Can you identify the relationship between the persons in the Photograph?

Learning Objectives

On completion of this chapter you will be able to:

1. State the principle of CO_2 Laser.
2. Describe the Vibrational modes of CO_2 molecule.
3. Explain the construction of CO_2 Laser.
4. Describe the working of a CO_2 Laser.
5. State the special features of this Laser.
6. State the applications of this Laser.

Introduction

Carbon dioxide laser

A test target is vaporized and bursts into flame upon irradiation by a high power continuous wave **carbon dioxide laser** emitting tens of kilowatts of infrared light.

The **carbon dioxide laser** (**CO_2 laser**) was one of the earliest gas lasers to be developed (invented by Kumar Patel of Bell Labs in 1964), and is still one of the most useful. Carbon dioxide lasers are the highest-power continuous wave lasers that are currently available. They are also quite efficient: the ratio of output power to pump power can be as large as 20%.

The CO_2 laser produces a beam of infrared light with the principal wavelength bands centering around 9.4 and 10.6 micrometers.

Principle of CO_2 Laser.

We have already seen that to achieve Laser transition between 2 levels it is necessary to obtain Population inversion between these 2 levels and also increase the energy density of incident radiation.

In Nd:YAG, He-Ne Lasers the transitions take place amomg the various electronic states of an atom or ion. In the case of **CO_2 Laser, Vibrational states** are involved.

As **CO_2** is a molecule, it can vibrate and rotate. Hence over and above electronic states, it possesses Vibrational and Rotational states also.

Transitions can occur either between the Vibrational states of the same electronic state or Vibrational states of different electronic states.

The principle of a Carbon-di-oxide laser is transition between Vibrational states of the same electronic state by achieving Population Inversion between these states.

Vibrational Modes of CO_2 molecule

When excited, the CO_2 molecule vibrates like masses connected by a spring, where the bond between the atoms is comparable to a spring of spring constant k. There are three normal modes of vibration for a molecule such as CO_2: the asymmetric stretch mode, the bending mode and the symmetric stretch mode. Figure 1. is a pictorial description of the dynamics of these three modes.

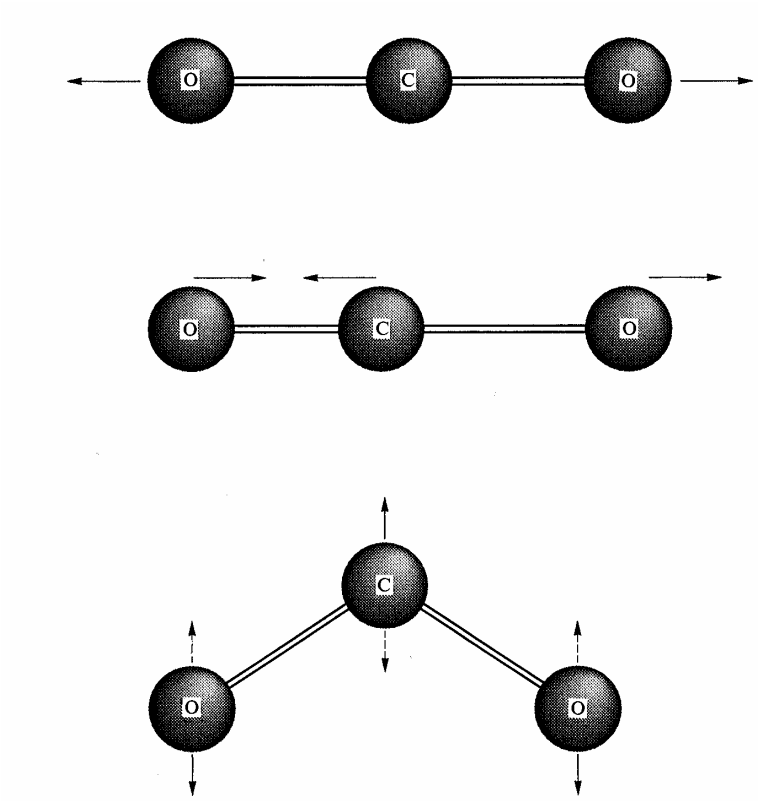


Figure 1

Vibrational modes of **CO_2** molecule (Symmetric stretching, Asymmetric stretching and Bending modes)

In general the modes are represented by 3 integers (mnq).

- (moo) represents Symmetric stretching & this implies that (100) is the fundamental mode of vibration in the Symmetric stretching mode. The frequency of this mode is 4.2 x 10^{13} Hz. (200) will be the second harmonic or the first overtone.
- (ono) is the representation of the Bending mode. (010) is the fundamental mode with frequency 2 x 10^{13} Hz. (020) is the next mode whose frequency is 4x 0^{13} Hz.
- (ooq) represents Asymmetric stretching with the highest fundamental frequency 7x 10^{13} Hz.This is designated as (001).

The CO_2 molecule behaves much like a simple harmonic oscillator. The vibrational energies can therefore be described by the relation $(\nu+1/2)*h\omega$, where ν, the vibrational quantum number = 0,1,2,3…. and ω = the classical frequency. The levels are evenly spaced by E = $1/2(h/2\pi)\omega$. Since each mode can be thought of as an individual oscillator independent of the other modes, each mode has its own set of allowed energy levels. This can be seen in figure 2 below.

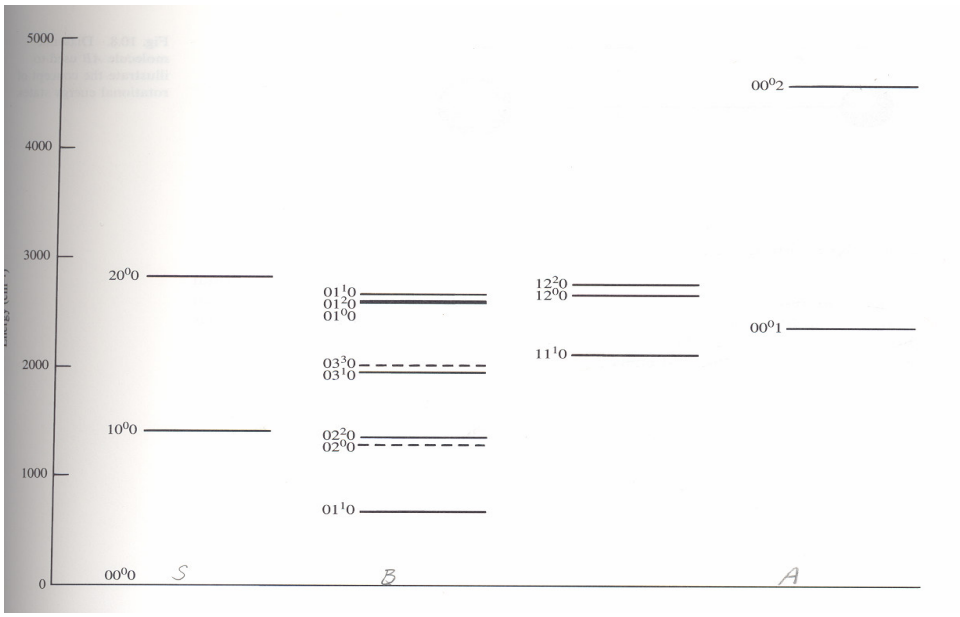


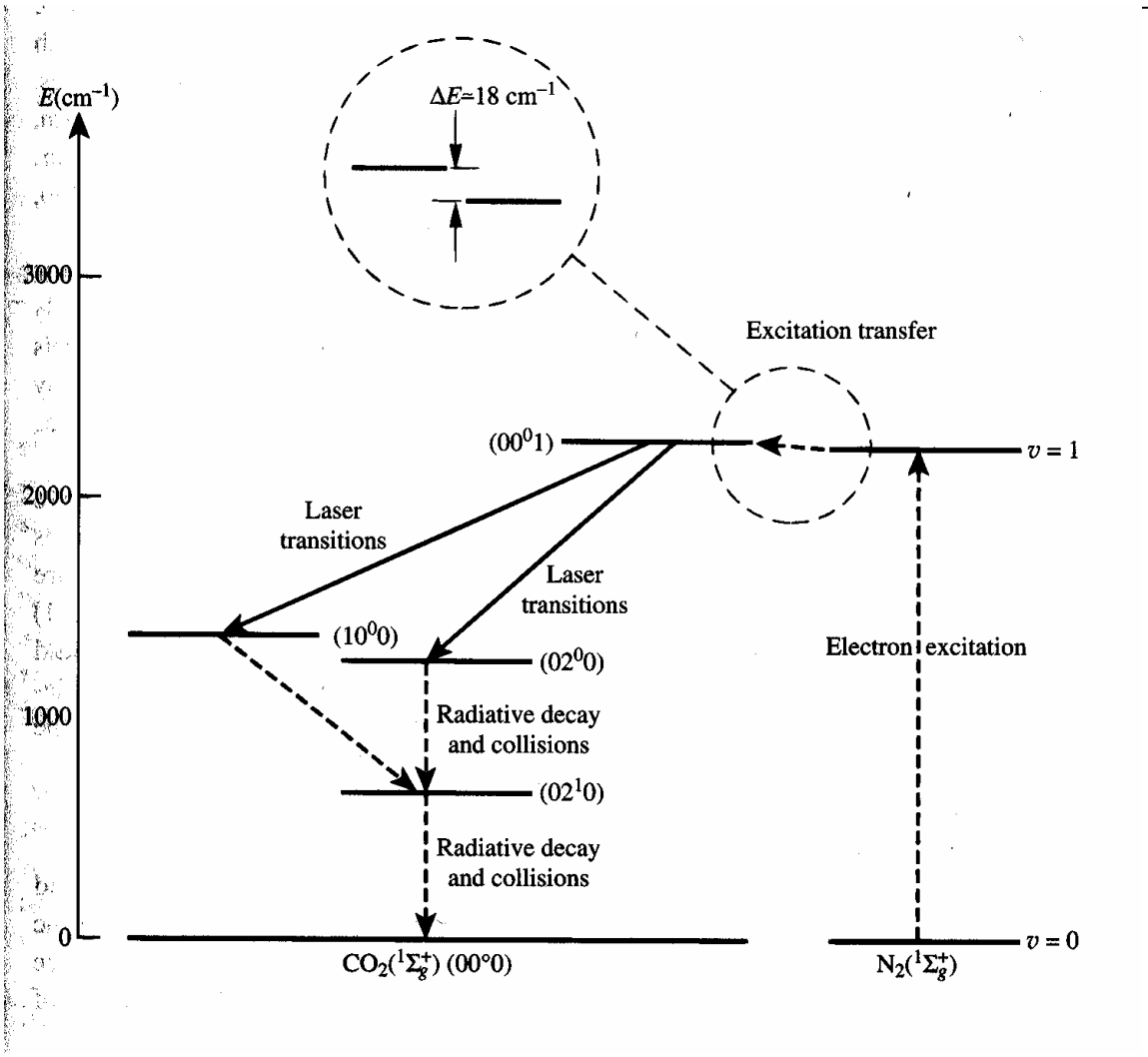
Figure 2

Y-axis in units of cm^{-1}

Construction & Working

The most basic form of a CO_2 laser consists of a gas discharge (with a mix close to that specified above) with a total reflector at one end, and an output coupler (usually a semi-reflective coated zinc selenide mirror) at the output end. The reflectivity of the output coupler is typically around 5-15%. The laser output may also be edge-coupled in higher power systems to reduce optical heating problems. The CO_2 laser gas mixture consists of 70% He, 15% CO_2, and 15% N_2.

The vibrational and rotational modes of the CO_2 cannot be excited themselves by photons. When a voltage is placed across the gas, electrons collide with the N_2 molecules and excite them to their lowest vibrational levels. These vibrational levels happen to be at an energy very close to the energy of the asymmetric vibrational states in the CO_2 molecule. Now, the excited N_2 molecules populate the asymmetric vibrational states in the CO_2 molecule through collisions. The infrared output of the laser is the result of transitions between rotational states of the CO_2 molecule of the first asymmetric vibrational mode (001) to rotational states of both the first symmetric stretch mode (100) and the second bending mode. (020). These transitions are shown in the Energy level diagram given below.



According to Hollas, the emitted photons as a result of these transitions occur at 10.6μm and 9.6μm, respectively.

. The (100) and (020) vibrational levels depopulate to lower vibrational levels. Again, through collisions, the CO_2 molecule transfers energy from these lower vibrational levels to the He atoms and the CO_2 return to ground state.

Special features and Applications

The efficiency of this Laser is very high (30%).The power output can be as high as 10kW. The nature of output may be continuous wave or pulsed.

Because of the high power levels available (combined with reasonable cost for the laser), CO_2 lasers are frequently used in industrial applications for cutting and welding, while lower power level lasers are used for engraving. They are also very useful in surgical procedures because water (which makes up most biological tissue) absorbs this frequency of light very well. Some examples of medical uses are laser surgery, skin resurfacing ("laser facelifts") (which essentially consist of burning the skin to promote collagen formation), and dermabrasion. Also, it could be used to treat certain skin conditions such as hirsuties papillaris genitalis by removing embarrassing or annoying bumps, podules, etc.(Connect this part of the application with the image shown at the start).

Because the atmosphere is quite transparent to infrared light, CO_2 lasers are also used for military rangefinding using LIDAR techniques.

Check your understanding

1. In a Carbon-di-oxide Laser, the transition giving rise to Laser beam occurs between _____ levels.(Vibrational/ Electronic).

2. _____ mode of Carbon-di-oxide molecule has the highest fundamental frequency of vibration.

3. The purpose of Helium in a Carbon-di-oxide laser is to _____ and _____.

4. The Population Inversion in a Carbon-di-oxide laser is achieved between the Levels a) 200 & 100 b) 100 & 200 c) 001 & 100 d) 001 & 020

5. The output of a Carbon-di-oxide laser is
   a) CW b) Pulsed c) CW & Pulsed

6. State 2 applications of Carbon-di-oxide laser.

Check the correct answers on page 9.

Summary

On completion of this chapter you have learned that:

1. The principle of a Carbon-di-oxide laser is transition between Vibrational states of the same electronic state by achieving Population Inversion between these states.

2. There are 3 modes of vibration in a Carbon-di-oxide molecule. They are a) Symmetric Stretching b) Bending & c) Asymmetric Stretching mode.

3. The active medium in a Carbon-di-oxide laser is a gas discharge tube filled with Carbon-di-oxide(10 – 20 %) , Nitrogen (10 – 20 %) & Helium (70%) Sodium Chloride Brewster windows are mounted at the end.

4. Electron impact excites Vibrational modes of Nitrogen which by collisions with Carbon-di-oxide excites its 001 mode leading to the desired Population Inversion required for Laser action.

5. The output of a Carbon-di-oxide laser is in the infra-red region with the power being around 10 kW. The efficiency is very high(30 %) .The nature of the output may be CW or Pulsed.

6. Cutting, Welding, Engraving, Surgery & Military range-finding using LIDAR are some of the applications of this Laser.

Suggested Reading

Please provide a few suggested reading material including text book, web pages, other references.

1.http://en.wikipedia.org/wiki/Carbon dioxide laser

2.http://www.phy.davidson.edu/StuHome/shmeidt/JuniorLab/CO2Laser/Theory.htm

3.Patel, C. K. N. (1964). "Continuous-Wave Laser Action on Vibrational-Rotational Transitions of CO_2". *Physical Review* **136** (5A): A1187–A1193.

Answers to CYU.

Provide the right answers to the Check your understanding section here.

1. Vibrational.
2. 001
3. Depopulate lower levels & conduct heat away from the walls of the discharge tube.
4. c & d
5. d
6. Welding & Surgery.