LASER

LASER stands for Light Amplification by Stimulated Emission of Radiation.

Laser pumping is the act of energy transfer from an external source into the laser gain medium. The energy is absorbed in the medium, producing excited states in its atoms. When the number of particles in one excited state exceeds the number of particles in the ground state or a less-excited state, population inversion is achieved. In this condition, the mechanism of stimulated emission can take place and the medium can act as a laser or an optical amplifier. The pump power must be higher than the lasing threshold of the laser.

The pump energy is usually provided in the form of light or electric current, but more exotic sources have been used, such as chemical or nuclear reactions.

Thermal equilibrium

The laser transition occurs between two defined levels or level groups - the upper (E2) and the lower (E1). Important in terms of laser operation is that an inverted condition is achieved between the two energy levels: the higher energy level must be more densely populated than the lower. This condition is never achieved in systems in thermodynamic equilibrium. Thermal equilibrium is thus characterised by the fact that the lower energy level is always more densely populated than the higher. Lasers must therefore operate in opposite conditions to those which prevail in thermal equilibrium.

Laser Modes

If one assumes a homogenous intensity distribution on one of the laser mirrors, the intensity distribution will change during propagation from one mirror to the other due to diffraction. After numerous passes back and forth, the intensity distribution takes shape and is reproduced with each pass. These marked intensity distributions represent the intrinsic solution of the optical resonator of which there are, in fact, several. One of these intrinsic solutions is, however, of particular importance: the so-called fundamental mode. In many cases, the fundamental mode approximates the so-called Gaussian beam. The Gaussian beam has a radial intensity distribution with a Gaussian profile.

It is one reason we can say that to get gaussian curve ,but not only.

Principles of working of a laser

In lasers, photons are interacted in three ways with the atoms:

- Absorption of radiation
- Spontaneous emission

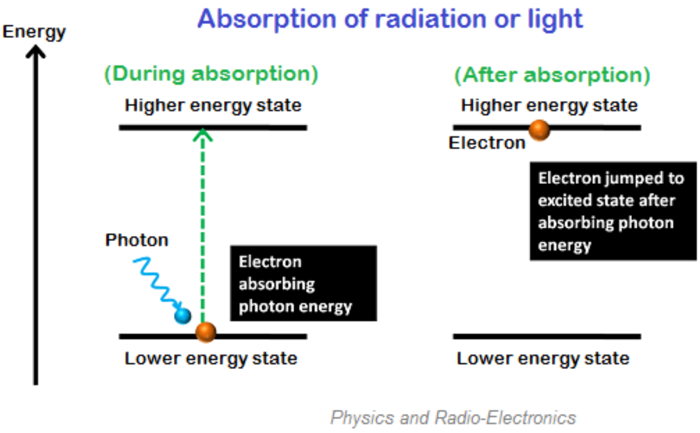
- Stimulated emission

Absorption of radiation

Absorption of radiation is the process by which electrons in the ground state absorbs energy from photons to jump into the higher energy level.

The electrons orbiting very close to the nucleus are at the lower energy level or lower energy state whereas the electrons orbiting farther away from the nucleus are at the higher energy level. The electrons in the lower energy level need some extra energy to jump into the higher energy level. This extra energy is provided from various energy sources such as heat, electric field, or light.

Let us consider two energy levels (E_1 and E_2) of electrons. E_1 is the ground state or lower energy state of electrons and E_2 is the excited state or higher energy state of electrons. The electrons in the ground state are called lower energy electrons or ground state electrons whereas the electrons in the excited state are called higher energy electrons or excited electrons.



In general, the electrons in the lower energy state can't jump into the higher energy state. They need sufficient energy in order jump into the higher energy state.

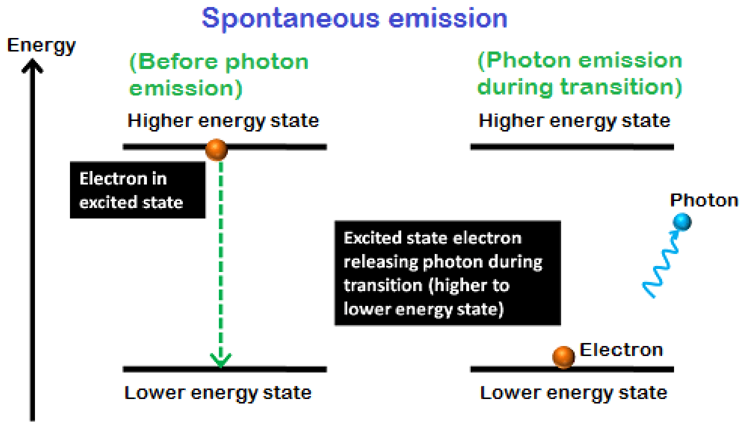
When photons or light energy equal to the energy difference of the two energy levels ($E_2 - E_1$) is incident on the atom, the ground state electrons gains sufficient energy and jumps from ground state (E_1) to the excited state (E_2).

The absorption of radiation or light occurs only if the energy of incident photon exactly matches the energy difference of the two energy levels ($E_2 - E_1$).

Spontaneous emission

Spontaneous emission is the process by which electrons in the excited state return to the ground state by emitting photons.

The electrons in the excited state can stay only for a short period. The time up to which an excited electron can stay at higher energy state (E_2) is known as the lifetime of excited electrons. The lifetime of electrons in excited state is 10^{-8} second.



Physics and Radio-Electronics

Thus, after the short lifetime of the excited electrons, they return to the lower energy state or ground state by releasing energy in the form of photons.

In spontaneous emission, the electrons move naturally or spontaneously from one state (higher energy state) to another state (lower energy state) so the emission of photons also occurs naturally. Therefore, we have no control over when an excited electron is going to lose energy in the form of light.

The photons emitted in spontaneous emission process constitute ordinary incoherent light. Incoherent light is a beam of photons with frequent and random changes of phase between them. In other words, the photons emitted in the spontaneous emission process do not flow exactly in the same direction of incident photons.

Stimulated emission

Stimulated emission is the process by which incident photon interacts with the excited electron and forces it to return to the ground state.

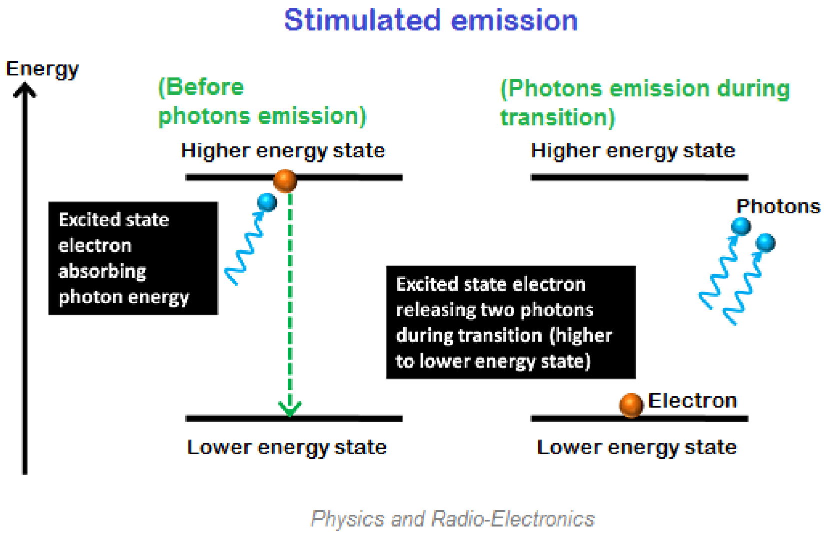
In stimulated emission, the light energy is supplied directly to the excited electron instead of supplying light energy to the ground state electrons.

Unlike the spontaneous emission, the stimulated emission is not a natural process it is an artificial process.

In spontaneous emission, the electrons in the excited state will remain there until its lifetime is over. After completing their lifetime, they return to the ground state by releasing energy in the form of light.

However, in stimulated emission, the electrons in the excited state need not wait for completion of their lifetime. An alternative technique is used to forcefully return the excited electron to ground state before completion of their lifetime. This technique is known as the stimulated emission.

When incident photon interacts with the excited electron, it forces the excited electron to return to the ground state. This excited electron release energy in the form of light while falling to the ground state.

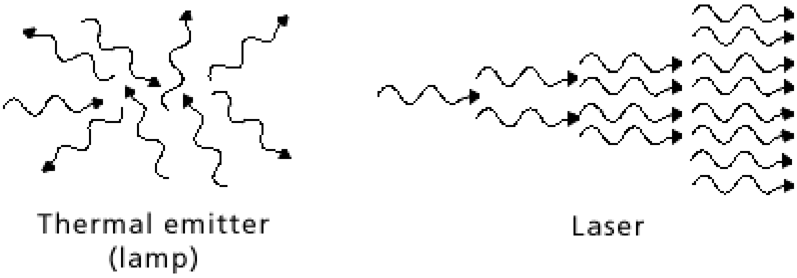


In stimulated emission, two photons are emitted (one additional photon is emitted), one is due to the incident photon and another one is due to the energy release of excited electron. Thus, two photons are emitted.

The stimulated emission process is very fast compared to the spontaneous emission process.

All the emitted photons in stimulated emission have the same energy, same frequency and are in phase. Therefore, all photons in the stimulated emission travel in the same direction.

The number of photons emitted in the stimulated emission depends on the number of electrons in the higher energy level or excited state and the incident light intensity.

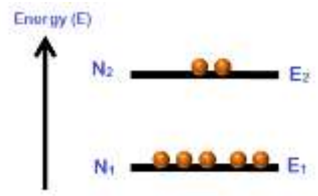


Population Inversion

Population inversion is the process of achieving greater population of higher energy state as compared to the lower energy state. Population inversion technique is mainly used for light amplification. The population inversion is required for laser operation.

Consider a group of electrons with two energy levels E_1 and E_2.

E_1 is the lower energy state and E_2 is the higher energy state.
N_1 is the number of electrons in the energy state E_1.
N_2 is the number of electrons in the energy state E_2.
The number of electrons per unit volume in an energy state is the population of that energy state.



Population inversion cannot be achieved in a two-energy level system. Under normal conditions, the number of electrons (N_1) in the lower energy state (E_1) is always greater as compared to the number of electrons (N_2) in the higher energy state (E_2).

$N_1 > N_2$

When temperature increases, the population of higher energy state (N_2) also increases. However, the population of higher energy state (N_2) will never exceed the population of lower energy state (N_1).

At best an equal population of the two states can be achieved which results in no optical gain.

$N_1 = N_2$

Therefore, we need 3 or more energy states to achieve population inversion. The greater is the number of energy states the greater is the optical gain.

There are certain substances in which the electrons once excited; they remain in the higher energy level or excited state for longer period. Such systems are called active systems or active media which are generally mixture of different elements.

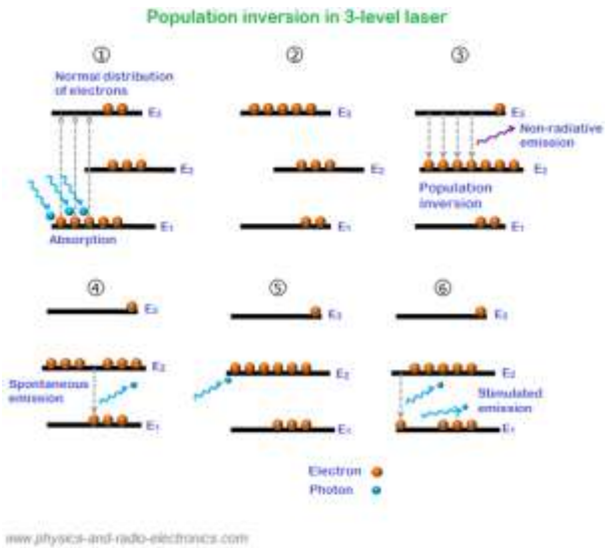
When such mixtures are formed, their electronic energy levels are modified and some of them acquire special properties. Such types of materials are used to form 3-level laser or 4-level laser.

3-level Laser

Consider a system consisting of three energy levels E_1, E_2, E_3 with N number of electrons.

We assume that the energy level of E_1 is less than E_2 and E_3, the energy level of E_2 is greater than E_1 and less than E_3, and the energy level of E_3 is greater than E_1 and E_2.

It can be simply written as $E_1 < E_2 < E_3$. That means the energy level of E_2 lies in between E_1 and E_3.



The energy level E_1 is known as the ground state or lower energy state and the energy levels E_2 and E_3 are known as excited states. The energy level E_2 is sometimes referred to as Meta stable state. The energy level E_3 is sometimes referred to as pump state or pump level.

The N number of electrons in the system occupies these three energy levels. Let N_1 be the number of electrons in the energy state E_1, N_2 be the number of electrons in the energy state E_2 and N_3 be the number of electrons in the energy state E_3.

To get laser emission or population inversion, the population of higher energy state (E_2) should be greater than the population of the lower energy state (E_1).

Under normal conditions, the higher an energy level is, the lesser it is populated. For example, in a three-level energy system, the lower energy state E_1 is highly populated as compared to the excited energy states E_2 and E_3. On the other hand, the excited energy state E_2 is highly populated as compared to the excited energy state E_3. It can be simply written as $N_1 > N_2 > N_3$.

Under certain conditions, the greater population of higher energy state (E_2) as compared to the lower energy state (E_1) is achieved. Such an arrangement is called population inversion.

Let us assume that initially the majority of electrons will be in the lower energy state or ground state (E_1) and only a small number of electrons will be in excited states (E_2 and E_3).

When we supply light energy which is equal to the energy difference of E_3 and E_1, the electrons in the lower energy state (E_1) gains sufficient energy and jumps into the higher energy state (E_3). This process of supplying energy is called pumping.

We also use other methods to excite ground state electrons such as electric discharge and chemical reactions. The flow of electrons from E_1 to E_3 is called pump transition.

The lifetime of electrons in the energy state E_3 is very small as compared to the lifetime of electrons in the energy state E_2. Therefore, electrons in the energy level E_3 does not stay for long period. After a short period, they quickly fall to the Meta stable state or energy state E_2 and releases radiation less energy instead of photons.

Because of the shorter lifetime, only a small number of electrons accumulate in the energy state E_3.

The electrons in the Meta stable state E_2 will remain there for longer period because of its longer lifetime. As result, a large number of electrons accumulate in Meta stable state. Thus, the population of metal stable state will become greater than the population of energy states E_3 and E_1.
It can be simply written as $N_2 > N_1 > N_3$.

In a three-level energy system, we achieve population inversion between energy levels E_1 and E_2.

After completion of lifetime of electrons in the Meta stable state, they fall back to the lower energy state or ground state E_1 by releasing energy in the form of photons. This process of emission of photons is called spontaneous emission.

When this emitted photon interacts with the electron in the Meta stable state E_2, it forces that electron to fall back to the ground state. As a result, two photons are emitted. This process of emission of photons is called stimulated emission.

When these photons again interacted with the electrons in the Meta stable state, they forces two Meta stable state electrons to fall back to the ground state. As a result, four photons are emitted. Likewise, a large number of photons are emitted.

As a result, millions of photons are emitted by using small number of photons.

We may get a doubt, in order to excite an electron, we hit the electron with a photon. This excited electron again emits photon when fall back to the ground state. Then how could light amplification or extra photons be achieved.

We may also use other types of energy sources such as electrical energy to excite electrons. In such case, a single photon will generate large number of photons. Thus, light amplification is achieved by using population inversion method. The system which uses three energy levels is known as 3-level laser.

In a 3-level laser, at least half the population of electrons must be excited to the higher energy state to achieve population inversion. Therefore, the laser medium must be very strongly pumped. This makes 3-level lasers inefficient to produce photons or light. The three level lasers are the first type of lasers discovered.

4-level Laser

Consider a group of electrons with four energy levels E_1, E_2, E_3, E_4.

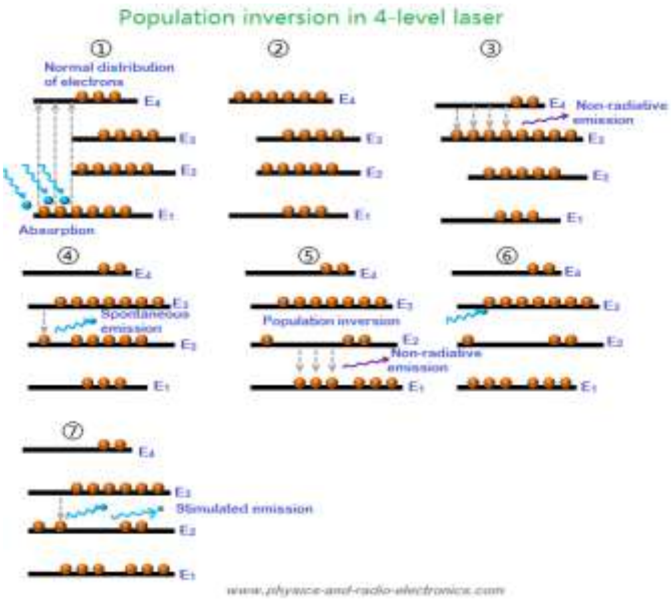
E_1 is the lowest energy state, E_2 is the next higher energy, E_3 is the next higher energy state after E_2, E_4 is the next higher energy state after E_3.

The number of electrons in the lower energy state or ground state is given by N_1, the number of electrons in the energy state E_2 is given by N_2, the number of electrons in the energy state E_3 is given by N_3 and the number of electrons in the energy state E_4 is given by N_4.

We assume that $E_1 < E_2 < E_3 < E_4$. The lifetime of electrons in the energy state E_4 and energy state E_2 is very less. Therefore, electrons in these states will only stay for very short period.

When we supply light energy which is equal to the energy difference of E_4 and E_1, the electrons in the lower energy state E_1 gains sufficient energy and jumps into the higher energy state E_4.

The lifetime of electrons in the energy state E_4 is very small. Therefore, after a short period they fall back into the next lower energy state E_3 by releasing non-radiation energy.



The lifetime of electrons in the energy state E_3 is very large as compared to E_4 and E_2. As a result, a large number of electrons accumulate in the energy level E_3. After completion of their lifetime, the electrons in the energy state E_3 will fall back into the next lower energy state E_2 by releasing energy in the form of photons.

Like the energy state E_4, the lifetime of electrons in the energy state E_2 is also very small. Therefore, the electrons in the energy state E_2 will quickly fall into the next lower energy state or ground state E_1 by releasing non-radiation energy.

Thus, population inversion is achieved between energy states E_3 and E_2.

In a 4-level laser, only a few electrons are excited to achieve population inversion. Therefore, a 4-level laser produces light efficiently than a 3-level laser. In practical, more than four energy levels may be involved in the laser process.

In 3-level and 4-level lasers, the frequency or energy of the pumping photons must be greater than the emitted photons.

Characteristics of Laser

Laser light has four unique characteristics that differentiate it from ordinary light: these are

- Coherence
- Directionality
- Monochromatic
- High intensity

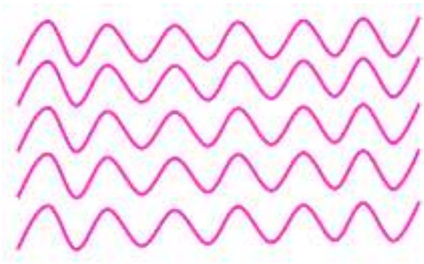
Coherence

We know that visible light is emitted when excited electrons (electrons in higher energy level) jumped into the lower energy level (ground state). The process of electrons moving from higher energy level to lower energy level or lower energy level to higher energy level is called electron transition.

In ordinary light sources (lamp, sodium lamp and torch light), the electron transition occurs naturally. In other words, electron transition in ordinary light sources is random in time. The photons emitted from ordinary light sources have different energies, frequencies, wavelengths, or colours. Hence, the light waves of ordinary light sources have many wavelengths. Therefore, photons emitted by an ordinary light source are out of phase.

In laser, the electron transition occurs artificially. In other words, in laser, electron transition occurs in specific time. All the photons emitted in laser have the same energy, frequency, or wavelength. Hence, the light waves of laser light have single wavelength or colour. Therefore, the wavelengths of the laser light are in phase in space and time. In laser, a technique called stimulated emission is used to produce light.

Thus, light generated by laser is highly coherent. Because of this coherence, a large amount of power can be concentrated in a narrow space.

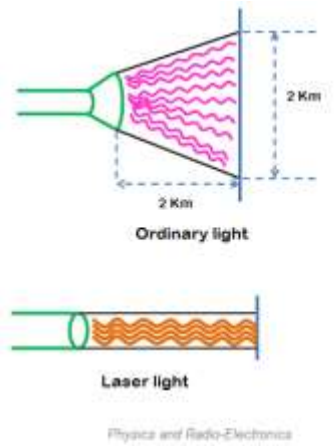

Coherent light waves

Directionality

In conventional light sources (lamp, sodium lamp and torchlight), photons will travel in random direction. Therefore, these light sources emit light in all directions.

On the other hand, in laser, all photons will travel in same direction. Therefore, laser emits light only in one direction. This is called directionality of laser light. The width of a laser beam is extremely narrow. Hence, a laser beam can travel to long distances without spreading.

If an ordinary light travels a distance of 2 km, it spreads to about 2 km in diameter. On the other hand, if a laser light travels a distance of 2 km, it spreads to a diameter less than 2 cm.



Monochromatic

Monochromatic light means a light containing a single colour or wavelength. The photons emitted from ordinary light sources have different energies, frequencies, wavelengths, or colours. Hence, the light waves of ordinary light sources have many wavelengths or colours. Therefore, ordinary light is a mixture of waves having different frequencies or wavelengths.

On the other hand, in laser, all the emitted photons have the same energy, frequency, or wavelength. Hence, the light waves of laser have single wavelength or colour. Therefore, laser light covers a very narrow range of frequencies or wavelengths.

High Intensity

You know that the intensity of a wave is the energy per unit time flowing through a unit normal area. In an ordinary light source, the light spreads out uniformly in all directions.

If you look at a 100-Watt lamp filament from a distance of 30 cm, the power entering your eye is less than 1/1000 of a watt.

In laser, the light spreads in small region of space and in a small wavelength range. Hence, laser light has greater intensity when compared to the ordinary light.

One assumption If we look directly along the beam from a laser (caution: don't do it), then all the power in the laser would enter your eye. Thus, even a 1-Watt laser would appear many thousand times more intense than 100-Watt ordinary lamp.

Thus, these four properties of laser beam enable us to cut a huge block of steel by melting. They are also used for recording and reproducing large information on a compact disc (CD).

Methods of Achieving Population Inversion

Under normal conditions, more electrons are in a lower energy state than in a higher energy state. Population inversion is a process of achieving more electrons in the higher energy state than the lower energy state.

In order to achieve population inversion, we need to supply energy to the laser medium. The process of supplying energy to the laser medium is called pumping. The source that supplies energy to the laser medium is called pump source. The type of pump source used is depends on the laser medium. Different pump sources are used for different laser mediums to achieve population inversion. Some of the most commonly used pump sources are as follows:

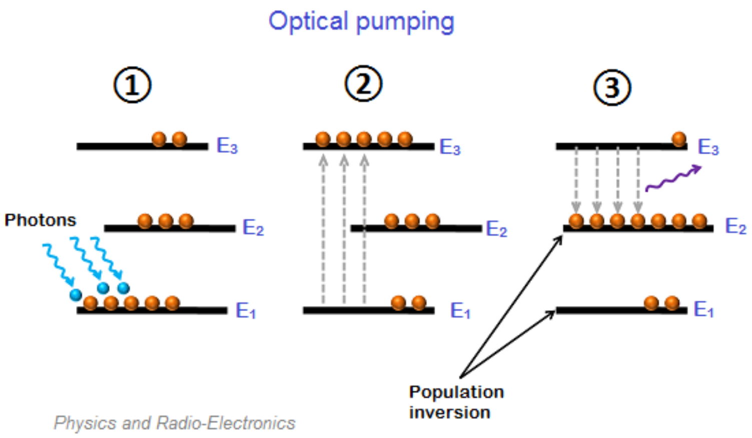
- Optical pumping
- Electric discharge or excitation by electrons
- Inelastic atom-atom collisions
- Thermal pumping
- Chemical reactions

Population inversion is easily achieved when the system of molecules or atoms have the energy levels with favourable properties. For example, the upper energy level has a long lifetime and the lower energy level has a short lifetime.

Optical Pumping

As the name suggests, in this method, light is used to supply energy to the laser medium. An external light source like xenon flash lamp is used to produce more electrons (a high population) in the higher energy level of the laser medium.

When light source provides enough energy to the lower energy state electrons in the laser medium, they jump into the higher energy state E_3. The electrons in the higher energy state do not stay for long period. After a very short period, they fall back to the next lower energy state or meta stable state E_2 by releasing radiation less energy.

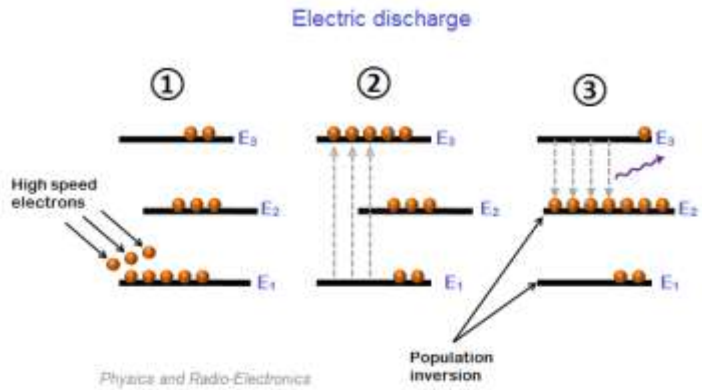


The meta stable state E_2 has greater lifetime than the lower energy state or ground state E_1. Hence, more electrons are accumulated in the energy state E_2 than the lower energy state E_1. Thus, population inversion is achieved. Optical pumping is used in solid-state lasers such as ruby lasers.

Electric Discharge or Excitation by Electrons

Electric discharge refers to flow of electrons or electric current through a gas, liquid or solid.

In this method of pumping, electric discharge acts as the pump source or energy source. A high voltage electric discharge (flow of electrons, electric charge, or electric current) is passed through the laser medium or gas. The intense electric field accelerates the electrons to high speeds and they collide with neutral atoms in the gas. As a result, the electrons in the lower energy state gains sufficient energy from external electrons and jumps into the higher energy state. This method of pumping is used in gas lasers such as argon lasers.



The process of achieving population inversion in the gas laser is almost similar to the solid laser. The only difference is the pump source used for supplying energy and the type of material or medium (solid or gas) used as a laser medium. In solid lasers, an external light source like xenon flash lamp is used as pump source whereas, in gas lasers, a high voltage electric discharge is used as a pump source.

Inelastic Atom-Atom Collisions

Like the electric discharge method, here also a high voltage electric discharge acts as a pump source. However, in this method, a combination of two types of gases, say X and Y are used. The excited state of gas X is represented as X^+ whereas gas Y is represented as Y^+. Both X and Y gases have the same excited states (X^+ and Y^+).

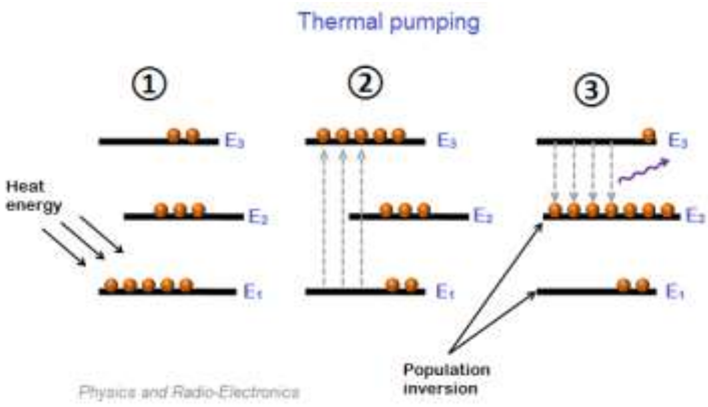
When high voltage electric discharge passes through a laser medium having two types of gases X and Y, the lower energy state electrons in gas X will move to the excited state X^+ similarly the lower energy state electrons in gas Y moves to the excited state Y^+.

Initially, during electric discharge, the lower energy state electrons in gas X or atom X gets excited to X^+ due to continuous collision with electrons. The excited state electrons in gas X^+ now collide with the lower energy state electrons in gas Y. As a result, the lower energy state electrons in gas Y gains sufficient energy and jump into the excited state Y^+. This method is used in the Helium–Neon (He-Ne) laser.

Thermal Pumping

Sometimes we can achieve population inversion by heating the laser medium. In thermal pumping, heat acts as the pump source or energy source. In this method, population inversion is achieved by supplying heat into the laser medium.

When heat energy is supplied to the laser medium, the lower energy state electrons gains sufficient energy and jumps into the higher energy level.



The process of achieving population inversion in thermal pumping is almost similar to the optical pumping or electric discharge method, except that in this method heat is used as pump source instead of light or electric discharge.

Chemical Reactions

If an atom or a molecule is produced through some chemical reaction and remains in an excited state at the time of production, then it can be used for pumping. The hydrogen fluoride molecule is produced in an excited state when hydrogen and fluorine gas chemically combine. The number of produced excited atoms or molecules is greater than the number of normal state atoms or molecules. Thus, population inversion is achieved.

For example, $H_2 + F_2 \rightarrow 2HF$, in this chemical reaction, hydrogen (H_2) and fluorine (F_2) molecules are chemically combined to produce hydrogen fluoride molecule (2HF) in an excited state.

The laser beam is very narrow and can be concentrated on a very small area. This makes laser light highly directional. The laser beam is very narrow and can be concentrated on a very small area. This makes laser light highly directional.

Types of lasers

Lasers are classified into 4 types based on the type of laser medium used:

- Solid-state laser
- Gas laser
- Liquid laser
- Semiconductor laser

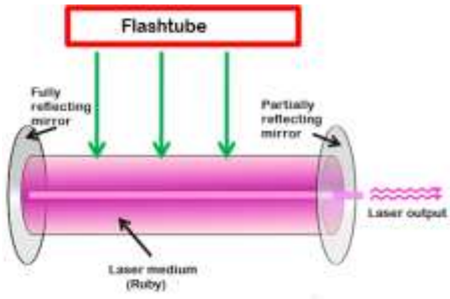
Solid-state laser

A solid-state laser is a laser that uses solid as a laser medium. In these lasers, glass or crystalline materials are used.

Ions are introduced as impurities into host material which can be a glass or crystalline. The process of adding impurities to the substance is called doping. Rare earth elements such as cerium (Ce), erbium (Eu), terbium (Tb) etc are most commonly used as dopants.

Materials such as sapphire (Al_2O_3), neodymium-doped yttrium aluminum garnet (Nd:YAG), Neodymium-doped glass (Nd:glass) and ytterbium-doped glass are used as host materials for laser medium. Out of these, neodymium-doped yttrium aluminum garnet (Nd:YAG) is most commonly used.

The first solid-state laser was a ruby laser. It is still used in some applications. In this laser, a ruby crystal is used as a laser medium.



In solid-state lasers, light energy is used as pumping source. Light sources such as flashtube, flash lamps, arc lamps, or laser diodes are used to achieve pumping.

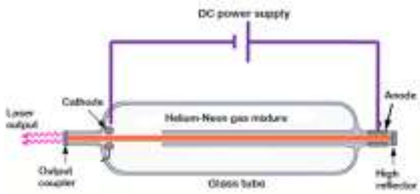
Semiconductor lasers do not belong to this category because these lasers are usually electrically pumped and involve different physical processes.

Gas laser

A gas laser is a laser in which an electric current is discharged through a gas inside the laser medium to produce laser light. In gas lasers, the laser medium is in the gaseous state.

Gas lasers are used in applications that require laser light with very high beam quality and long coherence lengths.

In gas laser, the laser medium or gain medium is made up of the mixture of gases. This mixture is packed up into a glass tube. The glass tube filled with the mixture of gases acts as an active medium or laser medium.



A gas laser is the first laser that works on the principle of converting electrical energy into light energy. It produces a laser light beam in the infrared region of the spectrum at 1.15 µm.

Gas lasers are of different types: they are, Helium (He) – Neon (Ne) lasers, argon ion lasers, carbon dioxide lasers (CO_2 lasers), carbon monoxide lasers (CO lasers), excimer lasers, nitrogen lasers, hydrogen lasers, etc. The type of gas used to construct the laser medium can determine the lasers wavelength or efficiency.

Liquid laser

A liquid laser is a laser that uses the liquid as laser medium. In liquid lasers, light supplies energy to the laser medium.

A dye laser is an example of the liquid laser. A dye laser is a laser that uses an organic dye (liquid solution) as the laser medium.

A dye laser is made up of an organic dye mixed with a solvent. These lasers generate laser light from the excited energy states of organic dyes dissolved in liquid solvents. It produces laser light beam in the near ultraviolet (UV) to the near infrared (IR) region of the spectrum.

Semiconductor laser

Semiconductor lasers play an important role in our everyday life. These lasers are very cheap, compact size and consume low power. Semiconductor lasers are also known as laser diodes.

Semiconductor lasers are different from solid-state lasers. In solid-state lasers, light energy is used as the pump source whereas, in semiconductor lasers, electrical energy is used as the pump source.

In semiconductor lasers, a p-n junction of a semiconductor diode forms the active medium or laser medium. The optical gain is produced within the semiconductor material.

Nd:YAG laser

Neodymium-doped Yttrium Aluminum Garnet (Nd: YAG) laser is a solid-state laser in which Nd: YAG is used as a laser medium.

These lasers have many different applications in the medical and scientific field for processes such as Lasik surgery and laser spectroscopy.

Nd: YAG laser is a four-level laser system, which means that the four energy levels are involved in laser action. These lasers operate in both pulsed and continuous mode.

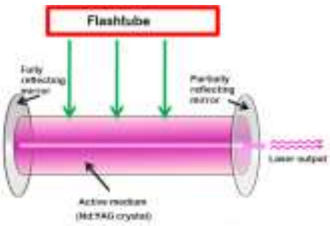
Nd: YAG laser generates laser light commonly in the near-infrared region of the spectrum at 1064 nanometres (nm). It also emits laser light at several different wavelengths including 1440 nm, 1320 nm, 1120 nm, and 940 nm.

Nd: YAG laser construction

Nd: YAG laser consists of three important elements: an energy source, active medium, and optical resonator.

The energy source or pump source supplies energy to the active medium to achieve population inversion. In Nd: YAG laser, light energy sources such as flashtube or laser diodes are used as energy source to supply energy to the active medium.

In the past, flashtubes are mostly used as pump source because of its low cost. However, nowadays, laser diodes are preferred over flashtubes because of its high efficiency and low cost.



Active medium

The active medium or laser medium of the Nd: YAG laser is made up of a synthetic crystalline material (Yttrium Aluminum Garnet (YAG)) doped with a chemical element (neodymium (Nd)). The lower energy state electrons of the neodymium ions are excited to the higher energy state to provide lasing action in the active medium.

Optical resonator

The Nd: YAG crystal is placed between two mirrors. These two mirrors are optically coated or silvered.

Each mirror is silvered or coated differently. One mirror is fully silvered whereas, another mirror is partially silvered. The mirror, which is fully silvered, will completely reflect the light and is known as fully reflecting mirror.

On the other hand, the mirror which is partially silvered will reflect most part of the light but allows a small portion of light through it to produce the laser beam. This mirror is known as a partially reflecting mirror.

Working of Nd: YAG laser

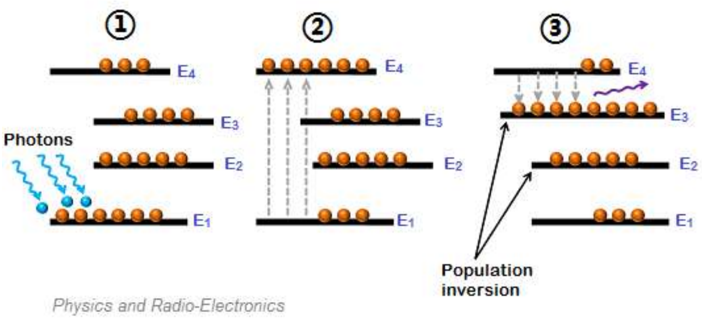
Nd: YAG laser is a four-level laser system, which means that the four energy levels are involved in laser action. The light energy sources such as flashtubes or laser diodes are used to supply energy to the active medium.

In Nd: YAG laser, the lower energy state electrons in the neodymium ions are excited to the higher energy state to achieve population inversion.

Consider a Nd: YAG crystal active medium consisting of four energy levels E_1, E_2, E_3, and E_4 with N number of electrons. The number of electrons in the energy states E1, E_2, E_3, and E_4 will be N_1, N_2, N_3, and N_4.

Let us assume that the energy levels will be $E_1 < E_2 < E_3 < E_4$. The energy level E_1 is known as ground state, E_2 is the next higher energy state or excited state, E_3 is the metastable state or excited state and E_4 is the pump state or excited state. Let us assume that initially, the population will be $N_1 > N_2 > N_3 > N_4$.

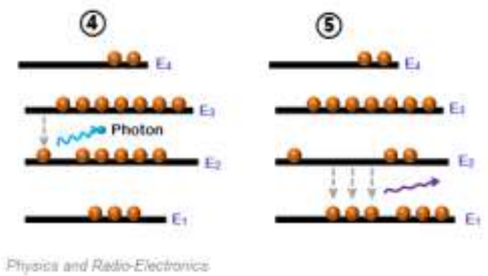
When flashtube or laser diode supplies light energy to the active medium (Nd: YAG crystal), the lower energy state (E_1) electrons in the neodymium ions gains enough energy and moves to the pump state or higher energy state E_4.



The lifetime of pump state or higher energy state E_4 is very small (230 microseconds) so the electrons in the energy state E_4 do not stay for long period. After a short period, the electrons will fall into the next lower energy state or metastable state E_3 by releasing non-radiation energy (releasing energy without emitting photons).

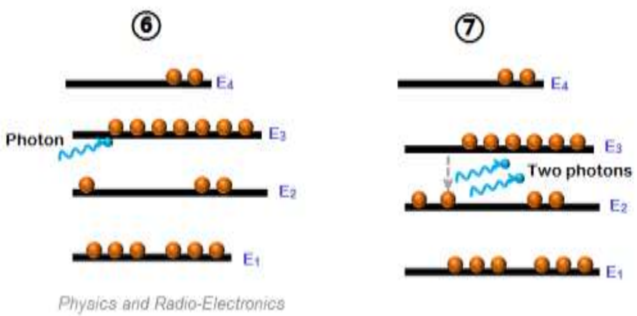
The lifetime of metastable state E_3 is high as compared to the lifetime of pump state E_4. Therefore, the electrons reach E_3 much faster than they leave E_3. This results in an increase in the number of electrons in the metastable E_3 and hence population inversion is achieved.

After some period, the electrons in the metastable state E_3 will fall into the next lower energy state E_2 by releasing photons or light. The emission is spontaneous emission.



The lifetime of energy state E_2 is very small just like the energy state E_4. Therefore, after a short period, the electrons in the energy state E_2 will fall back to the ground state E_1 by releasing radiation less energy.

When photon emitted due to spontaneous emission is interacted with the other metastable state electron, it stimulates that electron and makes it fall into the lower energy state by releasing the photon. As a result, two photons are released. The emission is stimulated one.



When these two photons again interacted with the metastable state electrons, four photons are released. Likewise, millions of photons are emitted. Thus, optical gain is achieved.

The light generated within the active medium is reflected many times between the mirrors before it escapes through the partially reflecting mirror. Advantages are Low **power consumption Nd: YAG laser offers high gain etc.**

Applications of Nd: YAG laser

Military

Nd: YAG lasers are used in laser designators and laser rangefinders. A laser designator is a laser light source, which is used to target objects for attacking. A laser rangefinder is a rangefinder, which uses a laser light to determine the distance to an object.

Medicine

Nd: YAG lasers are used to correct posterior capsular opacification (a condition that may occur after a cataract surgery).

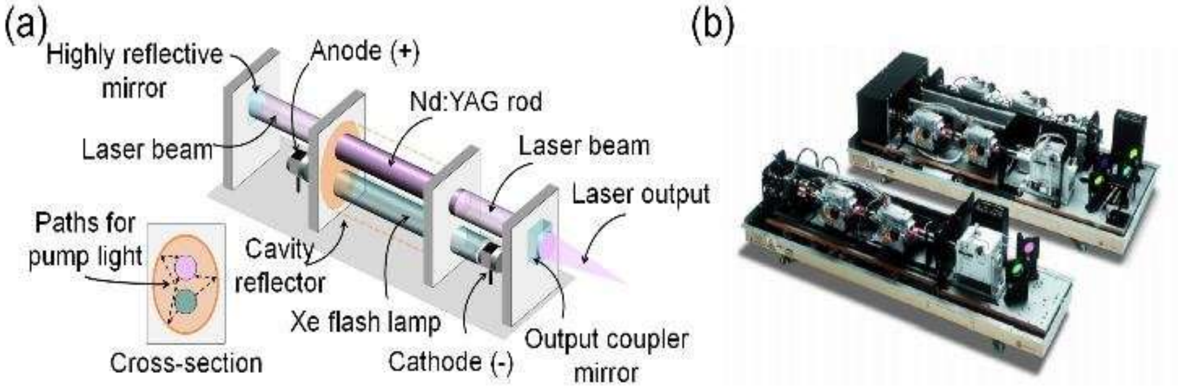
Nd: YAG lasers are used to remove skin cancers.

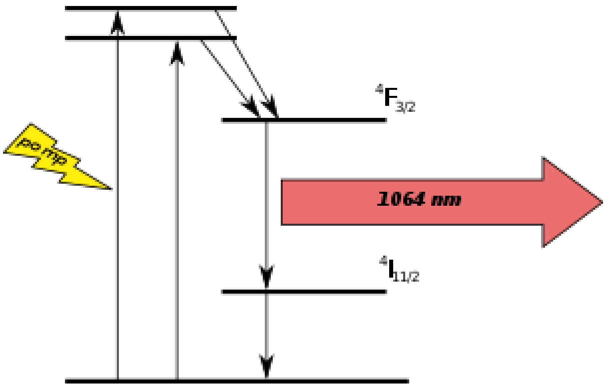
Manufacturing

Nd: YAG lasers are used for etching or marking a variety of plastics and metals.

Nd: YAG lasers are used for cutting and welding steel.

Laser etching





Energy level diagram of Nd: YAG Laser

Properties of Nd: YAG @ 25 °C (with 1% Nd doping)

- Formula: $Y_{2.97}Nd_{0.03}Al_5O_{12}$
- Weight of Nd: 0.725%
- Atoms of Nd per unit volume: 1.38×10^{20} /cm^3
- Charge state of Nd: 3^+
- Emission wavelength: 1064 nm
- Transition: $^4F_{3/2} \rightarrow {}^4I_{11/2}$
- Duration of fluorescence: 230 μs

Pockels cell

The Pockels cell thus acts as a *voltage-controlled Wave plate*. Pockels cells are the basic components of electro-optic modulators. and optical switches, used e.g., for Q-switching lasers and regenerative amplifier. They can also be used as sensors for electric voltages. Widely used for Q-switching, modulation, pulse picking and pulse slicing. Mostly used to control intense laser beams with high speed, precision, and repeatability.

Q-switch in laser

some its known as pulse formation or Q-spoiling, is a technique by which a laser can be made to produce a pulsed output beam. (on & off type)as a switch.

the large value of population inversion, the amplification provided by the gain medium is one round trip is very large as compared to the loss suffered in one round trip. Therefore, the power of the laser beam grows very fast with every pass in the gain medium. As a result of the population inversion decrease quickly and consequently the power of laser beam decreases. Hence, a giant pulse is generated when the mirrors of the resonator or cavity are switched on suddenly. Under this condition, the Q factor of the resonator or cavity is switched from a low value to high value, and hence the technique is known as Q switching.

The energy whatever is stored is very high so that the shutter is opened rapidly to release the energy in the form of single short pulse called as giant pulse. After this the shutter closed automatically. Again the same procedure will continue. So this shutter is nothing but Pockels cell.

Output coupler

The partial reflector of laser beam. (Mean mirror)

Mode locking

Mode locking is a technique to generate Ultrashort pulses of light of a very short duration [of the order of the Pico sec or Femto sec] from a laser beam.
The basic principle of mode-locking techniques is to induce a fixed phase relationship between the long longitudinal modes of the resonant cavity (intense pulses of light are produced in other words) of the laser. Then, the laser is known as **phase-locked** or **mode-locked**.