Quantifying the gap formed between the tool and the glass surface during SACE micro-drilling

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Abstract

With the great technological advancement that we are witnessing in the micro-technology field, micro-machining of various materials has become a vital task. Glass is, after silicon, the mostly used material in MEMS devices fabrication. Due to its unique properties, there is a growing trend to replace silicon with glass. A number of glass micro-machining technologies such as wet etching, laser, ultrasonic and mechanical machining are available. However, drilling high-aspect ratio micro-holes is still challenging due to the long machining times, high machining costs, or poor resulting surface quality. Spark assisted chemical engraving (SACE), a non-traditional glass micromachining technology based on glow discharge electrolysis, has already proven to be able to machine high-aspect-ratio micro-holes in a short time, where the etching rate is typically around 100µm/s for the first few hundred microns. Yet, at higher depths, the machining rate decreases significantly.

As of today, SACE is not used industrially since it is a blind drilling process. The absence of control strategies is due to a lack of understanding of the material removal mechanism. The aim of this work is to fill part of this knowledge-gap to provide the needed fundamentals that will allow the development of control strategies for SACE.

1 Introduction

It is generally agreed that the heat source from the discharges happening in the gas film formed around the tool-electrode attack the glass in some way. Three attack mechanisms are being debated in the literature: glass melting [1], localized glass sublimation by discharge impact [2], and high temperature chemical etching [3].

Important aspects in SACE drilling process are not yet understood. These include the tool-work piece gap, the nature of the locally formed surface layer and the mechanism responsible for the formed surface texture.

In this work, we propose using the information provided by the measurement of the force exerted on the tool to elucidate some of these aspects. As this signal provides directly local information about the machining zone, it is expected to reveal new insights about the machining mechanisms.

2 Experimental

The tool-electrode is mounted on an in-house built machining head, incorporating a spindle and a force sensor (based on the zero-displacement measurement principle), while the glass work-piece is clamped inside a processing cell containing the electrolyte (30wt% NaOH). Tool-work piece gap measurements were done with the following procedure. The tool is moved downwards at a constant feed-rate (10 µm/s) while the voltage is on. When reaching the desired depth, the machining voltage is switched off. The gap between the tool-electrode and the machined surface is measured by moving downwards, during a specific time until the surface is felt. This time during which the system cools down, is referred to as the “cooling-time”. All results were corrected for thermal expansion.

3 Results and Discussion

Figure 1 shows the tool-work piece gap for various conditions. A clear dependence on the machining depth (flushing) and the local temperature (machining voltage) is observed. In the light of these findings, earlier observations [4] reporting decreased material removal rate at high depths, appear as the consequence of the gap reduction with depth leading to a shortage in the local electrolyte supply.

Surprisingly the inspection of the bottom of the micro-holes didn’t reveal any clear imprint of the tool-electrode, even not at very short cooling-times, where one would expect a soft surface layer of reduced viscosity (according to the first debated machining mechanism). However, for short cooling times (less than 1s), a smoothening of the surface is observed. This is believed to be due to further etching caused by the contact between the hot tool and the surface.

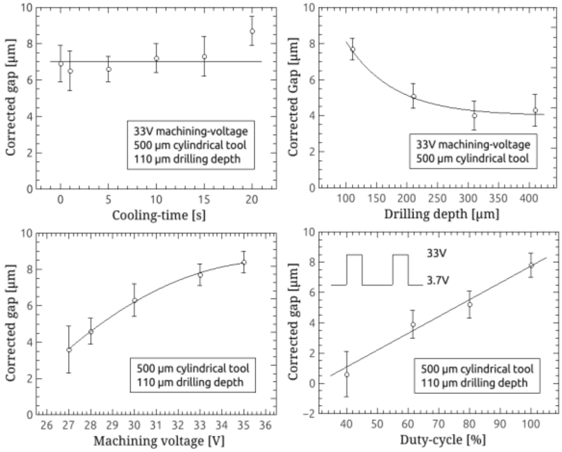

Figure 1: Dependence of the gap from a) cooling-time, b) drilling depth, c) machining voltage an d) duty cycle

These observations confirm that, contrary to what is claimed by some authors, the glass surface doesn’t reach a high enough temperature during machining which would allow it to be mechanically modified. However, for appropriate conditions (when the tool-work piece gap is reduced to zero), it is possible to stick the tool-electrode to the machined surface for few milliseconds. The corresponding surface textures show a clear imprint of the tool.

Based on the results obtained from the force and gap measurements combined with surface inspection, the following machining mechanism could be proposed:

During machining a relatively tiny gap (~10µm) is established in which electrical discharges hit the surface causing localized sublimation of the work-piece. The gap is filled with molten NaOH. Glass is etched by breaking Si-O bonds by OH attack, resulting in detachment of SiO_3^{2-}, which together with Na^+ react to form sodium silicate (water glass) eventually resulting in a glass forming melt. If the water glass isn't flushed away from the gap, its accumulation will cause reduced etching rate, resulting in poor machining witnessed by the appearance of forces exerted on the tool. Removing the heat source (discharges) will cause very rapid vitrification of the glass forming melt which covers the surface attacked by the discharges.

Two consequences result. On one side, as the glass forming melt has a low viscosity and vitrifies very quickly, it must be possible to imprint flow patterns on the glass surface. We confirmed this by freezing into the glass layer the flow patterns resulting from the tool rotation and translation (Fig. 2).

On the other side, it must be possible, by adding ions in the machining electrolyte, to create a glass layer with various chemical compositions. This was confirmed by recent EDS analysis of surfaces showing the incorporation of potassium ions.

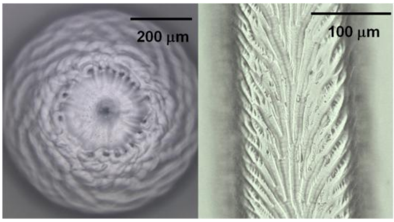

Figure 2: Hole surface texture resulting from a) tool rotation and b) tool travel motion [5].

4 Conclusion

In this work, a deeper insight into the SACE machining process is gained. It is shown that the layer formed on the hole's surface is likely to be due to the vitrification of sodium/potassium silicate (depending on the used electrolyte). This opens up new applications for SACE machining including flow visualization and surface functionalization by particles/ions incorporation.

Acknowledgement

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