Basic principle of co2 laser engineering essay

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The carbon dioxide laser emits infrared radiation between 9 and 11 micrometers, either at a single line selected by the user or on the strongest lines in untuned cavities. It can produce continuous output powers ranging from well under 1 W for scientific applications to many kilowatts for materials working. It can generate pulses from the nanosecond to millisecond regimes. Custom-made CO2 lasers have produced continuous beams of hundreds of kilowatts for military laser weapon research [1] or nanosecond-long pulses of 40 kilojoules for research in laser-induced nuclear fusion [2].

This versatility comes from the fact that there are several distinct types of carbon dioxide lasers. While they share the same active medium, they have important differences in internal structure and, more important to the user, in functional characteristics. In theory, the structural variations could range over a nearly continuous spectrum, but manufacturers have settled on a few standard configurations which meet most user needs. Thus users see several distinct types, such as waveguide, low-power sealed-tube, high-power flowing-gas and pulsed transversely excited CO2 lasers.

CO2 laser is a molecular laser, CO2 laser gas is a mixture of CO2, N2 and He gases. CO2 is a linear, symmetric molecule that vibrates in three different vibrational modes as show in Figure 2. 1. These are the symmetric mode (v1), two-fold degenerated bending mode (V2) and asymmetric mode (V3). The excitation of C02 laser is achieved by increasing the vibrational energy of the molecules. The actual laser pumping process is achieved by an electrical gas discharge [3, 4]

Figure 2. 1

Carbon dioxide is the light emitter. The CO2 molecules are first excited so they vibrate in an asymmetrical stretching mode. The molecules then lose part of the excitation energy by dropping to one of two other, lower-energy vibrational states as shown in Figure 2. 2. These two decay paths are the two principal laser, transitions: a shift to a symmetrical stretching mode accompanied by emission of a 10. 6-μm photon, or a shift to a bending mode accompanied by emission of a 9. 6-μm photon. Superposition of changes in the molecules rotational states on the vibrational transitions yields large families of laser lines surrounding the 9. 6- and 10. 6-μm transitions. Once the molecules have emitted their laser photons, they continue to drop down the energy-level ladder until they reach the ground state.

Figure 2. 2

The nitrogen molecules help to excite CO2 to the upper laser level. The lowest vibrational state of N2 is only 18 inverse centimeters lower in energy than the asymmetric stretching mode of CO2, a difference that is less than one-tenth the mean thermal energy of room-temperature molecules, and hence insignificant from a practical standpoint. This lets the nitrogen molecules absorb energy and transfer it to the carbon dioxide molecules, thereby raising them to the upper laser level.

Carbon dioxide molecules can also reach the upper laser level in other ways. They can directly absorb energy from electrons inserted into the gas in a discharge or electron beam. An alternative way of producing the population inversion needed for laser operation is to rapidly expand hot, high-pressure laser gas into a cool near-vacuum; this is the basic principle behind the gas-dynamic carbon dioxide laser. In practice, the presence of N2 significantly enhances laser operation, and that gas is almost always present in CO2 lasers.

Helium plays a dual role. It serves as a buffer gas to aid in heat transfer and helps the C02 molecules drop from the lower laser levels to the ground state, thus maintaining the population inversion needed for laser operation.

The optimum composition and pressure for the gas in a CO2 laser varies widely with the laser design. In a typical flowing-gas CO2 laser, the total pressure might be around 15 torr (2000 Pa), with 10 percent of the gas CO2, 10 percent N2, and the balance helium. In general, the concentrations of nitrogen and carbon dioxide are comparable, but much lower than that of helium. Low pressures are needed for continuous operation, but pulsed CO2 lasers can be operated at pressures well above 1 atm.

In some cases, other gases may be added to the laser mixture. For example, hydrogen or water can be added to the gas in a sealed tube to promote regeneration of CO2 during laser operation, and sometimes carbon monoxide is added for similar reasons. It is even possible to operate pulsed lasers with a 50: 50 mixture of air and carbon dioxide, albeit at reduced output power. [6]

– Types of CO2 laser:

The classification of carbon dioxide lasers into types is based on their internal structure. There are several key parameters involved, including gas pressure, gas flow, type of laser cavity, and excitation method. Many different combinations have been explored in the laboratory, but only a few have found their way into practical use.[6]

Sealed-tube lasers: A sealed gas laser sounds simple to operate: just fill the tube with the proper gas mixture, seal it, and fire away as shown in Figure 2. 3. In practice, life is not that simple because the electrical discharge in the tube breaks down the CO2. Left by itself, a sealed CO2 laser with an ordinary gas mixture would stop operating within a few minutes.

One solution is to add hydrogen or water to the gas mixture, so it could react with the carbon monoxide produced by the discharge to regenerate carbon dioxide. Alternatively, a 300°C nickel cathode can act as a catalyst to stimulate the recombination reaction. Such measures make it possible to produce sealed CO2 lasers which can operate for as long as several thousand hours before their output seriously degrades.

Figure 2. 3

Output powers of sealed CO2 lasers generally are limited to the hundred-watt range by a couple of problems. One is that output power is inherently limited to only around 50 W per meter of tube length. The other is the difficulty in properly cooling the laser tube without flowing gas. Several companies make sealed CO2 lasers, some of which incorporate the waveguide design described below.

Longitudinal (or axial) flowing gas lasers: The obvious way to solve the problems of the sealed CO2 laser is to flow the gas through the laser tube, as shown in Figure 2. 4. The oldest approach is to pass the gas through the length of the laser tube longitudinally or along the tube's axis, bench the name. Generally the electric discharge that excites the gas is also applied along the tube's axis. The gas pressure is low, and gas consumption can be reduced further by recycling options on many lasers.

Figure 2. 4

Axial-flow CO2 lasers produce continuous-wave output that is roughly linearly proportional to the tube length. Typical output limits are 40 to 80 W/m. The laser beam can be folded or bent with mirrors through multiple tube segments, avoiding the need for unwieldy packages, and the design is simple enough

That it remains common for CO2 lasers emitting less than a couple of kilowatts. Higher powers are impractical, however; obtaining 8. 8-kW output required a tube 750 ft (250 m) long. [5]

Transverse-flow lasers: Much higher powers, approximately 10 kW per meter of active medium length, are possible if the gas flows in a direction vertical to the laser cavity axis, as shown in Figure 2. 5. The electrical discharge that powers the laser is also practical transversely to the laser axis and is vertical to the gas flow. The gas flows much faster than in an axial-flow laser, quickly removing excess heat and dissociation products. The gas is generally recycled by passing it through a system which regenerates CO2 and adds some fresh gas to the mixture. The cavity length of transverse-flow lasers is comparatively short, and this can lead to beam-quality problems.

Figure 2. 5

The transverse-flow design is standard for most commercial multikilowatt CO2 lasers. Aerodynamics plays a critical role in performance. A drawing of the largest CO2 laser offered as a standard product, a 15-kW system built by Combustion Engineering’s laser group in Somerville, Massachusetts, identifies one key component as a wind tunnel. Variations on the transverse-flow design have been used in some high-power CO2 lasers custom-made for laser-weapon research.

Gas-dynamic lasers: Transverse flow is also used in another type of high-power CO2 laser, the gas-dynamic laser, shown in Figure 2. 6. In the gas-dynamic laser, the excitation energy comes from heat applied to the laser gas, which is initially at a pressure of several atmospheres. (Both the heat and some components of the laser gas may come from combustion of hydrocarbon fuels.) The hot gas is then widened, through a nozzle into a low-pressure chamber. The rapid cooling of the fast-moving gas produces a population inversion. That is to say, more CO2 molecules in the upper laser level than in the lower one. A laser beam is extracted from the gas by placing a pair of mirrors on opposite sides of the expansion chamber.

Figure 2. 6

At the end of the 1960s, the gas-dynamic laser was an important break-through that made it possible for the first time to reach power levels of 100 kW or more. Such powers are required only for military applications, and because of their complexity and high power, gas-dynamic lasers have never entered the commercial world. It now looks as if they are impractical for military field use as well.

Waveguide lasers: If the inner diameter of a CO2 laser tube is shrunk to a couple of millimeters and the tube is constructed in the form of a dielectric waveguide, the result is a “ waveguide” laser such as is shown in Figure 2. 7. The waveguide design limits diffraction losses that would otherwise impair the operation of a narrow-tube laser. The tube can be sealed (with a gas reservoir separate from the waveguide itself) or allow for flowing gas. The gas can be excited by an electrical discharge or by an intense radio-frequency field that can pass through the dielectric waveguide material and hence avoid the need for metal inside the waveguide structure.

Figure 2. 7

The waveguide laser is very attractive for powers on the low end of the CO2 range, continuous powers from under a watt to about 50 W. It provides a good-quality, continuous-wave beam and can readily be tuned to many discrete lines in the CO2 spectrum. Its most conspicuous advantage is its small size, comparable to that of a helium-neon laser. Waveguide CO2 lasers are inexpensive, starting at a few thousand dollars, and can cost as little as a few hundred dollars per watt for higher-power models bought in quantity.

TEA lasers: Discharge instabilities make continuous-wave operation of a transversely excited CO2 laser impractical at gas pressures above about 100 torr (13. 3 MPa) as shown in Figure 2. 8. However, it is possible to produce pulses lasting tens of nanoseconds to microseconds. Such lasers are called transversely excited atmospheric (TEA) lasers because they operate at or near atmospheric pressure, although sometimes the term is applied to pulse transversely excited CO2 lasers, which operate at higher or lower pressures.

The TEA laser’s prime attractions are the generation of short, intense pulses and the extraction of high power per unit volume of laser gas. High-pressure operation also broadens the laser’s emission lines, permitting the use of mode locking techniques to generate pulses lasting only about 1 ns. At pressures of around 10 atm, the broadening is sufficient to allow near-continuous tuning over most of CO2’s wavelength range.

Figure 2. 8

The basic TEA design is adaptable, and commercial models range in size from tabletop versions to dumpster-sized behemoths. The same basic design can be used with a variety of laser gases, and some companies offer “ multigas” lasers, which can be adapted for use as carbon dioxide, excimer, chemical, or carbon monoxide lasers simply by switching optics and gases. Some models intended for low-power operation can operate with sealed tubes, a feature that is particularly important when using gas fills of special isotopic composition.