CO_2 Lasers

CO_2 Lasers

The CO_2 laser was one of the earliest gas lasers in the infrared range.

The principal wavelength bands center on 9.4 μm and 10.6 μm.

It was invented by Kumar Patel of Bell Laboratory in 1964.

CO_2 lasers are the highest-power continuous wave lasers. This laser gives pulsed energy of 10 KJ and CW power of the order of 100 KW.

They are highly efficient; the ratio of output power to pump power can be as large as 20%.

The amplifying medium

The amplifying medium consists of a gas discharge that can be air or water cooled.

The amplifying gas mixture within the discharge tube may consist of the following:

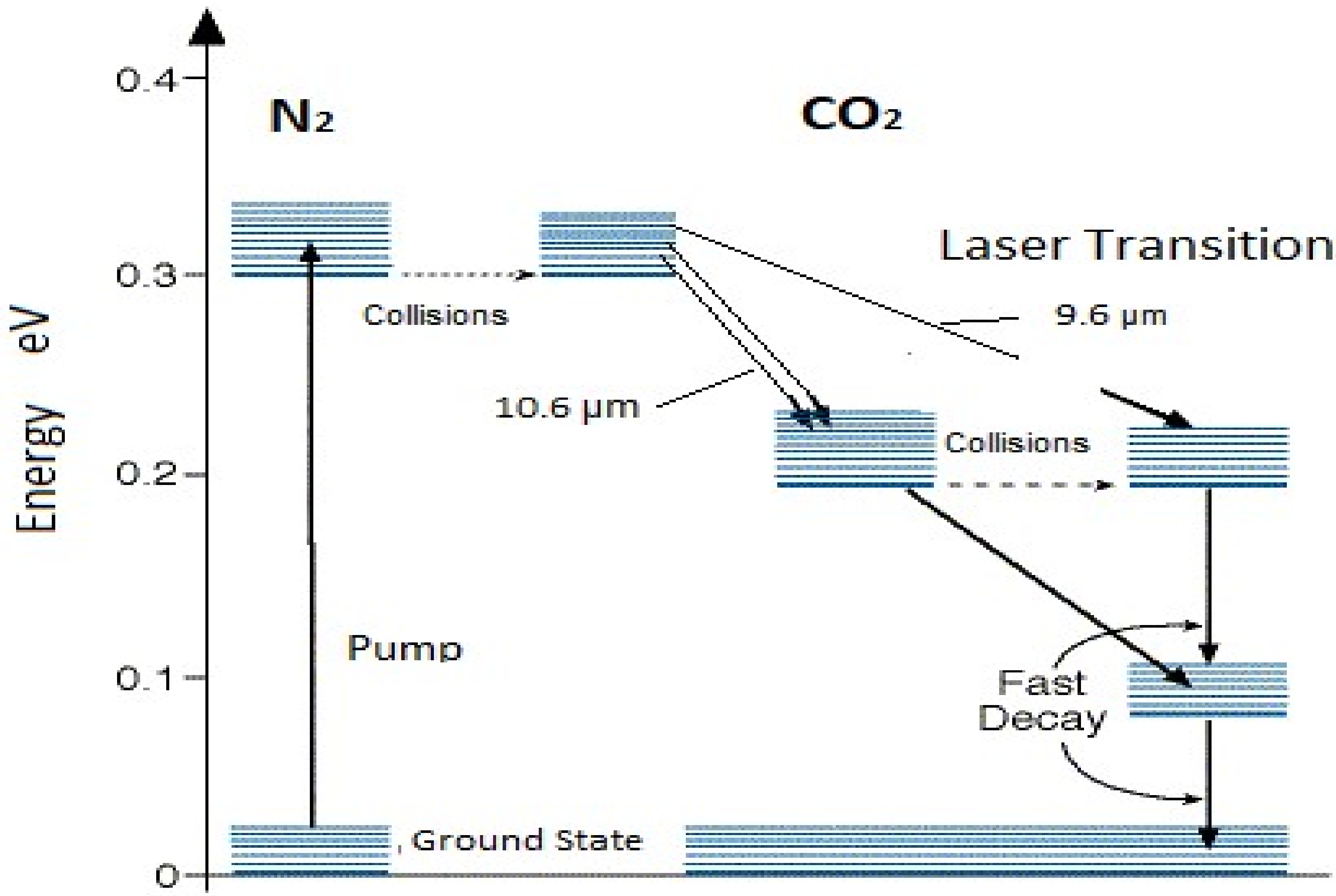
- 10–20% carbon dioxide (CO_2)
- 10–20% nitrogen (N_2)
- some percent hydrogen (H_2) and/or xenon (Xe), and
- the remainder of the gas mixture is helium (He).
- The specific proportions may vary according to the use of a laser.

The population inversion

Oscillations occur between two vibrational levels in CO_2 while efficiency is improved by N_2 and He. The population inversion in the laser is achieved by the following sequence:

The electron impact excites the vibrational mode quantum state of the nitrogen. Nitrogen is a homonuclear molecule, hence it cannot lose this energy by photon emission, and its excited vibrational modes are therefore metastable and relatively long-lived.

N_2 and CO_2 are nearly resonant; the total molecular energy differential is within 3 cm^{-1}. N_2 de-excites by transferring through collision its vibrational mode energy to the CO_2 molecule, causing the carbon dioxide to excite to its vibrational mode quantum state.



0.4
0.3
0.2
0.1
0
Energy eV
N2
CO2
Collisions
Laser Transitions
9.6 μm
10.6 μm
Collisions
Pump
Fast
Decay
, Ground State

The carbon dioxide molecules then make transition to their vibrational mode ground state by collision with cold helium atoms, thus maintaining population inversion.

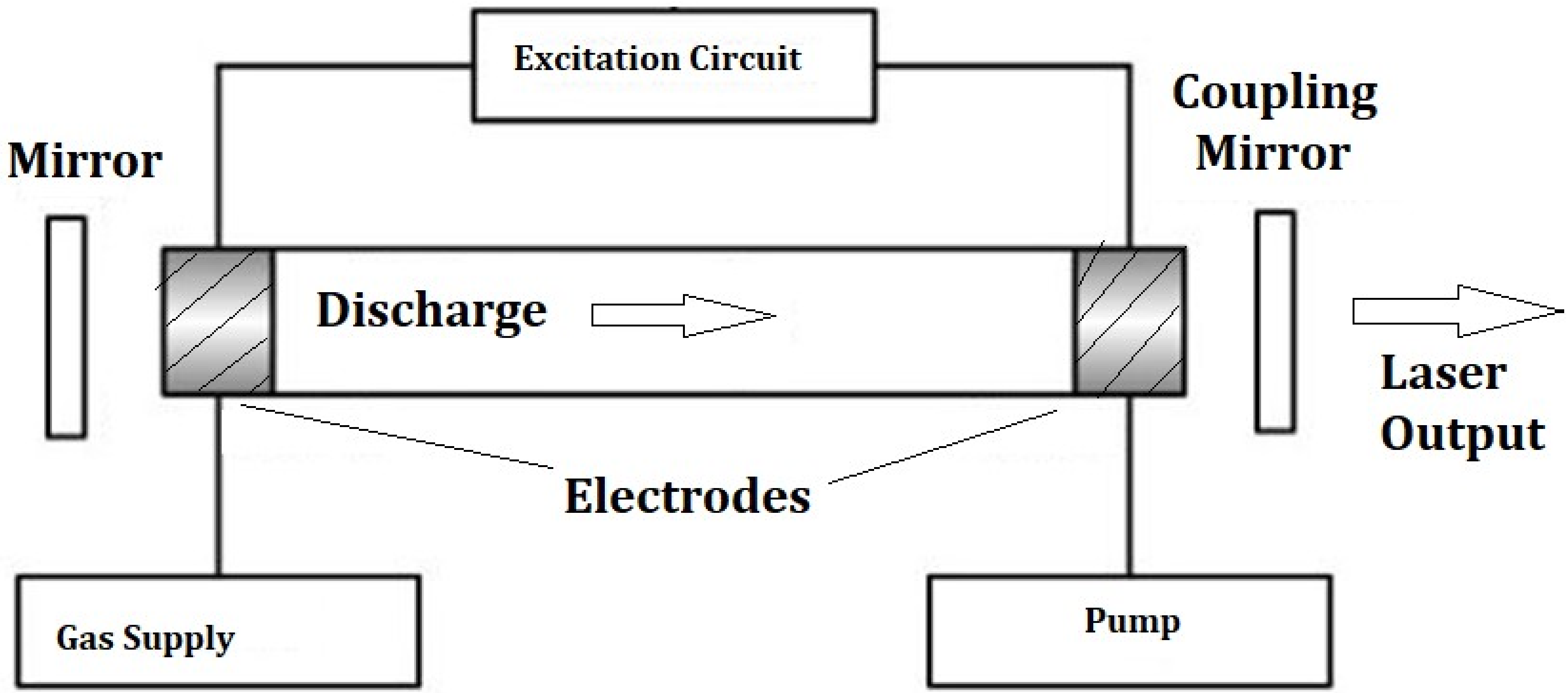
The resulting hot helium atoms must be cooled to sustain population inversion in the carbon dioxide molecules.

In sealed lasers, this takes place as the helium atoms strike the walls of the laser discharge tube.

In flow-through lasers, a continuous stream of CO_2 and nitrogen is excited by the plasma discharge and the hot gas mixture is exhausted from the resonator by pumps.

Longitudinally Excited CO_2 Lasers

These schemes work as conventional gas discharge lasers having long cylindrical, narrow glass enclosures with electrodes at both ends, which provides the current for excitation of the discharge. These lasers can operate in CW or pulsed modes. These tubes can be very long several meters. In some configurations, the enclosure of the discharge is sealed.



Longitudinal Excitation System

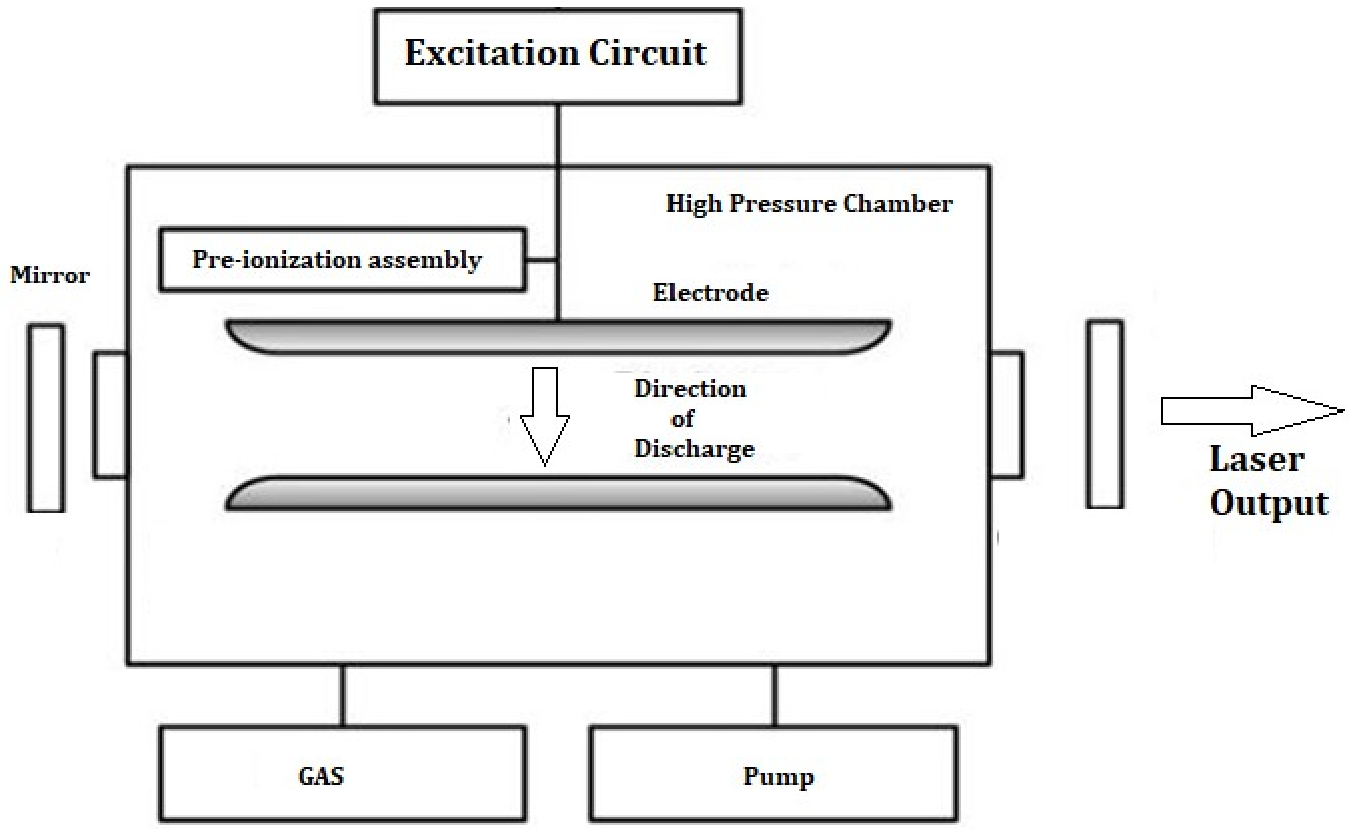
In the sealed tube, the CO_2 molecules can get disintegrated. The CO_2 molecules can break up and produce O_2, which can result in corrosion of the electrodes.

Water vapour is considered to improve the power output and operating life of a CO_2 laser. Water produces OH radical in the discharge which when combined with CO produces CO_2 and H. The enhanced output power of CO_2-N_2-He-H_2O (H_2) laser is believed to be due to the effective relaxation of the lower laser level by impact with H_2.

Sealed off lasers are compact and portable. The output spectrum is stable. Conservation of costly gases like He is also possible. However, they suffer the disadvantage of having smaller operating life time. The tube is required to be cooled with water to keep the temperature at about 20˚C because the output of the laser decreases as the walls of the tube becomes hotter.

Transverse Excited Laser at Atmospheric CO_2 Laser (TEA Laser)

In a TEA laser atmospheric pressure is maintained inside the discharge tube. The gas discharge is maintained by applying the electric field in the transverse direction.



Transverse Excitation System

The voltage required for transverse excitation is quite less since the gas discharge occurs at a critical electric field. The transverse dimensions are of the order of 10 mm which requires a voltage of about 0.12 KV. The discharge has to be maintained uniform all through the length of the discharge tube. The TEA lasers operate at a gas pressure of 1 atm or more. The energy output is a function of the volume of the gas.

Operating the laser at high pressure, with longitudinal discharge is very difficult because the operation demands very high voltage for initial ionization of the gas, moreover arching can occur within the discharge which may make the current to flow in random and irregular directions.

In a transverse discharge, the electrodes are placed parallel to each other, over the entire length of the discharge tube, separated by a few cm and the voltage is applied as shown in the Figure.

Before applying high voltage, a process of pre-ionization is done to ionize the region between the anode and cathode, which results in filling up of the area with electrons. The pre-ionization enables the discharge to be uniform through the entire electrode assembly and arcs due to generation of high current is avoided.

The process of pre-ionization involves flashing of UV rays from an array of pre-ionizing UV spark discharge. This ionizes a portion of the gas uniformly between the electrodes.

Since the CO_2 lasers operate in the infrared range, special materials are needed for their construction.

The mirrors are silvered, windows and lenses are made of either germanium or zinc selenide. For high power applications, gold mirrors and zinc selenide windows and lenses are preferred. Diamond windows and lenses are also used.

Diamond windows are very expensive, but their high thermal conductivity and hardness make them useful in rough environments and high-power applications. Optical elements made of diamond can even be sand blasted without losing their optical properties. Historically, lenses and windows were made out of inexpensive salt (sodium chloride or potassium chloride) but these lenses and windows degraded on exposure to atmospheric humidity.

The basic form of a CO_2 laser consists of a gas discharge having a perfect reflector at one end, a partially reflecting mirror at the output end. The second mirror acts as laser output coupling device.

The CO_2 laser operated on continuous wave (CW) mode may give powers from few milliwatts (mW) to hundreds of kilowatts (kW).

If the CO_2 laser is Q-switched by means of an electro optic modulator or an acousto-optice modulator we may have peak powers of up to giga watts (GW).

Applications

- Due to their high power levels and reasonable cost, CO_2 lasers are commonly used in material processing applications of cutting and welding, particularly for cutting die boards, metals, plastic, etc, welding metals such as copper, aluminum or stainless steel, and laser marking of different materials. The lower power level lasers are used for engraving.

- Carbon dioxide lasers have become useful in surgical procedures as water that makes up the most biological tissue absorbs the infra range frequency of light. CO2 lasers are often used in laser surgery and skin resurfacing; the laser facelift involves vaporizing the skin to promote collagen formation).

•The common plastic poly methyl methacrylate (PMMA) absorbs IR light in the 2.8–25 µm wavelength band, so CO_2 lasers have been used recently for fabricating microfluidic devices from it, with channel widths of a few hundred micrometers.

•Since the atmosphere is quite transparent to infrared light, CO_2 lasers are also used for military range-finding using LIDAR techniques.

- CO_2 lasers are also used in spectroscopy and the SILEX process to enrich uranium. The SILEX process exposes a cold stream of a mixture of uranium hexafluoride (UF_6) molecules and a carrier gas to energy coming from a pulsed CO_2 laser operating at a wavelength of 10.8 µm and optically amplified to 16 µm, which is in the infrared region. The 16 µm wavelength laser preferentially excites the $^{235}UF_6$, creating a difference in the isotope ratios in a product stream, which is enriched in ^{235}U, and a tailings stream, which has an increased fraction of the more common ^{238}U.

Prof. Narendra Kumar Pandey
Department of Physics
University of Lucknow
Lucknow-226007
Email: profnarendrapandey137@gmail.com