# 3D direct laser ablation of microchannels in technical glass

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## INTRODUCTION

Laser machining has emerged as enabling technology that holds immense potential for advancing the miniaturization across various industries. With the rapid advancement of laser technologies, the boundaries of what is attainable in the miniaturization have expanded significantly. In this paper 3D direct laser ablation of microchannels in glass for microfluidic and medical applications is reported. Process understanding and optimization plays a decisive role in achieving controlled volumetric material removal with specified surface roughness. By harnessing adequate combination of machining parameters, a trade-off between surface roughness and ablation rate is achieved to ensure the required quality, reproducibility, and process reliability.

## METHODS

A five-axis machining centre with ultrashort pulse laser GL.compact II from GFH GmbH (see Fig. 1) was used for the laser ablation experiments. SCHOTT D 263® bio glass substrates (75x25x1 mm) were ablated using an ultrashort pulse laser Carbide (Light Conversion) at wavelength of 1030 nm (IR), 10 ps pulse duration and 100 kHz repetition rate. A SCANLAB's excelliSCAN scan head was used to ablate the surfaces by means of cross-hatching. Process-specific parameters were studied to fit the targeted microchannel's geometry (see Fig. 2). Metrology was realized on a Sensofar S neox five axis 3D optical profiler in focus variation mode with a 20x objective.

*Fig. 1: Five-axis laser machining centre*

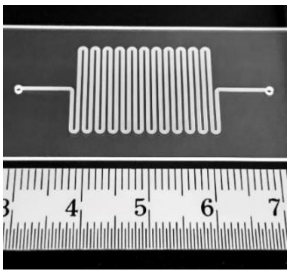


*Fig. 2: Overview of a ps-laser-ablated meander microchannel*

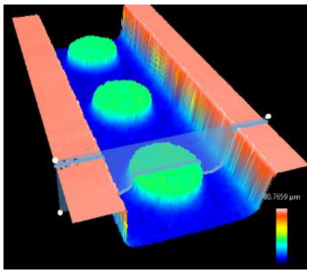

*Fig. 3: 3D imaging of a channel section. Ref. bottom surface in red*

## RESULTS

In this study, several process parameters were tested to directly ablate meandering shape microchannels of 0.5 mm width and depths ranging 0.075 – 0.125 mm directly in glass substrates. The aim was to find out an optimal compromise between Material Removal Rate (MRR) and good surface quality by avoiding cracks or material degradation due to high energy density peaks. First the laser beam focus z was varied in 0.1 mm steps through the glass substrate from the entrance (z=0, top) to the exit (z=-1 mm, bottom) surface at constant pulse energy to define the focus plane that enables the ablation process starting at the bottom surface. This was the case for z=-0.7 mm. Prior to the ablation, a first marking of the bottom surface is performed at z=-0.7 mm by a number of 10 scans without changing the beam focus plan after each scan. Afterward, the proper material removal begins in the +z direction in a bottom-up ablation process by applying a number of 17 to 24 scans while concurrently changing the laser beam focal plan of +0.005 mm after each scan toward the top surface direction. Each scan is filled with a pattern of parallel lines separated by a hatch distance. Smaller hatch distances (about 2-4 µm) lead to glass cracking because of too much energy and higher heat accumulation in a small distance, while longer distances (above 12 µm) influence negatively the surface roughness. By varying the beam scanning speed in a range 400 – 1200 mm/s, both MMR and surface quality can be adjusted. Finally, the laser pulse energy was varied in a range 30 – 40 µJ to find out the minimum energy needed to begin ablation and get the optimal MRR. The laser parameters summarized in Table 1 enable a crack-free and uniform material removal that best fit MRR processing time.

*Table 1: Laser parameters used for direct ablation in glass substrates*

| | | | |
|---|---|---|---|
| Pulse energy | 35 µJ | Hatch distance | 0.008 mm |
| Scanning speed | 800 mm/s | Number of scans | 10 to 24 |

As showed in Fig. 3 above and measured in Fig. 4 below, channel geometry with depth of 0.125 mm, and additional 3D cylindric structures (pits) of 0.05 mm height, starting at 0.075 mm in the middle of the channel below the glass surface could be directly ablated in the glass substrates. To achieve the different ablation depths, a three-steps bottom/up ablation process was thus used: 1) marking the lower glass surface, 2) ablating the whole channel until 0.075 mm depth, and 3) further ablating the channel until 0.05 mm depth by avoiding a circular surface of Ø 0.3 mm (pits). Additional surface roughness measurements in the ablated zones show values of Sa ranging 0.8 – 1 µm.

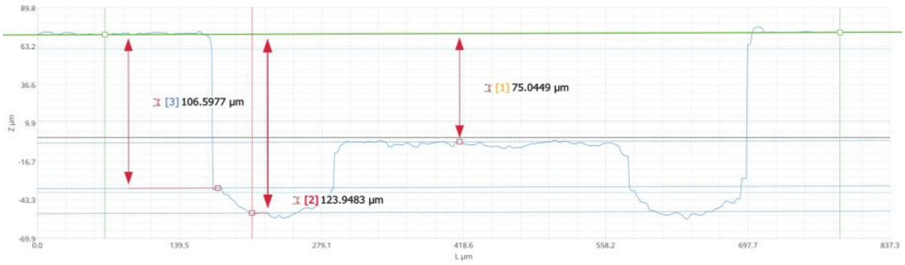


*Fig. 4: Channel cross-section profile of Fig. 3 showing a ≈50 µm pit heigh at 75 µm below the top glass surface (green line) and a ≈125 µm total channel depth*

## DISCUSSION & CONCLUSIONS

The bottom/up ablation strategy used on this study was possible by means of self-focusing [1,2,3] that occurs because of optical Kerr effect [4]: a refractive index change is induced when intense laser pulse enters transparent materials, since the non-linear component of the refractive index increases with increase of the intensity of radiation I, as described by the formula $n = n0 + n2 \times I$, where $n0$ and $n2$ are the linear and non-linear components of the refractive index $n$, and $I$ is the intensity of the laser beam. Therefore, an ablation process from the bottom surface could be started, enabling the formation of sharp edges along the ablation depth, and avoiding any taper typically observed when ablating from the top to the bottom surface of a transparent materials with Gaussian beams. The control of the ablation depth is made possible by adapting the number of scan repetitions with ablation rates of 3 – 5 µm/scan. Typical ablation times of ≈ 20 min for the whole channel (Fig. 2) could be reached. Further process optimizations are currently running to further decrease the surface roughness Sa <0.8 µm and avoid autofluorescence in the laser ablated zones. This work was supported by NTN Innovation Booster - Microtech powered by Innosuisse.

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