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New Lasers Improve Glass Cutting Methods

Over the past decade, glass has become an increasingly sophisticated structural and functional component in uses as varied as flat panel displays (FPDs), automobiles and architecture. For manufacturers, this has created a drive to improve the process for cutting glass, in terms of higher precision, greater speed, shape flexibility (e.g., tight curves), reduced environmental impact, and lower overall cost. Laser-based cutting is particularly well suited technologically to deliver on all these fronts, and, as a result, the field has become incredibly dynamic with several different methods well-established.

This white paper explains how the recent availability of two new types of industrial laser – high power ultrashort pulsed (femtosecond and picosecond) and carbon monoxide (CO) lasers – further expands the process window and applications range for two of the most popular methods, cleaving and laser scribing. Specifically, we see how the new Monaco laser series extends cleaving to mixed (e.g., laminates) substrates, such as polyimide on glass, and how the CO laser now enables laser scribing of a wider range of glasses and production of tighter curves.

Drawbacks of Mechanical Methods

The traditional mechanical technique for cutting glass involves scribing the surface of the glass with a hard, sharp tool (typically a diamond or carbide wheel), followed by a mechanical snapping force such as a “chopper bar.” The well-known drawbacks include microcracking and chipping of the edges, as well as debris formation, which all require post-processing (e.g., grinding, polishing), particularly for applications where a circuit must be subsequently created on the glass. For touchscreens, another common issue is unacceptable levels of residual edge stress because these reduce the mechanical strength. In addition, the cut edge is not always perpendicular to the surface, adding the need for additional grinding of the glass.

All these limitations have become even more acute given trends toward the production of higher precision parts, sometimes with complex shapes and cutouts, the use of thin (< 1 mm) substrates, and chemically strengthened glass (which can’t be readily cut using mechanical means). For the manufacturer, various edge grinding and cleaning steps 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, many glass applications now need curved edges, e.g., for the production of flat panel displays (FPDs) for portable devices. Mechanical methods often cannot be used as the second step in automatic laser-based separation for these curved substrates.

Direct Laser Cutting – Slow Speed

Traditional laser cutting methods rely on a pulsed laser to ablate material, that is, heat it up until it is vaporized. Pulsed lasers are used because they deliver the high peak powers necessary to accomplish this ablation.

With glass, there is a direct correlation between pulse width and the size of the removed particles. Chips in the single digit micron size range are produced by nanosecond pulse width lasers, and ultrafast (picosecond and femtosecond) lasers yield particles hundreds of nanometers in size.

Nanosecond pulse width lasers, operating in either the green (532 nm) or ultraviolet (355 nm), are usually employed in “bottom-up” cutting. Here, the laser enters through the top of the transparent substrate and is initially focused on the bottom surface. 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.

However, processing speeds for this type of direct 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 about 50 μm from the processed edge.

Direct ablation with ultrafast (picosecond and femtosecond) lasers is even slower, because these lasers are only available at lower average powers. So, in spite of the limitations of mechanical cutting, direct laser cutting has never gained widespread adoption.

Instead of direct ablation, several clever laser methods have been developed that combine the superior edge quality, shape control and dimensional precision of laser ablation with speeds closer to mechanical methods. Two of the most widely used are SmartCleave and Laser Scribing.

SmartCleave – Photolytic Process

SmartCleave is a patented glass cutting process based on “filamentation,” exploiting 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 Kerr optical effect) within the glass. 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 self-sustain. This forms a stable filament – a line of tiny voids – which extends over several millimeters in depth into glass or other optically transparent material. The typical filament diameter is in the range of 0.5 μm to 1 μm.

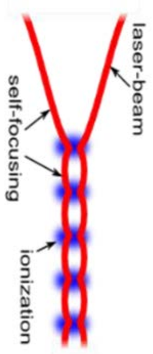

Figure 1. Schematic representation of the filament process.

In order to achieve effectively zero-gap cutting or perforation lines, these laser-generated filaments are produced close to each other by a relative motion of the work piece, creating a near-continuous curtain of voids through the glass. Motion speeds of 100 mm/s to 2 m/s can be achieved, depending on the material thickness and the desired cut geometry.

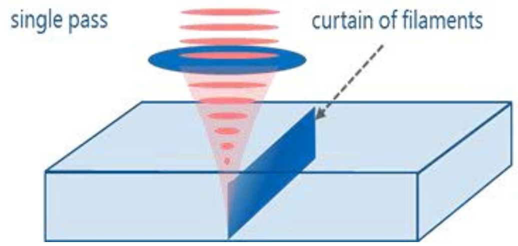

Figure 2. A relative movement between laser beam and work piece creates a line or curtain of filaments with 3 µm to 7 µm spacing between the filaments. The filaments weaken the material and enable a clean separation.

With chemically or thermally strengthened glass, internal stress within the part then causes spontaneous separation, without an additional step. For non-strengthened glasses and other transparent materials, e.g., sapphire, a separation step must follow filamentation. This can be accomplished with either a small mechanical or thermal force. For example, the latter is often achieved by heating with a CO_2 or CO laser (see the following section on laser scribing).

SmartCleave combines process technology acquired and further developed by Rofin, together with advanced industrial ultrafast lasers from Coherent. In particular, Coherent ultrafast lasers such as the HyperRapid NX provide burst mode operation where the laser provides a series of closely spaced pulses that act like a super-pulse with a total pulse energy > 700 µJ. This burst mode is key to successful filamentation. 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 several mm thickness. In addition, SmartCleave delivers smooth surfaces, with a R_a of less than 1 µm and with edge chip sizes less than 5 µm. This yields a bend strength in the final parts that is measurably superior to mechanical processes, which is why the process is now used by several touchscreen manufacturers.

Laser Advances in SmartCleave – Layered Substrates

Two new laser developments have further extended the capabilities of SmartCleave. First is the HyperRapid NX SmartCleave series of burst-mode optimized picosecond lasers. These smart lasers are the current industry standard, and offer a combination of high performance and superior reliability with output power capable of performing filamentation in glass up to 10 mm thickness. They are available as standalone lasers or packaged with SmartCleave optics and control as a complete package.

Another key development is the advent of industrial *femtosecond* lasers with the requisite power/cost economics for glass cutting. This addresses the one potential limitation of picosecond lasers. Specifically, there is a growing need to cut layered or laminated substrates containing more than one material; a typical application is to cut glass with a top coating of polyimide or PET. In many instances, this requires using a picosecond laser to cleave the glass and another laser process to scribe the other material(s).

Femtosecond lasers are well proven to process nearly any material by conventional ablation. However, femtosecond lasers have not been employed in filamentation applications because of their higher cost and lower power as compared to picosecond lasers. Now the increasing demand for cutting multi-layer substrates has led laser manufacturers to develop more cost-effective femtosecond lasers which also offer high average power. (This has been accomplished by switching to ytterbium-doped fiber, rather than the traditional titanium:sapphire, as the gain medium.)

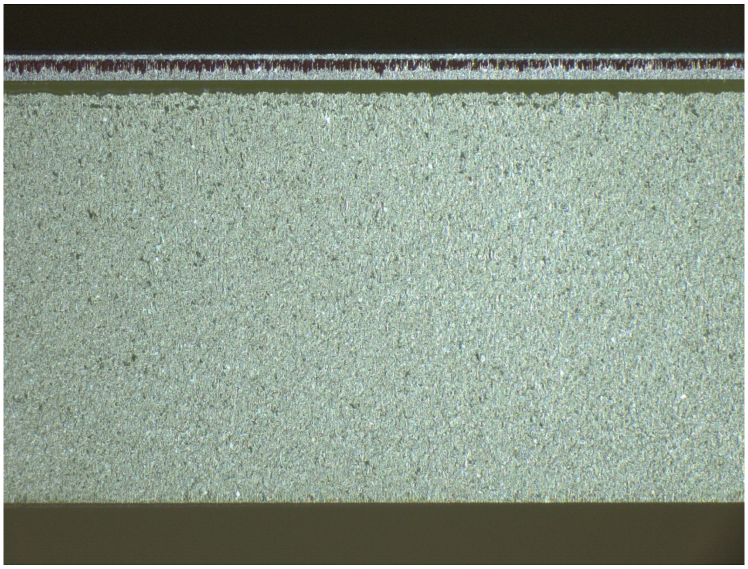

Figure 3. Example of mixed material cutting. This shows an edge view of 20 microns of polyimide on 0.5 mm glass, cut with a Coherent Monaco femtosecond laser with 40 watts of average power and a pulse width ~350 fs. The surface roughness was < 350 nanometers, as measured with an AFM.

The Coherent Monaco is an example of this new generation of industrial femtosecond lasers which already offer average power as high as 60 watts with higher powers expected soon. Moreover, the Monaco pulse width can be software tuned by the operator from ~350 fs to ~10 ps, enabling the output to be optimized for different filamentation conditions, as well as other material cutting and texturing processes. And critical for filamentation cutting, the Monaco SmartCleave supports burst mode operation.

Engineers in the Coherent applications laboratory have demonstrated that by careful process optimization, layered substrates with two or more dissimilar materials can be completely cut *in a single pass,* with superior edge quality, virtually no residual edge stress and no heat affected zone in the “delicate” layers. The example in figure 3 shows an edge view of 20 μm of polyimide on 0.5 mm glass, cut with a femtosecond laser with 40 watts of average power. The surface roughness was < 350 nm, as measured with an AFM and edge chip sizes were less than 4 μm.

Laser Scribe and Break – Photothermal Process

Another well-established glass cutting process is called laser scribing (or laser scribe and break) and uses carbon dioxide (CO_2) lasers with continuous wave output in the mid-infrared. CO_2 laser scribing can be used to cut thin glass (<1mm) and has been used commercially to cut glass panels for large format displays and glassware (e.g. wine glasses). However, it also has been finding increasing use as the second (thermal separation) step in SmartCleave processing.

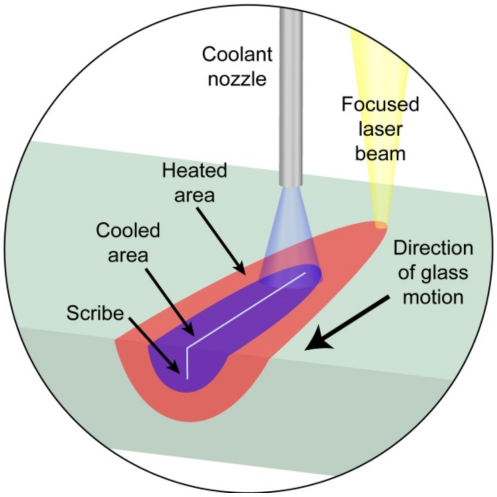

Figure 4. Schematic illustration of CO_2 laser scribing.

Laser scribing of glass works by thermal shock. 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. Alternatively, for thicker glass, a second step, either laser or mechanical, is used to finish the break; this is called laser scribe and break. In both formats, the laser process provides advantages over mechanical methods; laser scribing creates smooth, debris free edges with much less residual stress, so no post-processing is typically required. Eliminating the cost and time for post-processing also means laser scribing can be performed at an overall lower cost, even though the laser workstation itself may have a higher initial capital cost than a mechanical cutter.

New Laser – Tighter Curves and More Glasses

With laser scribing, the important new development has been the introduction of the carbon monoxide (CO) laser by Coherent (the J-3 series). The overall process is similar to the CO_2 laser, but with some important differences. Specifically, glass absorption of the 5 µm to 6 µm output of the CO laser is significantly lower than at 10.6 µm, 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 the surface. This absorption difference yields several benefits. For example, testing at Coherent demonstrates that the CO laser produces even lower residual stress than CO_2 cutting, yielding a stronger cut piece, together with a wider process window for the manufacturer.

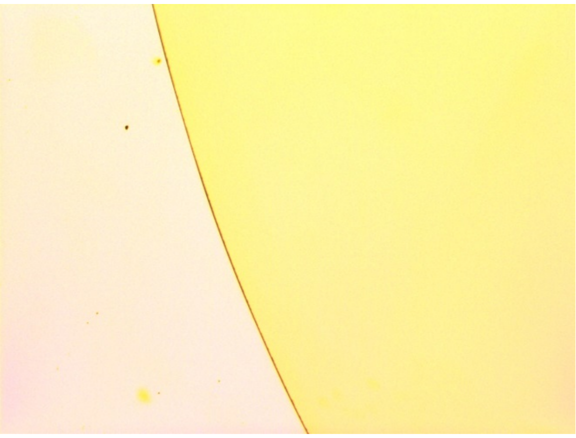

Figure 5. A CO laser with only 9W of output power produced this clean, curved cut (6 mm radius circle) in thin glass (50 µm thick) at a feed rate of 140 mm /sec.

Another key benefit of the CO laser is the ability to produce curved cuts with short radii, which is often not possible with CO_2 laser based scribing (see figure 5). 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 enables faster scribing of some glasses and successful scribing of glass types that are difficult or impossible to process with a CO_2 laser. In particular, the CO laser can cut strengthened glass and so now provides an alternative process to filamentation methods.

The relative effectiveness of the two laser types for cutting non-strengthened glasses has also been investigated independently in detail by the Laser Zentrum Hannover (Hannover, Germany). Their study focused on using the laser thermal shock as the separation step following SmartCleave. The results of this study were presented by Dr. Oliver Suttmann at the 2017 OSA Laser Applications Conference (Nagoya, Japan).

This work included a detailed comparison of the two laser types with two glasses having very different coefficients of thermal expansion (CTE): borosilicate glass with CTE = $3.3\ x10^{-6}/K$, and soda-lime glass with CTE = $8.7\ x10^{-6}/K$. Suttmann concluded the high CTE of soda-lime glass meant either laser type could be used as a separation step after SmartCleave. However, he noted that for the same laser power level, the CO laser provided a larger process window and enabled faster throughput. But in the case of borosilicate glass, with its lower CTE, the CO_2 laser struggled to support reliable separation, whereas the new CO laser enabled successful glass separation at commercially viable speeds: up to 100 mm/s when using 200 watts of laser power.

Summary

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 (femtosecond, picosecond, nanosecond, CO_2, and CO) Coherent is uniquely positioned to deliver the optimum, turnkey system or standalone laser for every given application.