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Straightforward Laser Machining of Thin Glass

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Abstract

The LMTB has been working very actively on the industrially related implementation of laser machining via micro-ablation of transparent substrates, such as float glass, borosilicate, soda-lime, quartz and sapphire. By selecting the right laser wavelength, machining can be initiated from the rear side of glass substrates. This very attractive method becomes difficult to control for glass thickness below 0.2 mm. For these thin glasses, the LMTB developed a short focal trepanning system type1.f18 for straightforward cutting and drilling. The machining can be characterized as micro milling, only using short or ultra-short laser pulses instead of a mechanical blade. This paper presents and discusses the system developments and laser processing strategies implemented at the LMTB laser application lab to optimize the cutting results for thin glass.

Keywords: laser micro processing; cutting; drilling; glass; quartz

1. Introduction

The demand for thin sheet glass (thickness of glass ≤ 0.2 mm) increased substantially over the last 20 years due to the introduction of all kinds of flat panel displays and solar energy applications. Thin glass sheets are superior to plastic films because of the inherent properties of glass, including gas barrier properties (which protect against gas and water), heat resistance, and transparency. For example, TFT-LCD (thin film transistor and liquid crystal displays) glass is found in many applications like computer displays, television screens, mobile phones, pda's, ebooks and pads. Thin glass is also used as substrate for thin film solar applications as well as in new developed high power automotive batteries and new lighting devices.

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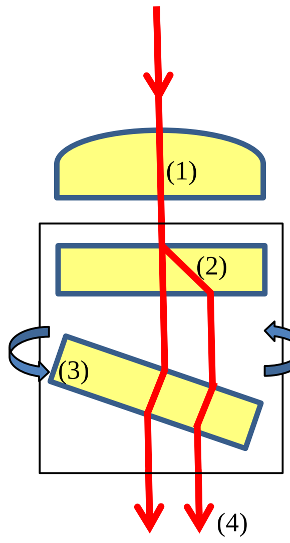
Hence, there is an increasing need for providing the processing technologies, i.e. a good tool box, capable of handling and machining thin glass. In this context a fast and precise cutting of thin glass into any shapes is of immense interest. The potential advantages of laser technology compared to conventional mechanical tooling increases while the glass sheets turn out to get thinner and more brittle. To exploit these advantages, the relevant laser parameters need to be optimized, such as the combination of wavelength and pulse width (providing for the appropriate optical and thermal penetration depths), laser beam alignment, energy distribution, relative movement of the work piece and optics and usually several other factors that consider certain material properties of the work piece, here the type of the thin glass, to be machined.

The laser application lab at the LMTB is strongly engaged in the development and research of laser processing strategies on laser micro machining, especially devoted for transparent materials. In this context, the mission of the non-profit institute LMTB is to be able to draw on the experience and fundamental understanding for a successful transfer of research results into industrial applications. In this specific case study, the paper highlights the recently obtained results in straightforward laser cutting and drilling of thin sheet glass.

2. Experiment

The studies on the laser machining of thin glass are performed using diode-pumped solid-state laser (DPSSL) systems at different wavelength and pulse width, however, overall with a fairly good beam quality (M2 better than 1,5). The laser pulse width in our studies on glass processing can range from 300 fs to ca. 30 ns. The laser beam feeds a three axis working station, which allows for a precise 3d CNC-motion of the work-piece relative to the laser focus position. On one translation stage, usually characterized as the z-axis for the motion perpendicular to the work-piece, the processing optics is mounted. In our study we compared the laser processing of thin sheet glass using either a conventional scanner system (IntelliScan 10, Scanlab) with a LMTB trepanning system (type1.f18).

The laser trepanning system type1.f18, depicted in Fig. 1, is a versatile, compact tool for laser cutting, milling and drilling, The rotating slanted plane-parallel-plate inside the type1.f18 generates a circular path of the focused beam on the work piece, where the cutting & drilling diameter can be easily adjusted between 10 and 1000 µm. The optical design of the LMTB trepanning system allows for a very flexible choice of the optical focusing element(s). In the case of type1.f18, the focusing element is an aspheric lens with a short focal length of f = 18 mm. Hence, the LMTB trepanning system can yield very small laser focus spots diameters DL << 5 µm at a well-defined Rayleigh length of z_R << 50 µm; competing well against the commercial scanner optics. In addition, the birefringent crystal (e.g. ca. 1 mm thick calcite for 532 nm) inside the compact type1.f18 allows for a 2-beam splitting, so that two focused laser beams process the work-piece simultaneously. The parallel displacement between these two narrowing beams is adjustable. The hollow shaft motor with a clear aperture of ca. 10 mm turns the calcite crystal and tilted plan-parallel-plate at a rotation speed of 1000 to 40000 rpm. The working distance between nozzle with the protective glass and the work piece remains between 3 to 5 mm. In essence, the well-defined energy distribution of the laser pulses on the work-piece using type1.f18 allows for a good controlled surface ablation on the work-piece. This is especially important for thin sheet glass at optical wavelengths, where non-linear absorption is a necessity for laser induced ablation. And for transparent materials, the non-linear absorption can be initiated on the exit side of the material. The method of rear side processing has been demonstrated to be very efficient for glass, especially using nanosecond laser pulses at 532 nm, e.g. Ashkenasi et al 2007. In addition, rear side laser-pulsed processing of glass allows for zero-taper cutting and drilling, making extreme high aspect ratios possible, e.g. Ashkenasi et al 2012.



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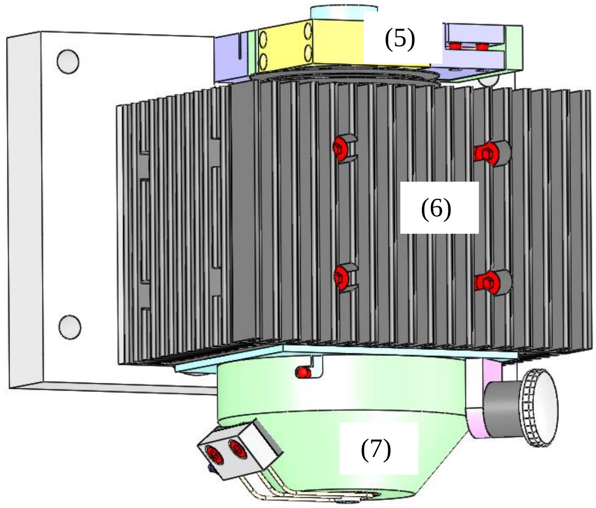

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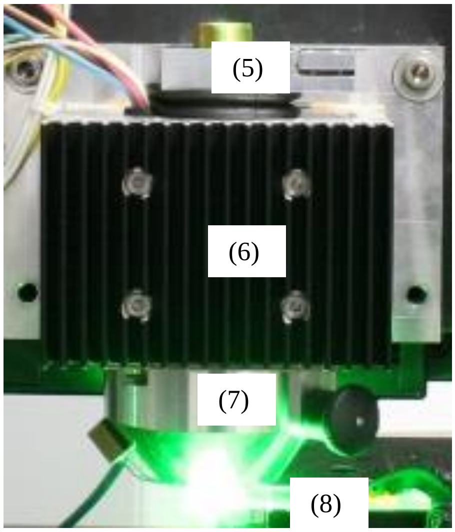

Fig. 1: Illustration of the LMTB trepanning system Type1.f18. **A:** Principle set-up with (1) focusing optics with a focal length of 18 mm, (2) birefringent crystal for polarization dependent laser light separation into two beams, (3) slanted plane-parallel-plate. Element (2) and (3) are rotated. (4) Parallel exit of the two focused laser beams rotating along a circular path with different diameters. B: CAD drawing of the mechanical setting, (5) holder of the focusing lens (1), which is located inside the hollow shaft motor (6). The metal case (7) with the gas port, nozzle and protective glass is connected to the trepanning head via a bayonet fitting and can be removed for user service purposes. **C:** Camera picture of the type1.f18 trepanning system integrated in a work stage while laser machining a glass substrate (8) using green laser pulses.

3. Results and Discussion

In the following, some interesting laser machining results for thin transparent work pieces are presented.

Fig. 2 depicts microscope pictures of 0.2 mm quartz, machined using a DPSSL system (Blade from Compact Laser Solutions) generating 25 ns laser pulses at 532 nm. The single pulse energy was in this case 300 µJ (at 15 kHz repetition rate). The chipping on the front and rear side of the quartz sample was evaluated. Using the type1.f18 in a single beam alignment, the maximum chipping on the edge is nearly 75 µm. The chipping is reduced to 30 to 40 µm with the type1.f18 system in the dual-beam configuration. In this case, the laser energy is split up for two focal spots, each with 150 µJ pulse energy. The dual-beam configuration improved the processing efficiency and quality for internal contour cutting of thin quartz plates significantly while using green nanosecond laser pulses.

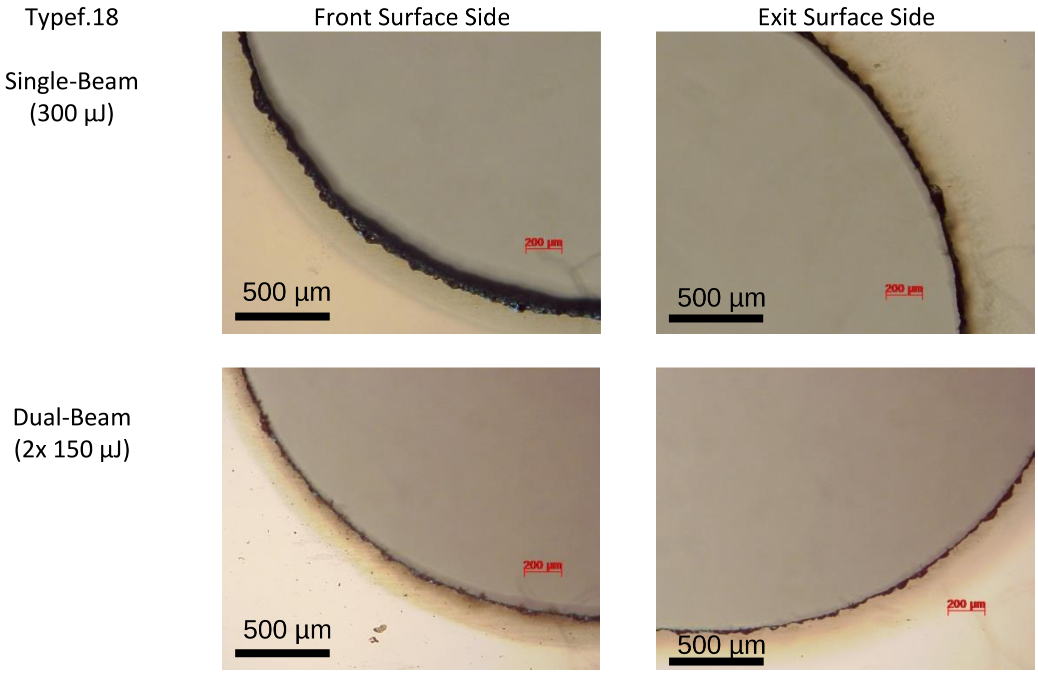

Fig. 2: Microscope images of a 0.2 mm thick quartz sample after internal contour cutting (ca. 2 mm diameter) using a nanosecond DPSSL system at 532 nm and a LMTB trepanning system type1.f18 in a single-beam (top) and dual-beam (bottom) configuration.

Another case study was performed on ca. 0.2 mm thick quartz using a sub-ns DPSSL system (Helios by Innolight, recently acquired by Coherent) with the following parameters: wavelength = 532 nm, pulse width = 0.6 ns, single pulse energy = 80 µJ (@ 16 kHz). The internal contour cut with an average diameter of approx. 8 mm, as presented in Fig. 3, is slightly more complex. The type1.f18 system was configured for single-beam applications due to the moderate single pulse energy. The observed chippings on the edges remain below 20 µm, which is most probably related to the shorter pulse width compared to the example in Fig. 2.

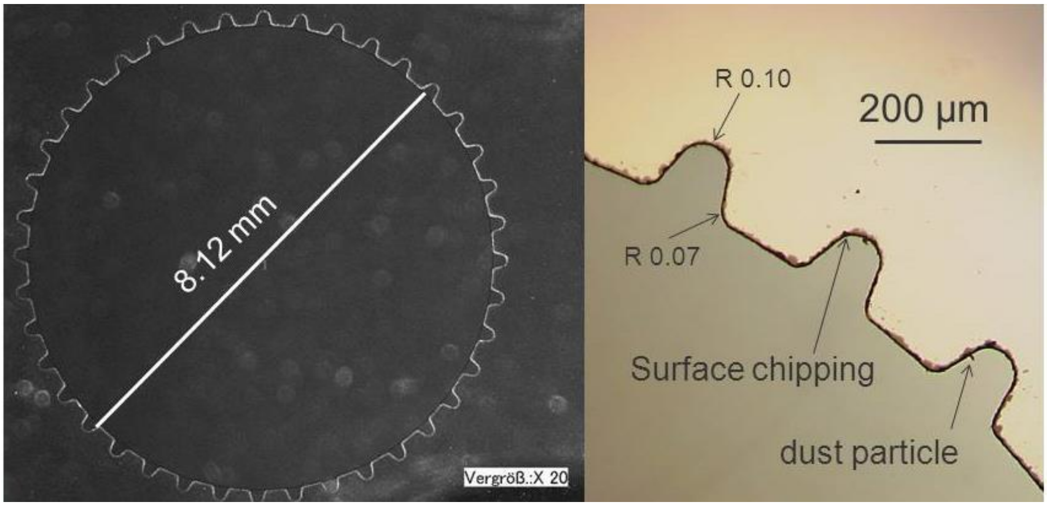

Fig. 3: Microscope images of a 0.17 mm thick quartz sample after a complex internal contour cutting (ca. 8 mm diameter) using a sub-ns DPSSL system at 532 nm and a LMTB trepanning system type1.f18 in a single-beam configuration.

Due to the larger thermal expansion of most glasses compared to quartz, such as borosilicate D263T or soda-lime glass, laser induced micro ablation of thin sheet glass can demonstrate severe edge chipping. For precise cutting or drilling of thin-sheet-glass, the choice of ultra-short laser pulses may be even more important. Fig. 4 depicts examples of ultra-short laser processing of sub-100µm thin D263T glass using picosecond laser pulses at 532 nm (Super Rapid, Lumera, recently acquired by Coherent). The single pulse energy was set to 15 µJ at a repetition rate of 100 kHz.

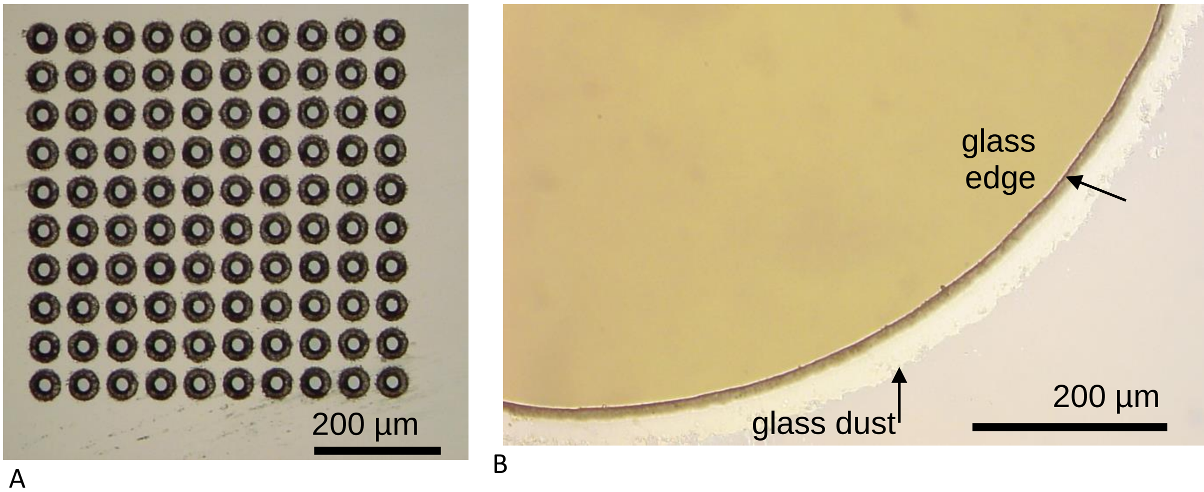

Fig. 4: Microscope images of a 0.05 to 0.07 mm thick D263T glass sample after laser machining using ultra-short laser pulses (7 ps) at 532 nm a LMTB trepanning system type1.f18 in a single-beam configuration. **A:** matrix of 10x10 50 µm holes at a pitch of 150 µm. **B:** internal contour cutting (ca. 2 mm diameter). Note the good quality of the smooth edge (minimal chipping << 5 mm) and the white rim of glass dust, which can be removed easily with a cloth or in a ultrasonic bath.

The combination of ultra-short laser pulses and the LMTB trepanning system type1.f18 for a strong focusing alignment and circular pulse distribution on the work-piece represents a good combination for precise cutting of thin sheet glass. Typically, a cutting width of 100 µm or less is chosen, while the XY-stages moves the sample at a predefined (closed) path and velocity to complete the contour cut, as in the example of Fig. 5. The 100 µm thin strengthened soda-lime glass was machined using a femtosecond laser source (JenLas D2.fs, Jenoptik). In this particular case, the results using the femtosecond demonstrated an improvement in quality compared to picoseconds laser machining. However, the processing results may differ strongly depending on the type of glass and the chosen surface of interaction, i.e. front or exit side of the transparent sample..

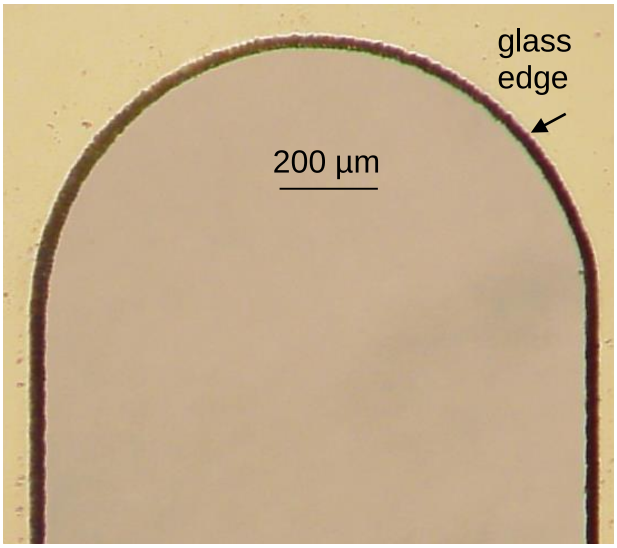

Fig. 5: Microscope images of a thin-sheet soda-lime glass sample after laser machining for internal contour cutting. A 0.1 mm thick soda-lime glass was machined using ultra-short laser pulses at a wavelength of 1025 nm, pulse width = 0.4 ps, energy = 50 µJ per pulse at 30 kHz.

In rear side laser processing of glass, the choice of pulse width can have a dramatic effect on the ablation rate and precision. Using green nanosecond laser pulsed focused on the rear side of glass, e.g. soda-lime glass, the average ablation rate per laser pulse can be in the range of 100 µm per shot or even higher. During laser cutting or drilling from the rear side upward, one will observe an up-pilling of glass dust or particles underneath the processed area. Same is true when using ultra-short laser pulses, e.g. in the picoseconds or femtosecond pulse width rang, however, at a much lower feed rate compared to the nanosecond case. Taking a closer look on the dust particles, such as under the electron microscope, on will observe significant differences in size distribution. Fig. 6 depicts this observation based on pictures taken under the SEM for the particles, collected and analyzed after nanosecond (left picture) and picosecond (right picture) pulsed laser rear side machining of 1 mm thick soda-lime at a wavelength of 532 nm. The dust particles or pieces in the nanosecond case are fairly large in size, ranging from 10 to 100 µm. In the picoseconds case, the dust particles are quite smaller in size, usually below 5 µm. This result is indicative for the strong mechanical weakening of glass using nanosecond laser pulses, which can be utilized for cutting and drilling, if the laser pulse energy is correctly distributed during machining. Hence, the LMTB trepanning system type1.f18 is a excellent optical tool to ensure an adequate focus position in laser machining of thin-sheet glass.

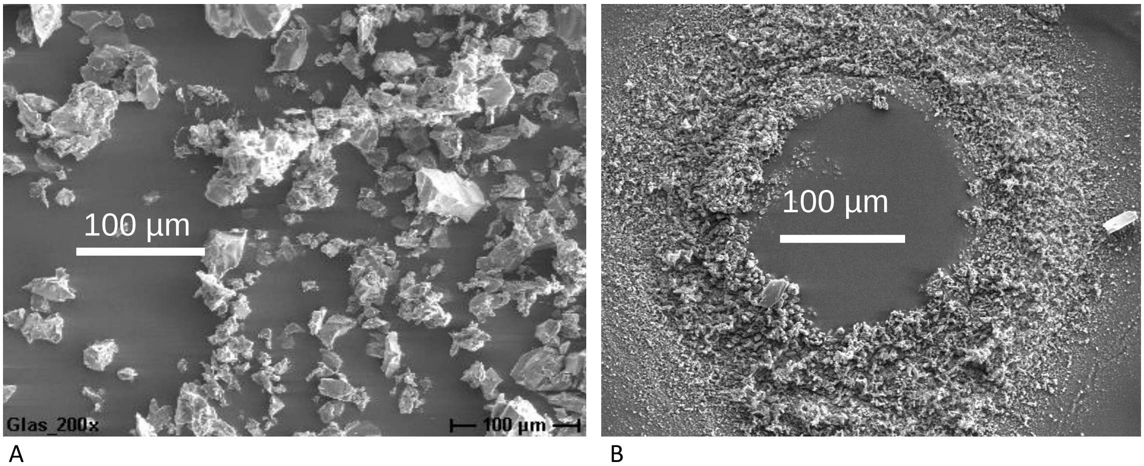

Fig. 6: SEM images of the glass dust or particles collected during rear side laser machining of soda-lime glass at 532 nm at different pulse width. **A:** 25 ns, **B:** 7 ps.

Conclusion and Outlook

Several examples in laser cutting and drilling of thin sheet glass, such as 0.2 mm thick quartz, < 0.2 mm thick borosilicate glass, and < 0.2 mm thick soda-lime glass, are presented. As laser source diode-pumped solid state laser generating short or ultra-short laser pulses in the green or IR have been utilized to initiate the processing either on the front or – more ideally – on the exit surface side of the transparent samples. To ensure a selective and well-controllable energy input, the LMTB has developed a short-focusing working optics, the trepanning system type1.f18. This system rotates one or even two tightly focused beams at a spot diameter < 5 µm on the sample. The dual-beam approach usually yields significantly less chipping on the edges. Laser induced ablation is initiated at the preferred surface side, even for glass thickness < 0.2 mm. Hence, the type1.f18 with a protective gas nozzle represents an attractive alternative to standard scanner systems. In combination with a standard XYZ-stage CNC unit, cutting and drilling of thin sheet glass with the type1.f18 can be completed in straightforward fashion for most given laser parameters and glass types.

At the present, the LMTB is working on

- Implementation of rear side laser machining for sapphire glass, which is actually more difficult than perhaps expected,
- Improvement of the type1.f18 to ensure a dynamic cutting width during machining,
- Including an independent additional circular displacement for larger diameters to allow for a orbit-in-orbit distribution of laser pulses,
- Investigations using nanosecond UV-laser light to improve feed rate **and** quality.

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