2.6 Molecular Gas Lasers

All the lasers described so far are based on electronic transitions between different main energy levels. In a molecule, the main energy levels are subdivided into vibrational energy levels. Each vibrational energy level can be subdivided into rotational energy levels:

1. Vibrational energy levels - energy levels associated with the oscillation of the atoms in the molecule.
2. Rotational energy levels - energy levels associated with the rotation of the molecule.

Since these energy levels are subdivisions of the main energy levels, the difference between the two vibrational energy levels in which lasing occurs, is much smaller than the difference between main electronic energy levels. Thus, the wavelengths associated with the energy transitions among these levels is longer, and is usually in the Infra-Red (IR) spectrum. Among the molecular lasers, the most common laser is the Carbon-Dioxide (CO_2) laser.

2.6.1 Carbon-Dioxide (CO_2) Laser

The carbon dioxide laser is by far the most important laser of its class and in terms of technological applications it is arguably one of the most important of all. It exhibits both high efficiency (up to 30%) and high power output; CW powers of several tens of kilowatts are available. Thus applications such as welding and cutting of steel, pattern cutting, weaponry and laser fusion become possible.

Lasing action in a CO_2 molecule was first demonstrated by C. Patel in 1964.He transmitted an electric discharge pulse through pure CO_2 gas in a laser tube, and got a small laser output. CO_2 is the gas in which the lasing process occurs, but other gas additives to the laser tube improve the total efficiency of the laser. The standard CO_2 laser includes in the active medium a mixture of CO_2 with N_2 and He. The optimal proportion of these three gases in the mixture depends on the laser system and the excitation mechanism, but in general the nitrogen and carbon dioxide concentrations are comparable, the helium concentration being larger than either. Low overall pressures (i.e. about 5-30 torr, of which 10%

CO_2 gas, 10% N_2 and the rest is He, i.e., the proportions are: CO_2:N_2:He - 1:1:8) are generally used for CW operation but short, high–energy pulse lasers operate at higher pressures.

Performance of CO2 lasers may be optimized in several ways: Maximize multimode power; maximize single-mode power; maximize efficiency; and/or minimize size and complexity.

CO_2 is a linear molecule, and the three atoms are situated on a straight line with the Carbon atom in the middle. The lasing transitions involved are different from all those considered hitherto since they involve the energy levels resulting from the quantization of the vibrational and rotational levels of the CO_2 molecule. As far as vibrations are concerned there are basically three different types or modes, which are illustrated in figure 2.14. The three vibrational modes of CO_2 molecule are:

1. Symmetric stretch mode (ν00).
2. Bending mode (0ν0).
3. Asymmetric stretch mode (00ν).

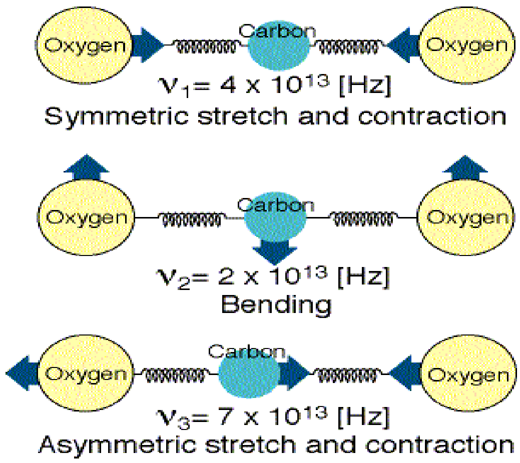

Figure 2.14: Oscillation Modes of CO_2 Molecule.

Each of these vibrations is quantized. That is to say the energy of the molecule, when it is in one of these modes, is an integral multiple of some fundamental value. We can refer to the particular state of the molecule by specifying this quantum number. In general we need a set of three such numbers (since we have three different modes). The numbers are quoted in the order referred to above: thus (0, 3, 0) refers to a state which is vibrating in a bending mode with three units of vibrational energy.

CO_2 laser operation

Electric discharge is created in the laser tube. The energy of the accelerated electrons is transferred by collisions to the Nitrogen molecules and to the CO_2 molecules. As in the He–Ne laser, excitation is a two-step process, this time with nitrogen involved as the intermediary. The first vibrational levels of N_2(V=1) are close to the (001) vibrational levels of CO_2(as can be seen in figure 2.15), so energy can be easily transferred from the excited Nitrogen molecules to the CO_2 molecules. This excitation process is very efficient process for many factors, among these factors:

1.The first excited state of nitrogen lies a mere 0.3 eV above the ground state, which contrasts markedly with the 20 eV or so required for the excitation of He in the He-Ne laser. There are many more

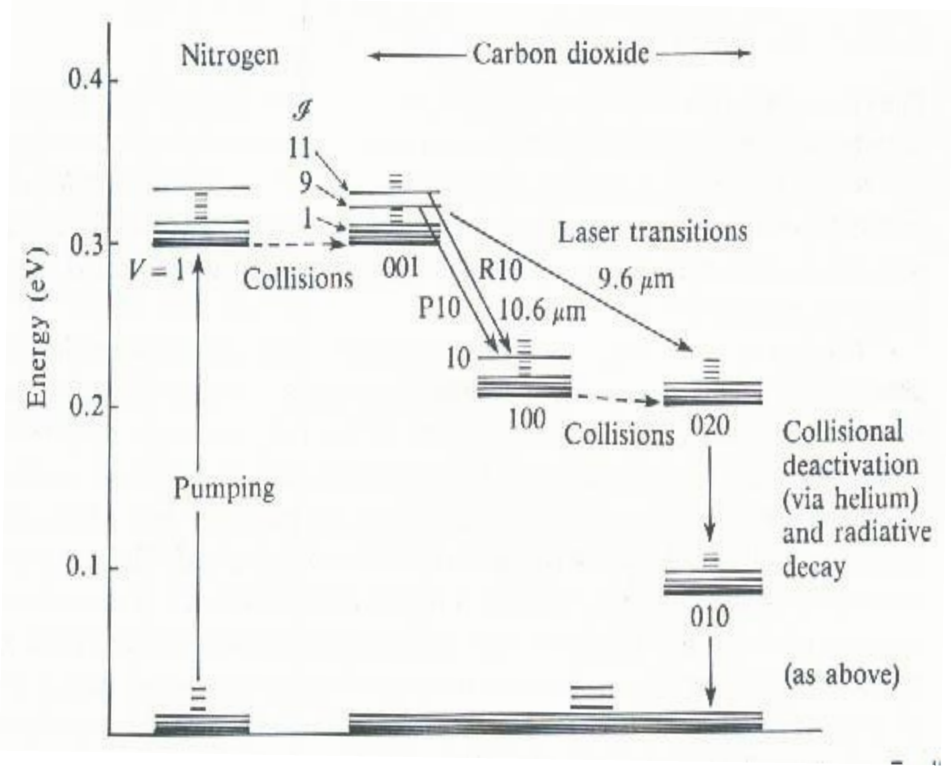

Figure 2.15: Energy Level Diagram of CO_2 Laser.

electrons in the discharge with 0.3 eV than there are with 20 eV of energy.

2. The first excited state, of nitrogen is metastable so that once excited the nitrogen is highly likely to exchange its energy with a carbon dioxide molecule before it de–excites by spontaneous emission.

The addition of a third gas, helium, helps to increase the efficiency still further. Helium acts in several ways, such as:

1. Transporting waste heat to the tube walls(due to high thermal conductivity of He gas and its large percentage): this has the effect to Stabilize the electrical discharge.
2. Assisting in the deactivation of the lower laser levels: this has the effect to maintain the population inversion.

Lasing Transitions in CO_2 Laser

Lasing transitions in CO_2 laser occur when the molecule is going from higher energy level of the asymmetric mode(001) into one of the other two (see Fig. 2.15):

1. The transition to the symmetric stretching mode(100) corresponds to the wavelength of 10.6 μm.
2. The transition to the bending mode(020) corresponds to the wavelength of 9.6 μm.

Each of the vibrational energy level is subdivided into many rotational levels. Transitions can occur between vibrational energy levels with different rotational levels, so there are many lasing lines around the main vibrational transitions. Actually, the 001 levels form the initial levels of a large number of laser transitions between 9.2 and 10.8 µm, with the strongest at 10.6 µm.

Types of CO_2 Lasers

There are a wide range of internal structures of CO_2 lasers depending on the power levels and beam quality required. All these structures based on the same physical principles. The difference between them is in their structure, excitation mechanism, and output radiation.

A few CO_2 lasers are described below.

-- Sealed off (Sealed-Tube) CO_2 lasers

The gas laser is filled with the appropriate mixture of gasses and sealed (as we saw in He-Ne laser). High electric voltage is applied to electrodes at both ends of the gas tube. The accelerated electrons excite the gas molecules.

The problem with sealed off lasers is the dissociation of the CO_2 molecules into CO and Oxygen with time. This reaction is sufficiently rapid that, if no precautions were taken, lasing would cease after a few minutes. To reduce this effect, a catalyzing agent is added to the gas mixture. One solution is to add hydrogen or water vapor to the gas mixture, to react with the CO and regenerate CO_2. Sealed off CO_2 lasers are usually limited to output power of less than 200 watts because the difficulty of gas cooling. For higher output power it is necessary to take away the heat generated inside the laser, and a flowing gas is needed.

Sometimes a gas reservoir is added to the sealed off tube to allow some refreshment of the lasing gasses from the reservoir to the tube. The new class of sealed CO_2 lasers is made from metal with no glass tube. These lasers are cheap, reliable and efficient. These lasers are not excited by direct high voltage that creates the electric discharge, but by a radio frequency (RF) voltage.

Sealed tube designs are not very common but are used in conjunction with the so-called <u>waveguide design</u>. When the laser tube diameter is reduced to a size of about 1 millimeter, a waveguide is made. Excellent beam quality is obtained together with a relatively large output in view of the small tube diameters (these small CO_2 lasers can produce up to 50 watts of continuous wave radiation). Excitation is obtained by means of either an electrical discharge or an intense radio-frequency field that can penetrate the waveguide material.

-- Gas-Flow CO_2lasers

Both degradation and cooling problems may be alleviated by allowing the gas to flow through the laser tube. In these lasers a fresh gas mixture is flowing continuously through the laser tube while lasing lasts. Flowing gas is used when the maximum power is needed out of the CO_2 laser. There are two designs of gas-flow CO_2 lasers:

-- Axial-Flow CO_2 lasers

In the simpler designs both the gas flow and the electrical discharge take place along the tube axis. There are two types of axial-flow: slow and fast axial-flow. In slow axial-flow, If no attempt is made