The CO_2 Laser: The Workhorse of the Laser Material Processing Industry

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GENERAL BACKGROUND

Introduction

In Calendar Year (CY) 2010, the laser will celebrate its 50th anniversary. Over this 50-year period, the laser material processing market has grown to become one of the largest, if not the largest, industrial application for lasers in terms of annual revenues. The CO_2 laser will be 46 years old in CY 2010. It has captured the largest portion of the revenues associated with the laser material processing market. It therefore appeared appropriate to summarize the basic state of the art of carbon dioxide lasers during the 50th anniversary of the first operation of the laser, which was the ruby laser by Dr. Ted Maiman at the Hughes Research Laboratory in Malibu, CA, in 1960.

Laser Material Processing Market Information

The largest laser industrial applications market in CY 2008 in terms of dollars was material processing. It represented 29% of all laser revenues, followed by communications (27%) and information storage (26%). (See Ref. 1: "Laser Marketplace 2009: Photonics enters a period of high anxiety," *Laser Focus World*, January 2009, Fig. 2, page 56). Of all laser units sold in CY 2008, 16% was attributed to CO_2 lasers which were a far distant second to the 58% unit share of the lower cost and much lower power diode lasers. All other laser technology revenues were below 10% (Ref. 1, page 64). As reported in the June 2009 issue of *Laser Focus World,* Optech Consulting of Tägerwilen, Switzerland, reported the worldwide market for all industrial lasers to be $8.45 billion in

CY 2008 with $3 billion of sales attributed to the laser material processing market segment. It was reported that the $3 billion was divided between CO_2 (40%), solid-state rod and disk (32%), excimer (19%), fiber (7%) and direct diode lasers (2%).

These numbers indicate that material processing is one of the largest, if not the largest, industrial application for lasers and that CO_2 lasers have the largest share of this market. It is therefore appropriate to summarize the present state of the art of the CO_2 laser as part of the commemoration of the 50th anniversary of the laser in CY 2010.

Advantages/Disadvantages of CO_2 Lasers

Optically pumped, solid-state lasers of the rod, disc, or slab variety; fiber lasers; excimer lasers; high-power laser diode arrays; and CO_2 lasers all play a role in the laser material processing industries. Of these commercially available lasers, the CO_2 laser offers the lowest cost per watt along with good beam quality. This figure of merit is presently well below $100 per watt for CO_2 lasers. This fact, coupled with the maturity of the CO_2 lasers (i.e., it was first reported by C. K. N. Patel in 1964) and the fact that commercial CO_2 lasers are available with a wide range of average output power ranging from a few watts up to over 60 kW has helped to make the CO_2 laser the workhorse of the material processing industry.

Adding to the attractiveness of the CO_2 laser is the high absorption of its infrared radiation. Numerous discrete output wavelengths can be selected between 9 and 11 microns with the use of isotopes in the laser's gas mixture. Radiation in this wavelength range is strongly absorbed by materials such as paper, wood, cloth, ceramics, oxides, plastics, glass, stone, liquids, and most complex molecules. The use of different CO_2 isotopes in the laser's gas mixture of CO_2:N_2:He offers the user a selection from hundreds of discrete IR wavelengths.

One fast growing market for low-average power CO_2 lasers (i.e., below 100W) is in the marking of products with date of manufacture and expiration, lot and serial numbers, etc., as required by law in most countries throughout the world. Laser marking is cutting into market share of the ink-jet industry. Cutting and welding with lasers has brought a revolution to manufacturing by reducing cost and waste while speeding up processing. The benefits have been felt especially in the automobile industry. Other fast expanding markets are the scribing of glass and cutting of plates for the display market, the cutting/drilling of plastics, and the drilling of holes in printed circuit boards. The introduction of miniature and relatively inexpensive electronic devices such as cell phones, laptops, hand-held computers, etc., has forced increased speed in the number of holes drilled per unit and a reduction in the cost per drilled hole in printed circuit boards. One approach that has gained favor for achieving the increased speed and lower cost per hole is the use of pulsed laser drilling systems instead of using mechanical drill machines.

The oldest and largest market for CO_2 lasers systems is cutting, welding, and drilling of sheet metal with high power CO_2 lasers, with the largest revenues coming from systems that use lasers with output average powers in the range of 2 to 6 kW. Even though the

CO_2 laser is at a low absorption disadvantage in processing metals over shorter wavelength lasers, such as Nd:YAG at 1.06 micron wavelengths and high power laser diodes arrays that operate between 0.808 and 0.975 microns (which I will round off at approximately 0.91 microns for convenience), CO_2 lasers still have the larger share of the market.

Listed in Table I are some absorption percentages for steel, iron (Fe), and aluminum (Al) at three of the main wavelength candidates for use in these applications. The three wavelength are: the strongest line of the CO_2 laser, namely 10.6 microns; 1.06 microns for Nd:YAG and its derivates lasers in either rod, slab, fiber or disc forms; and 0.91 micron as the average of the three high-power laser diodes arrays' wavelengths, 0.808, 0.94, and 0.975 microns. The table clearly shows that in general, the metal absorption of optical radiation increases with decreasing wavelengths.

TABLE I

Material	% Absorption	Wavelength, Microns
Steel	11	10.6
Steel	33	1.06
Steel	38	0.91
Fe	5.1	10.6
Fe	29	1.06
Fe	33	0.91
Al	~2	10.6
Al	5	1.06
Al	13	0.91

Unfortunately, the cost of laser devices per watt of output laser power increased dramatically with decreasing wavelengths. In addition, the output average power available from laser devices tends to decrease dramatically with decreasing wavelengths. Once a plasma is generated on the surface of a metal, the high absorption by the plasma of the CO_2 radiation results in efficient heating of the metal once plasma ignition occurs. These three facts, coupled with the lower cost per watt of CO_2 lasers usually favors the selection of the CO_2 laser for cutting sheet metal such as steel and aluminum at this point in time in the technological development of competing lasers.

Flexibility in the laser processing of materials tends to increase with the increased availability of a variety of laser output modulation formats. Various configurations of CO_2 lasers have achieved continuous-wave (CW) output power ranging from a few watts up to the 60kW. Operating efficiencies approaching 30% have been obtained, with 10% to 12% being more typical of commercially available CO_2 lasers. The CO_2 laser offers the option of operating continuously or in a wide variety of pulse repetition frequencies varying from a few Hertz to well over 100kHz.

CO_2 lasers are available commercially that are able to operate in one of three modes:

1) A super pulsed mode where the pulse peak power driving the laser discharge can be up to several times the average CW power
2) A gain-switched mode yielding megawatts of peak power but at low pulsed recurrence frequency, or PRF, (i.e., from a few hertz to about a kilohertz maximum) such as in Traverse Excited Atmospheric (TEA) lasers

3) A Q-switched mode where the pulse widths are tenths of microseconds wide at PRF up to 30 kHz and peak power is several hundreds of times the CW average power capability of the laser.

Radio-frequency (RF) excited, sealed off CO_2 lasers having operational lifetimes well in excess of 20,000 hours are commercially available. The CO_2 laser has been successfully energized electrically by RF and direct current (DC) energy as well as optically, gas-dynamically, chemically, and electron-beam excited (pumped). It has been excited by more different excitation approaches than any other laser. Electrical excitation is exclusively used in commercial applications.

The largest material processing markets served by CO_2 lasers are applications that require CW, pulsed, or super pulsed outputs from: 1) convectively cooled DC- or RF-excited lasers with output powers from 1kW to 60kW (with the largest market occurring in systems having laser output in the 5 to 6 kW range) and 2) sealed-off, diffusion-cooled, RF-excited lasers of either the slab or waveguide variety, having output power from a few watts up to approximately 2kW average power.

Deciding Which Laser Is Best for the Application

A convenient technique for reaching a decision on which type of laser to use in a material processing system is to fill in a matrix (see Table II for examples) consisting of parameters possessed by each candidate lasers and assigning a number ranging from, say

5 (highly acceptable) to 0 (unacceptable) to indicate how well the laser parameters satisfy the needs of the user's specific application. The laser type that accumulates the highest score is the laser best suited for the application. In general, one finds that below, say, 500 watts of average power with good beam quality, one has a wider selection of acceptable laser types that can be candidates for a given application. One finds that the number of laser candidates drop dramatically if output powers above approximately 100 to 1000W are needed for an application.

To first order, one should first decide on the usable wavelengths that can satisfy a specific material processing application and then decide on laser or lasers whose cost falls within the user's budget range.

TABLE II
Selecting a Laser Decision Matrix

Laser Type/ Parameter	**CO_2**	**Solid State**			**Excimer**	**Diode Array**	**Fiber**
		Rod	**Disc**	**Slab**			
Wavelength							
Average Power							
Peak Power							
Beam Quality							
Efficiency							
Fiber Delivery							
Capital Cost							
Operating Cost							
Size/weight							
Lifetime							
Etc.							
Totals							

The wavelength is usually selected based on the absorption of the material to be processed. The larger the absorption, the lower the power required from the laser; thereby, resulting in lower system cost. The wavelength can also be selected based on whether it can provide the smallest spot required on the work piece. Since the diameter of the focused spot scales inversely as the wavelength, one cannot obtain as small a spot size with a 10-micron wavelength diffraction-limited laser beam as with, for example, a diffraction-limited excimer ultraviolet laser beam.

The beam quality of a laser is usually specified as M^2. A $M^2 = 1$ indicates the laser beam is diffraction limited and capable of being focused down to its smallest theoretical spot size. A good beam quality number is $M^2 = 1.1$ or so. A $M^2 = 2$ means the beam's divergence is twice the diffraction limited divergence. A laser beam having a poor beam quality (i.e., a high M^2) usually requires higher average power to accomplish the same material processing task as a higher quality beam.

In general, the beam quality of a composite laser beam made up of a number of separate laser beams that are combined to generate a higher power beam than can normally be achieved with one laser is poorer than a single beam. This beam-combining approach is used if the laser technology does not exist to achieve the desired power from a single laser. High-power laser diode arrays fall within this power-combining category. High-power laser diode arrays have found a "niche" in metal heat treating, welding, or cladding metal parts where beam quality is not as important as in more demanding applications. As a matter of fact, poor beam quality is desirable in this specific application

The delivery of laser radiation to the work piece via a flexible glass fiber offers an advantage in many material processing applications over the use of an air path approach using multiple folding mirrors to direct the beam to non-line-of-sight locations. The shorter wavelength lasers (such as solid-state and fiber lasers) have an advantage in fiber delivery over CO_2 lasers because low loss, flexible fibers having comparable performance to glass fibers available at shorter wavelengths are not available for CO_2 laser IR wavelengths.

Types of Co_2 Lasers

A convenient method of naming different types of CO_2 lasers is by the means used to carry the heat away from the discharge. Since only on the order of 10% of the laser's input power generates laser energy, on the order of 90% of the input electrical power needs to be carried away as heat. Consequently heat removal is a primary concern in the design of a CO_2 laser as it is for all types of lasers. Since the laser's output beam quality is dependent on the alignment stability of the resonator's mirrors, it is important to have symmetric and uniform heat extraction from the laser discharged to avoid bending and twisting of the mechanical structure holding the resonators mirrors.

To obtain good beam output quality along with good beam-pointing stability in pulsed gas lasers, the laser designer has to minimize the optical distortions caused in the laser's gas mixture by acoustic shocks generated by the pulsing of the gas discharge. This problem is made difficult because the designer is limited to the use of materials that are compatible with good high-vacuum technology so as not to contaminate the laser's gas mixtures. Unfortunately, such materials are not usually good acoustic absorbers. The manufacturer usually specifies that the laser not be operated at pulse rates that are coincident with the acoustic resonances of the laser tube.

The two basic cooling techniques used in CO_2 lasers are: 1) convective cooling, where the heat is carried away by flowing the laser gas mixture that is at sub-atmospheric pressures within the laser tube, and 2) diffusion cooling, where the molecules within the laser discharge are cooled by making collisions with the cooled walls containing the gas discharge. Diffusion cooling requires that the cooled electrodes be separated by a small distance in order to shorten the time the hot CO_2 molecules need to reach them. The convectively cooled (also called flowing gas lasers) CO_2 laser is the oldest form of laser cooling. It has generated the highest average output power (~ 60 kW) in a commercial laser to date because of the large discharge volume allowed by this configuration. Diffusion cooling of CO_2 lasers is the newer of the two cooling technologies and has found a commercial niche in CO_2 lasers having average powers between a few watts to several kW. The output power capability of diffusion-cooled lasers is lower than for convectively-cooled lasers because of the small discharge volume resulting from the need to have the electrode cooling walls close together.

Convectively Cooled Co_2 Lasers

Figure 1 shows the basic building blocks of an RF-excited, capacitive couple discharge, convectively-cooled CO_2 laser. It usually consists of a dielectric tube (i.e., the laser tube), often made of Pyrex. The laser tube contains a totally reflecting mirror on one end and a partially reflecting mirror on the other end where the laser beam exits the laser tube. The laser tube has an input gas port for adding pre-mixed laser gases and an output port for circulating the laser gas mixture through the laser tube by means of a turbine or a blower fan. After the blower fan, the gas mixture is passed through a chiller for cooling.

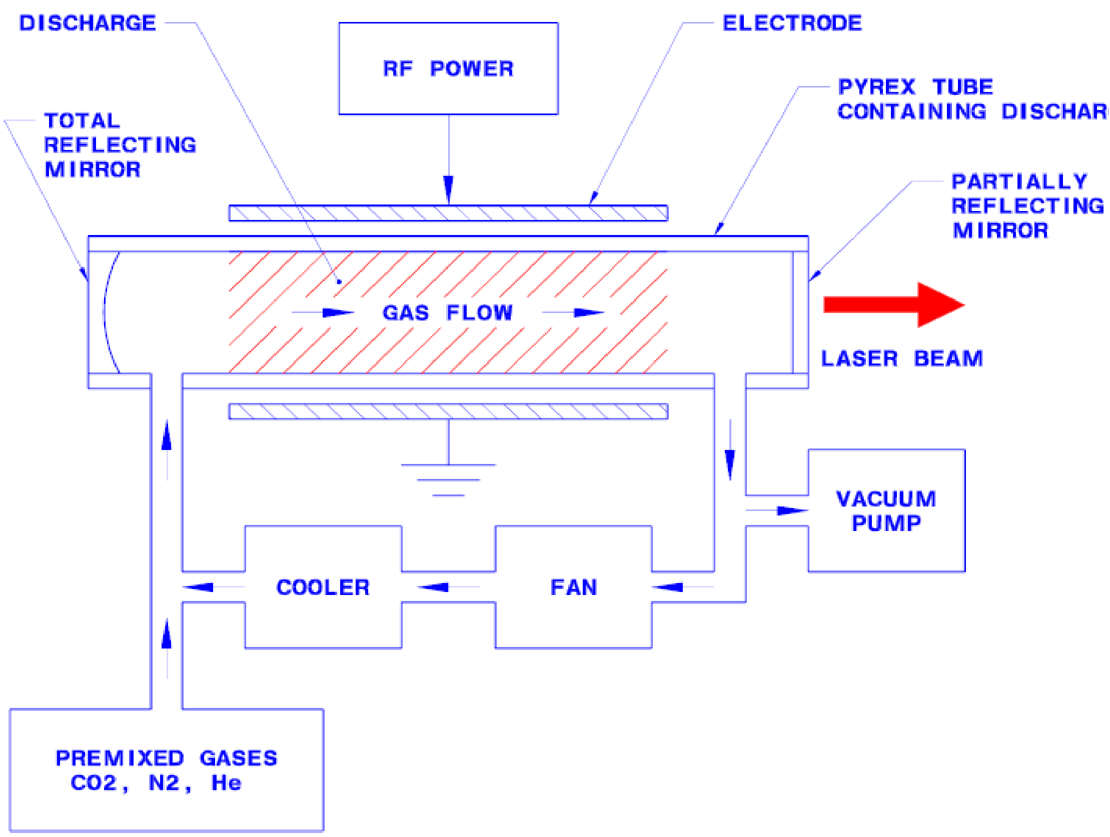

Fig. 1. Block diagram of a convectively-cooled CO_2 laser.

The laser tube has external electrodes placed along its length, both above and below the laser tube, if RF capacitive coupled excitation of the discharge is used. One of the electrodes is grounded and the other is connected to an RF power supply having a frequency in the RF industrial band. The electric field developed between the electrodes creates a gas discharge in the CO_2, N_2, and He gas mixture in the gas volume bounded by the parallel electrodes. This discharge volume provides the infrared gain. Mirrors are used to provide infrared feedback for generating the infrared resonant oscillation that creates the laser's output radiation.

The vacuum pump shown in the figure is used to pull a partial vacuum in the laser tube, usually between 50 to 150 Torrs. If the laser tube was to be sealed off without gas replenishing, the gas would soon be contaminated by the mechanical blower drive mechanism's lubricant. The contamination deteriorates the gas mixture's kinetics and the discharge behavior, leading to reduced laser output power and eventually causing the laser to stop lasing. The vacuum pump extracts a small amount of the laser gas, and new makeup gas from the pre-mixed gas input replenishes the gas extracted by the vacuum pump. By this technique, the buildup of the gas contamination to an unacceptable level is prevented.

For a given laser tube diameter, the output power scales with the gas flow velocity. The faster the gas flows, the higher the convective cooling and the higher the output laser power for a given length of discharge. Obtaining a higher amount of gas cooling of the gas flowing through the chiller will also increase the laser's output power, but vapor condensation forming on the outside of the laser tube in humid regions normally limits how much cooling can be achieved.

Figure 1 illustrates one example of a coaxial flow, convectively-cooled CO_2 laser configuration. In this configuration, the laser beam axis and the gas flow velocity are co-linear. For the approach shown in Fig. 1, the longer the separation between the electrodes, the faster the gas flow needs to be in order to minimize the amount of time a CO_2 molecule spends in the hot discharge before it is cooled and recirculated by the fan through the chiller. Higher gas flow velocity means a higher gas-pressure drop, which requires more electrical power to drive the turbine or fan.

It was realized that superior gas cooling could be obtained by flowing the gas in a rectangular-shaped duct and having the gas velocity flow (v) and the discharge current (I) perpendicular to the laser beam axis, thereby shortening the time the hot CO_2 molecule spends in the discharge. Superior cooling over the approach shown in Fig. 1 can be obtained by placing perforated electrodes, through which the gas can flow, both upstream and downstream of the laser-beam axes. This arrangement positions the electrodes on both sides of the cross-propagating laser beam with respect to the gas flow as shown in Fig. 2. Another variation for this superior convectively-cooling approach is to place the electrodes in the form of rods or bars on the top and bottom of the rectangular flow channel as shown in Fig. 3. In this arrangement, the current flow, the gas flow, and the laser beam propagating axis are all mutually perpendicular to each other. In both Figs. 2 and 3 cases, one needs to preserve laminar gas flow in order to obtain a high-quality laser beam.

Both the approaches for Figs. 2 and 3 considerably shorten the hot discharge distance "L" through which the excited CO_2 molecules flow; thereby providing superior convective cooling over the approach of Fig. 1 where the distance L is much longer. Unfortunately, the optical gain profile within the discharges of Figs. 2 and 3 are not symmetrical as the round-gain profile provided by the co-axial flow configuration of Fig. 1 because the discharge is not symmetrical. Consequently, the laser beam quality obtained by the configurations of Figs. 2 and 3 tend to be inferior to the beam quality obtained by the configuration of Fig. 1. This is the reason why the laser tube discharge approach of Fig. 1 is dominant in the marketplace.

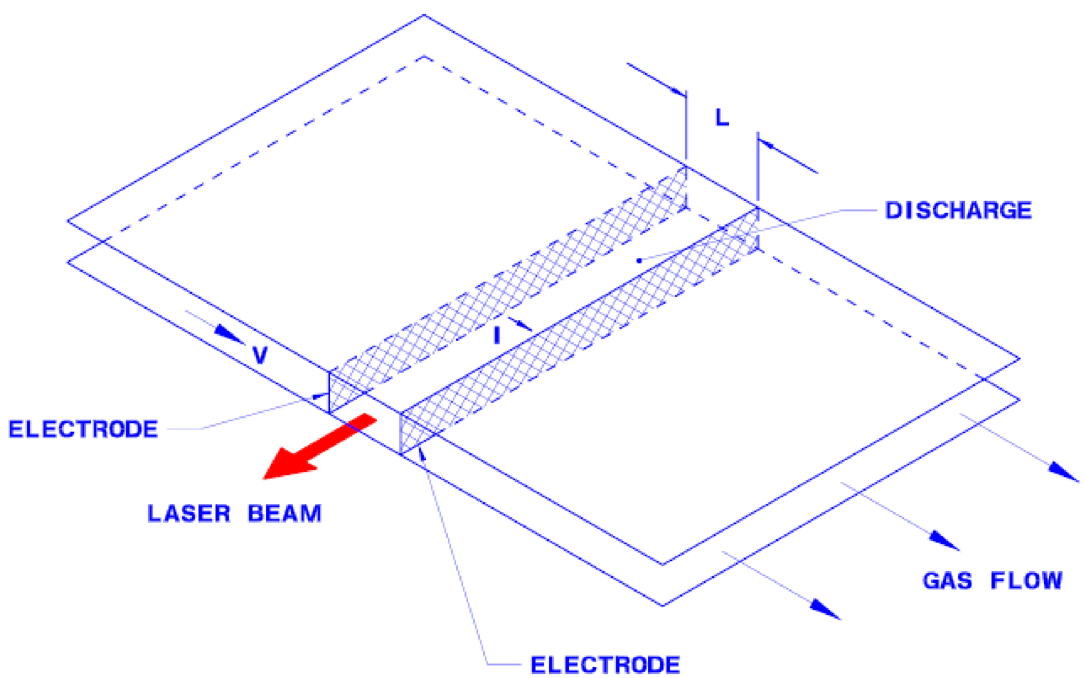

Fig. 2. Sketch of the flow channel of a convectively-cooled CO_2 laser with the gas flow (v) and RF current (I) perpendicular to the laser beam axis.

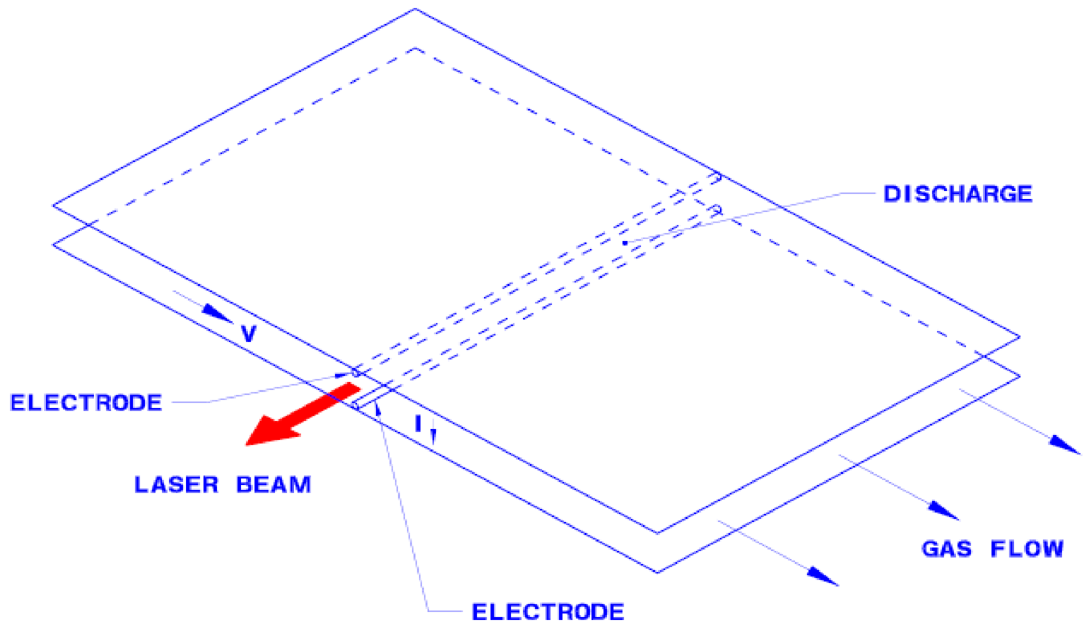

Fig. 3. Sketch of the flow channel of a convectively cooled CO_2 laser with gas flow (v) and RF current (I) mutually perpendicular to the laser beam axis.

For more discussions on different convectively-cooled CO_2 laser configurations, see Ref. 2, “Review of High Power CO_2 Lasers” by Anthony J. DeMaria, Proceedings of the IEEE, June 1973, pp. 731-74. This reference also provides information on the discharge gas kinetics and the physics responsible for the operation of the laser.

Instead of the use of RF excitation of the laser discharge shown in Fig. 1, DC excitation of the laser discharges is also used by some manufacturers. A DC-excited, convectively-cooled CO_2 laser has a similar configuration as Fig. 1 except that it has metal electrodes inserted into both ends of the laser tube. The discharge is generated between the ends of the inserted electrodes instead of between the externally located electrodes positioned above and below the laser tube as shown in Fig. 1. The DC-discharge approach is a more mature, easier to master, and less expensive technology to implement in CO_2 lasers than the RF-discharge approach, but it suffers from several disadvantages summarized below:

One disadvantage is the sputtering of the metal electrode material in contact with the discharge. These DC electrodes require periodic replacements because of wear resulting from the sputtering away of the electrode material caused by bombardment from energetic ions within the discharge. Another disadvantage is that the sputtering of the electrode material into the discharge contaminates the laser gas, thereby shortening the laser's lifetime. The sputtering also enhances the formation of arcs within the discharge, which reduces the quality of the laser beam. Still another disadvantage is the high electric fields required to maintain the discharge.

A voltage minimum of approximately 20 volts per centimeter separation between the DC electrodes per Torr of gas pressure is needed to maintain a uniform DC discharge in a CO_2 laser's gas mixture. For example, for a 100 cm long discharge having 100 Torr of gas pressure, a voltage as high as 200,000 volts is needed to maintain the discharge. Such a high voltage requires vacuum-tube electronic technology to be used in the RF power supply. The RF-capacitive-driven discharge approach can utilize semiconductor solid-state electronic technology, at least up to the few kW laser output power levels. Solid-state, RF-power supplies have smaller size and weight, longer lifetimes and require only tens of volts to energize the RF amplifiers instead of kilovolts for vacuum-tubes electronics. The mentioned solid-state power supply advantages that solid-state electronic has over vacuum tubes are obtained at higher cost and more complex electronic circuitry along with the need to protect the RF power supply from back reflections because of impedances mismatch. Solid-state power supplies are more susceptible to damage from back reflections the vacuum tube electronics.

In summary, convectively-cooled CO_2 lasers have generated the highest output power and are the most mature CO_2 laser technology. To date this technology has been the workhorse of the high-power laser material processing industry.

Diffusion Cooled Co_2 Lasers

Diffusion-cooled CO_2 lasers utilize the collision of hot CO_2 molecules that have given up photons into the laser's feedback cavity but have not been completely de-excited to the ground state, with the walls of the housing containing the discharge. These wall collisions de-excite the energy of the hot CO_2 molecules down to the ground state, thereby cooling the CO_2 molecules. The gas discharge container housing is in turn cooled externally by either liquid or air cooling, with air cooling being used for CO_2 lasers operating below 100watts.

In diffusion-cooled CO_2 lasers, the amount of heat carried away from the discharge scales inversely as the time required for the hot CO_2 molecule to migrate to the cooled walls of the discharge container. Since diffusion to the cooled walls occurs in a random-walk process, the power output of a diffusion-cooled laser scales inversely proportionate to the square of the separation of the walls containing the discharge. Consequently, the geometry of the discharges of diffusion-cooled CO_2 lasers are contained in either: 1) long and narrow optical waveguide channels machined in a ceramic slab where an RF metal electrode is placed on each sides of the channels, as shown in Fig. 4, or 2) the discharge is contained between two flat, metal, electrode plates separated by a small distance of the order of a 01 inch, as shown in Fig. 5. The higher the RF drive frequency of the RF power supply, the higher the gas pressure in the discharge and the smaller the required separations between the electrodes.

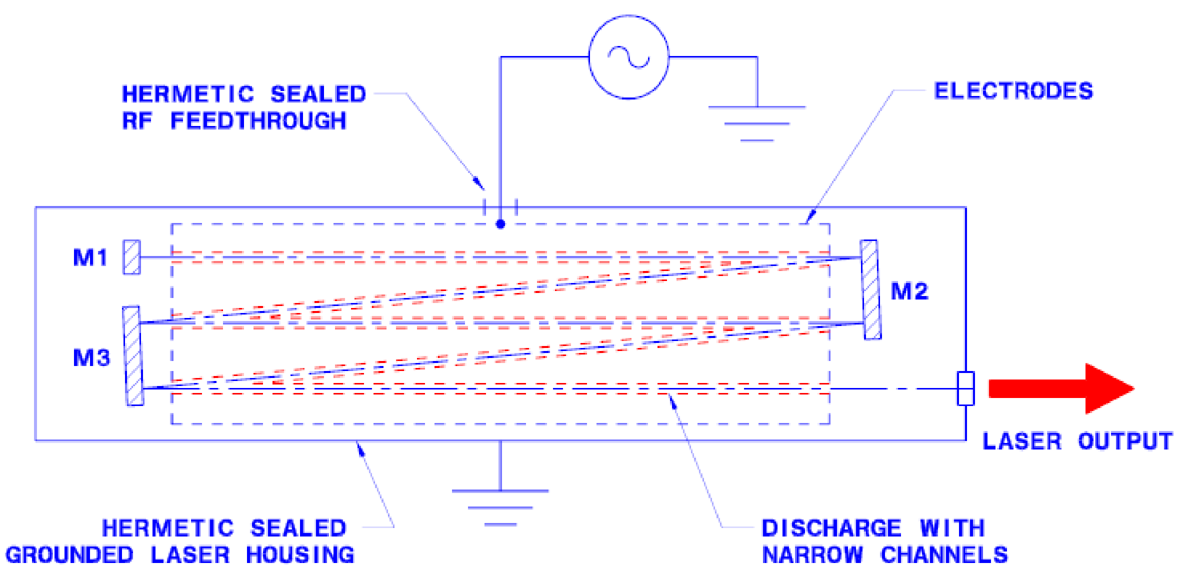

Fig. 4. Sketch of a 5-channel folded waveguide diffusion-cooled CO_2 laser.

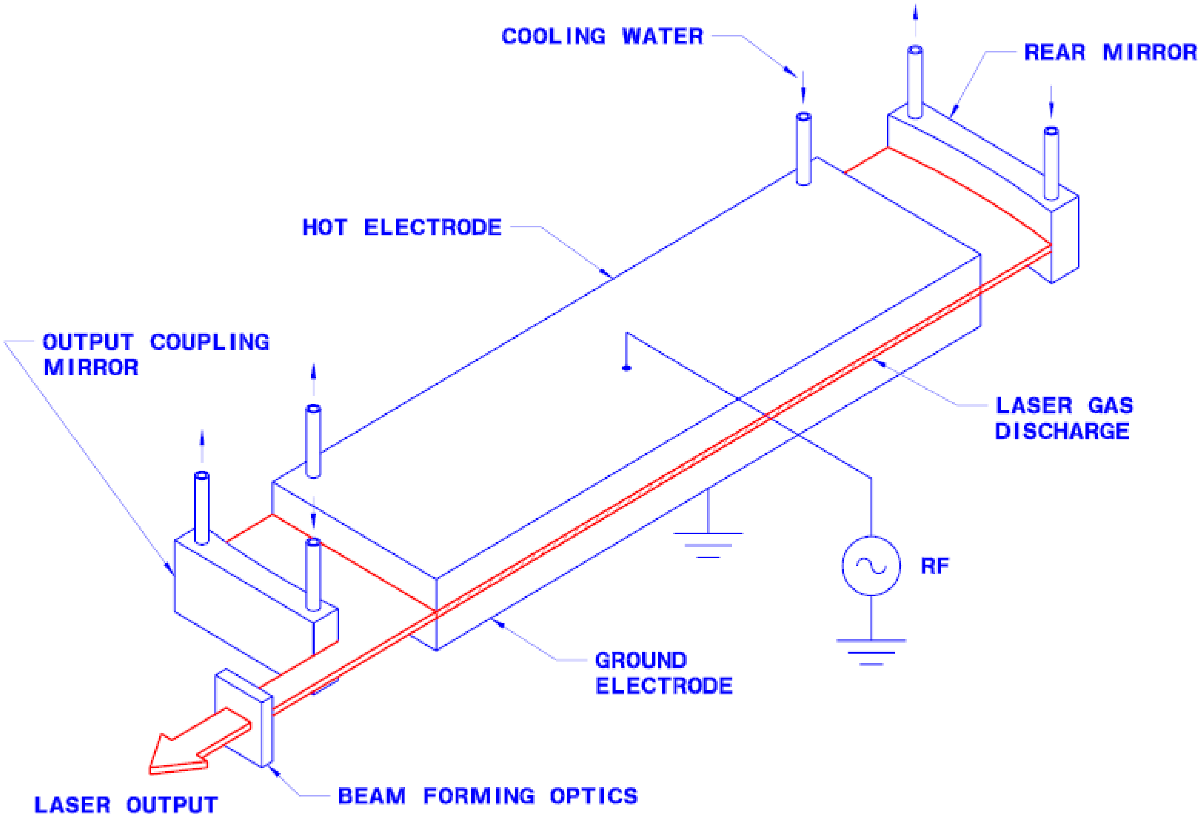

Fig. 5. Sketch of a diffusion cooled CO_2 slab laser with a negative branch unstable resonator.

Lasers utilizing the configuration of Fig. 4 are commonly known as waveguide lasers and are suitable for CO_2 lasers having sealed-off output powers from, say, lower then 10W up to slightly over 100 watts. Lasers utilizing the laser configuration of Fig. 5 are commonly known as slab lasers and are suitable for sealed-off output powers from say 75W to more than 2kW. Both configurations use RF-discharge excitation and can achieve sealed-off lifetimes greater than 20,000 hours. Sealed-off, diffusion-cooled discharge lasers having over 1kW output power have been recently introduced into the marketplace by Coherent, Inc. with its E-1000 model being the first sealed-off CO2 laser above 500W.

As an example, Fig. 4 illustrates a diffusion-cooled waveguide laser with five saw-tooth-folded channels in schematic form. Mirror M_1 is the high reflecting return mirror, while mirrors M_2 and M_3 are the waveguide beams “redirecting” or beam “folding” mirrors. M_0 is the partially reflecting mirror that provides the optical feedback into the laser resonator and also couples out power from the laser’s optical resonator. All the mirrors have thin-film coated flat surfaces and are usually fabricated from gold-plated copper, except M_o, which is usually ZnSe or silicon which are transparent at the CO_2 laser wavelength. The waveguide channels are usually machined within a dielectric slab material, such as an alumina ceramic. Rectangular electrodes are placed on top and bottom of the alumina slab, thereby sandwiching the waveguide channels between them. The use of a hermetic-sealed RF feed-through is used to couple RF energy to the hot electrodes within the hermetic-sealed laser housing. The laser housing serves as an electrical ground and as a container of the gas mixture and the optical resonator. The application of RF energy across the electrodes causes a discharge to be generated within the channels. The ground electrode is connected to the electrically grounded, hermetically sealed metal laser housing to prevent stray RF radiation from leaking out from the enclosed laser housing.

A laser having the five-pass folded waveguide configuration shown in Fig. 4 can yield 150W output power in a laser housing package having dimensions of 24 x 4 x 3 cubic inches without the RF power supply and with the metal laser housing being water cooled.

The RF power supply is usually mounted directly on the laser housing which adds about two additional inches to the height of the laser housing.

Figure 5 illustrates a diffusion-cooled slab laser with two curved mirrors that form an optical resonator known as a negative branch unstable resonator. In this slab laser configuration, the output coupling mirror is shorter than the reflecting mirror located at the opposite end of the laser housing. The opening provided by the shorter mirror provides an output port for coupling out radiation within the resonator. These mirrors are usually fabricated from gold-plated copper for good heat conductivity to efficiently carry away the heat from the thin-film coated concave reflecting surfaces. Dielectric-coated Si mirrors are also used in place of copper mirrors. The gold plating of the copper mirrors is needed to prevent the "gettering " of oxygen from the gas discharge by the oxidation of the copper .The deletion of oxygen unsets the gas kinetics chemistry, which reduces the laser sealed-off operational lifetime. For high power operation, i.e., above 500W, the mirrors are water cooled. The electrodes have a rectangular configuration as shown in Fig. 5. The space separating them is again about 0.1 inches. They are also water cooled.

The gas volume between the electrodes forms a heat discharge when RF power is provided across the electrodes. The two inner parallel surfaces of the electrodes form an optical waveguide for the laser radiation propagating down the length of the slab discharge that is formed between the electrodes inner surfaces. In addition to this waveguide mode, unstable optical resonators also have a free space mode propagating across the width of the discharge that is formed between the flat plate electrodes.

Consequently, an unstable resonator is a hybrid resonator having both waveguide and free space propagating modes existing within the same resonator. Unstable resonator technology has been primarily responsible for the rapid development of compact, high-power slab-laser technology and its application in the laser processing industry.

The output power of slab lasers scale directly as the area of the rectangular discharge rather than as the length of the discharge as in the waveguide lasers. The marketplace favors shorter and wider lasers because of the smaller footprint such lasers have on the factory floor. Diffusion-cooled, hermetic-sealed, RF-excited CO_2 lasers having over 1000W average power with discharge length-to-width ratios of slightly less than 6 have recently been introduced into the marketplace; thereby making commercially available lasers with dimensions including the RF power supply of approximately 57 inches long x 19 inches high and 15 inches wide, with a total weight of approximately 380 lbs.

The realization of such short, sealed-off, diffusion-cooled lasers, combined with the size reduction advancements in solid-state, high-power RF power supplies and the passive compensation of the changes in mirror curvature with temperature, have reduced the size and width of these CO_2 lasers to the point where a 1000W average output power diffusion-cooled CO_2 laser can be mounted directly on a robotic arm along with its RF power supply. Since the RF power supply is integrated onto the laser housing, the only outside attachments required for the laser are cooling lines for the laser and DC electrical power for the RF power supply.

Transverse Excited Atmospheric (TEA) Laser

Intuition leads one to correctly conclude that to obtain more power from a given CO_2 laser tube diameter, one can simply increases the gas pressure. It is well known that CO_2 lasers operate best with electric-fields-to-pressure ratio (E/P) of 20 to 50 volts/Torr. This means that for a 1-meter discharge at a high gas pressure, say, of 800 Torr, voltages in the neighborhood of 800,000 to 4,000,000 are needed to create the discharge. Steady-state discharges at such high gas pressures are difficult to maintain without having the discharge degenerate into an arc. Consequently, CO_2 laser operation at such high pressures is operated in a fast-rise, time-pulsed mode.

To lessen the high-voltage requirement at the high gas pressures, transverse excitation is favored to keep the spacing between the electrodes small. Transverse excitation has the pulsed current generating the discharge flowing perpendicular to the laser beam axis as in Fig. 1 rather than along the axis of the laser tube. This arrangement reduces the distance between the electrodes from, say a meter down to a centimeter or less; thereby reducing the voltage by approximately two orders of magnitude. In transverse-discharge excitation, the current flow is also transverse to the laser's optical axis as illustrated in Figs. 2 or 3. Either of the approaches shown for Figs. 1, 2, or 3 reduces the electrode spacing from say a meter, as in DC-excited, convectively-cooled lasers, down to centimeters or fractions of centimeters, with a corresponding order of magnitude reduction in the excitation voltage required for the discharge.

Arcing within a laser discharge is undesirable because arcing simply heats the gas and deteriorates laser operation in both efficiency and beam quality. To avoid discharge arcing, the high-excitation voltage is delivered in a fast-rise, time-pulse, preferably comparable to or faster than the time required to form an arc in the discharge. TEA lasers can produce short laser pulses (i.e. typically having pulse width of a microsecond or less) with sub-microsecond rise times and with megawatts of peak power.

TEA CO_2 lasers are the second most mature of the CO_2 laser types. Single-pulse energies up to 10 Joules at low-pulse-per-second or less rates and up to pulse-repetition rates of 800 Hz with approximately 1 Joule per pulse have been obtained. At such high-pulse energies, acoustic shocks need to be minimized by the laser designer because the shocks cause gas turbulence in the laser medium, which deteriorates the beam quality and the pointing stability of the beam. Acoustic shocks are one of the reasons for the low-pulse, repetition-frequency performance of TEA lasers.

TEA laser have found “niche” applications requiring high peak power (i.e., up to megawatts), high peak energies (i.e. up to several joules per pulse), and relatively low pulse-repetition frequencies (i.e., up to about 100 PRF with 10 PRF being typical). TEA CO_2 lasers have the smallest share of the laser material processing market. In most cases, TEA laser are manufactured to order, according to individual users’ unique specifications.

Conclusions

CO_2 lasers have become the workhorse of the material processing industry because of their low cost (below $100 per watt); relatively high efficiency (greater than 10%); small size per watt of output power; large variation in output power ranging from a few watts up to many tens of kilowatts; long sealed-off lifetime of greater than 20,000 hours; wide variety of output waveform formats; and high absorption of its output wavelengths by many materials.