

Carbondioxide laser

Carbon dioxide laser developed by Indian born American scientist Prof.C.K.N.Patel (Chandra Kumar Naranbhai Patel) at AT & T Bell laboratories,USA in the year 1963. It is a four-level laser, operates at

10.6 μm in the far IR region. It has a very high efficiency and is widely used for industrial drilling, cutting and welding. It is also used in medical surgery especially in cosmetic aspects. CO_2 laser is a molecular gas laser in which laser action is achieved by transitions between vibrational and rotational levels of molecules. Its construction is simple and the output of this laser is continuous. In the CO_2 molecular gas laser, transition takes place between the vibrational states of Carbon dioxide molecules.

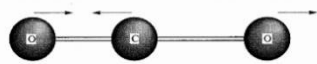
Vibrational energy level of carbon dioxide molecule

Carbon dioxide molecule has three different modes of vibrations shown below. The energies of associated with each of these vibrations are quantized in different sets.

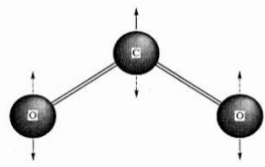
A



B



C



Symmetric stretching (a): In this mode, carbon atom remains stationary when the oxygen atoms oscillate simultaneously along the molecular. In this state CO_2 molecule will have energy that is intermediate as compared to that in the other two modes of vibrations (b and C). This state is referred in the spectroscopy as 100 state.

Asymmetric stretching (b): Here the two oxygen atoms move in one direction while the carbon atom moves in the opposite direction and vice versa. In this stretching mode the molecule possesses highest energy and this state is represented as 001 state.

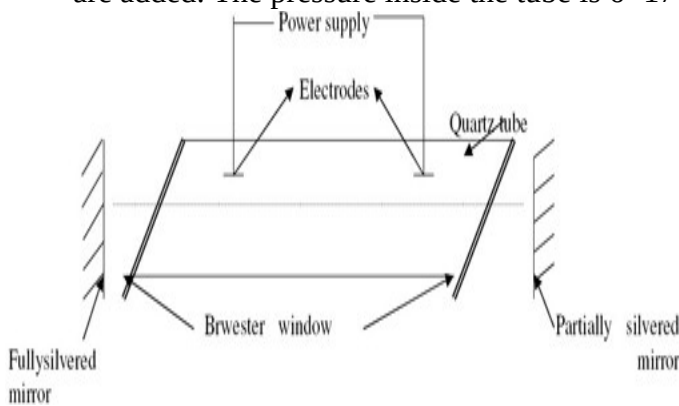
Bending mode (c): In bending mode, all the three atoms oscillate normal to the molecular axis. While vibrating, the two oxygen atoms pull together in one direction as the carbon atom is displaced in the opposite direction. This state is referred to a 010 state and the energy of the molecule in this state is the least among the three states of vibrations.

Note that 010 is the lowest excited state of bending mode. Next excited state in this mode is 020 state which is also involved in the laser transition in CO_2 laser. The energy of this state

is very close to the 100 state of symmetric stretching mode.

Construction of CO₂ laser:

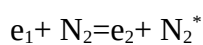
CO₂ laser consists of a quartz tube 5 m long and 2.5 cm in the diameter. This discharge tube is filled with gaseous mixture of CO₂ (active medium), Nitrogen (N₂) and Helium (He) gases in the ratio of 1:2:3 with suitable partial pressures. Sometimes traces of Hydrogen or water vapour are added. The pressure inside the tube is 6 - 17 torr.



The terminals of the discharge tubes are connected to a D.C power supply. The ends of the discharge tube are fitted with NaCl Brewster windows so that the laser light generated will be polarized. The optically plane mirrors are fixed on either side of the tube normal to its axis as shown in the figure. One of the mirrors is fully silvered and can reflect all the incident light whereas the other one is partially silvered to get polarized laser beam output.

Working:

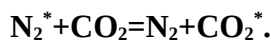
When a suitable voltage is applied across the two electrodes, a glow discharge of the gases is initiated in the tube. During discharge the free electrons from gas are accelerated towards positive electrode. These free electrons collide with the N₂ molecules and hence N₂ molecules are raised to the first vibrational level which is a metastable state designated as $v=1$ as shown in energy level diagram. This type of collision is called collision of first kind and can be written as



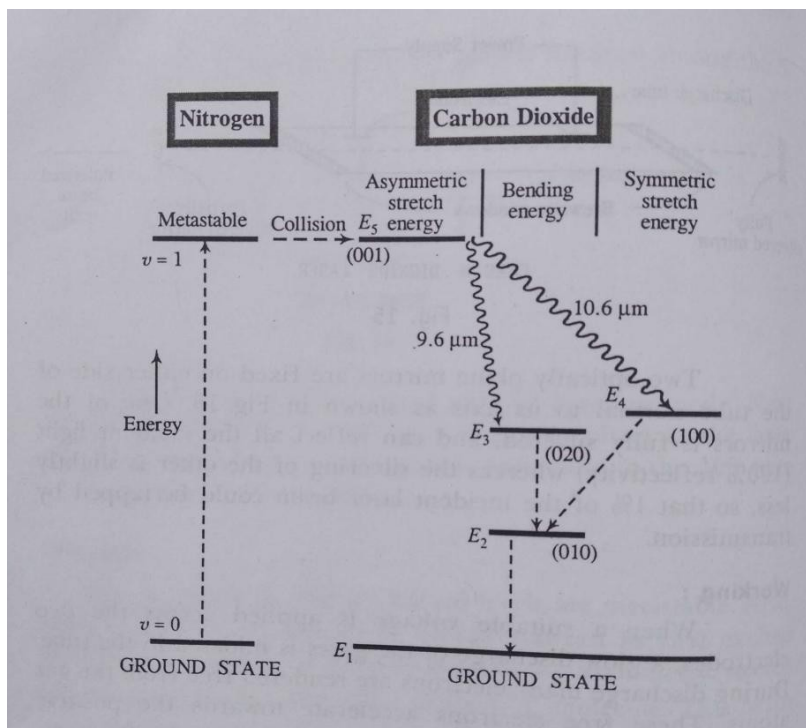
where e_1 and e_2 are electrons with different energies before and after collision respectively and N_2 and N_2^* are the nitrogen molecules in the ground and $v=1$ state

respectively.

Since $v=1$ state is the metastable state of N_2 , the molecules remain there for a relatively long time which leads to an increase of population in $v=1$ state. The vibrational energy level corresponding to the metastable state of $N_2(v=1)$ is close coincidence with the energy of 001 state of CO_2 . Because of matching of energy levels, there is a resonance transfer of energy takes place from the N_2 molecule to a CO_2 molecule through collisions. As a result, a greater number of CO_2 molecules get elevated to (001) state and N_2 molecule returns to the ground state. This type of collisions belongs to the class of collision of second kind and represented as



Where CO_2 and CO_2^* refer to the carbon dioxide molecule in the ground and excited state respectively. N_2^* and N_2 are nitrogen molecules in excited and ground states respectively



Energy level diagram of CO₂ laser

To understand the lasing action occurring in CO_2 molecule, let the ground state, (010), (020) (100), (001) are denoted as E_1 , E_2 , E_3 , E_4 and E_5 respectively. Due to the resonance transfer, the state E_5 is heavily populated and achieves population inversion with respect to E_3 and E_4 . Photons are emitted spontaneously by a few of the atoms at the energy level E_5 ,

these spontaneous photons travelling through the gas mixture triggers lasing between E_5 & E_3 and E_5 & E_4 energy levels.

- a) The transition from E_5 level to the E_4 level gives rise to radiation of wavelength $10.6 \mu\text{m}$ which is in the far infrared region

- b) The transition from E_5 level to E_3 level gives rise to radiation of wavelength $9.6 \mu\text{m}$ which is also in the far infrared region.

Further transitions

- In CO_2 molecule $E_3 - E_2 \cong E_2 - E_1$ As a consequence
- The CO_2 molecules in the E_3 level come down to E_2 level during collision with those in the E_2 level by giving up energy.
- The CO_2 molecules in the E_1 level collide with those in E_3 level and are elevated to E_2 level by absorbing the same energy.
- Since $E_3 \sim E_4$ then $E_3 - E_2 \cong E_2 - E_1$. This interaction is hindered by competing mechanism as follows.
- In the above energy level diagram, $(E_2 - E_1)$ is of the order of the thermal energy of the surroundings. Hence excitation of CO_2 atoms from E_1 to E_2 takes place thus leaving less energy states in E_2 for E_4 to E_2 transition.
- This high population of molecules at E_2 level is not desirable because this will hinder the depopulation of E_3 and E_4 levels which affects the population inversion of E_5 level.
- The collision of molecules in the E_2 level with He and water vapour leads to a quick E_2 to E_1 transition favouring the depopulation of E_3 and E_4 levels and population inversion of E_5 with E_3 and E_4 levels

The IR photons released parallel to the axis of the tube are reflected back and the multiplication of stimulated emission takes place. The

multiple reflections of the photons between the mirrors intensify the laser beam and it emerges through the partially reflecting mirror.

The laser beam consists of two components i.e. $10.6 \mu\text{m}$ and $9.6 \mu\text{m}$. One of the components of the beam can be eliminated by placing a

prism between the Brewster window and the partially reflecting mirror. The laser beam passing through the prism is dispersed, the mirror is placed normal to the component that is to be amplified, this component is reflected back into the laser tube and gets amplified. The other component will not be reflected back into the tube and hence is eliminated. CO₂ laser operates with an efficiency of up to 30%. Power output of a few kilowatts can be maintained continuously in a medium size unit.

Note: during discharge in the tube, some CO₂ molecules break into CO and O. The added hydrogen or water vapour help to re-oxidise CO to CO₂.

Applications of Laser in Medical field:

Laser in eye surgery: Historically, ophthalmology was the first medical field where lasers have found an application. Over more than five decades, use of lasers in ophthalmology has successfully shown effective and safe results in treating various eye conditions. Whether lasers are used to correct vision (refractive eye surgery) or repair damage (diabetic retinopathy) due to degenerative diseases dictates optimal laser type, wavelength, and pulse length. Lasers are also used for cataract treatment in ophthalmology.

Refractive eye surgery: LASIK eye surgery is the best known and most commonly performed laser refractive surgery to correct vision problems. Laser-assisted in situ keratomileusis (LASIK) can be an alternative to glasses or contact lenses. In eyes with normal vision, the cornea bends (refracts) light precisely onto the retina at the back of the eye. But with nearsightedness (myopia), farsightedness (hyperopia) or astigmatism, the light is bent incorrectly, resulting in blurred vision.

Cataract Treatment: Cataracts, or clouding of the eye's natural lens, are the most common cause of vision loss in the elderly population. Accordingly, cataract surgery is the most commonly performed surgical procedure in the world. Treatment involves removal of the lens for a prosthetic replacement. Lasers have recently been developed as a means to remove the lens via photodisruption. **Femtosecond lasers** are used in the treatment of cataracts and take advantage of the extremely high peak power densities to efficiently disrupt tissue with minimal surrounding thermal damage.

Retinal (Micro) Coagulation: Diabetic macular edema is the most

common cause of visual loss in persons under 50 years of age in the developed world. Retinal photocoagulation has been developed and recognized as a standard of treatment. Recently, the procedure was perfected due to introduction of micro-coagulation technique employing pulsed **diode lasers**.