

RUBY LASER

Ruby laser definition

A ruby laser is a solid-state laser that uses the synthetic ruby crystal as its laser medium. Ruby laser is the first successful laser developed by Maiman in 1960.

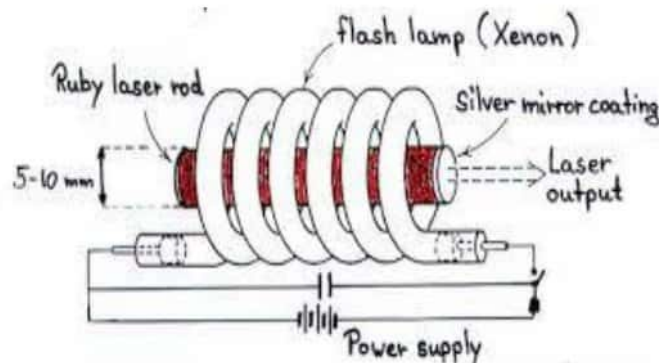
Ruby laser is one of the few solid-state lasers that produce visible light. It emits deep red light of wavelength 694.3 nm.

Construction of ruby laser

A ruby laser consists of three important elements: laser medium, the pump source, and the optical resonator.

Laser medium or gain medium in ruby laser

In a ruby laser, a single crystal of ruby ($\text{Al}_2\text{O}_3 : \text{Cr}^{3+}$) in the form of cylinder acts as a laser medium or active medium. The laser medium (ruby) in the ruby laser is made of the host of sapphire (Al_2O_3) which is doped with small amounts of chromium ions (Cr^{3+}). The ruby has good thermal properties.



Pump source or energy source in ruby laser

The pump source is the element of a ruby laser system that provides energy to the laser medium. In a ruby laser, population inversion is required to achieve

laser emission. Population inversion is the process of achieving the greater population of higher energy state than the lower energy state. In order to achieve population inversion, we need to supply energy to the laser medium (ruby).

In a ruby laser, we use flashtube as the energy source or pump source. The flashtube supplies energy to the laser medium (ruby). When lower energy state electrons in the laser medium gain sufficient energy from the flashtube, they jump into the higher energy state or excited state.

Optical resonator

The ends of the cylindrical ruby rod are flat and parallel. The cylindrical ruby rod is placed between two mirrors. The optical coating is applied to both the mirrors. The process of depositing thin layers of metals on glass substrates to make mirror surfaces is called silvering. Each mirror is coated or silvered differently.

At one end of the rod, the mirror is fully silvered whereas, at another end, the mirror is partially silvered.

The fully silvered mirror will completely reflect the light whereas the partially silvered mirror will reflect most part of the light but allows a small portion of light through it to produce output laser light.

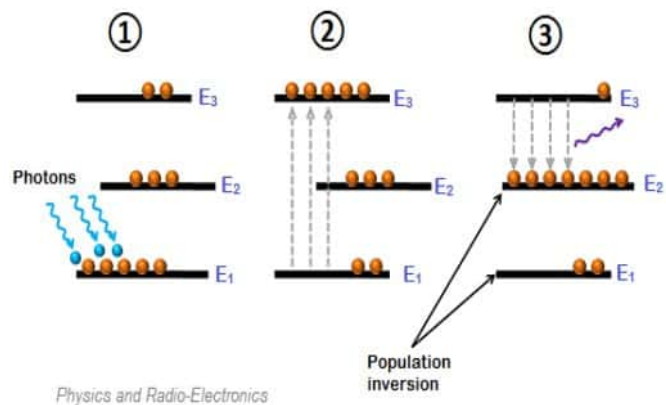
Working of ruby laser

The ruby laser is a three level solid-state laser. In a ruby laser, optical pumping technique is used to supply energy to the laser medium. Optical pumping is a technique in which light is used as energy source to raise electrons from lower energy level to the higher energy level.

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

We assume that the energy levels will be $E_1 < E_2 < E_3$. The energy level E_1 is known as ground state or lower energy state, the energy level E_2 is known as metastable state, and the energy level E_3 is known as pump state.

Let us assume that initially most of the electrons are in the lower energy state (E_1) and only a tiny number of electrons are in the excited states (E_2 and E_3)

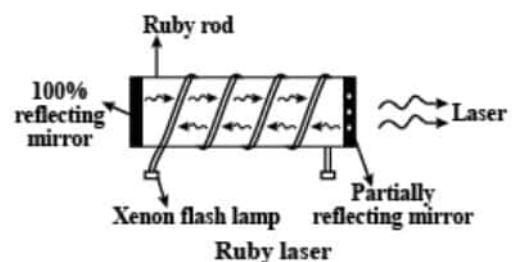


When light energy is supplied to the laser medium (ruby), the electrons in the lower energy state or ground state (E_1) gains enough energy and jumps into the pump state (E_3).

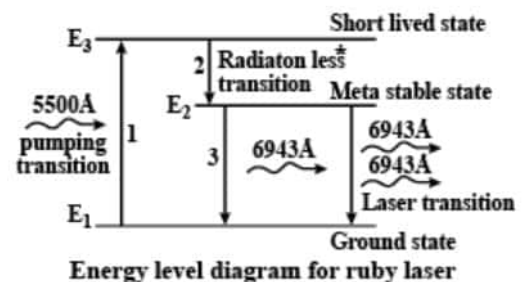
The lifetime of pump state E_3 is very small (10^{-8} sec) so the electrons in the pump state do not stay for long period. After a short period, they fall into the metastable state E_2 by releasing radiationless energy. The lifetime of metastable state E_2 is 10^{-3} sec which is much greater than the lifetime of pump state E_3 . Therefore, the electrons reach E_2 much faster than they leave E_2 . This results in an increase in the number of electrons in the metastable state E_2 and hence population inversion is achieved.

After some period, the electrons in the metastable state E_2 falls into the lower energy state E_1 by releasing energy in the form of photons. This is called spontaneous emission of radiation.

When the emitted photon interacts with the electron in the metastable state, it forcefully makes that electron fall into the ground state E_1 . As a result, two photons are emitted. This is called stimulated emission of radiation.



When these emitted photons again interacted with the metastable state electrons, then 4 photons are produced. Because of this continuous interaction with the electrons, millions of photons are



produced.

In an active medium (ruby), a process called spontaneous emission produces light. The light produced within the laser medium will bounce back and forth between the two mirrors. This stimulates other electrons to fall into the ground state by releasing light energy. This is called stimulated emission. Likewise, millions of electrons are stimulated to emit light. Thus, the light gain is achieved.

The amplified light escapes through the partially reflecting mirror to produce laser light.

Benefits or advantages of Ruby Laser

- ➔ They are economical.
- ➔ Beam diameter of ruby laser is comparatively less than CO₂ laser type.
- ➔ Output power of ruby laser is not as less as He-Ne laser type.
- ➔ Ruby is in solid form and hence there is no chance of wasting material of the active medium.
- ➔ Due to their low output power, they are known as class-I lasers. Hence they are used as toys for children. They can also be used as decoration piece and artistic display.

Disadvantages of Ruby Laser

- As the terminus of laser action is the ground state, it is difficult to maintain the population inversion. This fact results in ruby laser's low efficiency.
- The ruby laser requires high power pumping source.
- The laser output is not continuous but occurs in the form of pulses of microsecond duration.
- The defects due to crystalline imperfection are also present in ruby laser.

Helium-Neon laser

Helium-Neon laser definition

Helium-Neon laser is a type of gas laser in which a mixture of helium and neon gas is used as a gain medium. Helium-Neon laser is also known as He-Ne laser.

What is a gas laser?

A gas laser is a type of laser in which a mixture of gas is used as the active medium or laser medium. Gas lasers are the most widely used lasers.

Gas lasers range from the low power helium-neon lasers to the very high power carbon dioxide lasers. The helium-neon lasers are most commonly used in college laboratories whereas the carbon dioxide lasers are used in industrial applications.

The main advantage of gas lasers (eg: He-Ne lasers) over solid state lasers is that they are less prone to damage by overheating so they can be run continuously.

What is helium-neon laser?

At room temperature, a ruby laser will only emit short bursts of laser light, each laser pulse occurring after a flash of the pumping light. It would be better to have a laser that emits light continuously. Such a laser is called a continuous wave (CW) laser.

The helium-neon laser was the first continuous wave (CW) laser ever constructed. It was built in 1961 by Ali Javan, Bennett, and Herriott at Bell Telephone Laboratories.

Helium-neon lasers are the most widely used gas lasers. These lasers have many industrial and scientific uses and are often used in laboratory demonstrations of optics.

In He-Ne lasers, the optical pumping method is not used instead an electrical pumping method is used. The excitation of electrons in the He-Ne gas active medium is achieved by passing an electric current through the gas.

The helium-neon laser operates at a wavelength of 632.8 nanometers (nm), in the red portion of the visible spectrum.

Helium-neon laser construction

The helium-neon laser consists of three essential components:

- Pump source (high voltage power supply)
- Gain medium (laser glass tube or discharge glass tube)
- Resonating cavity

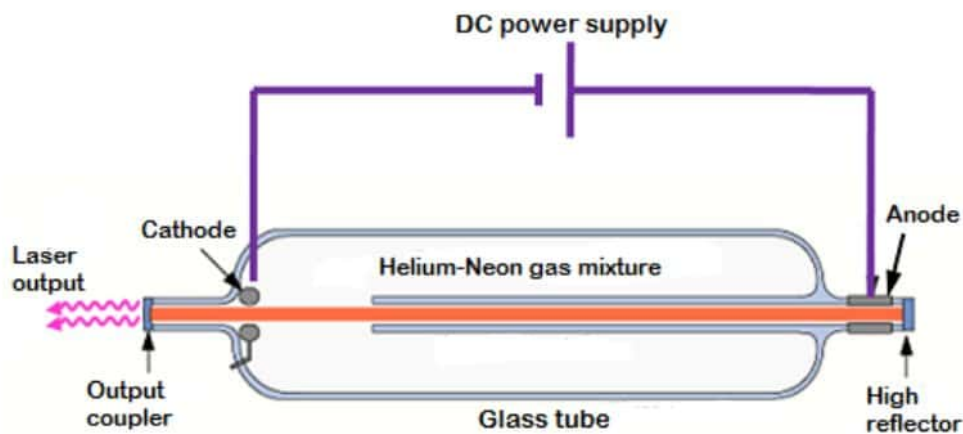
High voltage power supply or pump source

In order to produce the laser beam, it is essential to achieve population inversion. Population inversion is the process of achieving more electrons in the higher energy state as compared to the lower energy state.

In general, the lower energy state has more electrons than the higher energy state. However, after achieving population inversion, more electrons will remain in the higher energy state than the lower energy state.

In order to achieve population inversion, we need to supply energy to the gain medium or active medium. Different types of energy sources are used to supply energy to the gain medium.

In ruby lasers and Nd:YAG lasers, the light energy sources such as flashtubes or laser diodes are used as the pump source. However, in helium-neon lasers, light energy is not used as the pump source. In helium-neon lasers, a high voltage DC power supply is used as the pump source. A high voltage DC supplies electric current through the gas mixture of helium and neon.



Gain medium (discharge glass tube or glass envelope)

The gain medium of a helium-neon laser is made up of the mixture of helium and neon gas contained in a glass tube at low pressure. The partial pressure of helium is 1 mbar whereas that of neon is 0.1 mbar.

The gas mixture is mostly comprised of helium gas. Therefore, in order to achieve population inversion, we need to excite primarily the lower energy state electrons of the helium atoms.

In He-Ne laser, neon atoms are the active centers and have energy levels suitable for laser transitions while helium atoms help in exciting neon atoms.

Electrodes (anode and cathode) are provided in the glass tube to send the electric current through the gas mixture. These electrodes are connected to a DC power supply.

Resonating cavity

The glass tube (containing a mixture of helium and neon gas) is placed between two parallel mirrors. These two mirrors are silvered or optically coated.

Each mirror is silvered differently. The left side mirror is partially silvered and is known as output coupler whereas the right side mirror is fully silvered and is known as the high reflector or fully reflecting mirror.

The fully silvered mirror will completely reflect the light whereas the partially silvered mirror will reflect most part of the light but allows some part of the light to produce the laser beam.

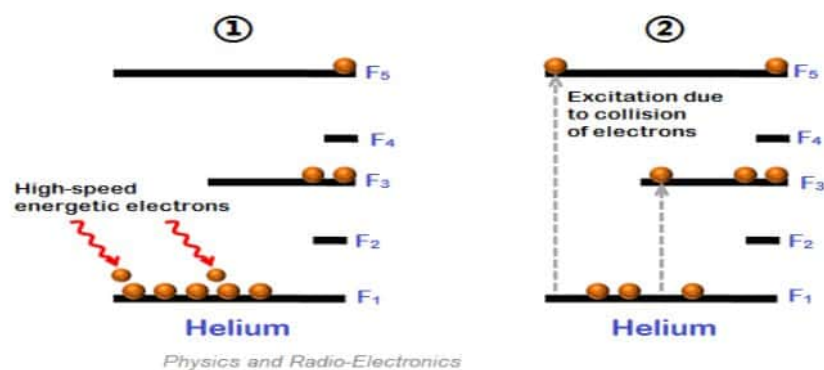
Working of helium-neon laser

In order to achieve population inversion, we need to supply energy to the gain medium. In helium-neon lasers, we use high voltage DC as the pump source. A high voltage DC produces energetic electrons that travel through the gas mixture.

The gas mixture in helium-neon laser is mostly comprised of helium atoms. Therefore, helium atoms observe most of the energy supplied by the high voltage DC.

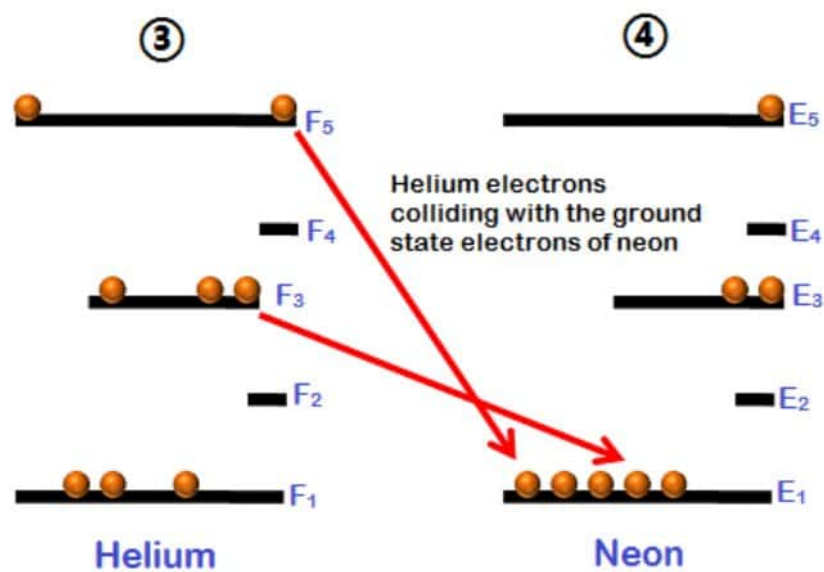
When the power is switched on, a high voltage of about 10 kV is applied across the gas mixture. This power is enough to excite the electrons in the gas mixture. The electrons produced in the process of discharge are accelerated between the electrodes (cathode and anode) through the gas mixture.

In the process of flowing through the gas, the energetic electrons transfer some of their energy to the helium atoms in the gas. As a result, the lower energy state electrons of the helium atoms gain enough energy and jumps into the excited states or metastable states. Let us assume that these metastable states are F_3 and F_5 .



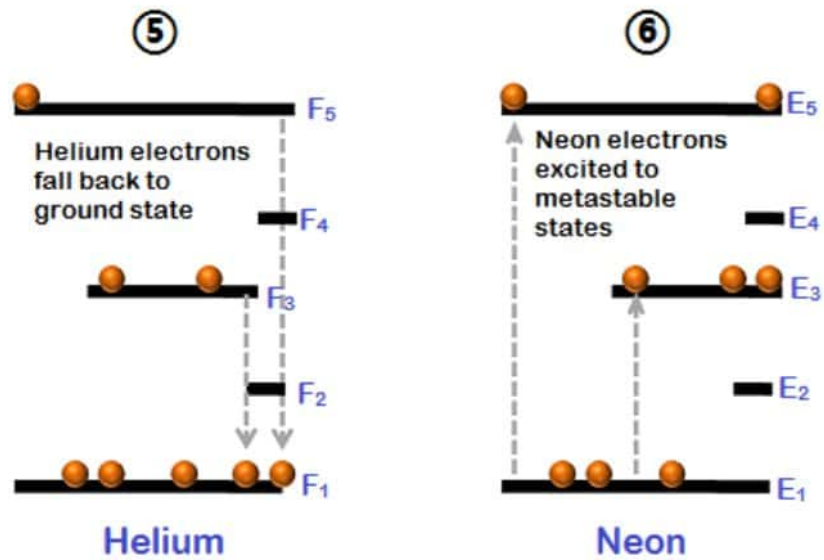
The metastable state electrons of the helium atoms cannot return to ground state by spontaneous emission. However, they can return to ground state by transferring their energy to the lower energy state electrons of the neon atoms.

The energy levels of some of the excited states of the neon atoms are identical to the energy levels of metastable states of the helium atoms. Let us assume that these identical energy states are $F_3 = E_3$ and $F_5 = E_5$. E_3 and E_5 are excited states or metastable states of neon atoms.



Physics and Radio-Electronics

Unlike the solid, a gas can move or flow between the electrodes. Hence, when the excited electrons of the helium atoms collide with the lower energy state electrons of the neon atoms, they transfer their energy to the neon atoms. As a result, the lower energy state electrons of the neon atoms gain enough energy from the helium atoms and jumps into the higher energy states or metastable states (E_3 and E_5) whereas the excited electrons of the helium atoms will fall into the ground state. Thus, helium atoms help neon atoms in achieving population inversion.

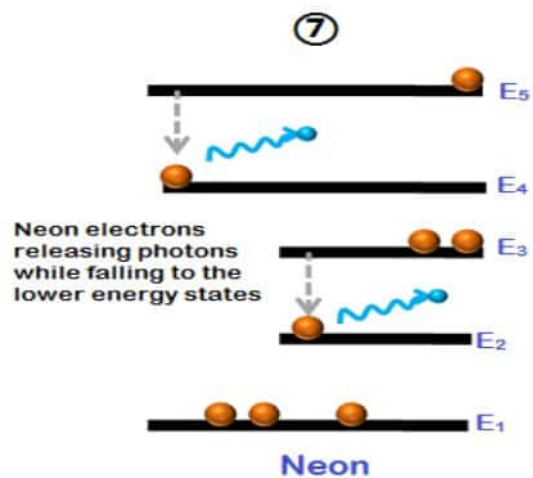


Physics and Radio-Electronics

Likewise, millions of ground state electrons of neon atoms are excited to the metastable states. The metastable states have the longer lifetime. Therefore, a large number of electrons will remain in the metastable states and hence population inversion is achieved.

After some period, the metastable states electrons (E_3 and E_5) of the neon atoms will spontaneously fall into the next lower energy states (E_2 and E_4) by releasing photons or red light. This is called spontaneous emission.

The neon excited electrons continue on to the ground state through radiative and nonradiative transitions. It is important for the continuous wave (CW) operation.



The light or photons emitted from the neon atoms will move back and forth between two mirrors until it stimulates other excited electrons of the neon atoms and causes them to emit light. Thus, optical gain is

achieved. This process of photon emission is called stimulated emission of radiation.

The light or photons emitted due to stimulated emission will escape through the partially reflecting mirror or output coupler to produce laser light.

Advantages of helium-neon laser

- Helium-neon laser emits laser light in the visible portion of the spectrum.
- High stability
- Low cost
- Operates without damage at higher temperatures

Disadvantages of helium-neon laser

- Low efficiency
- Low gain
- Helium-neon lasers are limited to low power tasks