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Spark Assisted Chemical Engraving (SACE) – an innovative technology with high potential for industry

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Abstract
Glass micromachining is nowadays becoming essential for the fabrication of micro-devices including optical micro-electro-mechanical-systems (MOEMS), miniaturized total analysis systems (µTAS) and microfluidic devices for biosensing. Moreover, glass is radio frequency (RF) transparent, making it an excellent material for sensor and energy transmission devices. Advancements are constantly being made in this field, yet machining smooth high-aspect-ratio features remain challenging due to poor machinability of glass. The hybrid technology Spark Assisted Chemical Engraving (SACE) is a promising answer to these challenges.
In this contribution the first available industrial SACE-machine on the market is presented, developed by Posalux SA, Switzerland, and the Electrocatalytic Green Engineering (EGE) Group, Concordia University, Canada. This machine offers micro-drilling, micro-milling, micro-cutting and micro 2.5D machining operations while leaving the glass surface intact such to allow subsequent glass-to-glass bonding. Its force-sensitive machining head allows the use of ultra-thin machining tools (d < 100 µm), applying force-feedback algorithms and ability of the head as profilometer to measure machined features within the same setup.

Micromachining, micro-hole drilling, SACE, glass, electrochemical discharges, microfluidics, direct glass bonding

1. Introduction

With the great technological advancement in the micro-technology field, micromachining of various materials has become a key task. Glass is essential for the fabrication of micro-devices including micro electro mechanical systems (MEMS), optical MEMS (MOEMS), miniaturized total analysis systems (µTAS) and microfluidic devices [1, 2]. This is mainly because of its unique properties, such as mechanical strength, thermal properties, transparency, chemical inertness and bio-compatibility. Moreover, glass is RF transparent, making it an excellent material for sensor and energy transmission devices. Another advantage of using glass in microfluidics is its relatively high heat resistance, which makes these devices suitable for high temperature microfluidic systems [1] and sterilization by autoclaving. However, the hardness and brittleness of glass complicates its micro-fabrication. In particular machining high-aspect ratio structures is still challenging due to long machining times, high machining costs and poor surface quality [3].

Methods to micro-machine glass can be divided into four groups: thermal, chemical, mechanical and hybrid. Thermal processes, e.g. laser, are fast and flexible but usually form bulges around the rims of the micro-hole entrances leading to bonding difficulties and often making post process steps necessary. Chemical processes produce smooth surfaces but require expensive masks while mechanical methods are relatively slow and exhibit poor surface roughness. Hybrid technologies, like Spark Assisted Chemical Engraving (SACE), are favourable as they attempt to combine the good outcomes of each process to satisfy most requirements for the desired micro-structures in glass [3].

In this contribution we demonstrate how SACE is developed to an industrial level by presenting the first available industrial SACE-machine on the market developed by Posalux SA, Switzerland [4], and EGE Group, Concordia University, Canada. This machine offers various machining operations for glass substrates, allows the use of ultra-thin machining tools (d < 100 µm), and usage of the head as profilometer to measure machined features within the same setup.

2. Glass micromachining

Main requirements to achieve novel glass micro-devices as in MEMS, MOEMS and bio-MEMS are high aspect ratio drilled micro-holes with low surface roughness. These features are essential for macro-to-micro connection and interconnecting multiple layer devices [5]. An overview of the four identified machining categories related to surface roughness and aspect-ratio are presented in Figure 1.

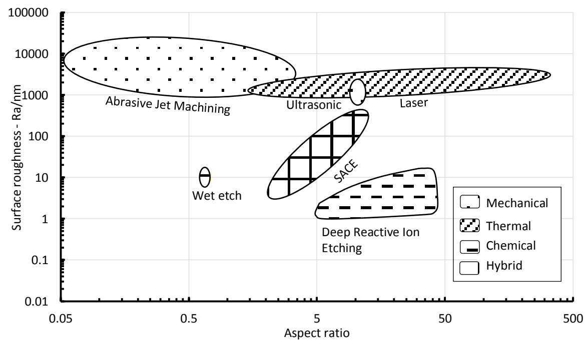

Figure 1. Surface roughness Ra/nm vs. aspect ratio for different glass drilling methods, categorized in four categories (Mechanical, Thermal, Chemical and Hybrid).

Mechanical methods cannot achieve high aspect ratio. Thermal techniques as laser machining obtain high aspect ratio, however they have to deal with heat affected zones. Chemical methods like wet etching (HF) and deep-reactive-ion-etching (DRIE) accomplish very smooth surfaces. However wet etching is limited in aspect ratio and DRIE is a complex and expensive technology requiring clean room facility.

Hybrid methods such as SACE perform well in drilling high aspect ratio and smooth surface micro-holes. These assets of SACE technology combined with its relative high machining speeds compared to chemical methods and low-cost compared to femto-laser technologies make SACE perfectly suitable for rapid prototyping of micro-scale glass devices.

3. SACE Principles and Machine design

In SACE technology, a voltage is applied between tool and counter electrode dipped in an alkaline solution (typically NaOH). At high voltages (around 30 V), the bubbles evolving around the tool electrode coalesce into a gas film and discharges occur from the tool to the electrolyte through it. Glass machining becomes possible due to thermally promoted etching (breaking of the Si-O-Si bond) and bombardment by discharges as illustrated in Figure 2.

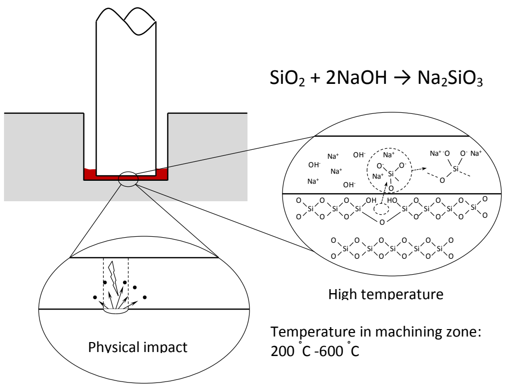

Figure 2. Electrochemical discharge machining mechanism of SACE technology on a glass substrate.

The developed versatile industrial SACE-machine is presented in Figure 3 and offers high precision glass micro-drilling, micro-milling, micro-cutting and micro 2.5D machining operations (Figure 4) while leaving the glass surface micro-crack, debris and bulge free such to allow subsequent glass-to-glass bonding. The implementation of a force-sensitive machining head allows the use of ultra-thin machining tools (diameter down to 30 μm), applying force-feedback algorithms (detecting forces down to 1 mN) and usage of the head as profilometer to measure machined features within the same setup.

Figure 3. Industrial machine *Microfor FP1 SACE* developed by Posalux SA and EGE Group, Concordia University, consisting of a versatile force-sensitive head for SACE machining and use as profilometer [4].

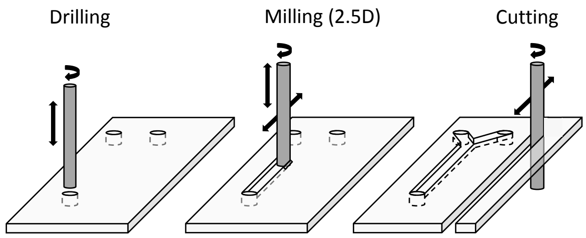

Figure 4. Versatile glass machining by SACE: drilling, milling and cutting by the same technology on the same setup.

4. Machining results

Drilling of through and blind holes of diameters from 100 μm to several millimetres can be achieved with low circularity error (typically < 1 μm circularity error) and depths as deep as 3 mm. Drilling is relatively fast (a 700 μm deep hole is drilled in typically 2 seconds).

Machining of channels with straight walls (taper angle < 5°) and a wide range of dimensions (widths > 100 μm) can be achieved at machining speeds of typically 20 mm/min and removing up to 100 μm - 200 μm in a single pass.

Cutting from thin (100 μm) to thick glass (3 mm) is possible as well at similar feed rates as channel machining. Cuts are very sharp and straight (taper angle < 5°), allowing machining of very precise structures. Figure 5 presents a sub-millimetre hinge fabricated from a thin glass sheet (thickness = 200 μm) to highlight the capabilities of SACE technology. It can be clearly observed that very smooth cut surfaces (Rz < 1 μm) can be achieved in the hinge part where polishing parameters were applied contrary to the rest of the structure where only rough cutting was done.

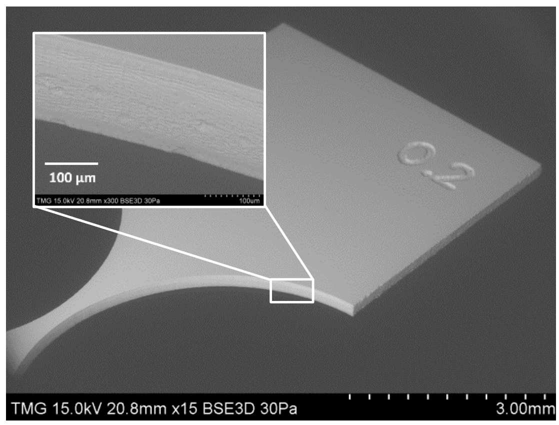

Figure 5. Smooth cutting of glass (Rz < 1 μm) by SACE technology.

5. Conclusions

SACE technology can successfully be implemented in industrial manufacturing processes for high precision glass machining (resolution down to 1 μm) by use of the presented Microfor FP1/HP4 SACE machine.

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