Carbondioxide laser (Molecular gas laser)

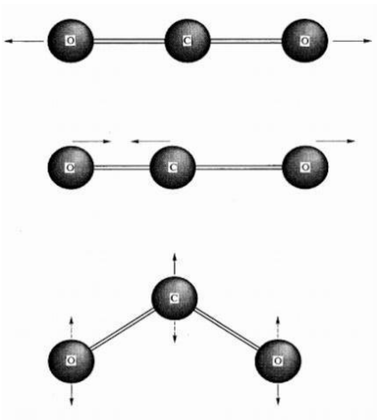
Carbon dioxide laser developed by Indian born American scientist Prof.C.K.N.Patel (Chandra Kumar Naranbhai Patel) at AT & T Bell laboratories,USAintheyear1963.Itisafour-levellaser,operatesat

10.6µminthe far IRregion. It hasaveryhighefficiencyand iswidely 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 betweenvibrationaland rotational levels of molecules. Its construction issimpleandtheoutputofthislaseriscontinuous.IntheCO2 moleculargas laser, transitiontakesplace betweenthe vibrational states of Carbon dioxide molecules.

Vibrationalenergylevelsofcarbondioxidemolecule

Carbondioxide molecule hasthreedifferent modesofvibrationshown 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 stationery 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): Herethe two oxygenatoms 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.

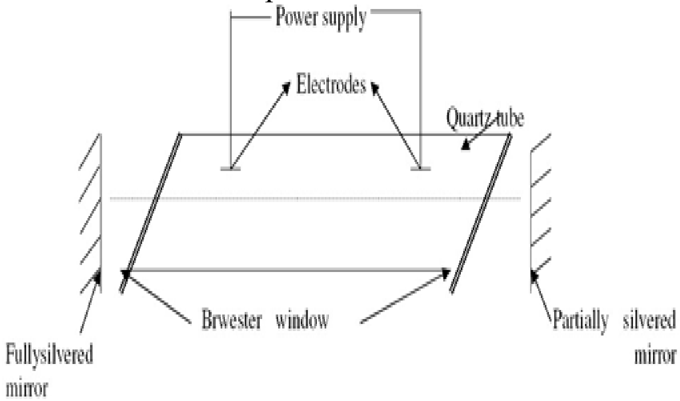
Bending mode (c): In bending mode, all the three atoms oscillate normal to the molecular axis. While vibrating, the two oxygen atoms pull together in one direction as the carbon atom is displaced in the opposite direction. This state is referred to a 010 state and the energyof the molecule in this state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

Notethat010isthe lowest excitedstateofbending mode.Next excited state in this mode is 020 state which is also involved in the laser transition in CO_2 laser. The energyofthis state is veryclose to the 100 state of symmetric stretching mode.

ConstructionofCO$_2$laser:

CO_2 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(activemedium),Nitrogen(N_2)andHelium(H_2)gassesintheratio

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 opticallyplane mirrorsare fixed oneither side ofthetube normalto its axis as showninthe figure. Oneofthe mirrors is fullysilveredandcan 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 gasses is initiated in the tube. During discharge the free electron from gas are accelerated towards positive electrode. Thesefree electrons collide with the N_2 molecules and hence N_2 molecules are raised to the first vibrational level which is meta stable

state designated as ν=1 as shown in energy leveldiagram. This type of collision is called collision of first kind and can be written as

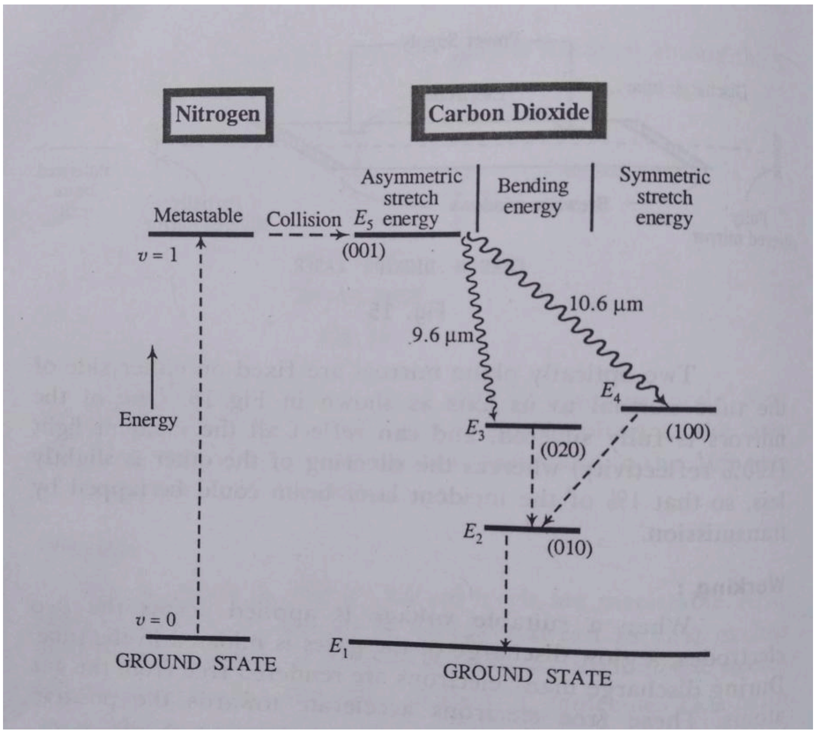
$e_1 + N_2 = e_2 + N_2^*$

where e_1 and e_2 are electrons with different energies before and after collisionrespectivelyandN_2 andN_2^*arethenitrogenmolecules inthe ground and ν=1 state respectively.

Sinceν=1stateisthe metastablestateofN_2,the moleculesremainthere for a relatively long time which leads to an increase of population in ν=1state. The vibrationalenergylevelcorrespondingtothe metastable state of N_2(ν=1) is close coincidencewith the energy of 001 state of CO_2.Because of matching of energy levels, there is a resonance transfer ofenergytakes place fromthe N_2 molecule to a CO_2 molecule throughcollisions.Asa result, agreater number ofCO_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

$N_2^* + CO_2 = N_2 + CO_2^*$.

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 leveldiagramofCO_2laser

To understand the lasing action occurring in CO_2 molecule, let the ground state,(010),(020) (100),(001) are denoted asE_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 inversionwith respect to E_3 and E_4. Photons are emitted spontaneously by a few ofthe 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 µm which is in the far infrared region

b) ThetransitionfromE$_5$ leveltoE$_3$ levelgivesrisetoradiationof wavelength 9.6 µm which is also in the far infrared region.

Furthertransitions

- InCO$_2$ moleculeE$_3$–E$_2$≅ 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.
- TheCO$_2$ moleculesintheE$_1$levelcollidewiththose inE$_3$ leveland are elevatedE$_2$ level by absorbing the same energy.
- SinceE$_3$ ~E$_4$thenE$_3$ –E$_2$≅ E$_2$–E$_1$.This interactionis hindered by computing mechanism as follows.
- In the above energy level diagram, (E_2 – E_1) is of the order of the thermalenergyofthe surroundings. Hence excitationofCO$_2$ atoms from E_1 to E_2 takes place thus leaving less energy states in E_2 forE$_4$ to E_2 transition.
- This high population of molecules at E_2 level is not desirable because this will hinder the depopulation E_3 and E_4 levels which affects the population inversion of E_5 level.
- The collisionofmolecules in the E$_2$levelwithHe and water vapour leads to a quick E$_2$to E$_1$transition favouring the depopulationofE$_3$ 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 backandthemultiplicationofstimulatedemissiontakesplace.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 10.6µm and 9.6µm.One of the components of the beam can be eliminated by placing a prismbetweentheBrewsterwindowandthepartiallyreflecting mirror. The laser bem passing through the prism is dispersed, the mirror is placed normaltothecomponent that isto beamplified,thiscomponent is reflected back into the laser tube and gets amplified. The other component ill not be reflected back into the tube and hence is eliminated. CO_2 laser operates with an efficiency of upto 30%. Power outputofa fewkilowattscanbemaintained continuouslyina medium size unit.

Note: during discharge in the tube, some CO2 molecules breakinto CO and O. The added hydrogen or water vapour help to re oxidise CO to CO_2.

ApplicationsofLaserinMedicalfield:

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(diabeticretinopathy)duetodegenerativediseasesdictates 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 alternativeto glassesorcontact lenses.Ineyes withnormalvision, the cornea bends (refracts) light preciselyontothe retina at the back ofthe eye. But with near sightedness (myopia), far sightedness (hyperopia)orastigmatism, the light isbent 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 thelens for a prosthetic replacement. Lasers have recently beendeveloped as a means to remove the lens via photodisruption. **Femtosecondlasers**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 isthe most commoncauseofvisualloss inpersonsunder50 yearsofage in the developed world.

Retinalphotocoagulationhas beendeveloped and recognized as a standard of treatment. Recently, the procedure was perfected due to introduction of micro-coagulation technique employing pulsed **diode lasers**.