which reproduce themselves after a full resonator round trip.
- More precisely, that means that the full amplitude profile (including the optical phase) must be unchanged after one round trip, apart from a possible loss of optical power.
- Such modes exist whether or not the resonator is geometrically stable, but the mode properties of unstable resonators are fairly complicated. In the following, only modes of stable resonators are considered.
- The integers n and m define the beam shape in the x and y directions, respectively. An ideal Gaussian beam is defined by the mode TEM00, which occurs when n and m are both equal to 0



Cont.

- **The resonator cavity's path length determines the longitudinal resonator modes**, or electric field distributions which cause a standing wave in the cavity. The modes of a beam give it its shape.
- In order for a resonant mode to occur, it must also experience a phase shift equal to an integer multiple of 2π over one closed loop path



The phase shift of a complete loop in an optical resonator must be an integer multiple of 2π in order for a resonant mode to occur

Types of laser modes

- **Transverse mode**
- Determines the distribution of intensity in the beam's cross-section. The Gaussian mode is a simple transverse mode that's often the preferred output for lasers. Gaussian beams are circularly symmetric, stable, and have a high intensity.
- **Longitudinal mode**
- Describes the laser's frequency and is related to the length of the laser cavity. The only wavelengths at which a laser can emit and amplify light are the longitudinal modes.
- **Axial modes**
- Represent the resonant frequencies at which there are half-wavelengths along the resonator axis.
- **Single-mode**
- A laser that sustains only one specific optical mode, resulting in a focused and coherent output beam.
- **Multimode**
- A laser that supports multiple optical modes, resulting in a broader and less coherent output beam

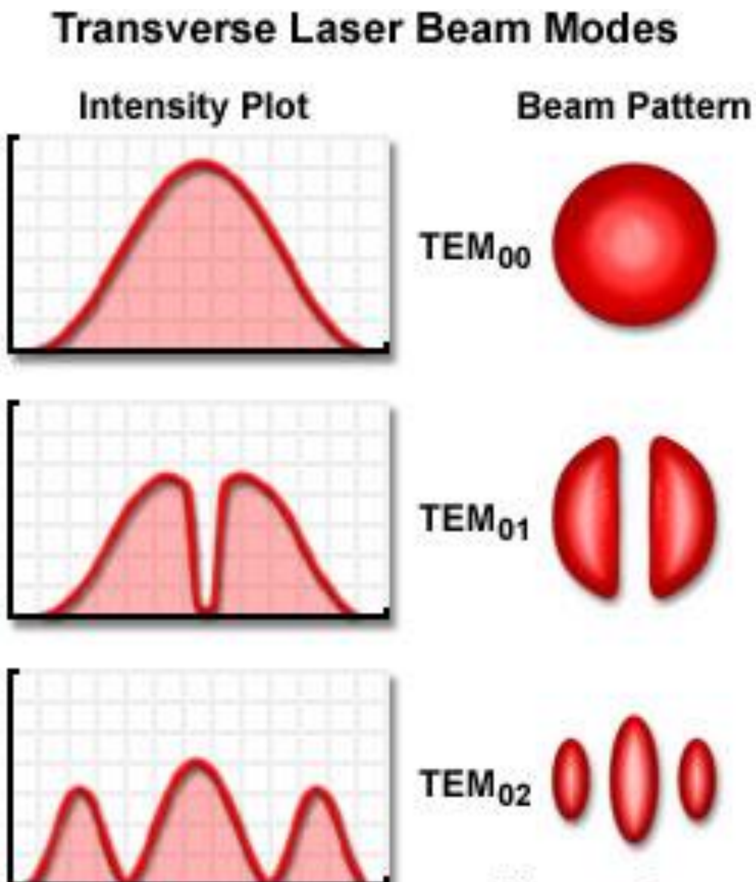
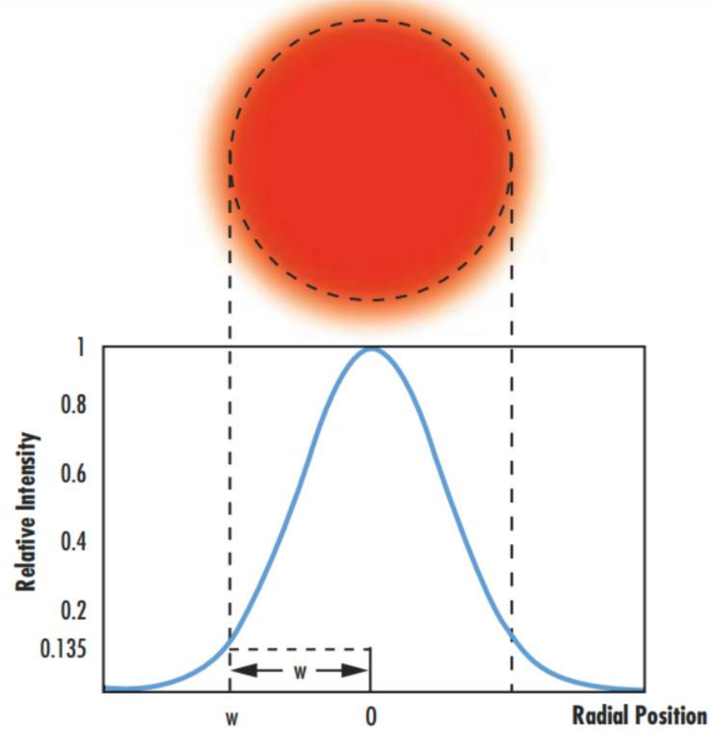
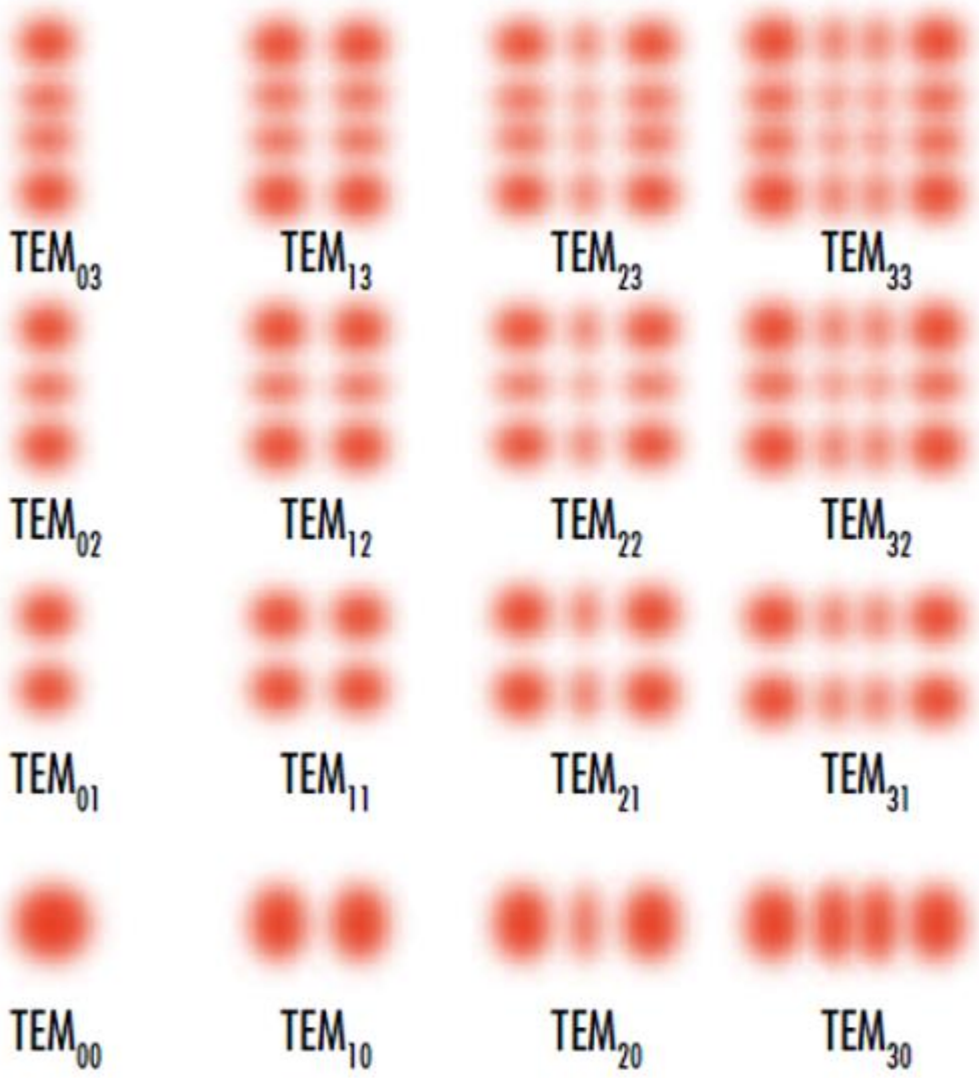

Transverse Laser Beam Modes
Intensity Plot
Beam Pattern
TEM_{00}
TEM_{01}
TEM_{02}

Figure 8


1
0.8
0.6
0.4
0.2
0.135
Relative Intensity
w
w
0
Radial Position

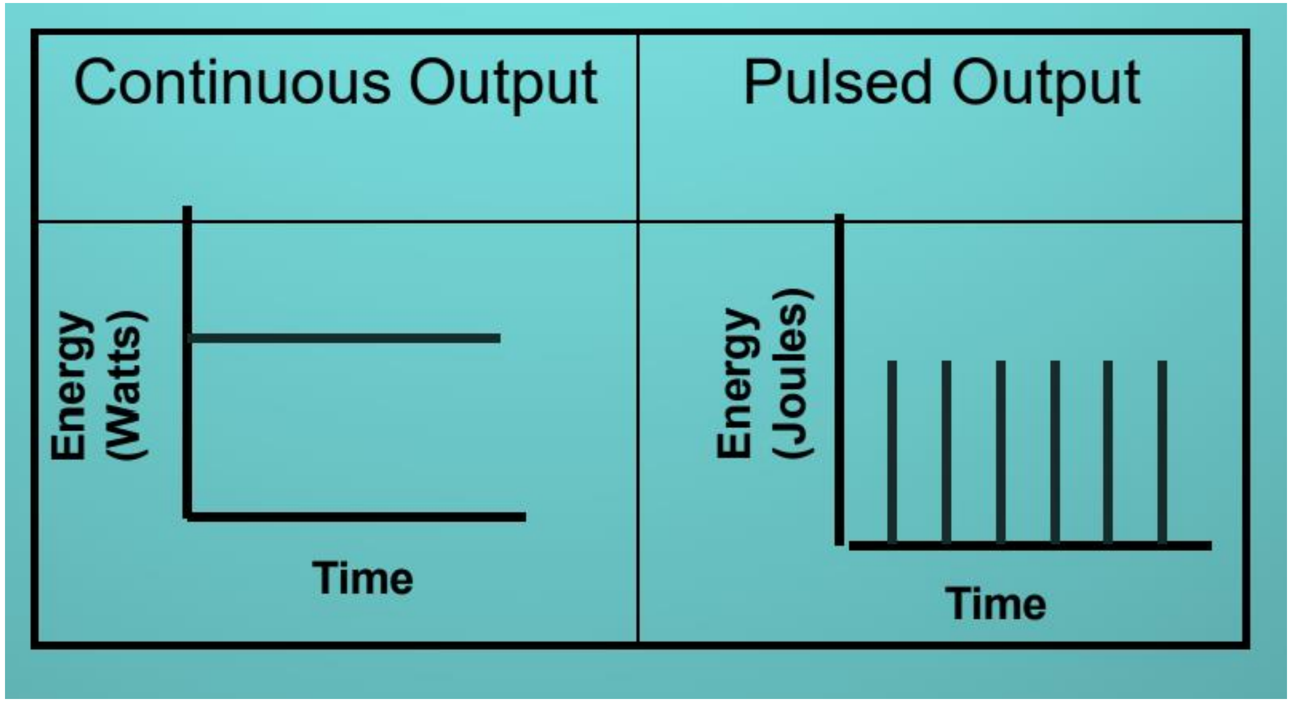

TEM_{03}
TEM_{13}
TEM_{23}
TEM_{33}
TEM_{02}
TEM_{12}
TEM_{22}
TEM_{32}
TEM_{01}
TEM_{11}
TEM_{21}
TEM_{31}
TEM_{00}
TEM_{10}
TEM_{20}
TEM_{30}

Laser Beam Output

- Characteristics that affect laser performance are the power output and mode of emission - continuous wave, pulsed, Q-switched or Mode –locked lasers.
- • CW laser- emits a continuous beam of light as long as medium is excited.
- • Pulsed laser- emit light only in pulses- from femtoseconds to second
- • Q-switched laser-pulses from micro to nanosecond are produced
- • Mode-Locked laser –pulses from pico (10-12s) – to femtoseconds (10-15s) are produced

Laser Beam Output

- Lasers operated in Continuous Wave (CW) or Pulsed modes.
- CW lasers-energy is continuously pumped - producing a continuous laser output.
- Pulsed lasers - the pump energy is applied in pulses usually with a flash lamp

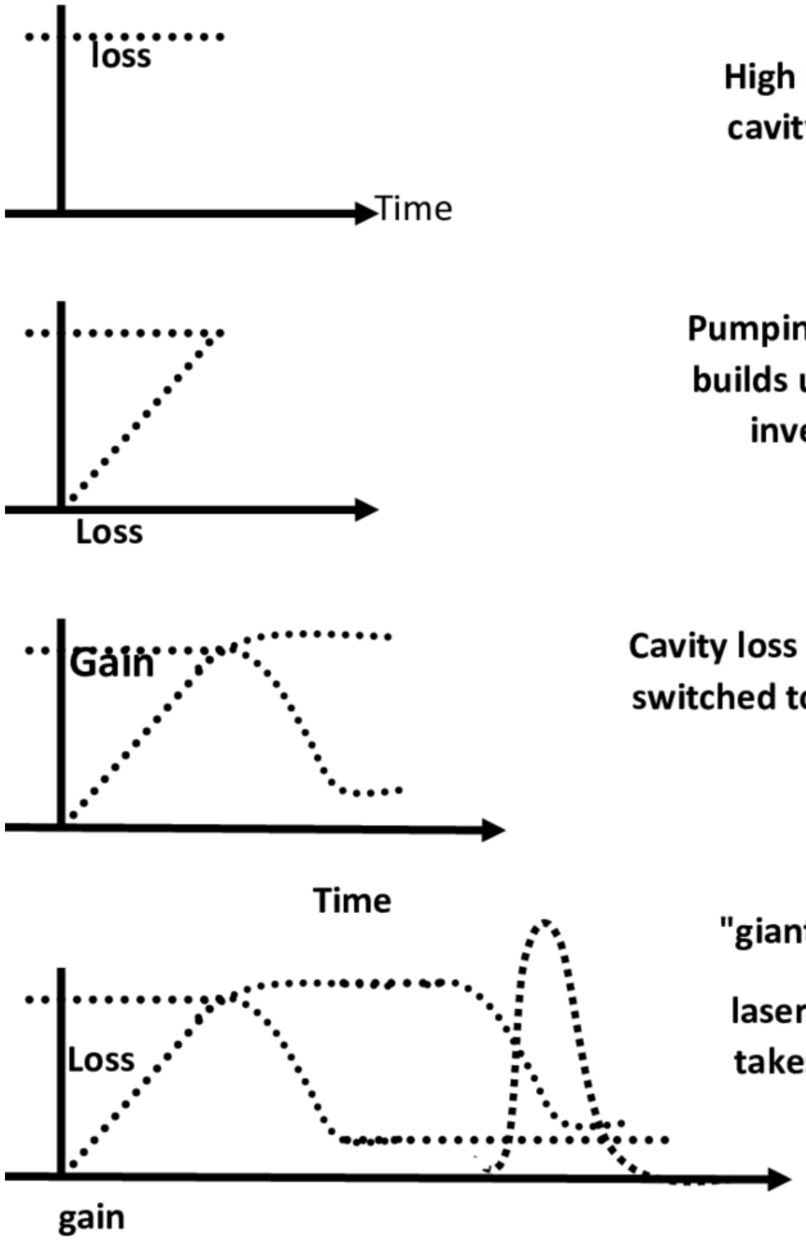


Laser: Q-switching

- Methods of Q-switching: There are many ways to Q-switch a laser
- • **Active Q-switching**
- 1. Mechanical devices- shutters, chopper wheel or
- spinning mirror.
- 2. Electro-optic device: Pockel cells and kerr cells.
- 3. Acousto-optic device
- • **Passive Q-switching**
- 1. Q-switch is a saturable absorber.

Cont.

- The active medium is excited without feedback -by blocking the reflection from one of the end mirrors of the cavity
- The end mirror is then suddenly allowed to reflect
- Suddenly applied feedback causes a rapid population inversion of the lasing levels
- Results in a very high peak power output pulse of short duration



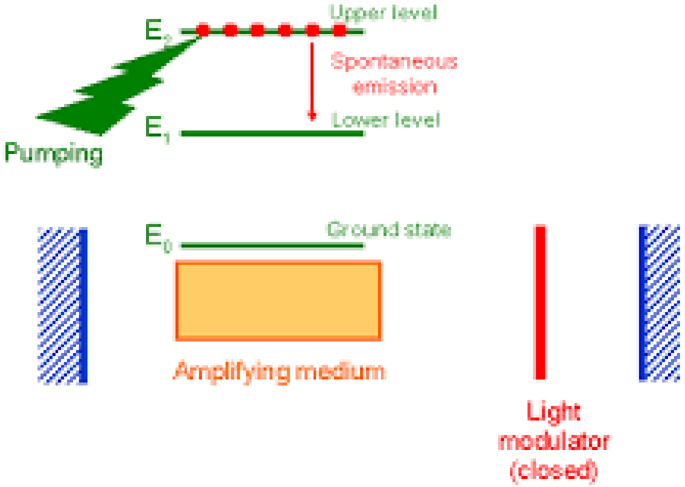
High initial cavity loss

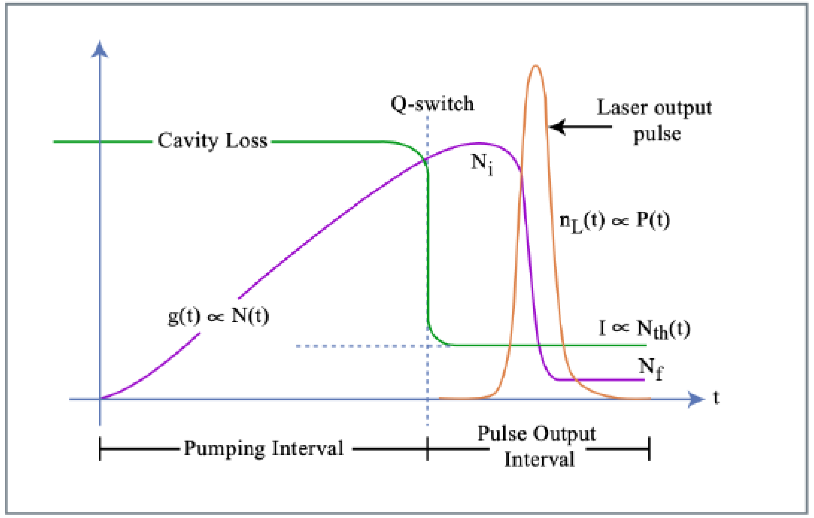
Pumping process builds up a large inversion

Cavity loss is suddenly switched to low value

"giant pulse"

laser action takes plase



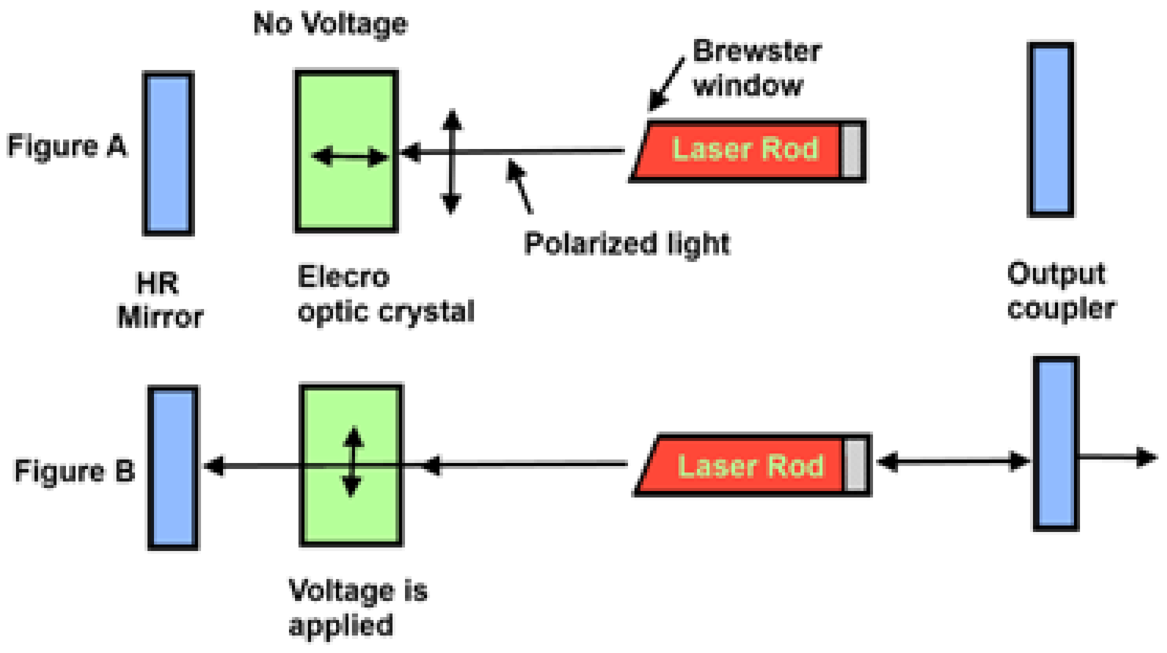


Techniques for Q switching

- Using a **mechanically driven device**
- • A rotating prism or mirror
- • Rotate one of the mirrors about an axis perpendicular to the laser
- • Rotating speed cannot be made very large
- • Q switching does not take place instantaneously

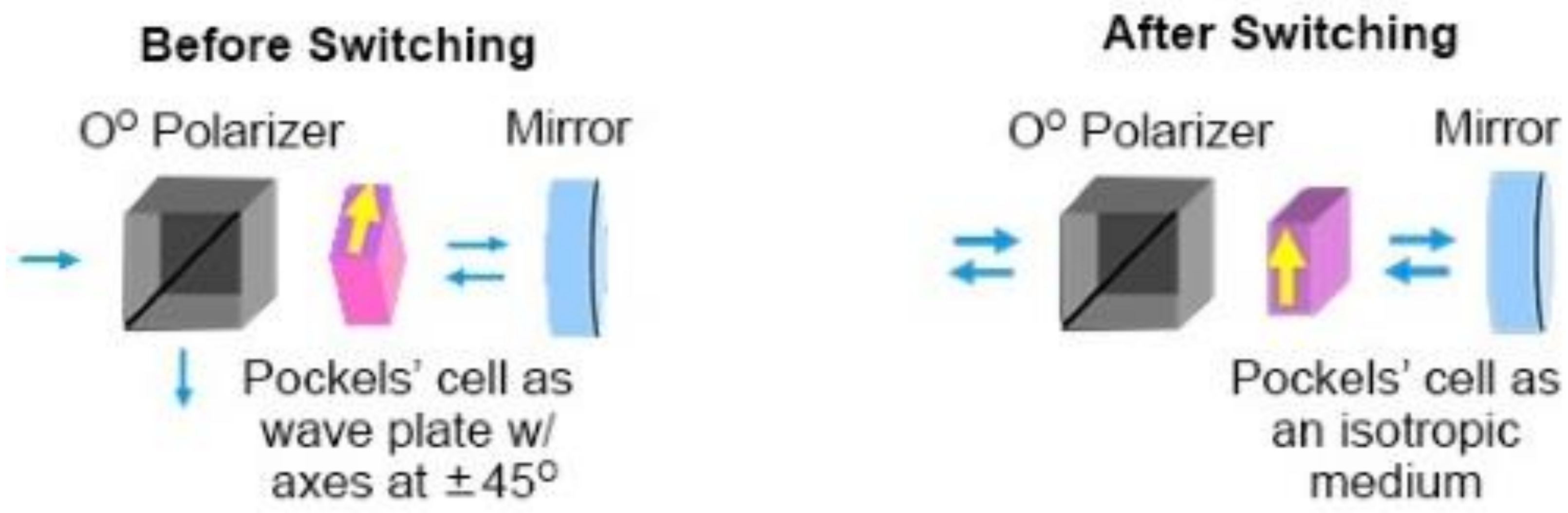
Electro-optical Switches

- Light passes through a polarizer and an Electro-optic cell (controlling the phase or polarization of the laser beam)
- When appropriate voltage is applied- the material inside the cell becomes birefringent
- By varying the voltage – cell blocks or transmits beam.
- Two kinds of electro-optics switches are used-namely Kerr and Pockels’ cell.



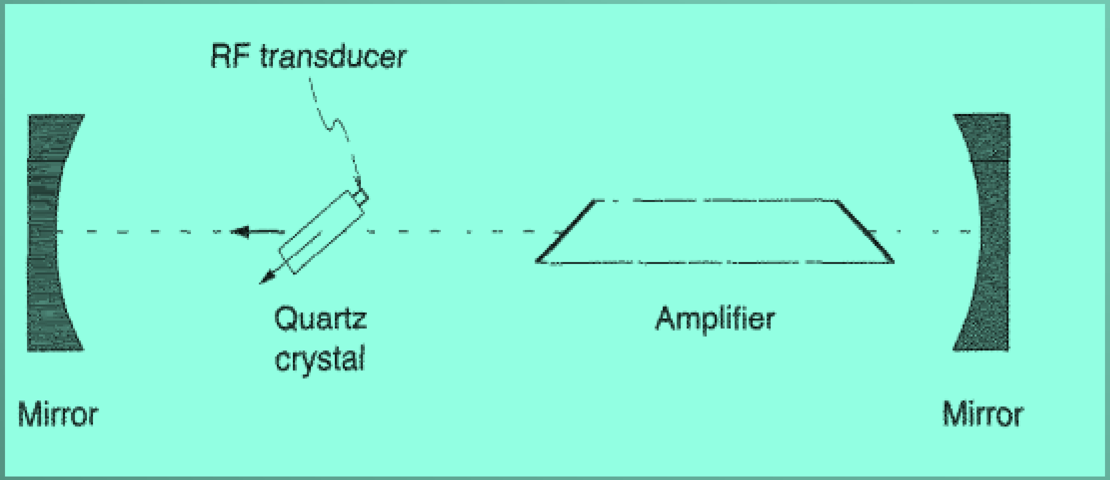
Pockels' Cell

- A Pockels' cell switches (in a few nanoseconds) from a quarter-wave plate to nothing.
- Light becomes circular on the first pass and then horizontal on the next and is then rejected by the polarizer.
- Light is unaffected by the Pockels' cell and hence is passed by the polarizer.



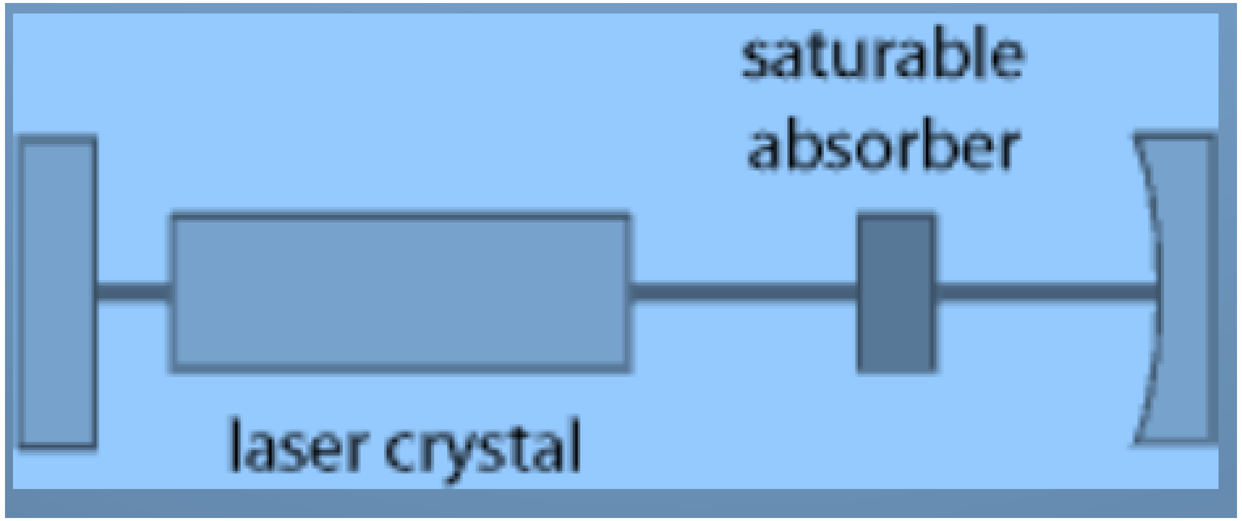
Acousto-optic Shutter

- •Uses a quartz crystal
- •RF on- beam deflect out of the cavity yielding high loss
- •RF off-beam transits the cavity with low loss



Passive Q- switching

- Initially light output absorbed by dye-preventing reflection
- • After a particular intensity is reached- dye is bleached(allows light)
- • Now reflection from mirror is possible
- • Results in rapid increase in cavity gain



Laser: Mode-Locking

- Mode Locking is a technique to generate ultra-short pulses in the order of picoseconds (10-12) or femtoseconds (10-15).
- Lasers that generate a train of periodic ultra-short pulses are called mode-locked lasers.
- Laser light does not have a single, unmixed frequency or wavelength. All lasers emit light over a natural frequency spectrum or bandwidth.
- In a laser cavity, when two light waves of the same frequency and amplitude move in the opposite direction create a standing wave.
- These standing waves form a discrete set of frequencies called longitudinal modes of the cavity.
- These multiple longitudinal modes of oscillation with frequencies are separated by intermodal spacing

$$\nu_F = \frac{c}{2L}$$

Cont.

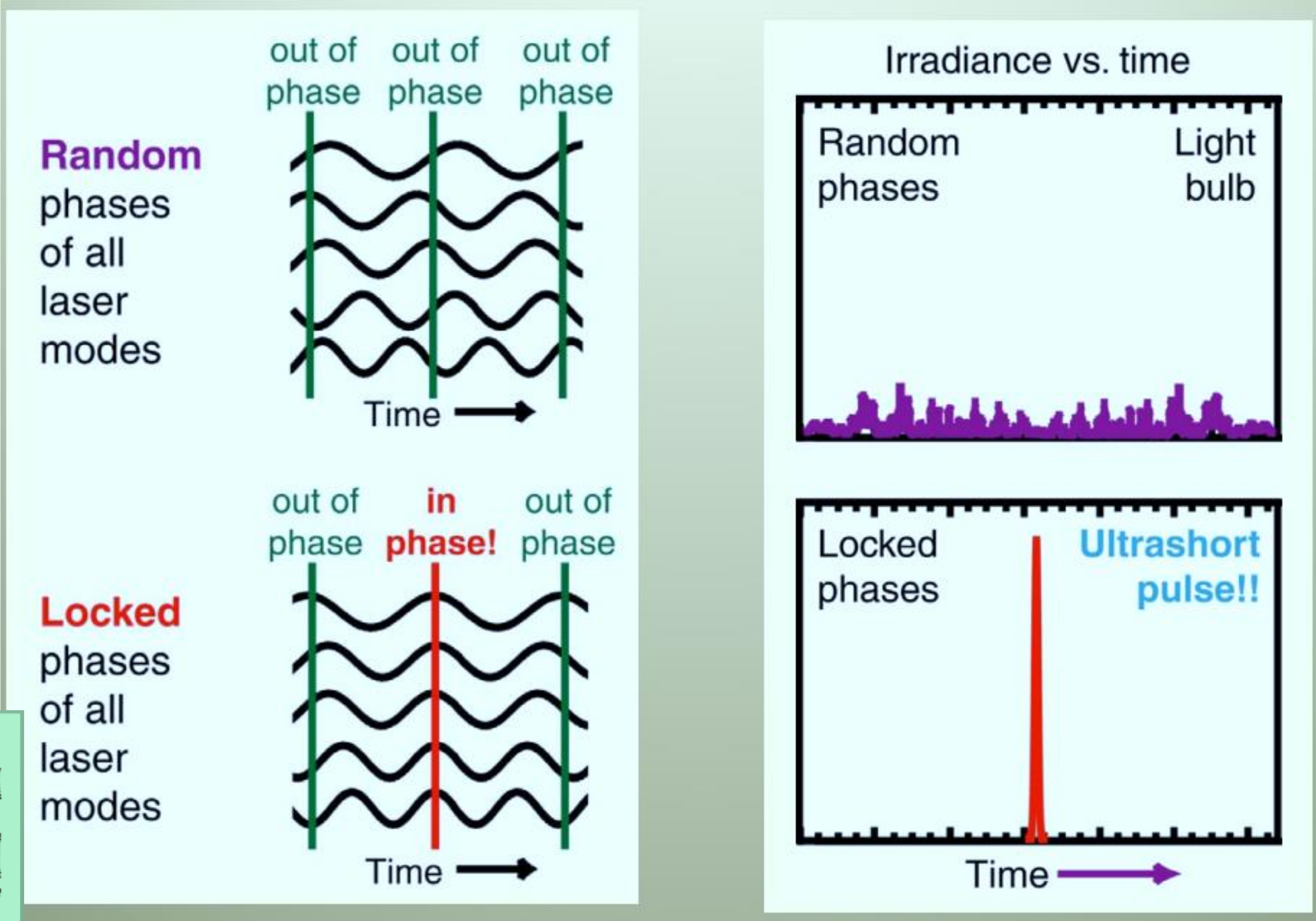
- These longitudinal modes will interfere with each other. If their phases are not having a definite relationship, they will interfere destructively causing a fluctuation in the laser intensity irregularly with time. But if there is a fixed phase (in-phase) relationship, they interfere constructively which causes the generation of a series of ultrashort pulses as the laser output and it is mode-locking. The mode-locked pulses are separated in time

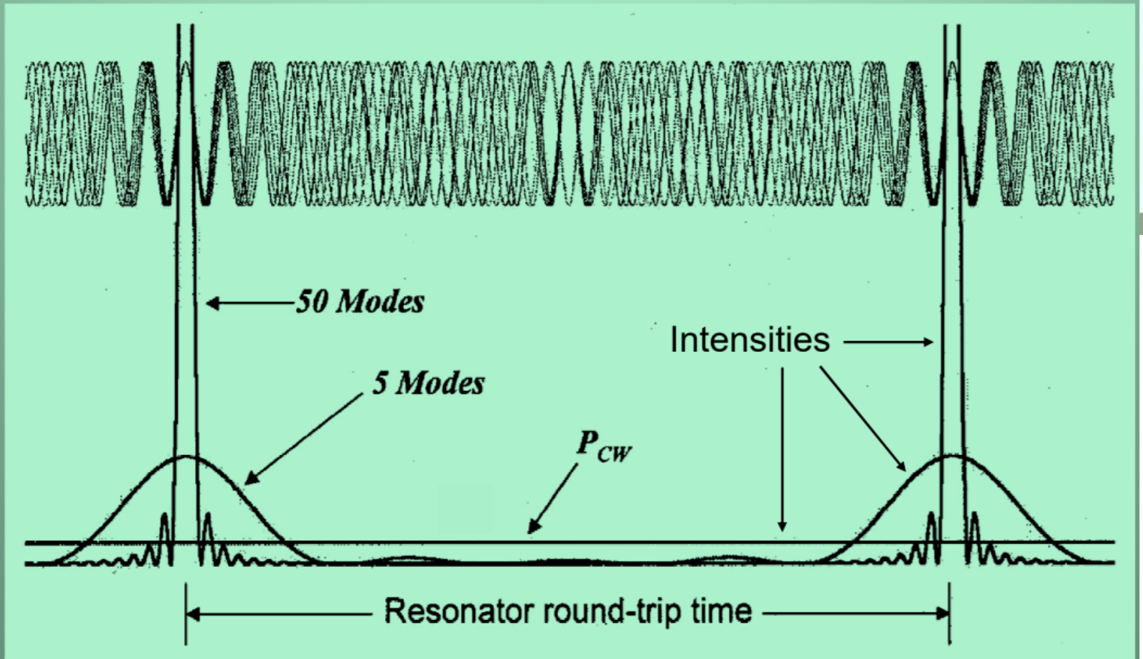
$$T = \frac{2L}{c}$$

- which is the round-trip time TR for a laser light beam. This time corresponds to a frequency equal to the laser's mode spacing given by

$$\Delta\nu = \frac{1}{T}$$

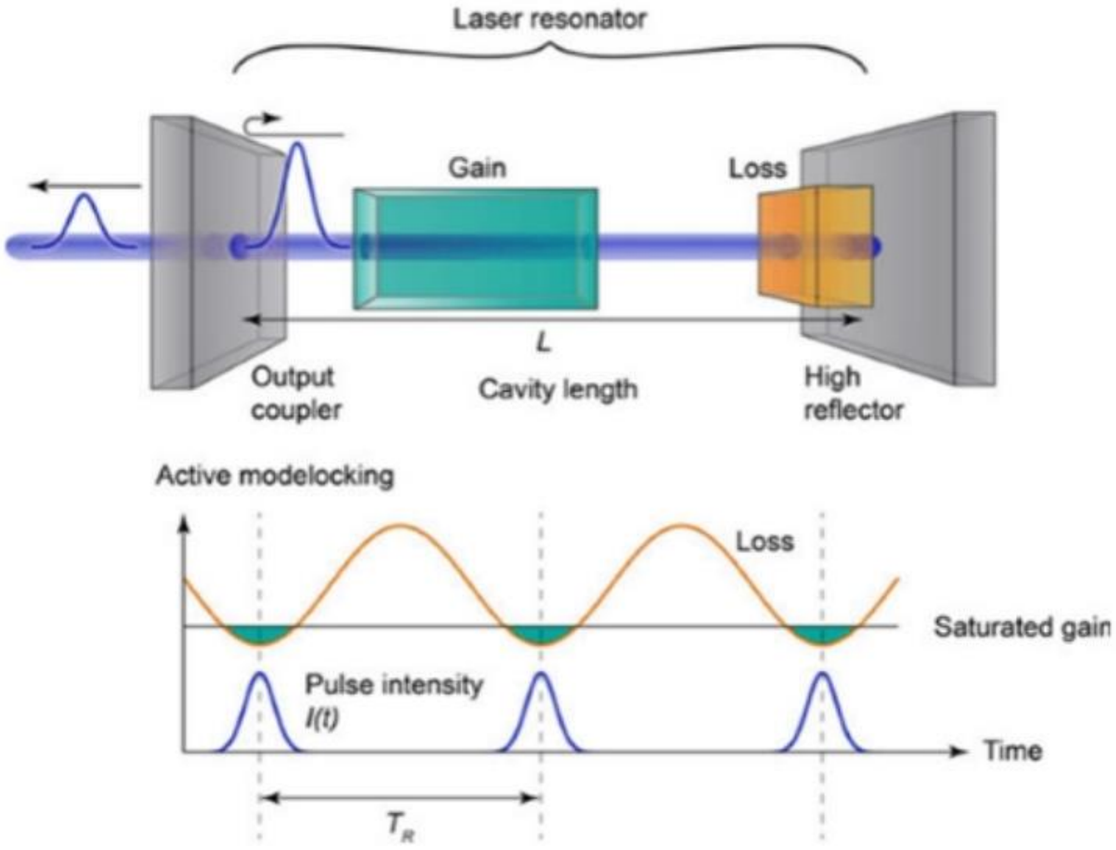
- The number of modes that are oscillating in phase determines the length of each light pulse. If there are N number of modes separated by a frequency Δv, then the overall mode-locked bandwidth is NΔv.


out of phase
out of phase
out of phase
Random phases of all laser modes
Time
out of phase
in phase!
out of phase
Locked phases of all laser modes
Time
Irradiance vs. time
Random phases
Light bulb
Locked phases
Ultrashort pulse!!
Time


50 Modes
Intensities
5 Modes
P_{CW}
Resonator round-trip time

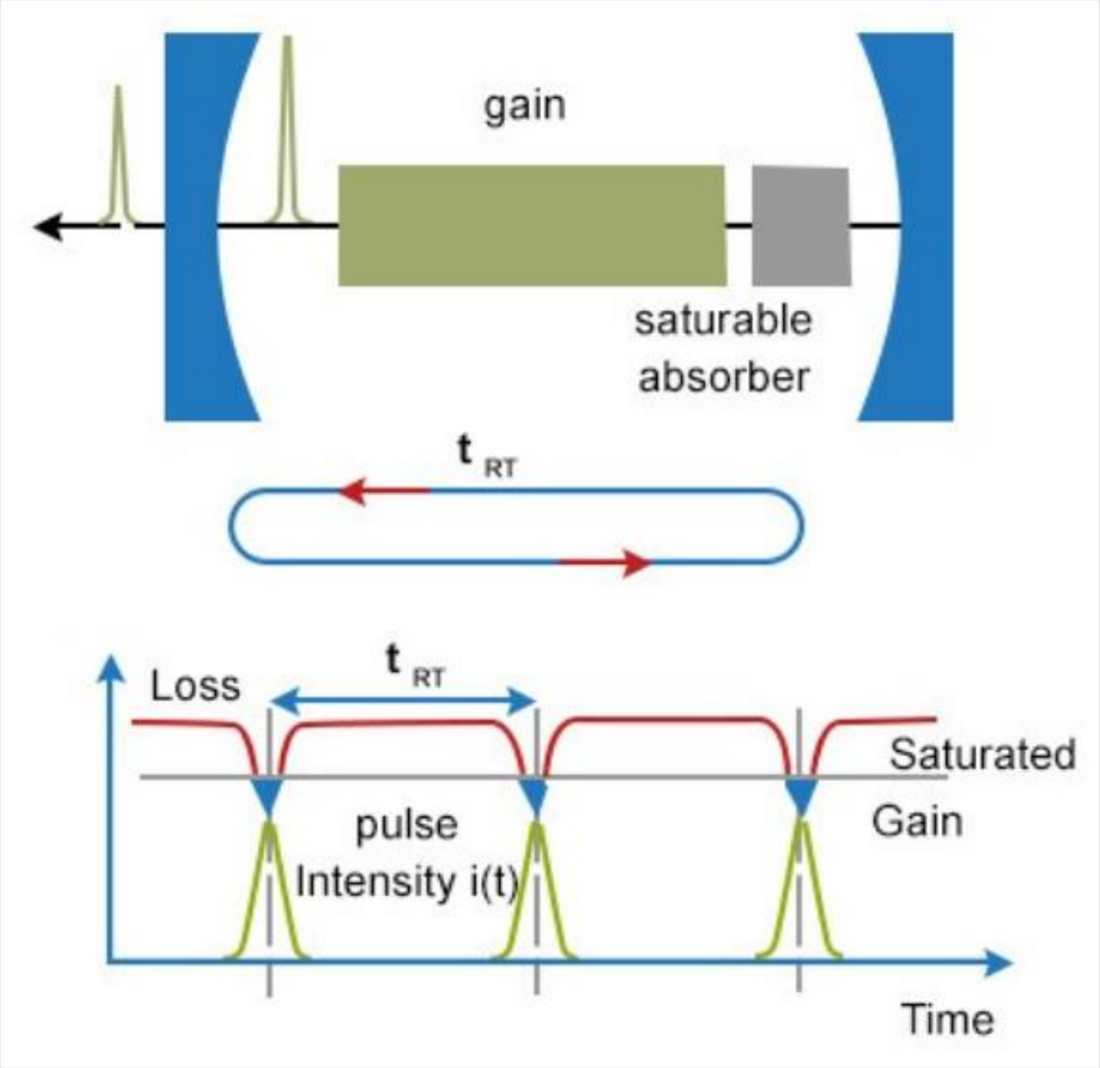
Types of mode locking

- There are mainly two types of mode-locking in lasers:
- Active mode locking
- Passive mode locking
- **Active mode locking** is mainly performed on continuous wave lasers like Nd:YAG laser, Nd:YVO4 laser, DPSS lasers, etc.
- They generate equal pulses with a repetition rate in the range of 80-250 MHz having nanojoules pulse energy range.
- Figure shows active mode locking in a laser. The resonant cavity of the laser contains a gain medium and an optical loss modulator which changes the resonant cavity loss with time.
- When an external signal is applied to the optical modulator, amplitude or phase modulation takes place inside the cavity which causes the mode-locking of the laser.
- An acousto-optic (AO) or electro-optic (EO) effect is used to introduce a periodic modulation of the loss in the laser cavity.
- The optical modulator blocks the passage except when the pulse is about to pass. It will be open only during the pulse durations thus creating a giant narrow pulse.



Passive mode locking

- Passive mode locking is a method of generating ultra-short pulses in a laser using non-electronic means.
- This is achieved with a saturable absorber.
- A saturable absorber is an optical component whose absorption coefficient decreases with an increase in the intensity of incident light.
- It absorbs weak pulses while transmitting strong ones with comparatively little absorption.
- A saturable absorber is made from organic dyes that have the ability to absorb light at the specific wavelength of the laser.
- Liquid organic dyes are commonly used for saturable absorbers. At higher pulse intensities, the ground state of the dye gets depleted, which decreases resonator losses.
- The saturable absorber is kept inside the optical resonator cavity next to the gain medium. They do not require an external signal for this type of mode-locking.
- The laser light within the cavity itself will make changes in the intracavity elements.

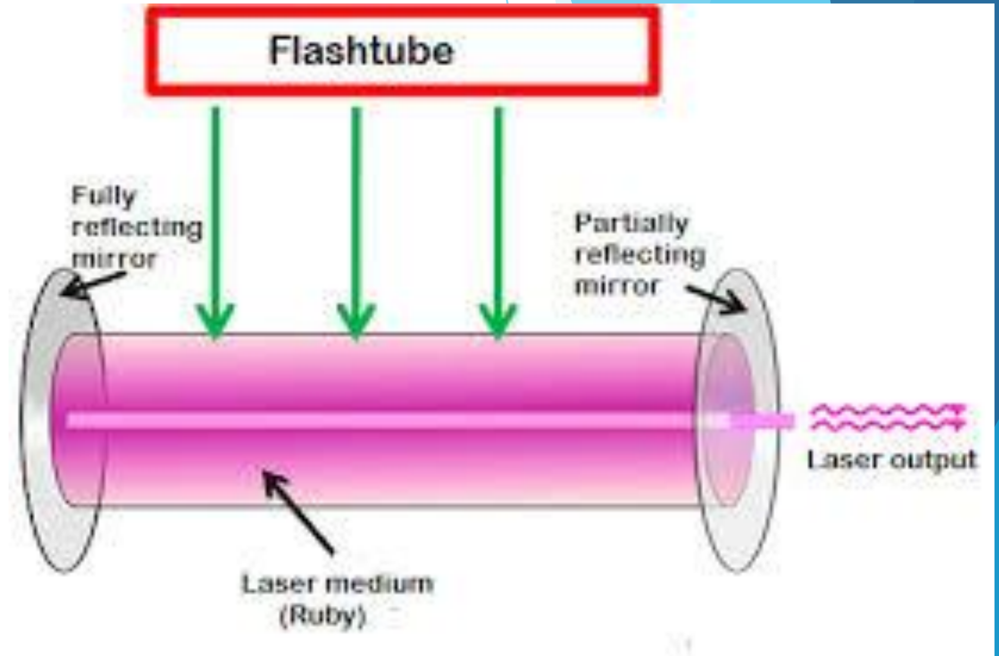


Types of Laser

- Lasers are usually classified in terms of their active (lasing) medium. Major types are:
- • Solid-state lasers
- • Semiconductor Lasers
- • Dye Lasers
- • Gas Lasers
- • Excimer Lasers

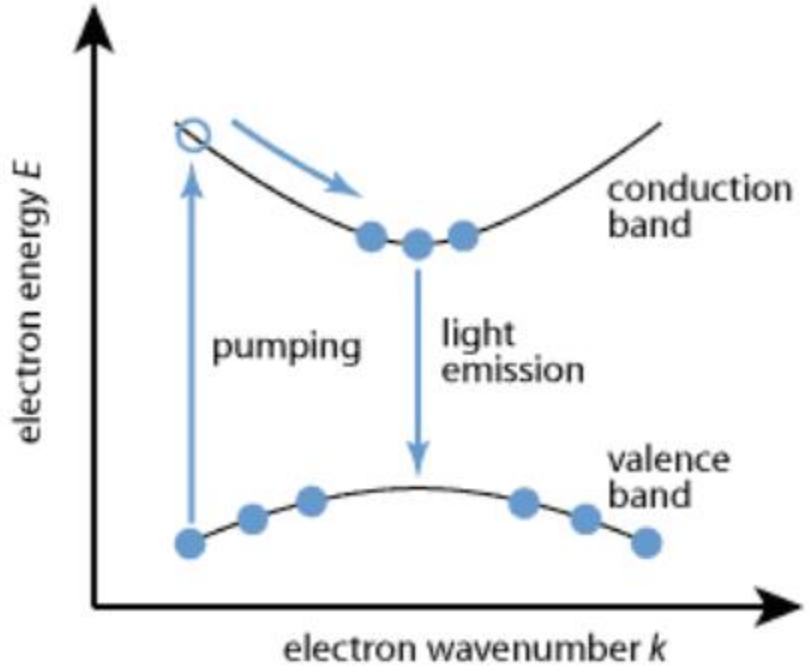
Types of Lasers

- Solid-state lasers are lasers based on solid-state gain media such as crystals or glasses doped with rare earth or transition metal ions.
- Semiconductor lasers are also solid-state lasers, but they are not always meant with that term.
- Ion-doped solid-state lasers (also sometimes called doped insulator lasers) can be made in the form of bulk lasers, fiber lasers, or other types of waveguide lasers.
- Solid-state lasers may generate output powers between a few milliwatts and (in high-power versions) many kilowatts.
- The first solid-state laser – and in fact the first of all lasers – was a pulsed ruby laser, demonstrated by Maiman in 1960.
- Later on, however, other solid-state gain media were preferred because of their superior performance.
- A major problem with ruby is its pronounced three-level nature.



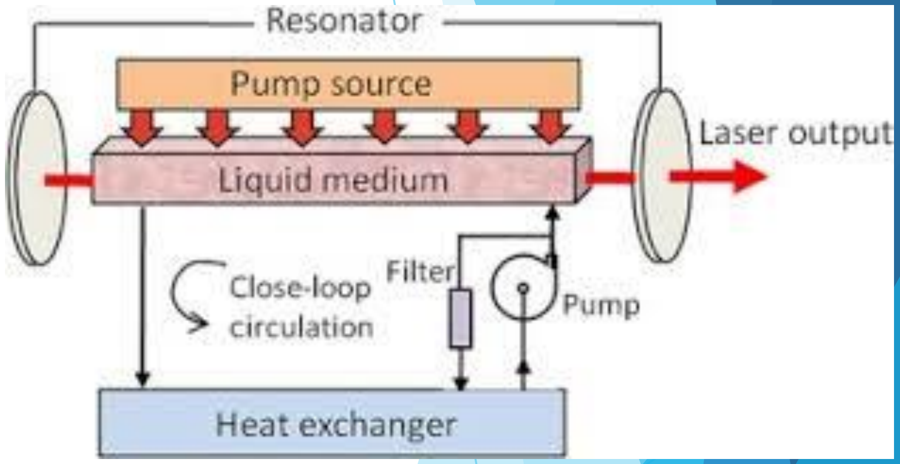
Semiconductor lasers

- Semiconductor lasers are solid-state lasers based on semiconductor gain media, where optical amplification is usually achieved by stimulated emission at an interband transition under conditions of a high carrier density in the conduction band.
- The physical origin of gain in an optically pumped semiconductor (for the usual case of an interband transition) is illustrated in Figure.
- Without pumping, most of the electrons are in the valence band.
- A pump beam with a photon energy slightly above the band gap energy can excite electrons into a higher state in the conduction band, from where they quickly decay to states near the bottom of the conduction band.
- At the same time, the holes generated in the valence band move to the top of the valence band.
- Electrons in the conduction band can then recombine with these holes, emitting photons with an energy near the bandgap energy.
- This process can also be stimulated by incoming photons with suitable energy.
- A quantitative description can be based on the Fermi–Dirac distributions for electrons in both bands.



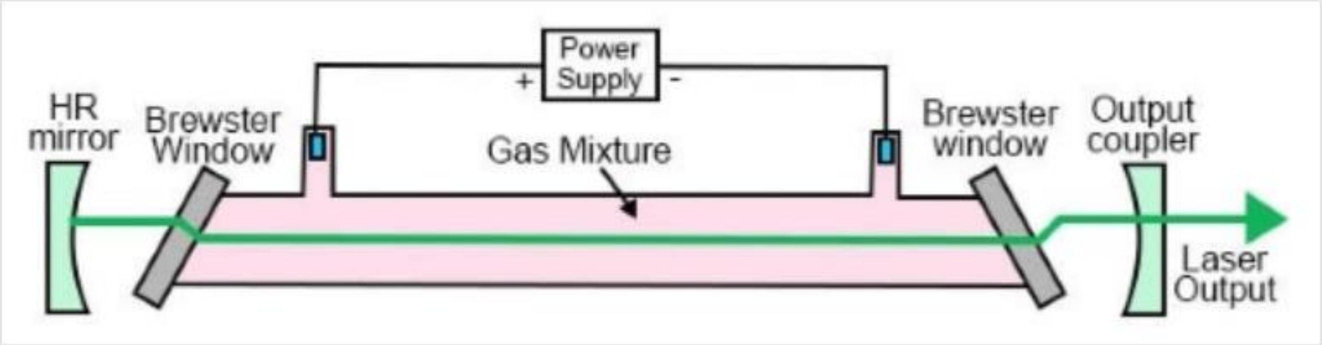
Liquid laser

- Liquid lasers are optically pumped lasers in which the gain medium is a liquid at room temperature. And the most successful of all liquid lasers are dye lasers.
- These lasers generate broadband laser light from the excited energy states of organic dyes dissolved in liquid solvents.
- Output can be either pulsed or CW and spans the spectrum from the near-UV to the near-IR, depending on the dye used.
- The large organic molecules of the dye are excited to higher energy states by arc lamps, flashlamps, or other lasers such as frequency-doubled Nd:YAG, copper-vapor, argon-ion, nitrogen, and even excimer.
- The dye solution is usually pumped transversely through the laser cavity and contained by a transparent chamber called a flow cell.
- Broadband laser emission originates from interactions between the vibrational and electronic states of dye molecules that split the electronic energy levels into broad energy bands similar to those of vibronic lasers.
- Wavelength-selective cavity optics such as a prism or diffraction grating can be used to tune to a desired frequency.
- The efficiency, tunability, and high coherence of dye lasers make them ideal for scientific, medical, and spectroscopic research.
- In addition, their broadband emission makes them particularly well suited for generating ultrashort laser pulses.



Gas Laser

- A gas laser is a type of laser that uses a gas-filled medium to produce coherent and amplified light.
- Gas lasers operate based on the principles of stimulated emission and optical amplification.
- These lasers are excited by different pumping mechanisms such as electrical discharge, chemical reactions, or optical pumping.
- The gas atoms, ions, or molecules interact with energetic electrons, leading to their excitation. This method of electrical excitation is preferred over optical excitation because gases have narrow absorption lines, unlike solids.
- This excitation energizes the gas atoms or molecules, causing them to transition from lower energy states to higher energy states.
- As they return to lower energy states, they emit photons, which are then reflected and amplified within an optical resonator formed by two mirrors.
- The partially reflective mirror allows a portion of the light to escape as a coherent laser beam.



Excimer laser

- An excimer laser is a powerful kind of laser which is nearly always operated in the ultraviolet (UV) spectral region (→ ultraviolet lasers) and generates nanosecond pulses (→ nanosecond lasers).
- The excimer gain medium is a gas mixture, typically containing a noble gas (rare gas) (e.g. argon, krypton, or xenon) and a halogen (e.g. fluorine or chlorine, e.g. as HCl), apart from helium and/or neon as buffer gas.
- An excimer gain medium is typically pumped with short (nanosecond) current pulses in a high-voltage electric discharge (or sometimes with an electron beam), which create so-called excimers (excited dimers) – molecules which represent a bound state of their constituents only in the excited electronic state, but not in the electronic ground state.
- A dimer is a molecule consisting of two equal atoms, but the term excimer is normally understood to include asymmetric molecules such as XeCl as well.
- A key point is that after stimulated or spontaneous emission, the excimers rapidly dissociate, so that reabsorption of the generated laser radiation is avoided.
- This makes it possible to achieve a fairly high gain even for a moderate concentration of excimers.

Different applications of laser

- Scientific Applications.
- Commercial Applications.
- Medical Applications

Scientific Applications

- **Laser Spectroscopy**: atmospheric physics - pollution monitoring-cancer detection
- **Optical metrology:** optical distance measurement- optical temperature measurements etc.,
- **Optical frequency metrology:** for precise position measurements
- **Laser induced breakdown spectroscopy:** Solid materials can be analyzed
- **Laser cooling:** makes it possible to bring clouds of atoms or ions to extremely low temperatures
- **Optical tweezers:** used for trapping and manipulating small particles- such as bacteria or parts of living cells.
- **Laser microscopes:** provide images of, e.g., biological samples with very high resolution - often in three dimensions
- **Communication and computing**

Commercial Applications

- Cutting, welding, marking,
- Rangefinder / surveying,
- LIDAR / pollution monitoring,
- CD/DVD player,
- Laser printing,
- Laser engraving of printing
- plates,
- Laser pointers,
- holography, laser
- light displays
- Optical communications.

Medical Applications

- Cosmetic surgery
- Dentistry
- Dermatology
- Eye surgery
- Cardiology
- Neurology
- Optical Imaging
- Optical biosensors