Glass and Laser: A Combination Offering Numerous of Automated Material Processing Applications

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ABSTRACT

This papers reviews activities within the field of laser based glass processing. Lasers can be used to mark, cut, drill and weld glass materials. Dedicated processes are explained with respect to recent research developments. Special attention has been paid to the current automation level of the different processes within the industrial environment. A high automation level was found in the field of flat glass, display glass and glass tubes where cutting, marking and welding processes were performed. Recently, automated laser welding of complex hollow glass structures for medical applications are on the way to substitute the state-of-the-art manual gas flame processes.

1 INTRODUCTION

Glass is one of the oldest materials produced by mankind which history goes back to the ancient Egyptians. Lasers on the other hand have been invented in the last century. The increasing use of glass within different industrial sectors and the breakthrough of handheld devices with touchscreens created a demand for new and automatable glass processing technologies. At present, laser systems are available at different power levels, wavelength and pulse duration. In this context, lasers offer new possibilities for glass processing because the energy of the laser radiation can be deposited on the glass surface or within the volume. For example, continuous wave CO_2 laser which emit laser radiation at a wavelength of λ=10.6 µm are absorbed on the glass surface. In contrast, ultrafast laser systems with pulse durations down to several femtoseconds and wavelength below 1 µm are absorbed due to nonlinear effects within the focal area. This enables the deposition of energy within the glass volume. The broad range of current laser systems and the subsequent different physical interactions with glass are the reason for the variety of laser based glass processing technologies where selected processes are presented in the following.

2 LASER PROCESSING OF GLASS

The paper has been organized according to the different laser material processing technologies. For each process, available solutions are presented and discussed regarding to its level of automation.

2.1 LASER MARKING OF GLASS

Laser radiation can be deflected in 3 directions by galvanometric scanner systems which makes laser marking processes flexible. Glass marking can be performed within the volume to create 3D images or on the glass surface for 2D patterns. Volume marking of glass is mostly found for commercial applications. Here, systems are available which achieve the whole process from image acquisition, data conversion and laser volume marking, Fig. 1.

Fig. 1 From left to right: Image, data conversion, marked glass cube [1]

The volume marking process is achieved with pulsed nanosecond lasers emitting green laser radiation. The laser radiation is tightly focused to focus diameters below 10 µm. The high laser intensity within the focal zone leads to nonlinear absorption of the laser radiation only within the laser focus. The deposited energy creates micro cracks which afterwards scatter the ambient light resulting in reduced transmission und thus an adaptable greyscale voxel.

Tempered glass which is used within the architecture and automotive sector because of its higher strength and fine-grained fracture appearance has to be marked on the glass surface where compressive stress is present. The volume of tempered glass consists of tensile stresses which would lead to glass failure if micro cracks are generated in this area. Thus, pulsed CO_2-lasers are used. These lasers emit infrared laser radiation with λ=10.6 µm which is completely absorbed on the glass surface. The marking process is achieved by individual laser pulses which evaporate a defined volume depending on the applied pulse energy, Figure 2.

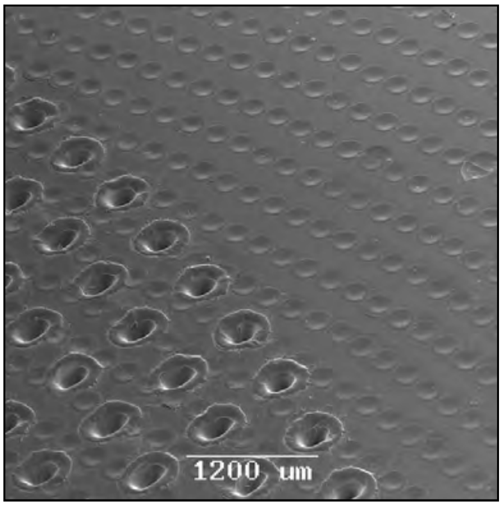

Fig. 2 Surface modification after laser marking

The material removal leads to small surface craters which scatter the incident ambient light.

Fig. 3 Glass door with laser surface marking [2]

The greyscale can be varied by the distance of laser pulses and the size of the surface modification achieved by each laser pulse. This marking process is mostly performed on flat glass used for interior and exterior architecture applications. Fig. 3 shows a marked woman (Marilyn Monroe) on a glass door.

Available marking machines perform the marking jobs fully automated. A handling unit carries the flat glass substrates and loads and unloads the marking system so that multiple marking jobs can be completed within a 24/7 operation.

2.2 LASER CUTTING AND DRILLING OF GLASS

The increasing use of touchscreens for handheld devices, within automobiles or even kitchenware and the development of glass based interposer for electronics lead to an increasing use of thin glass. In this context, the glass sheets need to be cut to the desired shape and also drill holes have to be generated. Thin glass materials are chemically strengthened aluminosilicate glass for the touchscreen cover glass or borosilicate glass as interposer or display glass. The glass thickness is in between 50 µm and 700 µm which makes contactless optical processing technologies necessary.

Cutting of glass which refers to the generation of outer contours can be achieved by thermal stress cutting [3] or filament cutting [4] or a combination of both processes. Filament cutting is achieved by ultrafast laser sources which modify the glass volume along the desired cutting path. After this modification which can be seen as a gap-free separation, chemically strengthened glasses separate on their own due to their internal stresses. Stress-free borosilicate glasses have to be separated after filament cutting by an external force. In this context thermal stress cutting can be applied which is explained in the following.

In thermal stress cutting, the laser beam heats up a specific area on the glass surface followed by a cold jet of air or liquid mixture from a cooling nozzle. This thermally induced tension causes precise fissuring of the glass. Usually, an initial crack at the glass sheet edge is guided through the glass. This process gives the best cutting edge quality leading to highest strength after separation. However, the accuracy of autonomous thermal stress cutting is lower compared to filament cutting. In addition, crack guiding along curvatures require well-controlled process parameters [5]. Figure 4 shows an example of cut borosilicate glasses (thickness 0.7 mm) which have been separated by thermal stress cutting. The cutting edge surface shown in the microscope image is very smooth.

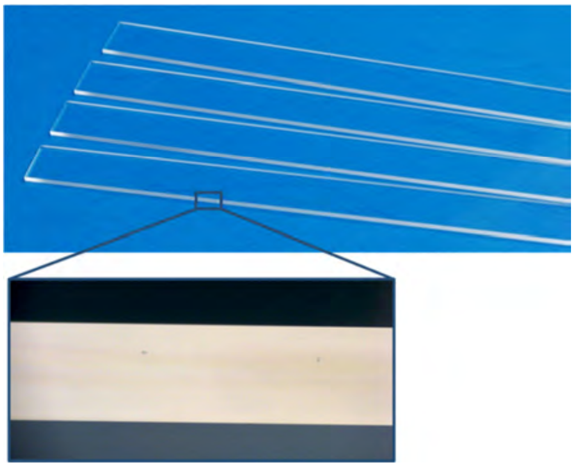

Fig. 4 Thermal stress cutting of 0.7 mm thick borosilicate glass

Filament cutting and thermal stress cutting do not create a gap between the two separated parts.

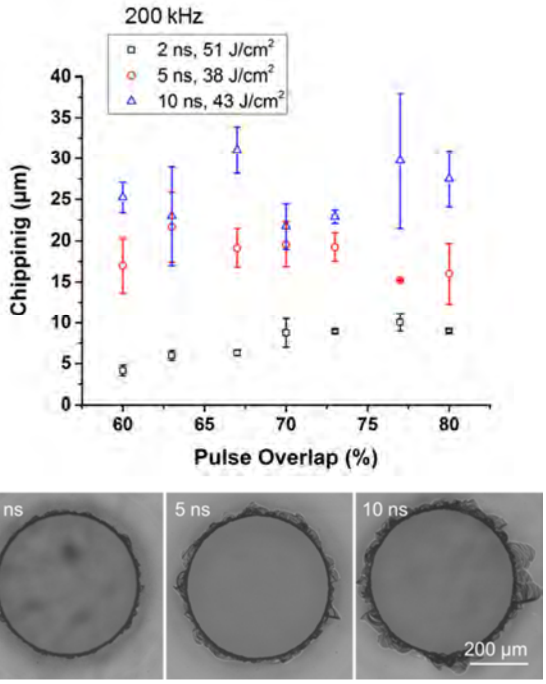

Fig. 5 Top: Chipping measurements from line scribing experiments, Bottom: Drill holes in 50 µm thin borosilicate glass [6]

Therefore, drill holes, for example for the smartphone home button or loudspeaker, are not possible with these processes because the inner part could not be removed. Here, laser ablation is used where the through hole is evaporated in total or along a defined path to create a gap between the two parts. Drilling of non-strengthened glass can be performed from the glass top to the bottom or in the other direction. Used laser sources are ultrashort and short pulsed laser sources with wavelength in between 300 – 1100 nm. The material removal creates chipping at the cutting edges. The extent of chipping is dependent on the pulse duration where shorter laser pulses lead to less chipping. Figure 5 shows chipping measurements of line scribing on borosilicate glass with different pulse durations (diagram on top) and corresponding drill holes in 50 µm thin borosilicate glass. The increased formation of cutting edge chipping when longer pulse durations were used is obvious.

Drilling of chemically strengthened glass requires a specific process strategy. These glasses consist of layers with compressive stress on both glass surfaces within the ion-exchanged area. The ion-exchange process reaches a depth of approximately 40 µm. In order to prevent glass breakage during drilling, both ion-exchanged areas have to be removed in the area of the drill hole. Afterwards, laser ablation through the bulk material can be performed. Figure 6 illustrates this drilling strategy in the sketch on top. Below this sketch, Figure 6 shows optical strain measurements of the individual process steps. The highest strain is reached after removing both compressive layers. The strain is reduced during process step 3 when the bulk material is removed.

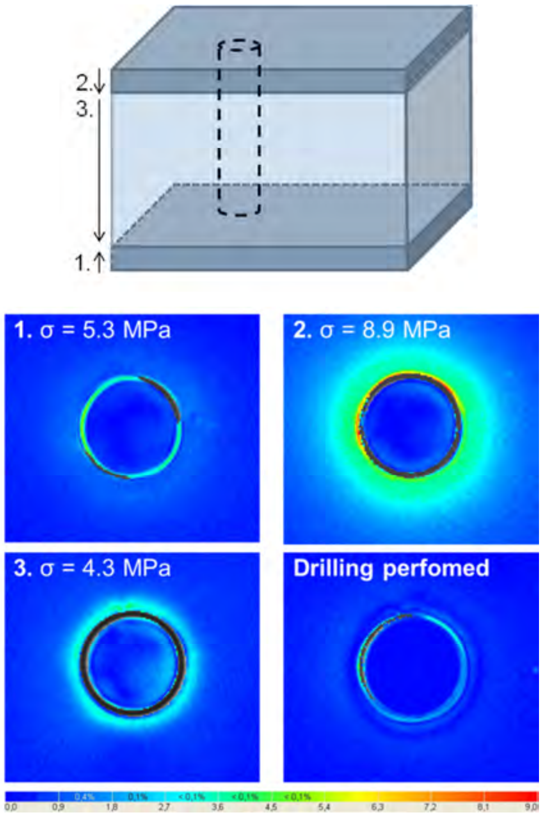

Fig. 6 Top: Process strategy, Bottom: Strain measurement for different processing steps [7]

If the glass is drilled from top to bottom, high strains appear at the end of the drilling process where the thin residual glass has an increased risk of breakage. Figure 7 shows an example drill hole performed in chemically strengthened glass with the presented drilling strategy.

Fig. 7 Example drill hole in chemically strengthened glass [7]

Automated laser cutting and drilling of glass is an industrial proven process. The glass sheets are loaded horizontally to the laser processing machine which performs the cutting or drilling processes or both processes with multiple laser processing heads.

2.3 LASER WELDING OF GLASS

Laser welding of glass can be achieved with ultrafast and CO_2 lasers. Ultrafast lasers are focused into the connecting area where the laser radiation leads to free electrons followed by increased absorption and heating of the glass. The connection of the two parts arises during cooling. This process requires well defined glass surfaces and handling devices because both glass parts have to be in close contact [8].

Laser welding of glass with CO_2 lasers is comparable to laser welding of metals within the heat-conduction regime. The laser radiation is absorbed at the glass surface and the temperature rises in the bulk due to heat transfer. Usually borosilicate and quartz glass products require welding processes. These materials are found within solar receivers, chemical devices and medical components. After welding residual stresses stay within the welding zone and might lead to glass breakage. In this context, borosilicate glasses show higher stresses due to the higher coefficient of thermal expansion in comparison to quartz glass. In order to reduce residual thermal stresses, the cooling phase during welding has to be extended. In tube welding, this can be achieved by rotating the tubes at a high rotational speed. The welding zone is illuminated by the laser radiation multiple times which leads to a quasi-homogenous welding temperature along the connecting zone. This allows a defined heating and cooling rate.

Available automated laser machines operate with a pyrometer based temperature control which is used to set the laser power during heating and cooling of the welding zone.

Laser welding of non-rotational glass components where the welding zone is illuminated once requires elevated temperatures (above annealing point) for borosilicate glass components. Quartz glass can be welded at room temperature because of its small coefficient of thermal expansion. Typical quartz glass components are used for medical applications because of its high chemical inertness. These components are complex hollow glass structures which require multiple welding steps. A challenge is the gap bridging between the joining partners. Here, glass rods or fibers are used as additive material. Figure 8 shows an image of the welding process of two quartz glass plates to a corner joint with a glass fiber as welding additive.

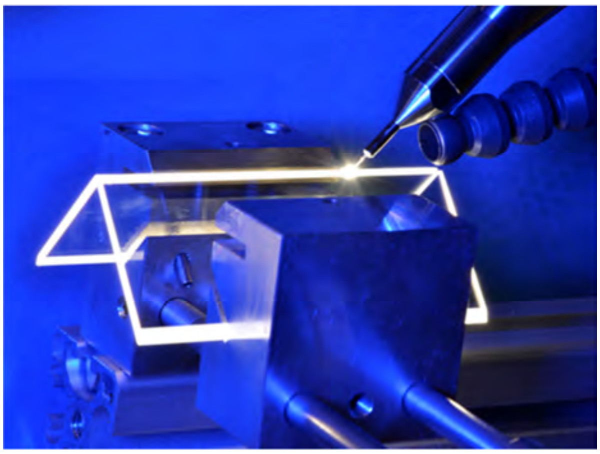

Fig. 8 Image of quartz glass welding [9]

The glass fiber is fed from the unit in upper right. The welding direction is from left to the right

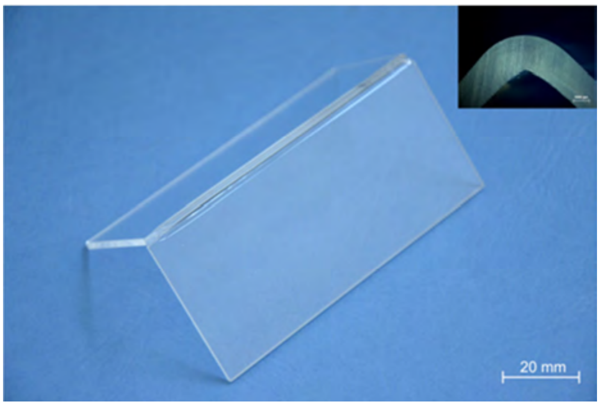

Fig. 9 Welded corner joint [9]

Figure 9 shows a welded corner joint. The laser based process achieves a higher throughput and a smaller heat affected zone than the conventional manual process with gas flame. However, the complex movement between the glass raw material and the fiber additive and the simultaneously superimposed laser process still require research and development actions in order to establish automated laser welding machines.

3 CONCLUSION

The laser is a tool which offers a variety of possible glass processing applications. In general, pulsed lasers with wavelength from the ultraviolet to the near-infrared and CO_2-lasers emitting pulsed or continuous wave laser radiation within the far-infrared are used for laser based glass processing. Marking, cutting and drilling of flat and display glass is industrial established where automated laser machines are available. Laser welding of glass is industrially used for joining of glass tubes. Research in laser welding of complex hollow glass structures which are required in medical products is ongoing. It is expected that machine suppliers will adapt this process in the near future.

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