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Micromachining glass with *in situ* fabricated micro-tools

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Abstract
Glass is used as material in MEMS devices and microfluidics in industry and academia. This is mainly because of its unique properties, like mechanical strength, thermal properties, transparency, chemically inertness and biocompatibility.
However, the hardness and brittleness of glass complicates its micro-fabrication. Among micromachining methods, Spark Assisted Chemical Engraving (SACE) is an interesting candidate to fulfil this requirement. In this hybrid micromachining technology, electrochemical discharges around a micro-tool are promoting the local etching of glass. Cylindrical, smooth micro-tools allow for best quality structures. However, the micro-tool in SACE technique is still an expensive consumable and this tool is breakable in the clamping process and it is sensitive to runout when rotating the tool during machining.
Therefore, a method for *in situ* fabricating smooth micro-tools is presented in this study. In this method, a high speed spindle (5000 rpm - 35000 rpm) with grinding wheel is mounted on precision x-y stages (resolution = 1 µm). The initial material (stainless steel, diameter = 500 µm) for micro-tool fabrication is fixed in the same head as used for subsequent micromachining. After grinding the tool is electrochemically polished with pulse technology (polishing time = 20s, pulsed voltage settings: high level = 22.5V, low level = 10.5V, duty cycle = 20%, period = 1 ms). It is shown that the surface roughness of the fabricated micro-tools can be reduced from Ra 1.5 µm | Rz 12.4 µm down to Ra 70 nm | Rz 500 nm by electro-polishing post-process after the mechanical grinding process.

Microtools, micromachining, electrochemical postprocessing, precision grinding, abrasive machining, electro-polishing, SACE

1. Introduction

Increasing demands for compact and multifunctional devices have initiated global interest in micro-scale devices like MEMS and microfluidics. Whereas silicon is still the most used material for these devices, there is a trend to replace silicon by glass. This is mainly due to its thermal and electrical properties, mechanical strength, heat resistance and optical transparency. However, because of its hardness and brittleness glass is still challenging to micro-machine.

Among micromachining methods, spark assisted chemical engraving (SACE) is a promising candidate [1]. In this hybrid micromachining technology, electrochemical discharges around a micro-tool are promoting the local etching of glass. Smooth, high aspect ratio micro features can be machined in glass. One of the key factors in SACE technology determining high resolution and smooth features is the quality of the micro-tool. Cylindrical, smooth micro-tools allow for best quality structures. SACE is relatively flexible and low-cost compared to competitive technologies as femto-laser for micromachining glass [1].

Nevertheless, the micro-tool in SACE technique is still an expensive consumable limiting the industrial advancement of SACE. Moreover, the micro-scale tool-electrode is breakable in the clamping process and it is sensitive to runout when rotating the tool during machining.

In order to solve these challenges, a method for in situ fabricating smooth micro-tools is proposed in this paper, thereby eliminating the need for a separate machining setup for tool fabrication, which minimizes micro-tool handling in SACE micromachining.

The design of the setup for mechanical grinding and post process by electro-polishing (EP) [2] and the followed methodology of the process is detailed in section 2. Subsequently the experimental results of grinding and EP post-process are presented by a graph and optical microscopic pictures. Conclusions of the proposed study are outlined in the final section.

2. Design of setup

Figure 1 presents the designed *in situ* setup for microtool fabrication by mechanical grinding followed by electro-polishing and positioning of the tool for SACE glass machining.

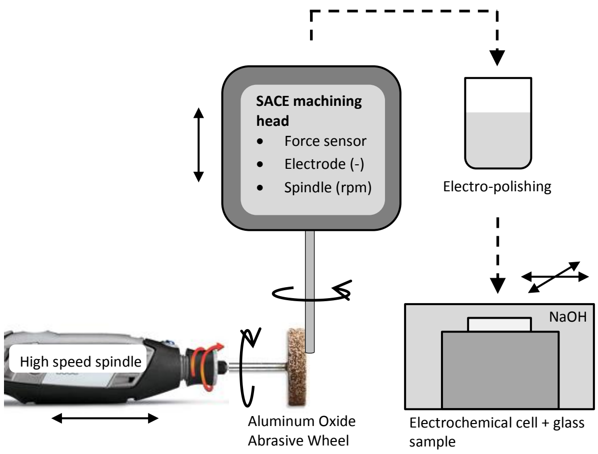

Figure 1. Integrated *in situ* microtool fabrication setup for glass micro-machining by SACE. Tool fabrication starts with mechanical grinding followed by electro-polishing. Hereafter, the tool is complete for glass micro-machining by SACE.

In this method, a high speed spindle (5000 rpm - 35000 rpm) with grinding wheel is mounted, besides the electrochemical cell for SACE machining, on high precision x-y stages (Newport®) with a lateral resolution of 1 µm. Here, we consider stainless steel wire with diameter of 500 µm as tool, mounted on the SACE machining head, to start with.

First, the bottom surface of the tool is grinded by rotating the tool (300 rpm) and at the same time translating fine grit abrasive paper (grit 800 – 1200), glued to a glass work-piece, at 100 µm/s during 10 min while the tool is pressed against it (a force < 0.1 N is applied). This ensures that the tool bottom surface and the substrate are aligned.

In a second step lateral grinding to achieve the desired micro-tool diameter is conducted as follows:

a. Rotation of the tool – 500 rpm – mounted on the SACE machining head
b. High speed rotation of the abrasive wheel (Al_2O_3) – 20000 rpm – generating sufficient tangential speed of the abrasive wheel surface with respect to the tool
c. Low speed translation – 10 µm/s – of the grinding wheel towards the tool
d. The process is monitored with a USB-microscope, to determine when the desired tool diameter is achieved (see figure 2)
e. Upward tool movement – 100 µm/s

In addition, runout of the tool can be eliminated by this method as long as the runout is smaller than the desired tool radius.

After grinding the tool is dipped into ethylene glycol solution with 0.9 molar NaCl and it is connected as anode for EP with pulse technology [2].

Finally, the completed micro-tool is positioned at the glass surface for glass micro-machining by SACE technology.

Results of the grinding and EP process are assessed qualitatively by optical microscopy and quantitatively by a laser profilometer (Olympus®).

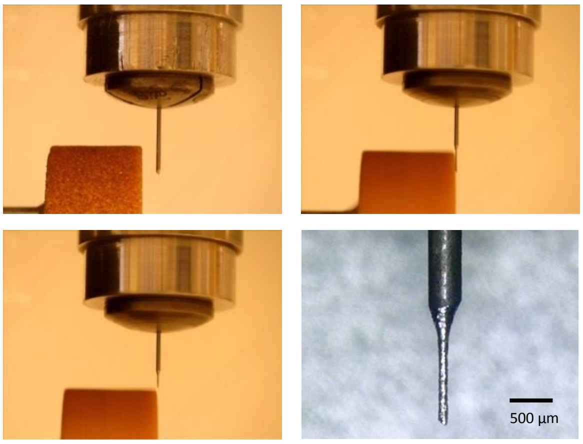

Figure 2. On-line monitoring of the grinding process by microscopy.

3. Experimental results

Grinding results of the tool bottom surface alignment before and after EP post-process are presented in figure 3 and figure 4. EP with pulse technology is applied: high level = 22.5V, low level = 10.5V, duty cycle = 20%, period = 1 ms, and polishing time = 20s. It is observed that the EP process is most effective in reducing surface roughness at applying the pulses for 40 seconds (see figure 4). The tool bottom surface roughness is reduced from Sa 0.26 µm | Sz 8.31 µm down to Sa 0.077 µm | Sz 2.22 µm.

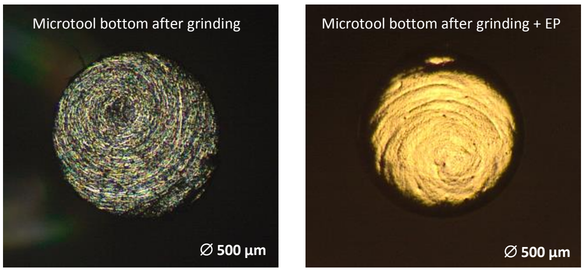

Figure 3. Microscope images of the grinded tool bottom surface before and after EP post-process.

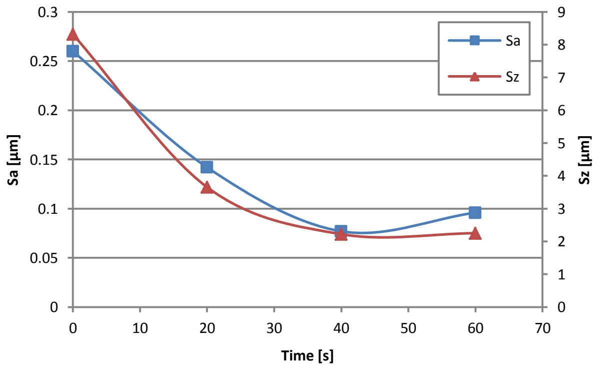

Figure 4. Surface roughness values (Sa and Sz) of the tool bottom surface directly after grinding and after EP process for varying polishing time. Measurements are conducted by a laser profilometer.

Results of the fabricated micro-tool from a stainless steel wire with a diameter of 500 µm are presented in figure 5. Cylindrical tools with relative smooth surfaces are obtained by the grinding method and subsequent EP post-process.

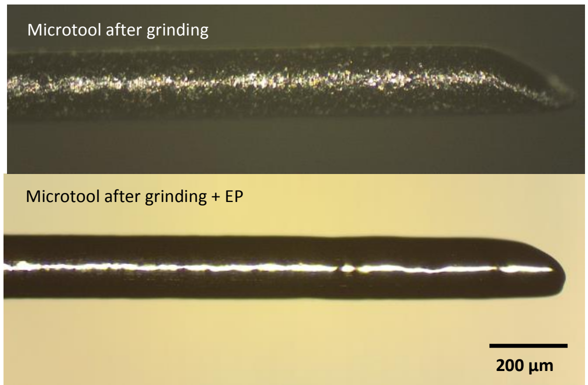

Figure 5. Fabricated stainless steel micro-tool before and after EP post-process.

4. Conclusion

A low-cost *in situ* micro-tool fabrication method is successfully developed for glass micro-machining by SACE.

It is shown that the surface roughness of the fabricated micro-tool sides can be reduced from Ra 1.5 µm | Rz 12.4 µm down to Ra 70 nm | Rz 500 nm by EP process after the mechanical grinding method.

Micro-tool handling in SACE technology is minimized avoiding alignment and tool runout issues.

References

[1] R. Wüthrich and J. D. Abou Ziki 2015 *Micromachining Using Electrochemical Discharge Phenomenon* Elsevier

[2] A. F. Teixeira, 2011 Master of Applied Science – Thesis Concordia University