Ahead of the Curve – Lasers Enable Superior Glass Cutting for Demanding Applications

Over the past decade, glass has become an increasingly sophisticated structural and functional component in uses as varied as flat panel displays, automobiles and architecture. For the manufacturer, this has created a drive to enhance the characteristics of the glass itself, to develop more advanced coatings, and also to improve the process for cutting glass, in terms of higher precision, greater speed, reduced environmental impact, and lower cost. This article provides an overview of laser glass cutting technology, and explores how it can be superior to traditional mechanical processing methods for some applications.

Traditional Methods

The traditional technique for cutting glass, in use in various forms literally for centuries, involves scribing the surface of the glass with a hard, sharp tool (typically a diamond or carbide wheel), followed by a mechanical snapping force to propagate the crack completely through the glass. In automated systems, this separation is usually implemented by using a "chopper bar" which descends on the glass.

Unfortunately, this method has certain drawbacks, particularly for the very thin substrates which are being increasingly employed in flat panel displays (FPDs). In particular, the mechanical force of the scribing tool produces microcracks in the material, and the subsequent breaking step yields small chips and debris, plus an edge that is not necessarily perpendicular to the glass surface. Furthermore, mechanical cutting leaves significant mechanical stress in the finished edge. (In fact, it becomes difficult to use mechanical cutting at all with substrates below about 1 mm in thickness because the glass is so easily broken). To prevent further cracking or breaking of the glass after the original cut, it may therefore be necessary to grind or polish the cut surface. Also, a post-process cleaning step may be required to remove debris that could interfere with subsequent processes, such as circuit formation (when the glass is used as a substrate in microelectronics fabrication).

For the manufacturer, various edge grinding and cleaning post processing steps all represent additional production time and costs. They may also have negative environmental impacts, in terms of the generation of debris which cannot be easily disposed of, or due to the use of large amounts of water required for cleaning. In addition, mechanical glass cutting doesn't readily support the production of curved edges, which are increasingly desirable, especially in FPDs for portable devices.

All these limitations have become even more acute given the current trends in the use of glass. Specifically, the market moving towards the production of higher precision parts, sometimes with complex shapes and cutouts, the use of thin (< 1 mm) substrates, and the advent of chemically strengthened glass (which can't be readily cut using mechanical means).

Laser Cutting Advantages

There are several different laser technologies currently being employed for glass cutting, and these are utilized in a variety of different ways. However, all laser glass cutting techniques offer some similarities in their main benefits.

First, all laser methods are non-contact processes that largely eliminate the problems of microcracking and chipping. Also, laser cutting methods minimize residual stress (to varying degrees) in the glass, resulting in higher edge strength. This is critical, because even when force is applied to the center of a glass panel, any break usually initiates at the edge. Consequently, laser cut glass can typically withstand two to three times as much force as mechanically cut glass.

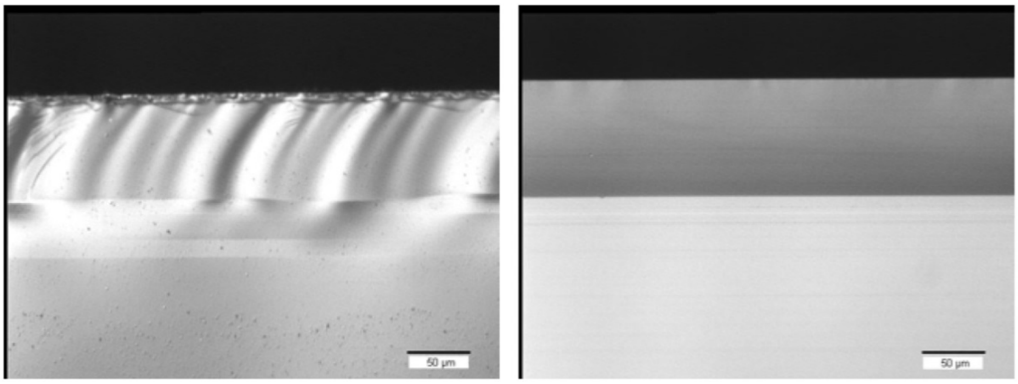

Figure 1. *Comparison of mechanically cut (left) and laser cut (right) glass. The mechanically cut glass shows significant residual stress, and substantial debris from the cutting process.*

Laser cutting can also reduce the number of process steps, since it requires few, if any, subsequent cleaning or grinding stages. So while the capital cost for a laser cutting station is higher than for a mechanical system, the overall investment in laser cutting can be lower than for mechanical processing if an additional grinding machine can be eliminated. The reduced need for post processing and cleaning also makes laser cutting greener than mechanical methods, and reduces or eliminates the need for water.

Finally, some laser cutting methods enable the production of curved cuts in glass. The demand for curved cuts is increasing, especially in mobile phones, where many manufacturers would like to produce more complex geometries in their screens, including holes to accommodate buttons, controls, LEDs and camera lenses.

CO_2 and CO Lasers

Carbon dioxide (CO_2) lasers have been used in glass cutting for many years. In contrast, carbon monoxide (CO) lasers, which were first introduced as practical, industrial tools by Coherent in 2015, are just beginning to be deployed in this application. Both CO_2 and CO lasers offer rapid glass cutting and high process throughput.

Both CO_2 and CO sources process glass by causing intense, local heating. Specifically, all glasses absorb strongly at the 10.6 µm CO_2 laser wavelength, so a focused laser beam causes rapid heating at or near the surface of the glass. To produce a cut, the glass is translated relative to the beam, and either liquid or air is delivered by nozzles on to the glass to quickly cool it. The resulting thermal shock produces a continuous crack. Depending upon the glass thickness, this crack can be propagated all the way through the substrate to complete the cut; this is called full body cutting. Alternately, for thicker glass, a second step, either laser or mechanical, is used to finish the break; this is called laser scribing.

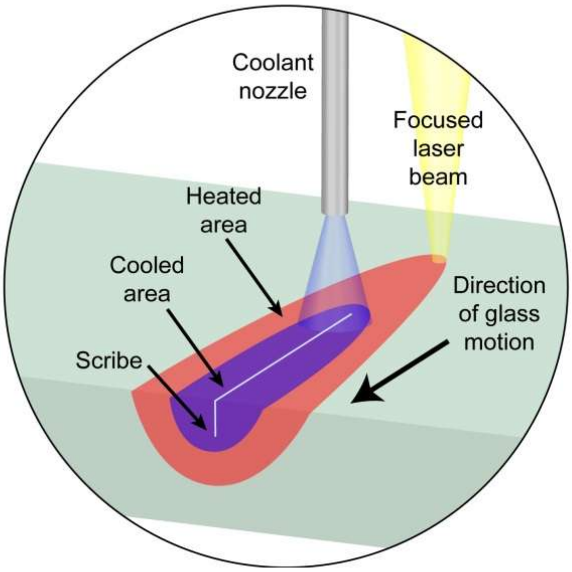

Figure 2. *Schematic illustration of CO_2 laser scribing.*

The overall process is much the same with the CO laser. However, glass absorption of the 5 µm to 6 µm output of the CO laser is significantly lower, allowing the light to penetrate much further into the bulk material. Thus, heat is introduced to the bulk glass directly and does not rely on diffusion from surface. Testing at Coherent demonstrates this produces even lower residual stress than CO_2 cutting, 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. 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 better 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–without adverse heat effects. In addition, the CO laser can cut chemically strengthened glass.

***Figure 3. 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.*

Laser Ablation

Laser ablation relies on a completely different mechanism to process glass than CO_2 and CO lasers, which utilize thermal shock to create a crack. Rather, ablation is the actual removal of material, with high precision, to create the scribe. Ablation occurs when sufficient laser power is achieved to drive non-linear absorption in the glass. This results in material removal through intense local heating (thermal ablation), or at very high peak powers, the direct breaking of interatomic bonds (photo-ablation).

Ablation is accomplished with either q-switched, diode-pumped, solid-state lasers having pulsewidths in the nanosecond range, or industrial ultrafast lasers with pulsewidths in the picosecond, or even femtosecond, regime. These industrial ultrafast lasers typically utilize a mode-locked, diode-pumped, solid-state laser as a seed for one or more stages of subsequent amplification.

There are several different variations on the way laser ablation is used to cut glass, but in all of them, each laser pulse blasts off microscopic chips from the substrate. Generally, there is a direct correlation between pulsewidth and the size of the removed particles. Chips in the single digit micron size range are produced by nanosecond pulsewidth lasers, and ultrafast lasers yield particles hundreds of nanometers in size.

Nanosecond pulsewidth lasers, operating in either the green (532 nm) or ultraviolet (355 nm), usually enter through the top of the transparent substrate and are initially focused on the bottom surface. In this so-called "bottom-up" approach, ablated chips fall out of the material interaction zone due to gravity. Scribes or cuts of virtually any edge profile, including curved cuts, slots, holes, trenches, bevels and chamfers, can be generated by moving the beam focus up through the substrate and then along it to create the desired contour.

Processing speeds for this type of ablation are relatively slow compared to other methods. For example, it takes about 1 second to drill a 1 mm diameter hole in 3 mm thick soda lime glass. The cutting speed for free contours is in the single digit mm/s range. Other drawbacks are that this method cannot process strengthened glass, and the edges typically show significant chipping from about 10 μm to 50 μm from the processed edge.

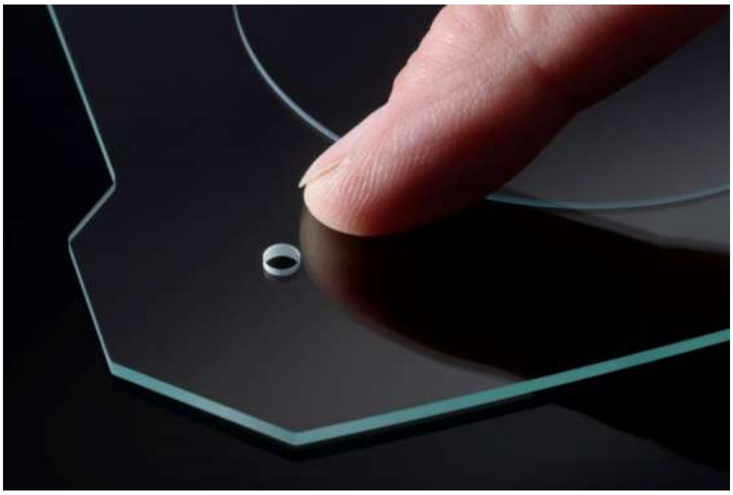

Figure 4. *Bottom-up processing of through-holes*

With ultrafast lasers, scribing is most commonly performed with the laser initially focused on the top surface of the substrate, and then the beam focus is adjusted to work down through the material. This is because the very small particles generated don't readily fall out of the scribe on their own (although there are methods to remove them) and therefore it is challenging to use ultrafast lasers for bottom-up drilling or cutting. In addition to limited cutting speed and some edge roughness, the other limitation of topside scribing using an ultrafast laser is a taper always remains on the scribe or hole, usually in the 8° to 12° range.

Within ultrafast lasers, cut quality using a femtosecond laser has proven to be superior to a picosecond laser, although usually at a reduced cutting speed due to lower available average power of industrial lasers.

SmartCleave Filamentation Cutting

Glass cutting can also be accomplished through a specific form of internal modification, called filamentation, which again utilizes the very high power densities achieved with focused, ultrafast lasers. In this case, the high laser intensity produces self-focusing of the beam due to the nonlinear Kerr optical effect. This self-focusing further increases power density, until, at a certain threshold, a low density plasma is created in the material. This plasma lowers the material refractive index in the center of the beam path and causes the beam to defocus. If the beam focusing optics are properly configured, this focusing/defocusing effect can be balanced to repeat periodically and form a stable filament which extends over several millimeters in length within an optically transparent material. The typical filament diameter is in the range of 0.5 µm to 1 µm.

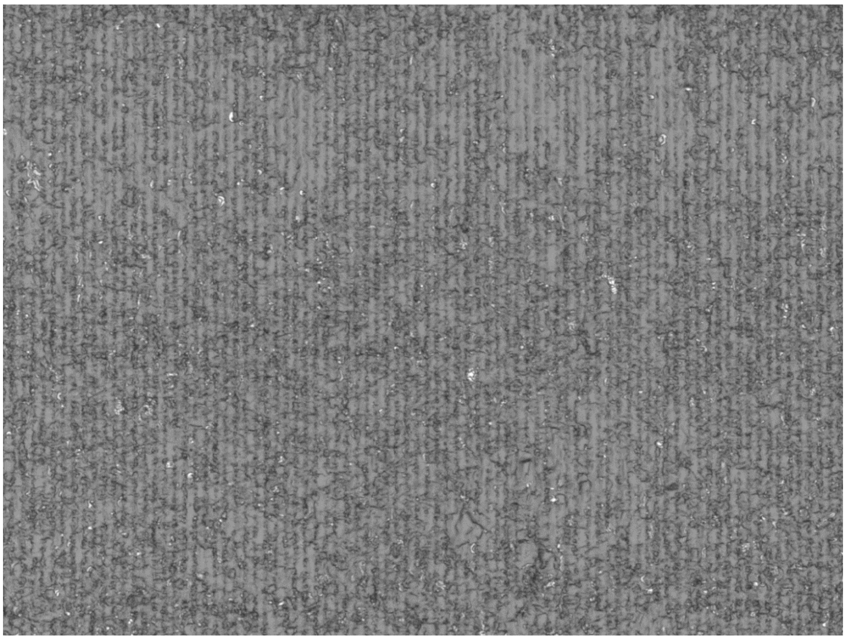

Figure 5. *Laser filamentation creates a series of parallel voids in 0.5 mm thick sapphire.*

In order to achieve effectively zero-gap cutting or perforation lines, these laser-generated filaments are produced close to each other by a relative movement of the work piece with respect to the laser beam. Cutting speeds of 100 mm/s to 2000 mm/s can be achieved, depending on the material thickness and the desired cut geometry.

The Coherent | Rofin embodiment of the filamentation technology is called SmartCleave. It pairs process technology acquired, and further developed by Rofin, together with advanced industrial ultrafast lasers from Coherent. The resulting process enables high speed cutting of arbitrary shapes, including curves, freeform cuts and insets, *without* taper, into transparent and brittle materials from 0.05 mm to 10 mm thickness. SmartCleave delivers smooth surfaces, with a R_a of less than 1 µm, which are essentially free of chips and debris. This yields bend strength in the cut parts superior to mechanical processes.

For non-strengthened transparent materials, such as soda lime, borosilicate and alumino-silicate glass, as well as sapphire, a separation step must follow filamentation. This can be accomplished with a small mechanical or thermal force. For example, the latter can be provided by heating with a CO_2 laser. With chemically or thermally strengthened glass, internal stress within the part provides for automatic separation of outer contours, without an additional step.

Figure 6. *SmartCleave enables high speed cutting of curves and insets into glass, e.g. used for substrates of displays.*

Implementing SmartCleave

With Coherent's acquisition of Rofin in 2016, SmartCleave technology has now been mated with the Coherent range of industrial ultrafast lasers, such as the HYPERRAPID series. These offer a unique combination of output power, reliability and operational flexibility, including burst mode and pulse on demand operation. The result is an unmatched ability to effectively implement filamentation cutting in a specific application.

Furthermore, Coherent | Rofin supplies products to enable SmartCleave processing in a variety of integrated configurations. This starts with just laser sources, such as HYPERRAPID series products. We also provide sub-systems, which integrate a laser with beam delivery optics and control electronics. These can also be configured as a so-called "black box" subsystem, in which the particular configuration to enable and optimize a specific process has already been developed and programmed. Finally, Coherent | Rofin can deliver complete, turnkey systems for SmartCleave processing, which are ready for use in a production setting.

In conclusion, lasers have proven to be a viable alternative to traditional glass cutting techniques in a wide range of different applications. In general, lasers are most useful when mechanical means fail to deliver the cut quality or characteristics required, or when older methods become too expensive due to the extensive post processing required. However, laser glass cutting is actually a broad term covering a variety of different techniques, each having their own unique characteristics and advantages. As the only supplier of virtually all types of lasers for glass cutting, Coherent is uniquely positioned to deliver the optimum solution for a given application. For SmartCleave filamentation cutting, Coherent mates the patent protected know-how and superior laser technology necessary to successfully implement this outstanding technology in a production environment.

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