



# **LASER APPLICATIONS**

## **Chapter Two**

### *Types of Laser*

- ✓ **Introduction**
- ✓ **Solid State Laser**
- ✓ **Gas State Laser**
- ✓ **Liquid Laser (Dye Laser)**
- ✓ **Semiconductor Laser**
- ✓ **Chemical Laser**
- ✓ **Laser Classifications**

**Assist.Prof. Dr. Sahar Naji Rashid**

## **CHAPTER TWO: TYPES OF LASER**

### **2-1) Introduction**

The type of laser and its beam characteristics are determined by the type of active material, the type of pump source, and the feedback method used. Lasers can be classified into three main types based on the active material: solid-state lasers, gas-state lasers, and liquid-state lasers. Chemical lasers and semiconductor lasers are also included. Although the active medium in a semiconductor laser is a solid, its fundamental operating principle differs from that of a solid-state laser. Similarly, chemical lasers differ from all these types in their energy pumping mechanism.

There are several pumping methods, such as using visible light, radio waves, electrical discharges, or chemical reactions, which are among the ways lasers are classified. Feedback methods depend on the type of active material. For solid-state lasers, this involves surface polishing, while for liquid-state or gas-state lasers, it involves using mirrors. The shape of the mirrors (flat or concave) also plays a role. Within each of these main types, there are subtypes that are distinguished by different characteristics such as the wavelength of light, the intensity of the emitted light, the cross-sectional area of the beam, the angle of divergence of the beam, whether the light is continuous or pulsed, the ability to control the rate and width of the pulses, as well as the size and weight of the laser device, the value of the voltage and current required to operate it, the conversion efficiency, and the expected operating life.

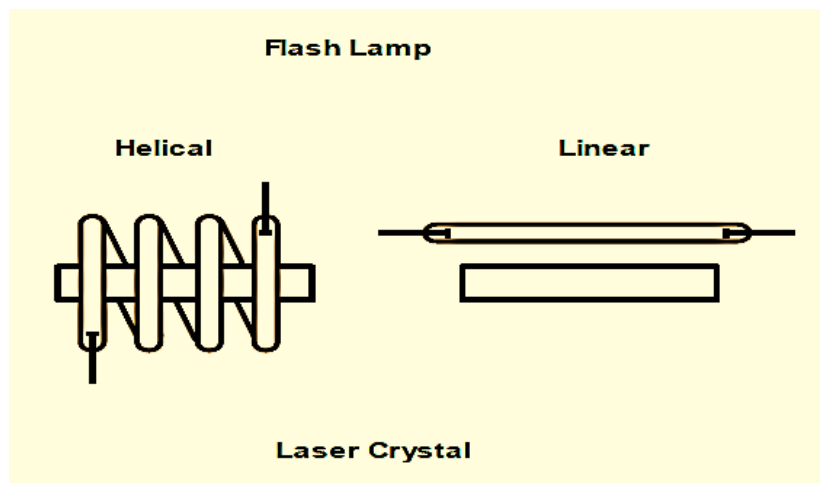
### **2-2) Solid State Laser**

A solid-state laser is a laser in which the active medium is either a dielectric crystal or glass. Active ions are introduced into the medium to generate the laser beam. Commonly used crystals include ruby, Nd: YAG, Nd: glass, alexandrite, and titanium-sapphire. A semiconductor laser can be considered a solid-state laser, but its active medium is a semiconductor structure (not a crystal) and is pumped by an electric current. The pump source in a solid-state laser is a flash lamp. A solid-state laser consists of the active medium, the pump source, the power supply, and other peripheral components.

- 1) **Active Medium:** It is a crystal of solid material into which active ions are introduced for the purpose of generating lasers.
- 2) **Pumping Source:** The most common method is using a flash lamp, where an electric voltage is applied across the lamp's terminals, producing light that is absorbed by the active medium crystal, causing it to become excited. Alternatively, the active medium crystal can be pumped using another laser beam, such as a semiconductor laser; this method is more efficient than using a flash lamp.
- 3) **Power Supply:** It is an electrical circuit that supplies the flashing lamp with the power required to operate it. The power supply can operate in pulsed or continuous mode, which affects the laser's operating pattern. There are simple power supply circuits and more complex circuits depending on the laser system's requirements, such as operating power and operating speed.
- 4) **Accessories:** These accessories are determined according to the laser system's needs, such as the cooling system, the mechanical stabilization system, and the optical systems for focusing and aiming, among others. The efficiency of the laser system ( $\eta$ ) is defined as the ratio between the output power ( $P_{out}$ ) of the laser system (laser power) and the input power ( $P_{in}$ ) (pumping power), as follows:

$$\eta = \frac{P_{out}}{P_{in}} \dots\dots\dots(2-1)$$

**The Flash Lamp:** a glass tube containing electrodes at both ends, filled with an inert gas (usually xenon or krypton). Flash lamps are manufactured in a linear or helical shape, as shown in Figure (2-1).



**Figure (2-1): Flash lamp in a solid state laser**

These flashlights have specific standard specifications regarding the wall thickness, internal diameter, length, and inert gas pressure inside the bulb. The electrodes in flashlights are made of metals that can withstand high temperatures and high currents. Both the type of material and the shape of the electrodes affect the flashlight's operation. Tungsten or tungsten alloys are commonly used for these electrodes. The glass casing of the flashlight must be transparent to allow the light emitted from the bulb to pass through to the active medium. The casing material must also withstand high temperatures and mechanical shocks. Quartz is the most commonly used type of glass in the manufacture of flash lamp casings for laser systems because it allows the passage of light between (200 and 4000 nm) and can withstand temperatures up to (1300 °C).

The relationship between the electrical discharge voltage (**V**) and the electrical discharge current (**i**) inside the flash lamp is as follows:

$$V = K_0 i^{1/2} \dots\dots\dots(2-2)$$

where **K<sub>0</sub>** is a constant called the impedance constant of the flash lamp, and its units ( $\Omega \text{ A}^{1/2}$ ). Its value is given as follows:

$$K_0 = K \frac{l}{d} \dots\dots\dots(2-3)$$

where **K<sub>0</sub>** is a constant that depends on the type of gas used inside the flash lamp, **l** represents the distance between the electrodes of the electrical discharge inside the flash lamp, and **d** is the internal diameter of the flash lamp. The value of **K<sub>0</sub>** is (1.27) for a xenon lamp at a pressure of (450 Torr). For other pressures, the relationship is different. As follows:

$$K_0 = 1.27 \left(\frac{P}{450}\right)^{0.2} \left(\frac{l}{d}\right) \dots\dots\dots(2-4)$$

**P** represents the gas pressure. However, in the case of using krypton gas, the relationship is as follows:

$$K_0 = 1.27 \left(\frac{P}{805}\right)^{0.2} \left(\frac{l}{d}\right) \dots\dots\dots(2-5)$$

The process of the voltage or electrical discharge current rising in a flash lamp from zero to its maximum value takes a specific time period called the rise time (**t<sub>r</sub>**), and it is given by the following relationship:

$$t_r = \sqrt{LC} \dots\dots\dots(2-6)$$

Where **L** represents the inductance of the coil and **C** is the capacitance of the charge capacitor. As for the total pulse time of the flash lamp (**t<sub>p</sub>**) it is given by the following relationship:

$$t_p = 3t_r = 3\sqrt{LC} \dots\dots\dots(2-7)$$

There are properties that must be present in the material for it to be an effective laser medium, which are low cost, high efficiency, good emission characteristics, a wide absorption bandwidth and a narrow emission (fluorescence) bandwidth, and resistance to mechanical and thermal operating conditions are all essential. Solid state lasers have very high power outputs because the concentration of active ions that produce the laser is very high ( $10^{22}$ – $10^{25}$   $\text{cm}^{-3}$ ), known as the doping ratio. In contrast, the concentration of active ions is typically only ( $10^{18}$ – $10^{23}$ ) in liquid and gaseous lasers. The three main functions of the crystal housing the active ions in solid-state lasers are: it provides a stable medium in which the active ions are distributed, which determines the power of the emitted laser beam; it determines the density of the active ions (doping ratio); and the type of crystal affects the wavelength of the emitted laser beam.

❖ **Eg.:** A flash lamp has an internal diameter of (10 mm) and a distance between the electrodes of (20 cm) and contains xenon gas at a pressure of (600 Torr). If the electrical discharge voltage at which the lamp operates is (3 KV), calculate the electrical discharge current, then calculate the total pulse time of the flash lamp if the capacitance of the charge capacitor is (10  $\mu\text{F}$ ) and the magnitude of the coil inductance is (0.1 H). Then repeat the calculations in the case of using krypton gas at a pressure of (1000 Torr).

❖ **Sol.:** We calculate the impedance characteristic constant for xenon gas:

$$K_o = 1.27 \left( \frac{P}{450} \right)^{0.2} \left( \frac{l}{d} \right) = 1.27 \left( \frac{600}{450} \right)^{0.2} \left( \frac{20}{1} \right) = 26.9 \Omega A^{1/2}$$

$$\therefore V = K_o i^{1/2}$$

$$\therefore i = \left( \frac{V}{K_o} \right)^2 = \frac{(3 \times 10^3)^2}{(26.9)^2} = 12.437 \text{ KA}$$

Then we calculate the total time of the lamp pulse:

$$t_p = 3t_r = 3\sqrt{LC} = 3\sqrt{10 \times 10^{-6} \times 0.1} = 3 \times 10^{-3} \text{ s} = 3 \text{ ms}$$

Then we calculate the impedance characteristic constant for krypton gas:

$$K_o = 1.27 \left( \frac{P}{805} \right)^{0.2} \left( \frac{l}{d} \right) = 1.27 \left( \frac{1000}{805} \right)^{0.2} \left( \frac{20}{1} \right) = 26.526 \Omega A^{1/2}$$

$$\therefore V = K_o i^{1/2}$$

$$\therefore i = \left( \frac{V}{K_o} \right)^2 = \frac{(3 \times 10^3)^2}{(26.526)^2} = 12.79 \text{ KA}$$

And we calculate the total time of the lamp pulse:

$$t_p = 3t_r = 3\sqrt{LC} = 3\sqrt{10 \times 10^{-6} \times 0.1} = 3 \times 10^{-3} \text{ s} = 3 \text{ ms}$$

The most important solid-state lasers are as follows:

- Ruby Laser:** Ruby was used in the first successful laser in 1960. Ruby is a naturally occurring gemstone, specifically aluminum oxide ( $\text{Al}_2\text{O}_3$ ) doped with chromium ions ( $\text{Cr}^{3+}$ ) at a doping rate of approximately (5 % wt.). Pumping is achieved using a flash lamp, and the laser operates in a three-level system, requiring very good cooling. This laser operates in a pulsed mode, with output wavelengths of (694.3 nm) and (692.9 nm), and can deliver power ranging from (10 to 50 mW) with a pulse duration of (10 to 20 ns).

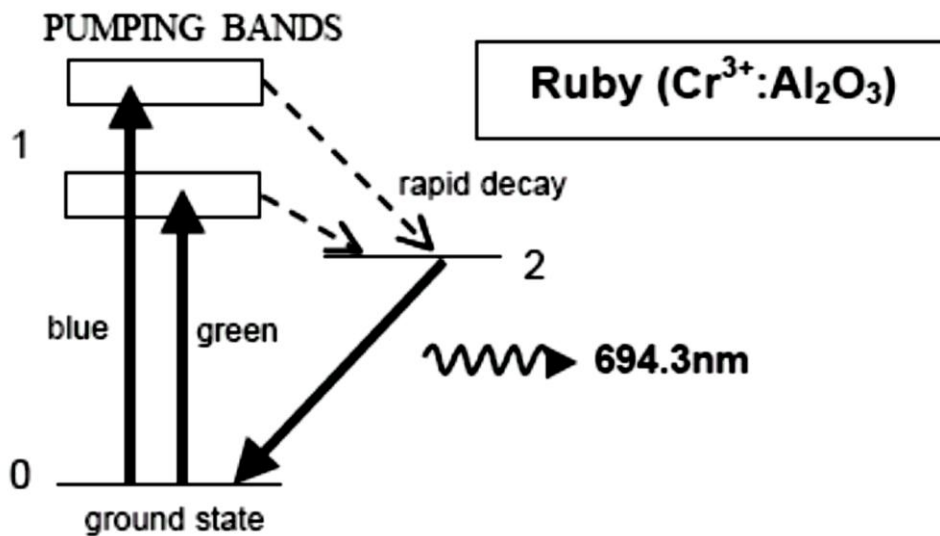


Figure (2-2): Three-level system of ruby laser

- Neodymium–YAG (Nd: YAG) Laser:** It is one of the most important types of lasers overall, and it was discovered in 1964. Its active medium is a purple YAG crystal, which is yttrium aluminum oxide ( $\text{Y}_3\text{Al}_5\text{O}_{12}$ ) doped with neodymium ions ( $\text{Nd}^{3+}$ ) at a doping concentration not exceeding (1.5 %). Pumping is achieved using a flash lamp or a semiconductor laser. This laser operates in a four-level system and requires good cooling. Its operating mode is continuous or pulsed. The most common wavelengths emitted by this laser are (1064 nm) and (532 nm), among others. The YAG crystal is characterized by high resistance to damage, high fracture toughness, and high optical quality.

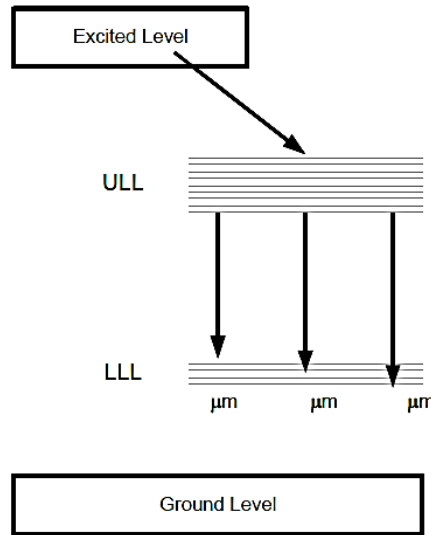


Figure (2-3): The four-level system of the Nd: YAG laser

- Neodymium–Glass Laser:** The active medium is glass doped with neodymium ions ( $\text{Nd}^{+3}$ ) at a doping ratio of up to (6 %). Pumping is done using a flash lamp or using a semiconductor laser. This laser operates in a four-level system and requires good cooling. Its operating mode is pulsed, and the wavelengths produced by this laser are (1400 nm), (1064 nm), and (900 nm).

The Nd: YAG and Nd: Glass lasers can be compared as follows:

Nd: YAG Laser	Nd: Glass laser
High resistance to damage	Lower resistance
High hardness against fracture	Less hardness
Ten times higher thermal conductivity	Lower thermal conductivity
Operates in continuous and pulsed modes	Operates in pulse mode only
Operates in a four-level system	Operates in a four-level system
Neodymium ions are the active ions	Neodymium ions are the active ions
Active ion concentration is approximately (1.5 %)	Active ion concentration up to (6 %)
Cannot be manufactured in large dimensions	Can be manufactured in large dimensions
Higher melting point	Lower melting point
Smaller emission line width	Larger emission line width
Higher gain	Lower gain
Narrow absorption band	Wide absorption band
Lower spontaneous emission rate	Higher spontaneous emission rate
Lower energy storage	Greater energy storage
Lower overall efficiency	Higher overall efficiency
Operates as an oscillator	Operates as an amplifier

- **Alexandrite Laser:** Discovered in 1973, its active medium is a  $\text{BeAl}_2\text{O}_4$  crystal doped with chromium ions ( $\text{Cr}^{+3}$ ). This laser can operate in both three-level and four-level systems. The output laser beam has a wavelength of (680 nm) when the system is operated in three-level mode, and a range of wavelengths of (700–820 nm) when operated in four-level mode.

### **2-3) Gas State Laser**

The energy levels of a gas are generally narrower than those of a solid, resulting in less pronounced spectral transitions between them. Since the gas pressure is typically low, gases are not pumped using lamps, which typically have a continuous spectrum, because the absorption band of the gas is narrow, making the pumping process inefficient. Gas can be pumped electrically by passing a high current (direct or pulsed) through the gas. Most gas lasers have a similar arrangement, with the gas contained in a tube of suitable diameter (from a few millimeters to a few centimeters). The length of the tube is determined by two windows at its end, each fixed to the tube end at an angle known as Brewster's angle. This angle reduces light losses caused by reflections at the tube end surface and also determines the polarization of the transmitted light.

A gas laser consists of the active medium, the pumping source (power supply), and auxiliary components. The active medium is a glass or ceramic tube containing a single gas, such as in argon, xenon, hydrogen, or nitrogen lasers, or a mixture of two gases, such as in helium-neon and hydrogen fluoride, xenon chloride lasers, or a mixture of more than two gases such as  $\text{CO}_2:\text{N}_2:\text{He}$  lasers. This type uses a pumping source that converts electrical energy into two electrodes in the tube (anode and cathode) containing the gas or gases. This causes an electrical discharge (plasma generation), generating radiation and producing the laser. The discharge tube can be cooled by passing water or cold air around it, or by pumping the gases at high speed into the tube. The gas laser mirrors are usually attached to the discharge tube but can also be detached.

The different types of gas lasers are sometimes classified according to the composition of the gas used as the active medium for the laser's operation, including neutral atom lasers, positive ion lasers, and molecular gas lasers.

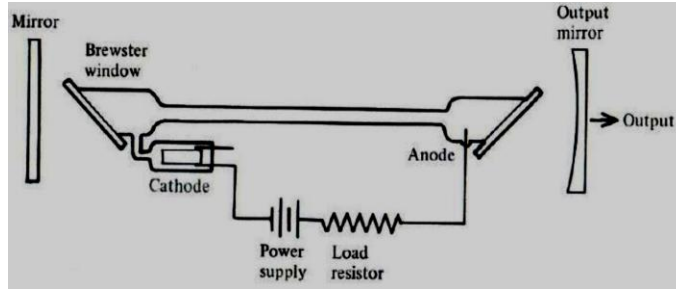


Figure (2-4): Simplified model of gas laser assembly

### 1) Atomic Gas Laser

It is also called a neutral atom laser, where the active medium is a monatomic gas. This group includes rare gas lasers and another group of metal vapor lasers, such as the (He-Ne) laser and the (He-Cd) laser.

- He-Ne Laser:** This laser is important because it is inexpensive, versatile, operates continuously, and is safe to use. The active medium is a mixture of helium (He) and neon (Ne) gases contained in a glass tube (10–80 cm) long and (2–10 mm) in diameter, under a pressure of (8–12 Torr). The power supply is small because this system requires little electrical power to operate. The wavelength of the resulting laser is (632.8 nm).

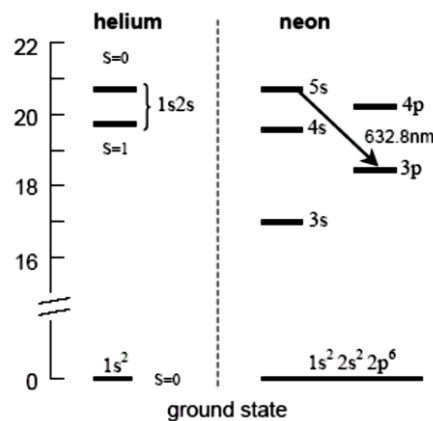


Figure (2-5): Energy level diagram for a He-Ne laser

### 2) Ionized Gas Laser

The active medium in this laser is an ionized gas or a metal vapor whose atoms are ionized. This means that a slight stretching of the energy scale of the material's atom's energy level diagram occurs; that is, the distance between the energy levels of the ionized atom is slightly greater than that of the same neutral atom.

This causes a shortening of the wavelength of the emitted spectral lines, meaning that the spectrum of the ionized atom shifts slightly from the atomic spectrum towards visible or ultraviolet radiation. The current density required to operate an ion gas laser is much higher than that required for an atomic gas laser, and it is also less efficient than an atomic gas laser. This field of lasers includes two groups: rare-gase ion lasers and metal ion lasers.

- **Argon Gas Laser:** The active medium is ionized argon gas. The upper stage of the laser beam in this type of laser is qualified in two steps, i.e., through two successive collisions with electrons generated by the electrical discharge. The first collision ionizes the atom, and the second excites the ion. For this reason, a high discharge current density is required to complete the pumping process. This system is cooled by water. The construction of an argon ion laser differs from that of a He-Ne laser due to the high pumping current density and the resulting high temperature in the tube.

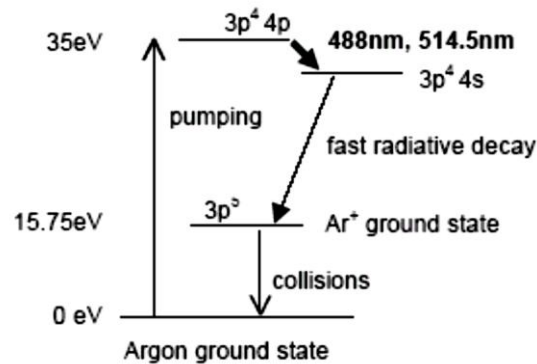


Figure (2-6): Main energy level diagram of argon ion laser

The argon laser ( $\text{Ar}^+$ ) is the most common in this group, especially in atomic research laboratories. Another commonly used type is the krypton ion laser ( $\text{Kr}^+$ ), well known in atomic physics research for its deep red color at a wavelength of (647.1 nm). It also includes other lines of less intensity and shorter wavelength.

### 3) Molecular Gas Laser

Laser action occurs between different energy levels of a molecule, and spectral transitions can occur between two of these levels. Based on this, different types of molecular gas lasers are classified. The first type involves transitions between vibrational and rotational levels belonging to a single electronic state.

The energy difference between corresponding levels produces laser transitions in the far-infrared range. The most important of these types is the widely used carbon dioxide (CO<sub>2</sub>) laser.

- CO<sub>2</sub> Laser:** The active medium is a mixture of carbon dioxide, nitrogen, and helium gases in specific proportions. To increase the efficiency of this laser, nitrogen and helium gases are added. The mixture is placed in a glass tube containing two electrodes (the cathode and the anode). An electric voltage is applied to the gas mixture between the electrodes, generating laser light from the CO<sub>2</sub> gas. The role of nitrogen (N<sub>2</sub>) is to improve the pumping process, and the role of helium (He) is to cool the CO<sub>2</sub> gas; therefore, this laser is called a CO<sub>2</sub> laser. This laser can operate in continuous or pulsed mode and produces very high power output. It is used in numerous fields and is one of the most widely used types of lasers. The efficiency of this laser reaches approximately (30 %), which is high compared to other types of lasers. This laser emits a range of wavelengths between (9.2 and 10.8 μm), but the strongest wavelength is (10.6 μm).

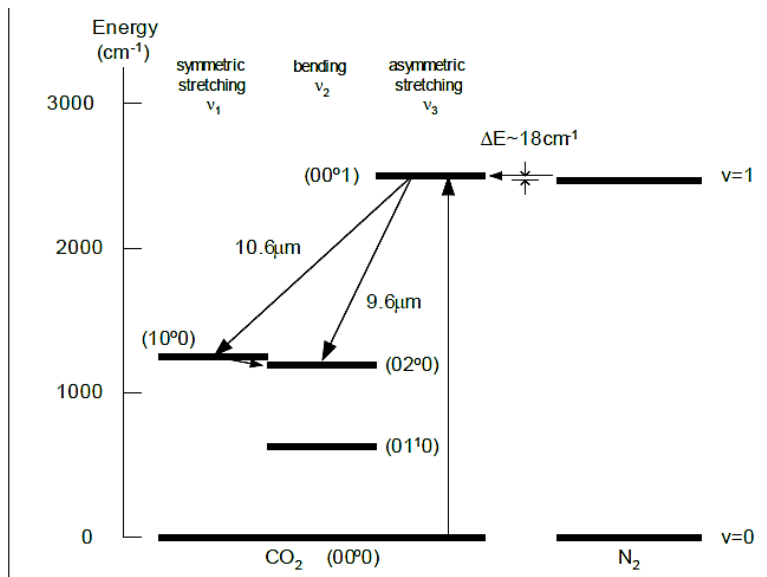


Figure (2-7): Energy level diagram for CO<sub>2</sub> laser

There are six types of this laser:

- ✓ Longitudinal-Flow Axial-Discharge CO<sub>2</sub> Laser.
- ✓ Fast Flow CO<sub>2</sub> Laser.
- ✓ Sealed-off CO<sub>2</sub> Laser.
- ✓ TE CO<sub>2</sub> Laser.
- ✓ TEA CO<sub>2</sub> Laser.
- ✓ Dynamic Gas CO<sub>2</sub> Laser.

- Nitrogen Laser:** The active medium consists of nitrogen gas molecules ( $N_2$ ) in a glass tube containing two electrodes (cathode and anode). An electric potential is applied to the gas between the electrodes, generating a laser. This laser operates only in pulsed mode and produces very low power. The wavelength of this laser beam is (337 nm), and it also has wavelengths in the infrared range. The nitrogen laser is a three-level laser, where the laser is directly pumped with electrons using sufficient energy to excite the gas electrons to higher energy levels.
- Excimer Laser:** This laser is produced by spectral transitions between electronic energy levels and is given a special name: excimer laser or stimulated binary molecule laser. An excimer is a molecule in an excited state consisting of the bonding of two atoms. This molecule cannot exist in its ground state. If the excited molecule decays to its ground state, it immediately dissociates into its two constituent atoms, such as the bonding of a noble gas atom (Ar, Xe, Cr) with a halogen atom (Cl, F). In this case, the lowest energy level of such a transition, belonging to the excimer molecule, is empty, resulting in the inverse distribution. Pumping is achieved either optically or using an electrical discharge.

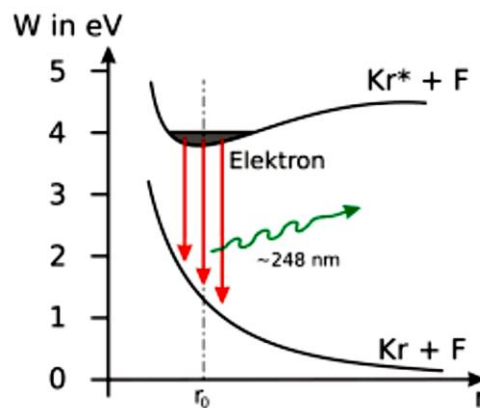
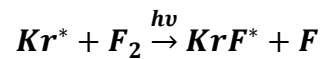
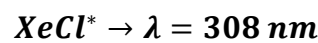
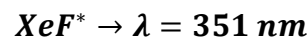
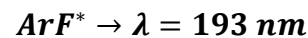
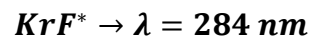


Figure (2-8): Diagram of oscillatory energy levels for an excimer laser



### **2-4) Liquid State Laser (Dye Laser)**

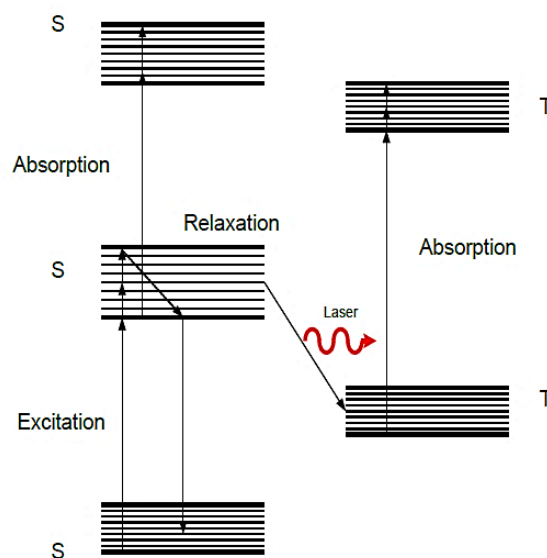
Liquid lasers differ from both solid state and gas lasers in several ways. The challenge with solid-state lasers lies in preparing the crystal, which must be highly homogeneous and have a specific concentration of active ions. Its properties cannot be altered by changing the concentration of the active material. Furthermore, there is a risk of crystal damage due to the high temperatures it may be exposed to during operation. Gas lasers, on the other hand, do not contain a high concentration of active atoms or molecules due to their low density. Therefore, liquids or solutions of various materials were chosen. Liquids contain a high concentration of active atoms or molecules whose concentration can be easily changed. Moreover, preparing the active liquid is simple, inexpensive, and straightforward.

Like other types of lasers, dye lasers consist of the active medium, a pumping source, a power supply, and auxiliary components. The active medium is an organic dye dissolved in a suitable solution such as water, ethyl alcohol, or other similar substances. The pumping source uses a flash lamp, as in solid state lasers. Alternatively, the active medium can be pumped using a different laser beam, such as a copper vapor laser. This latter method is more efficient than flash lamp pumping. The power supply and associated components are as described for solid state lasers. Many organic materials can be used as active laser media when dissolved. One example is dye lasers (a solution of a specific organic dye in a solvent, such as ethyl alcohol, methyl alcohol, or water, forms an active medium for liquid lasers and is called a dye laser). This type was discovered in 1965 by Sorokin and his team during their experiments to find a dye solution that could be used as a saturable absorbent in quality control processes. Dye lasers are typically classified into groups based on the wavelength of the radiation they emit. Each group emits a specific range of wavelengths, generally between (0.4 and 1  $\mu\text{m}$ ).

Some of the most prominent types of dye lasers include:

- ✓ Rhodamine (R6G) 6G dye laser, emitting in the (570–610 nm) range.
- ✓ Rhodamine (RB) B dye laser, emitting in the (605–635 nm) range.
- ✓ Coumarin dye laser, emitting in the (400–575 nm) range.
- ✓ Polymethane dye laser, emitting in the (710–950 nm) range.

Because the wavelength of this type of laser can be easily tuned across a considerable range of wavelengths, dye lasers have played a significant role in many applications, contributing to their continuous development. Among the most important of these fields are spectroscopy, photochemistry, and isotope separation. Organic dye molecules are large and complex, soluble in certain known solvents, and possess high absorption capacity across a broad spectrum within the visible and violet portions of the incident light. For this reason, solutions of these materials are excited by optical pumping using flash lamps or solid-state lasers. The light emitted from these solutions covers a relatively wide spectral range, depending on the solvent and the dye concentration. The emission spectrum is slightly shifted from the absorption spectrum towards longer wavelengths.



**Figure (2-9): Energy level chart of dye laser**

The advantages of liquid-state lasers can be summarized as follows:

- 1- The ability to obtain a broad spectrum of laser wavelengths, a process known as tuning.
- 2- The ease of preparing the active medium (dissolving the dye in the solution).
- 3- The ability to easily change the dye concentration (decreasing it by diluting the solution or increasing it by concentrating the solution).
- 4- The absence of crystalline defects.
- 5- The ease of cooling through agitation of the solution.

The disadvantages of liquid-state lasers include:

- 1- Instability due to fluid movement.
- 2- The solvent can prevent laser generation.
- 3- They are highly sensitive to heat.
- 4- The dye degrades upon exposure to light.

## **2-5) Semiconductor Laser**

This type of laser was discovered in 1961 and is considered a solid state laser because the active medium is a solid material. However, it is not a crystal doped with active ions, but rather a composite of donor (n-type) and acceptor (p-type) semiconductor materials. The conduction beam represents the upper laser plane, while the valence and equivalence beams represent the lower laser plane. Pumping is achieved through an electric current that moves electrons and holes between these two beams.

A semiconductor is a crystalline solid material in which individual atoms form a periodic lattice. Its electrical conductivity is much lower than that of metals. It differs from the ionic solid crystals used in solid-state lasers in how energy levels are represented, and consequently, in the pumping mechanism and the process of light emission. Energy levels in a semiconductor represent a general property of the crystal lattice as a whole; it is not possible to speak of an energy level for a single atom, molecule, or ion in a semiconductor, or for a doped ion in its crystal. Furthermore, semiconductor lasers differ from solid-state lasers in most of their physical and engineering properties, most notably in size. The largest dimension in a semiconductor laser does not exceed (1 mm).

Additionally, the physical properties of semiconductors, which are relevant to laser operation and change with external conditions such as pressure and temperature, differ from the properties and conditions under which ionic crystals or glass change in solid-state lasers. Gallium arsenide (GaAs) is the most commonly used semiconductor material as a base for manufacturing semiconductor lasers. This type of semiconductor laser emits light in the near-infrared region, around a wavelength of (870 nm).

The advantages of semiconductor lasers can be summarized as follows:

- 1- Small size.
- 2- Low cost.
- 3- Direct pumping using an electric current.
- 4- High efficiency, reaching up to (32 %).
- 5- The intensity of the emitted laser beam can be controlled by adjusting the pumping current.
- 6- The output laser can be tuned, meaning specific wavelengths can be obtained from the same device.

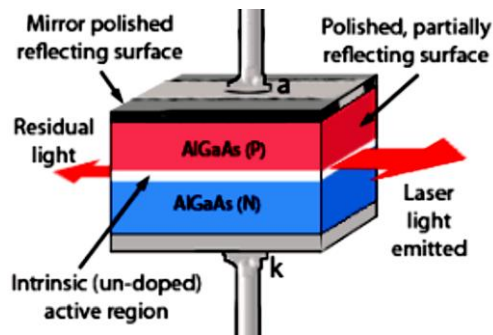


Figure (2-10): Semiconductor laser diagram

### 1) p-n Junction Laser

When a light wave (photon) with energy greater than the energy gap ( $E_g$ ) of a semiconductor material strikes it, the material becomes excited and rises from the ground state (valence band) to the excited state (conduction band), leaving behind holes. Electrons remain in the excited state for a specific period called the level lifetime, after which they return to the ground state, recombine with the holes, and emit radiation. This process is called spontaneous emission. If electrons are in the excited state and a photon with energy equal to the energy gap strikes them, the electrons are excited back to the ground state, recombine with the holes, and emit radiation. This process is called stimulated emission, which is a prerequisite for laser generation.

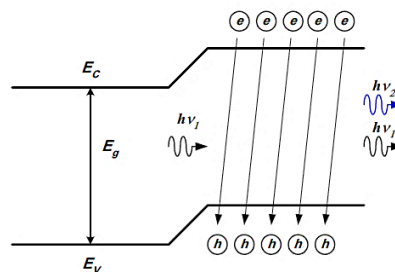


Figure (2-11): Energy level diagram of a semiconductor diode laser

This type of semiconductor diode laser operates in forward bias, meaning the positive terminal of the voltage source is connected to the positive (p-type) region and the negative terminal to the negative (n-type) region of the diode. The diode itself is the active region where the laser is generated and emitted. This type of semiconductor laser operates only in pulsed mode because it requires a high forward bias current and because the high temperature of the components can damage the laser. The emitted laser beam is multimode. The wavelength of the emitted laser beam depends on the energy gap of the semiconductor material, as follows:

$$\lambda = \frac{hc}{E_g} \dots\dots\dots(2-8)$$

❖ **Eg.:** Calculate the wavelength emitted by a gallium arsenide laser at room temperature where the energy gap value of gallium arsenide is (1.43 eV).

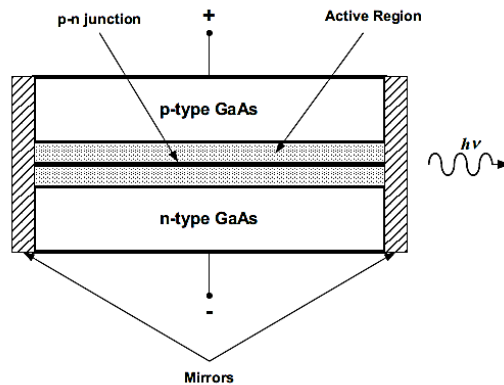
❖ **Sol.:**

$$\lambda = \frac{hc}{E_g} = \frac{6.63 \times 10^{-34} \text{ J.s} \times 3 \times 10^8 \text{ m/s}}{1.43 \text{ eV} \times 1.6 \times 10^{-19} \text{ J}} = 0.87 \text{ } \mu\text{m}$$

**2) Injection Laser**

In this type of semiconductor laser, charge carriers (electrons and holes) are injected into the active region to increase the concentration of emitted laser photons. It is superior to bidirectional forward-biased lasers in the following ways:

- 1- Higher output laser power (mW).
- 2- Narrower emission line width (9–10 m).
- 3- Greater modulation capability at higher frequencies (GHz).
- 4- Higher transmission efficiency within optical fibers.



**Figure (2-12): Injection laser diagram**

A semiconductor laser is pumped by another semiconductor laser with a shorter wavelength, such as pumping a (5.3 μm) InSb laser with a wavelength of (0.84 μm) by a (0.84 μm) GaAs laser. Alternatively, a fast beam of electrons can be used to strike the semiconductor material, generating electron-hole pairs that recombine to produce the laser beam.

**Efficiency calculations for semiconductor lasers:** The overall quantum efficiency ( $\eta_T$ ) of a semiconductor laser is calculated as follows:

$$\eta_T = \eta_D \left(1 - \frac{I_{th}}{I}\right) \dots\dots\dots(2-9)$$

where  $\eta_D$  represents the external quantum efficiency,  $I_{th}$  is the threshold current, and  $I$  is the injection current. The efficiency of the laser system ( $\eta_{ep}$ ) is given as follows:

$$\eta_{ep} = \eta_T \left(\frac{E_g}{V}\right) \times 100\% \dots\dots\dots(2-10)$$

where  $V$  is the applied voltage to the laser device.

❖ **Eg.:** Calculate the efficiency of a gallium arsenide semiconductor laser at room temperature where the energy gap value is (1.43 eV) if the threshold current value is ( $10^{-6}$  A) and the injection current value is four times the threshold current value, the external quantum efficiency is (90 %) and the applied voltage is (4 V).

❖ **Sol.:**

$$\eta_T = \eta_D \left(1 - \frac{I_{th}}{I}\right) = 0.9 \left(1 - \frac{I_{th}}{4I_{th}}\right) = 0.675$$

$$\eta_{ep} = \eta_T \left(\frac{E_g}{V}\right) \times 100\% = 0.675 \left(\frac{1.43}{4}\right) \times 100\% = 24.13$$

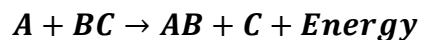
Other modern types of semiconductor lasers widely used in optical communication systems include:

- 1- Fabry-Perot (FP) laser.
- 2- Distributed Feed-Back (DFB) laser.
- 3- Brack Reflective Diffraction (DBR) laser.
- 4- Coupled Chamber (CCC) or (C3) laser.
- 5- Quantum Potential Well (QW) laser.
- 6- Multiple QW or MQW quantum potential well lasers.

CCC, DBR, and DFB lasers operate in single-mode mode, which is crucial in optical communication as it reduces noise and improves communication system efficiency. Quantum potential well lasers are also capable of producing a specific wavelength for the output laser beam, meaning they are tunable.

## 2-6) Chemical Laser

This type of laser does not describe the state of the active medium, but rather the method of pumping and reverse distribution. The chemical materials used in the reaction may be in a solid, liquid, or gaseous state, although gas is most commonly used in this type of laser. In a chemical laser, the active medium molecule is formed as a result of the chemical reaction between the materials. The energy released from the reaction excites these molecules, causing stimulated emission between their oscillatory levels. Therefore, most of the radiation is in the infrared range. The importance of this laser lies in the fact that its operation does not require complex electronic circuits or external sources for continuous energy supply, unlike other types of lasers. This laser can produce pulses with higher power than other types. The chemical reaction in this type of laser can be represented as follows:



The molecule **AB** produced from the reaction serves as the active medium for the laser, and the energy released from the reaction excites these molecules. Examples of such lasers include hydrogen fluoride (HF) lasers, hydrogen chloride (HCl) lasers, hydrogen bromide (HBr) lasers, and deuterium fluoride (DF) lasers. An energy source is required to initiate the reaction. The device's design depends on the type of reaction and the chemical materials involved.

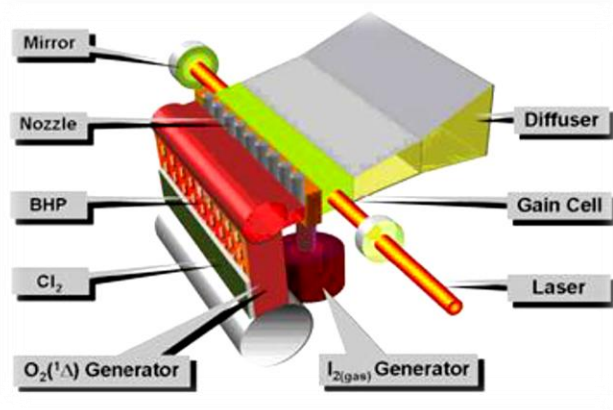


Figure (2-13): Chemical laser

## **2-7) Laser Classifications**

Lasers are classified into a range of categories based on their danger to living cells. When dealing with lasers, attention must be paid to the indicator that clarifies their classification.



**Figure (2-14): Laser warning sign**

Lasers are classified according to international safety standards based on their degree of harm to the human body. Most damage from laser use is not caused by the laser beam itself, but rather by the misuse of energy sources, particularly those used by large lasers. This includes high-voltage power generators or chemicals harmful to humans. While the damage from laser beams is most often to the user's eyes, it does not mean that other organs are safe. The damage that lasers can cause to the human eye depends on the following:

- 1- Duration of exposure to the laser beam.
- 2- Intensity of the laser beam.
- 3- Color of the laser (wavelength).

The maximum light intensity that the human eye can tolerate without damage is approximately ( $5 \mu\text{J}/\text{cm}^2$ ). Since the energy to which the human eye is exposed decreases as the distance from the laser source decreases, the safe distance is the minimum distance between the eye and the laser device that would prevent damage if the eye were directly exposed to a laser pulse. This distance varies depending on the following factors:

- 1- Atmospheric conditions.
- 2- Optical magnification devices used in vision devices.
- 3- Harmful reflections.
- 4- Laser beam focus.
- 5- Laser material type.
- 6- Laser beam type (pulsed or continuous).

Lasers are classified according to their degree of danger as follows:

- 1- **Class I**: This means the laser beam has low energy and does not pose a danger. It is safe as its energy does not exceed the maximum permissible radiation level for the eye.
- 2- **Class IA**: This classification indicates that the laser is harmful to the eye if one looks in the direction of the beam. The energy of lasers in this classification is (4 mW).
- 3- **Class II**: This classification refers to a visible light laser with low energy not exceeding (1 mW). This energy is safe, and the safety factor here is the eye's sensitivity to involuntary blinking upon direct exposure to this beam, i.e., after a quarter of a second.
- 4- **Class IIIA**: This laser has a medium power output (1-5 mW). Its danger to the eye lies in the risk of direct beam entry. Most pointers and toy lasers fall into this category.
- 5- **Class IIIB**: This laser has a power output above average.
- 6- **Class IV**: This category includes visible and invisible (infrared and ultraviolet) lasers with high power outputs, reaching up to (500 mW) for a continuous beam, while pulsed lasers have an energy output of approximately (10 J/cm<sup>2</sup>). These lasers pose a risk to the eyes and skin, and their use requires specialized equipment and safety precautions.
- 7- **Class V**: These are high-power lasers that emit visible and invisible beams. Care must be taken to avoid beam reflection, even from rough or opaque objects. This type of laser can cause a fire.