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New Approach of Laser Processing of Transparent Materials

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Abstract

The classical way of processing materials using laser ablation with galvanometer scanners or other optical elements limits the possible structures and geometries of features and parts. Holes without taper or other structures such as trenches with rectangular profile are hardly possible to machine.

In this paper 3D-Micromac AG presents a novel laser micromachining method for transparent materials using ultra short pulsed lasers. With this new method the described limits can be overcome. Structures like taper-free or negative taper walls walls can be achieved with very high aspect ratios. Typical dimensions of those structures are in range of a few 10 microns up to a few 100 microns. This type of structures are interesting as inkjet or other fluidic nozzles, for friction reducing surfaces or as casting moulds for polymer parts for life science and medical applications. Furthermore, laser machined micro parts like micro gears are presented. Such parts are of interest for micro drives, pumps for micro fluidics and other upcoming applications.

In the presentation the concept of the process flow, latest results and limitations will be shown.

1. Introduction

3D-Micromac AG has become one of the leading suppliers of highly efficient laser micromachining systems as well as innovative coating and printing technologies on the international market since its foundation in 2002. In the recent years of this development we see a constant marked request for taperless micromachined

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structures for moulding, microfluidic or stamping parts out of various industries that cannot be fulfilled by electro-discharge machining or only by cost intensive electro forming processes.

Those industries are driven by the request on:
- Following the product development processes in highly integrated production processes
- Rapid prototyping with repeatable high process quality
- Usage of alternative materials
- Scalable production processes

In general, the following requested properties can be identified:
- small width structure sizes (<200 µm)
- medium aspect ratio (<1:5)
- defined wall angle or in best case no wall angle
- Sidewall roughness < 1 µm

1.1. Problem description

Taper formation seems to be inevitable in laser ablation based on ultra-short pulse micromachining. Conventional ablation strategies cause a larger entry diameter than exit diameter. This effect is influenced by various entry parameters, such as fluence, beam profile, rayleigh length and plasma shielding during the ablation. The effect itself seems so far not completely explained.

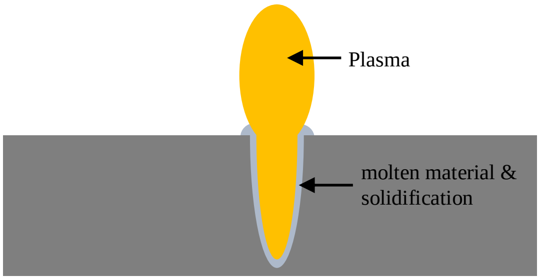

Fig. 1: Schematic view on plasma processes by laser drilling in bulk material [Poprawe 2005]

Additionally, the ablated material re-condensates by cooling down beside the plasma torch. This condensated cellular material shows a different material – laser interaction than the bulk material. Especially in brittle materials like glass or sapphire this might cause cracks in multiple pulse treatment.

1.2. State of the art processes for laser micromachining

There are several solutions in the market to solve the challenges in brittle and transparent materials.

ISLE (in- volume Selective Laser Etching)
The strategy was developed at Fraunhofer ILT, the glass bulk material is scanned with fs laser and completely etched by HF or KOH. Free defined tapers are possible and the surface roughness fulfill costumer's request.

But ablation and etching rates are low and furthermore, this process is hardly to integrate into complex production processes e.g. for mounted parts.

Backwards Treatment

First presented by Dr. K. Du in 2003 by Edgewave by focusing the laser on the backside or inside the material gives the possibility to micro-machine any kind of taper. All transparent materials can be processed. But surface roughness is described to be in the area of 10µm. In the practice of 3D-Micromac's application lab this process was observed to caused cracks with structure sizes <1 mm and could not be implemented using ultra-short pulsed laser sources. After treatment with ultra short pulses sublimation of the ablated material on the sidewalls was observed, on additional pulses the interaction of the laser with the bulk material and the condensate caused instable behavior.

Trepanning optics / spiral drilling

A common technique to influence the taper is the usage of angled focused laser beam. Therefore various scanning-, trepanning- and helical drilling solutions are available. The laser beam, which is inclined to the optical axis (angle of incidence>0), is moved on a circular path during the ablation process. The typical results are drilled holes with minimum diameter < 50 µm and a well controllable taper angle. In combination with an X-Y-movement of the sample more complex structure dimensions are generable, but always with a correlation between minimum structure size and minimum diameter of the drilled hole. Such tools are mainly used for drilling injection nozzles and spinnerets based on non-transparent materials.

1.3. Problem solution (patent pending)

3D-Micromac AG was facing this problem by using their Know-How on their product MicroPrep. With an angled sample and a strong laminar flow zero taper applications are possible. These are used for transmission electron microscopy (TEM) sample preparation and support the focused ion beam (FIB) preparation tools with high ablation rates. In transparent materials the combination of "backwards treatment strategy" and the usage of a strong laminar flow the limitations of the common process can be overcome. An angling of the sample is not necessary anymore. The sample has to be fixed face down and the ablation area needs a strong laminar flow. An ultra short pulsed laser source (6-12 ps) was used at a frequency of 1 MHz at a wavelength of 1030 - 1064 nm. A galvanometer scanner equipped with a focal lens (f = 45 mm) provided an optimal tradeoff in process speed and accuracy.

With this optical setup ablation rates up to 10 mm^3/min and a surface roughness lower than 1 µm can be achieved, although it has to be noted that there is a tradeoff between roughness and process speed. Materials with a thickness from 0.05 mm to more than 50 mm can be processed. The process was developed on sapphire, soda lime glass and other transparent materials. The aspect ratio of 1:5 was successfully shown in industrial dimensions. In addition, the surface quality can be improved by post-process removing molten particles such as etching in KOH or HF.

1.4. Process advantages of 3D-Micromac's solution

- Avoiding a process defined taper is an absolute advantage of the process
- Process speed and ablation rates are overcoming the limits of other techniques like etching
- Using a scanning system without the need of any kind of mask-projection provides higher flexibility

- Surface roughness can be improved by additive post process techniques like etching or plasma polishing
- The intra material stress level is minimized due the usage of an ultra short pulsed laser source; in first tests a depth of 10 µm was determined.

In the following pictures some of the achieved results are shown. In Fig. 2 the complete sample structure is presented. The total gear width is 2000 µm, the web width is 80 µm. The material was ablated to a depth of 500 µm with taper-free walls. In a second test structure through holes were drilled as shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. The diameters range from 200 µm to 2000 µm through the complete material (1000 µm). In **Fehler! Verweisquelle konnte nicht gefunden werden.** the entrance region is shown.

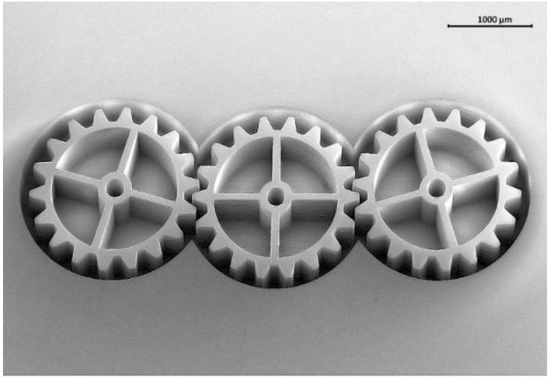

Fig. 2: Overview on micro machined soda lime glass

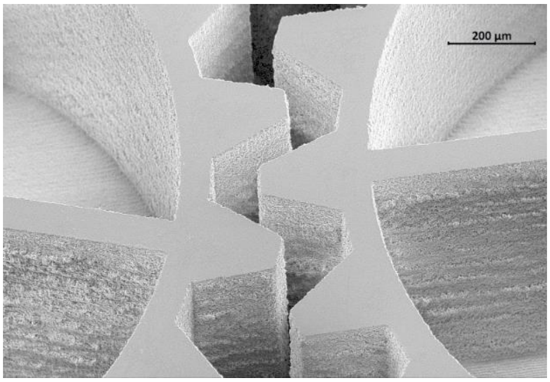

Fig. 3: Detail intervention point

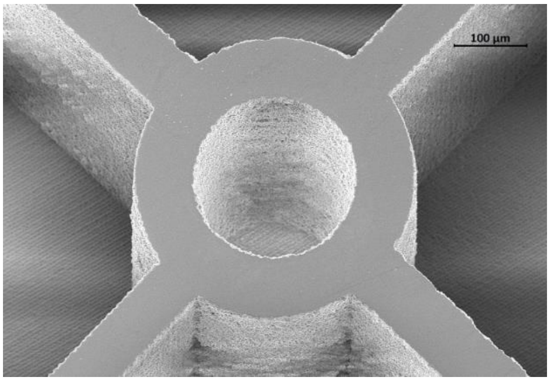

Fig. 4: Detail shaft-to-collar connection

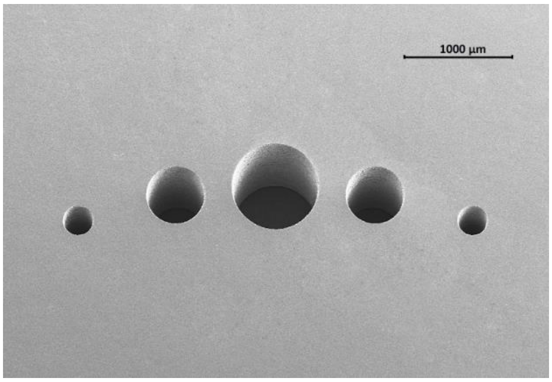

Fig. 4: Overview of drilled structures in 1000 µm thick soda lime glass

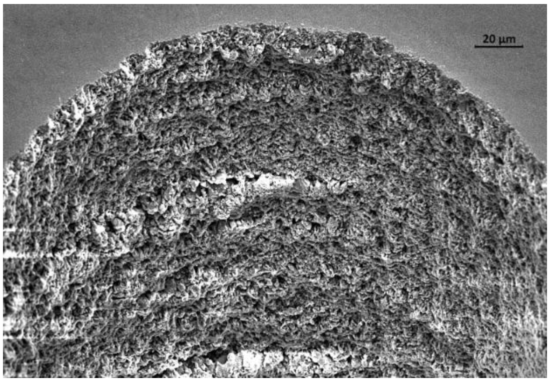

Fig. 5: Detail on entry of a 200 µm drilling trough soda lime glass

1.5. Summary and Outlook

A new strategy and the first results for laser micromachining of transparent materials were introduced. The approach shows high potential for the generation of microstructures with high aspect ratios. The new approach opens the way to structure properties which were not able to achieve with common laser based. Remarkable ablation rates and very low surface roughness properties are achieved which opens the use of this technique for industrial relevant applications. The process was developed on a industrial tool platform and is proved to be very robust and reliable. In a next step this process will be transferred to additional substrate materials and applications.

References

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