New CO Laser Technology Offers Processing Benefits

Andrew Held[⊠]
Director of Marketing, Coherent Inc.

Abstract

The development of a reliable, high-power source of mind-IR laser light gives process develop important tool with unique characteristics that will significantly impact a diverse range of applications.

Keywords: Glass cutting(유리 절삭), Glass drilling(유리 구멍 드릴링), Film cutting(필름 절삭), Converting(컨버팅), Polyethylene(폴리에틸렌), Displays(디스플레이)

1. Introduction

The first carbon monoxide (CO) lasers were built over 50 years ago. The technology showed promise for several reasons. First, CO lasers are inherently electrically efficient (in terms of their conversion of input electrical energy into light). For example, they are potentially about twice as efficient as the more commonly used carbon dioxide (CO_2) lasers. Also, CO lasers output in the 5 μm to 6 μm spectral range, whereas CO_2 lasers typically lase at 10.6 μm. This shorter wavelength provides processing benefits in many applications.

Given these advantages, why have CO lasers remained largely a laboratory curiosity until now, while CO_2 lasers, which were developed around the same time, have found widespread use in a diverse range of industrial processing applications? The answer is that CO laser technology could not be made practical, reliable and cost effective enough for commercial use. In particular, early CO lasers required cooling in order to reach high output power (cryogenic cooling for very high powers). Also, while the first sealed CO_2 lasers could operate at high powers for hundreds of hours, early sealed CO laser lifetimes were measured in just hours before output power dropped substantially.

투고일 : 2015년 9월 15일 심사완료일 : 2015년 9월 30일
게재승인일 : 2015년 10월 15일
교신저자 : Andrew Held ⊠ Andrew.Held@coherent.com

This situation has now changed dramatically with the development of new CO laser technology that addresses these practical limitations. This has enabled the production of sealed CO lasers which operate at very high output powers, with excellent efficiency at room temperature, and which demonstrate lifetimes in the thousands of hours range. This article reviews the technology behind this new generation of CO lasers, and examines how their unique output characteristics lead to significant benefits in some important commercial applications.

2. Body

2.1 CO laser development

In order to appreciate the inherent difficulties associated with developing and manufacturing a gas discharge laser like the CO laser, it is useful to examine the challenges met with the more familiar CO_2 laser. The dynamics involved within fully sealed gas discharge lasers are complex, to say the least. Critical chemical dynamic control involves the gas chemistry within and outside the laser discharge volume (including laser on and off), the chemistry between the gas and resonator materials (metals, ceramics), the chemistry between the many different materials used to construct the laser, and the chemistry involved with potential contaminants. Cleaning is critical within the sealed resonator tube.

Coherent over the years has learned how to control the chemical dynamics in fully sealed CO_2 lasers, enabling higher performance and improved reliability. Today's CO_2 lasers offer higher average powers and peak powers, as well as better power and pulse stability, than ever before. At the same time, the reliability of these lasers has increased by five fold over the last 10 years. This can be attributed in large part to our ability to control the complex chemistry involved in CO_2 lasers. Some of this is improved engineering design and development, and part is manufacturing process optimization, including supplier development (coatings, electronics, etc.). The design improvements and critical manufacturing process optimizations, developed over many years, for CO_2 lasers, are now being applied to the new CO lasers.

The gas dynamics in a CO_2 laser is a carefully controlled symphony of chemical activity. In CO_2 lasers, nitrogen gas is vibrationally excited via electron impact in a radio frequency (RF) generated plasma discharge volume. The nitrogen then transfers it vibrational energy to the CO_2 molecules, which can now emit photons (9.6 μm or 10.6 μm) as they drop to lower energy vibrational states. From these lower vibrational energy states, the CO_2 molecules transition ultimately to the lowest energy state through collisions with helium, i.e., vibrational-translational (V-T) energy transfer. From this lowest energy state they can then be re-excited.

In addition to the "lasing" gas dynamics, there is also the chemical decomposition and recombination of CO_2, which is carefully controlled by trace gas elements in the mix like Xe, H_2, D_2, H_2O, CO, etc. Pressure and resonator geometry optimization also plays a critical role in controlling the gas dynamic and chemistry. Further, contaminants missed through the cleaning process or created in the chemical pool can disrupt the gas dynamic chemical balance and adversely affect the lasers performance.

The chemical dynamics of the CO laser are different, but equally complex. Vibrational excitation of the CO molecules take place directly via electron impact from the same RF sources used to create the discharge plasma in CO_2 laser. However, CO lasers don't necessarily need nitrogen. Once vibrationally excited, the CO molecules can further excite other CO molecules through vibrational-vibrational (V-V) transfer.

Laser emission comes from successive transitions between pairs of populated vibrational levels in the diatomic energy level ladder. Each transition to a lower energy level then becomes the upper state for a subsequent transition. This is the definition of a cascade laser. As in the CO_2 laser, there are many different processes that compete with effective lasing that need to be accounted for. Where the helium V-T cooling is critical for CO_2 lasers, in CO lasers, the helium translational energy transfer (V-T) can actually compete with the efficiency of the V-V CO pumping process. This is partly why early CO lasers were often cryogenically cooled. Room temperature operation was not practical (until now).

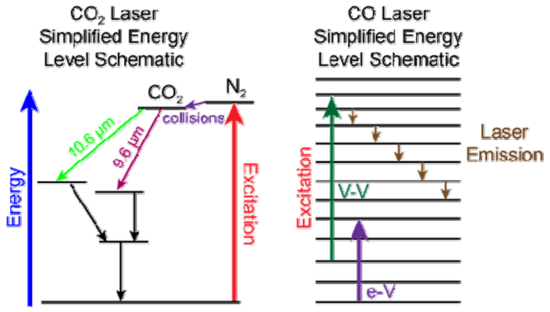

Fig. 1 In a CO_2 laser, energy transfer from N2 raise the CO_2 molecules into an excited state, which then decays into one of two possible lower states by emitting a photon. Non-radiative losses cause the molecule to return to the ground state. In a CO laser, several pumping mechanisms can raise the energy of the molecule to various excited states. It then cascades back down to the ground state, emitting several photons along the way.

2.2 Mid-IR Wavelength Advantages

Much of the interest in CO lasers derives from the fact that its mid-infrared output offers two important advantages, in terms of applications, as compared to the far infrared output of the CO_2 laser. The first of these is the fact that many materials exhibit significantly different absorption at the shorter wavelength, leading to disparities in their processing characteristics which can be exploited. Specifically, in cases where the absorption is higher at the shorter wavelength, material can be processed more efficiently using lower laser power, and with a smaller heat affected zone (HAZ). This stronger absorption occurs in many metals, films, polymers, PCB dielectrics, ceramics and composites. On the other hand, when the transmission is higher at the shorter wavelength, the light penetrates farther into the material, which is also sometimes advantageous.

The other major difference is that shorter wavelengths can be focused to smaller spot sizes than longer wavelengths due to diffraction, which scales linearly with wavelength. The final spot size depends on working distance, and the numerical aperture of the focusing lens. The theoretical, diffraction limited spot size for 10.6 μm CO_2 lasers is about 55 μm, while the minimum spot size achieved in practice in industrial applications is 80 - 90 μm. The 5 μm CO laser can reach theoretical spot sizes of about 25 μm under the similar focusing conditions, with practical spot sizes in the 30 - 40 μm range. As a result, the CO laser spot can have a power density (fluence) that is four times higher as compared to the CO_2 laser. The higher power density, when combined with stronger absorption in some materials at 5 μm, enables these materials to be processed with a CO laser at significantly lower powers.

Diffraction also dictates that a shorter wavelength spreads more slowly over distance, leading to improved depth of field. Specifically, depth of field (or the distance over which the beam size increases by a factor of √2) is related to laser wavelength (λ) and input beam diameter (D) by:

$$Depth\,of\,field = \frac{\pi D^2}{2\lambda} \tag{1}$$

Thus, for a given input beam diameter, as wavelength decreases, depth of focus increases. The benefits of a longer depth of focus include higher aspect ratio processing and an increased process window, especially for materials with uneven surfaces and/or variations in thickness.

2.3 Glass Cutting

CO_2 lasers are already employed in cutting thin (< 1 mm thick) glass sheets, most importantly the specialty glass (strengthened and non-strengthened) used in many smart phone and tablet displays. The 10.6 μm output of the CO_2 laser is strongly absorbed by glass, whereas absorption around 5 μm is much lower. But this actually leads to significant potential advantages in this application.

In CO_2 laser-based glass cutting, the light is absorbed strongly at the surface, generating heat which must then diffuse into the bulk material. After laser exposure, a jet of water or air is used to thermally shock the material and create a precisely controlled scribe or vent. Mechanical means are then employed to actually break the glass along the laser scribed line.

The overall process is much the same with the CO laser, however, the lower absorption allows the light to penetrate much further into the bulk material. Heat is introduced to the glass directly and does not rely on diffusion from surface. Coherent has performed tests which indicate that this eliminates surface melting, avoids the creation of cracks, and produces no residual stress in the glass. The results are a better quality scribe yielding a stronger cut piece, together with a wider process window for the manufacturer.

The other exciting aspect of CO lasers in glass cutting is their ability to support the cutting of curves. This is of particular importance in smartphone display applications as curved or shaped corners are often required to accommodate buttons, controls, LEDs and camera lenses. CO_2 lasers are typically limited to cutting glass in straight lines because their round output beam must be reshaped into a long, thin line in order to distribute the intense heat generated at the surface. In contrast, the lower absorption of the CO laser allows its round beam to be used directly because without adverse heat effects.

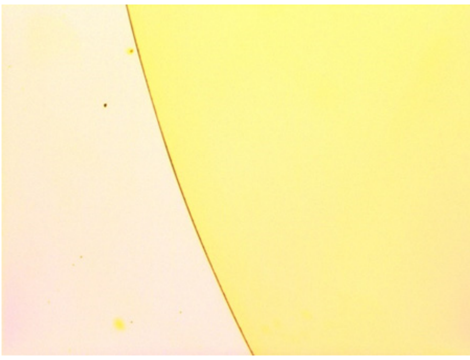

Fig. 2 A CO laser with only 9W of output power produced this clean, curved cut (6 mm radius circle) in thin glass (50 μm thick) at a feed rate of 140 mm/sec.

The CO laser also enables processing of very thin glass (below 300 μm thick). This material is almost impossible to cut mechanically, and also challenging to process using the CO_2 laser. In this case, the CO laser can cut completely through the glass, eliminating the need for a subsequent mechanical breaking step, which is particularly difficult to accomplish with very thin glass.

2.4 Glass Hole Drilling

Another important glass processing application is glass drilling for glass interposers used in so-called 2.5D and 3D advanced circuit packaging techniques. This application takes advantage of both the superior focusability and lower absorption of 5 μm light in glass. Specifically, it enables very small holes to be drilled in glass with precise depth control and no heat damage or cracking.

2.5 Film cutting

Polyethylene (PE) has strong absorption at 3.5 μm, with mild overtones at 7 μm and ~14 μm. Unfortunately, no high power lasers are available at any of these wavelengths, and so laser cutting of PE has been not been practical in the past.

While low level absorption can always be driven with high powers at CO_2 laser wavelengths, the residual heat generated by the unabsorbed light creates unacceptable collateral damage. But, the higher focused fluences that can be achieved with the CO laser avoid this problem, enabling PE to be effectively cut.

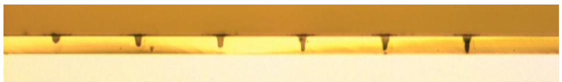

Fig. 3 A 50 μm thick glass substrate drilled with successively more pulses from a CO laser demonstrates the ability of this source to drill glass interposers, as well drill micro dots on light guide panels (LGP) used in display backlights. CO_2 drilling of this material typically results in heat related cracking.

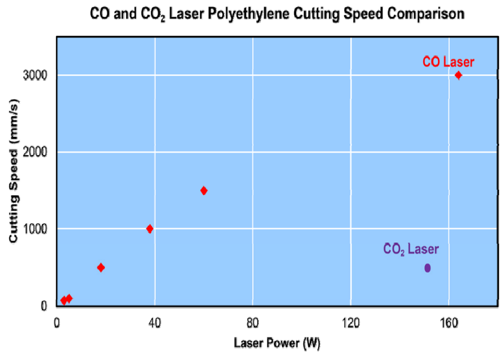

Fig. 4 Polyethylene cutting speed of CO lasers of various output power levels as compared to a CO_2 laser. A 20W CO laser cuts at about the same speed as the 150W CO_2 laser.

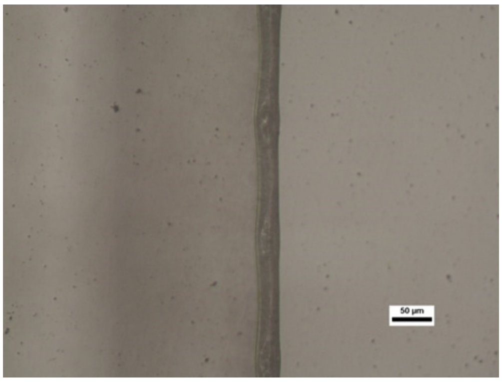

Fig. 5 Top view of the edge of a 20 μm thick polyethylene sheet (at left), cut using a 164W CO laser at a feedrate of 3,000mm/s. The laser produced a clean cut edge, with a heat affected zone (HAZ) of about 29 μm.

Testing at Coherent has shown that thin (20 μm) PE can be cut at speeds beyond 3,000 mm/sec with a limited HAZ (30 μm). CO_2 laser cutting of this material at similar power levels reaches 500 mm/sec at best, and creates 500 μm of HAZ. At 60 μm thickness, the CO_2 laser simply cannot cut the PE without destroying the material, whereas the CO laser cuts with acceptable speed and cut quality.

3. Conclusion

In conclusion, the development of a reliable, high power source of mid-infrared laser light gives process developers an important new tool with unique characteristics. Expect it to have an impact in a diverse range of applications.

Author:
Andrew Held, a director of marketing at Coherent for the company's CO_2 laser products.