CO Lasers from Lab to Fab

Developments in CO laser technology enable the production of robust CO lasers that offer benefits in glass cutting applications

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First demonstrated over fifty years ago, carbon monoxide (CO) and carbon dioxide (CO_2) lasers are similar technologies that took two different paths of development. CO_2 lasers are deployed extensively in a wide range of industrial applications, and their use continues to grow. In contrast, CO lasers were largely restricted to laboratory applications, primarily because it was found to be difficult to produce CO lasers which offered the same high level of reliability and lifetime as CO_2 lasers.

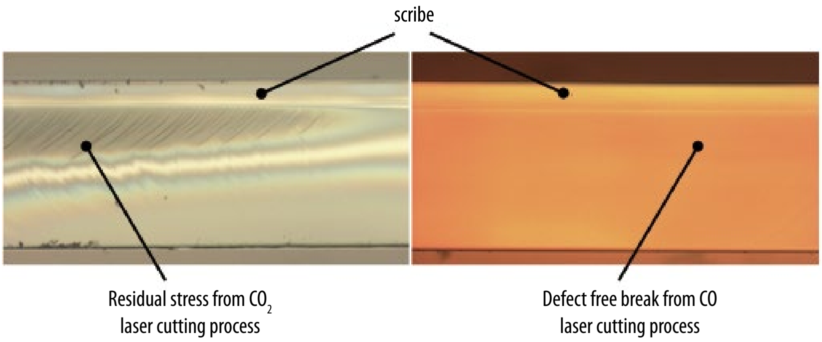

Fig. 1 Scribing with a CO_2 laser leaves some residual stress after the glass is mechanically broken, while CO laser scribing produces virtually none.

This situation has now changed dramatically with the recent development of robust CO laser technology from Coherent. This has enabled the production of sealed CO lasers that deliver high output powers, and have lifetimes in the thousands of hours. Plus, important differences in the output characteristics of these two laser types make CO lasers a better choice in certain applications. This article reviews the unique output characteristics of CO lasers, and shows how these lead to significant benefits in the specific example of glass processing.

Mid-IR wavelength advantages

CO lasers output mid-infrared light (approximately 5.5 µm), as opposed to the far infrared output (10.6 µm) of the widely used CO_2 laser. This shorter wavelength output can be an advantage in some applications for two main reasons. First, many materials exhibit very different absorption characteristics at these two wavelengths. This leads to differences in their processing characteristics which can sometimes 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 absorption is lower 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. 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.

Reliable CO lasers

Given these advantages, why have CO lasers remained largely a laboratory cu-

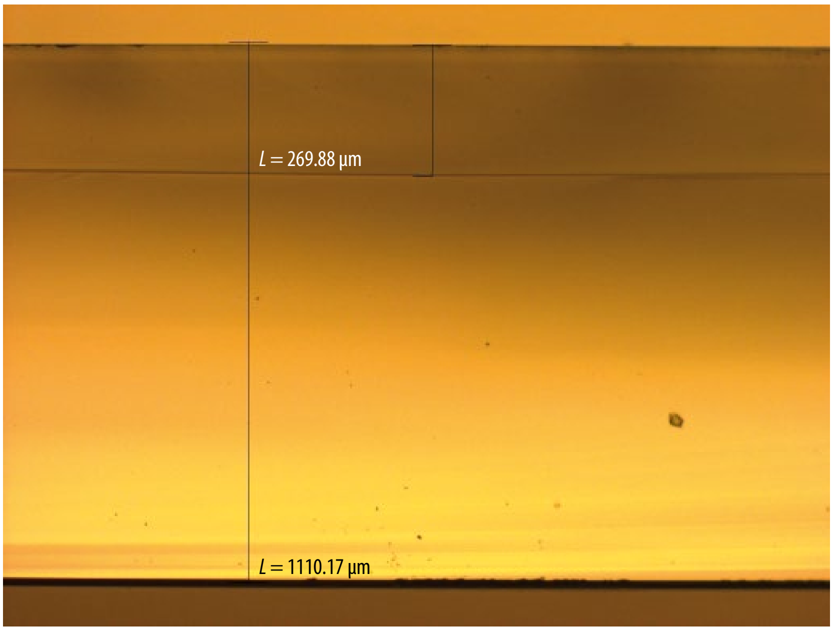

Fig. 2 A 270 µm deep cut (25 %) in a 1.1 mm thick glass substrate shows virtually no stress or microcracking.

riosity until now, while CO_2 lasers 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, e.g. 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.

The degradation in power is typically associated with changes is the CO gas mixture. Coherent has developed an effective process for exchanging the older gas mixture with a fresh mixture that restores 100 % of the laser's performance. The gas exchange can be done in-situ in the field, so no laser realignment in the tool will be needed.

Over the past 25 years, Coherent has also learned how to manipulate the complex chemical dynamics in fully sealed CO_2 lasers, enabling higher performance, improved reliability and a massive increase in sealed laser lifetime. Our engineers have demonstrated that many of these innovations and improvements originally developed for CO_2 lasers are directly applicable to CO lasers. The results are the first fully sealed commercial CO lasers that deliver high power output (200 W) at 5.5 µm, which operate with high efficiencies at room temperature, and which have lifetimes of thousands of hours.

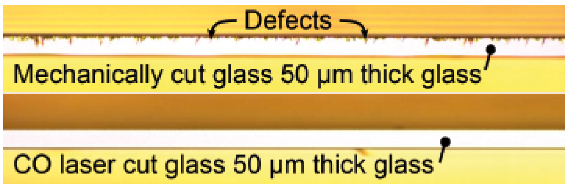

Fig. 3 CO laser cutting of 50 µm thick glass produces no cracks or defects as compared with traditional mechanical cutting.

Display glass cutting

Chemically strengthened glass (typically around 0.7 mm thick) is now widely used for touchscreen displays in cellphones and tablet computers because it is much more resistant to cracking than standard glass. However, strengthened glass is more difficult to cut than standard glass, which has posed some difficulties for manufacturers.

The traditional mechanical glass cutting method involves making an initiation scribe (a limited depth cut), followed by mechanical breaking to separate the scribed pieces. Unfortunately, this initiation scribe produces cracks which tend to propagate (randomly) on their own due to internal stresses in the glass, resulting in low production yields.

CO_2 lasers have offered an attractive alternative to traditional, mechanical cutting methods for strengthened glass because they produce less residual stress and microcracking, and yield virtually no cutting debris. In CO_2 laser glass cutting, the laser is used to make the initiation scribe, again followed by mechanical breaking.

However, the absorption of glass at the 10.6 µm CO_2 wavelength is quite high, and this actually creates some problems. Specifically, the strong absorption means that all the laser energy is deposited in the top surface layer of the glass. This can still result in the introduction of some stress into the glass (albeit much lower than that produced by mechanical cutting), so care must be taken to limit the amount of heat input into the glass, without lowering the laser power and thereby unduly slowing the process. This is accomplished by elongating the round beam (typically in a > 10 : 1) so as to evenly distribute the heat. However, using an elongated beam means that only straight cuts, and not curves, can be produced.

In contrast, the CO laser wavelength is absorbed much less strongly by glass, allowing for deeper penetration of the light within the material. This volumetric, as opposed to surface, heating, enables a much more controlled application. This 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 lower absorption of the mid-infrared CO output also allows cutting to be performed using a round beam. This, in turn, provides the ability to cut 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.

Architectural glass cutting

CO lasers are also proving advantageous for cutting so called low emissivity (or low-e) architectural glass, which is now widely used in both commercial and residential construction (emissivity is the ability of a material to radiate thermal energy). Specifically, low-e coatings, which pass visible light and reflect some portion of the infrared spectrum, greatly improve the insulating properties of the glass. By blocking heat

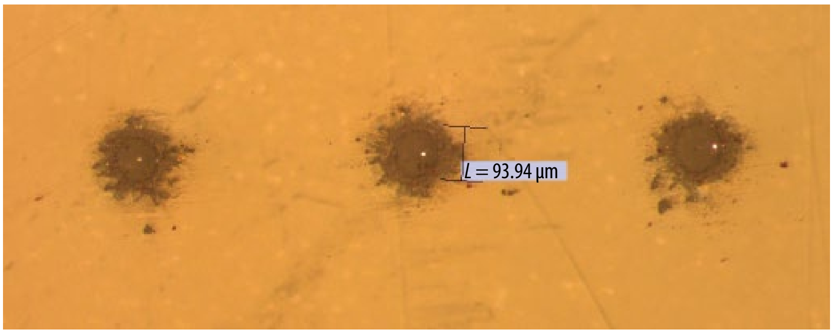

Fig. 4 Holes with a diameter of about 90 µm are successfully drilled in a 50 µm thick glass substrate using the CO laser.

from entering during summer months, and retaining heat generated inside the building during the winter, the energy efficiency and carbon footprint of a building are greatly improved.

The problem for glass manufacturers is that the transparent conductive oxide materials that form the low-e coating cannot withstand the temperatures required for tempering, a process performed for safety reasons. Tempering involves heating glass and then rapidly cooling it to create internal stress. This, in turn, makes the glass shatter into small pieces, rather than larger, more dangerous shards, when it is broken.

Because a controlled amount of bulk stress cannot be created in this way, minimizing edge stress becomes very important; edge stress is now the primary determining factor in overall panel strength (breakage resistance). The ability of the mid-infrared CO laser output to penetrate far into the glass again provides an advantage here. Specifically, CO_2 laser scribes are typically limited to about 15 % of the glass thickness due to the strong absorption at 10.6 µm. In contrast, testing with the CO laser shows that it can produce scribes that reach depths of nearly 25 % of the total substrate thickness. The result is the ability to cut glass in thicknesses of over 3 mm without inducing any significant stress, resulting in the maximum possible strength of the finished, cut piece.

Thin glass cutting

On the other end of the thickness range, the cutting of thin glass (50 µm to 100 µm) is proving of increasing interest. This is because thin glass offers an attractive alternative over plastic for the encapsulation of certain types of displays, such as LEDs and OLEDs. In particular, glass offers lower permeability, high thermal stability, and better dimensional stability than plastic. However, these applications all require that the glass withstand handling and even dropping of the display. Since the strength (bendability) and resistance to mechanical shock of thin glass is a function of edge quality, the ability to cut with low defects is critical for this application.

Glass of this thickness is nearly impossible to cut mechanically, and even challenging to process using the CO_2 laser. The CO laser can cut thin glass (in the 50 µm to 300 µm thickness range) directly, without the need for an air or water cooling jet often required in tandem with the CO_2 laser. The CO laser not only eliminates the need for a subsequent mechanical breaking step, in addition, the cuts produced are virtually stress-free. The result is a very high bend strength for the glass. Furthermore, CO laser cutting of thin glass is also performed with a round beam, allowing radial (free form) cutting of curves and other shapes.

Hole drilling in glass

So-called “3D packaging” is an important emerging technology for achieving higher density of packaged microelectronics. In 3D packaging multiple, individual integrated circuits (ICs) are stacked like a sandwich. An interstitial substrate serves as an interconnector and redistribution circuit between the dies. This substrate, called an interposer, might be constructed of silicon or glass. Currently, actual microelectronics production utilizes 2.5D packaging. This is an intermediate step where just a single set of circuit dies is stacked on the interposer.

A critical process is the creation of small through holes (vias) which are used to make electrical connections between the circuit components. Target via diameters are currently in the 25 µm size range. These vias can be produced using several techniques, including photolithography, etching, sand blasting, ultrasound drilling, or laser ablation.

As with cutting, hole drilling in glass interposers is extremely sensitive to the excess heat generated by the strong absorption of CO_2 laser light. The lower absorption of 5 µm light in glass again provides an advantage in this application, since it means that the heat is absorbed over a much longer distance within the substrate.

This application also benefits from the superior focusing and longer depth of field achievable at the shorter, CO wavelength. Specifically, when square pulsed with an acousto-optic modulator (AOM), the CO can drill very small holes in glass, with relatively little taper, with precise depth control and no heat damage or cracking.

Conclusion

In conclusion, the development of a reliable, high power source of mid-infrared laser light delivers advantages over longer wavelength sources, when processing certain materials. For glass, in particular, lower absorption at these shorter wavelengths produces significantly better cut quality, a broader process window, the ability to handle a larger range of substrate thicknesses, and even the ability to cut tightly curved shapes.

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