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Microgravity-induced wet chemical etching of borosilicate glass – towards enhanced microfabrication methods

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Summary:

This study investigates the impact of simulated microgravity on wet chemical etching of borosilicate glass to identify the potential microfabrication efficiency. For the first time, straight microchannels were etched in HF-based solutions using microgravity simulators (RWV, RPM). In result, with RPM the highest etching rate could be achieved (3.06 µm/min), showcasing a novel approach to chemical processing. Moreover, the structures formed under microgravity were found to be of high-quality—RPM gave the deepest, and most uniform channels, while RWV ensured the best reproducibility. These findings offer a strong basis for further research in microgravity conditions, especially in the context of reaction kinetics.

Keywords: microgravity simulators, lab-on-a-chip, microfluidics, wet chemical etching, etching rate

Introduction

The growing interest in space science and human space exploration has triggered a wave of innovation in materials processing, experimental techniques, and autonomous manufacturing systems [1]. One of the most prominent technological directions in this area is miniaturization [1]. Devices are being scaled down to reduce weight, energy consumption, and spatial footprint—making them ideal for integration into spacecraft environments.

To explore space environments without the need for spaceflight, microgravity simulators have emerged as powerful research tools. Devices like the Random Positioning Machine (RPM) and Rotating Wall Vessel (RWV) allow scientists to mimic the effects of weightlessness in Earth-based labs, enabling them to study reaction kinetics, material behaviors, and biological systems in controlled quasi-zero gravity conditions [2].

This paper is a response to current space-related scientific trends and contributes to the ongoing effort by investigating how simulated microgravity influences microfabrication processes, specifically wet chemical etching in borosilicate glass—widely used in microelectronics, MEMS, and lab-on-chip technologies.

Materials and methods

In the studies, borosilicate glass substrates with dimensions of 76 × 26 × 1.1 mm were used (BOROFLOAT® 33 Schott, Mainz, Germany). As the research is fundamental, the typical microfluidic patterns, i.e. microchannels, were prepared for the microgravity-induced microfabrication (Fig. 1).

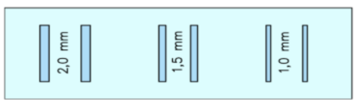

Fig. 1. Mask designed for wet chemical etching of glass substrates with straight microchannels of different widths (1.0, 1.5 and 2.0 mm).

A dedicated experimental setup was developed to safely perform wet chemical etching in hydrofluoric acid under simulated microgravity conditions (Fig. 2). The core of the setup was a custom 3D-printed stand designed to securely hold two glass substrates while allowing easy placement and removal with standard laboratory tweezers. To ensure safety during the process, the stand was positioned inside a PTFE container containing the etching solution, which was further secured within an external container acting as a leak barrier.

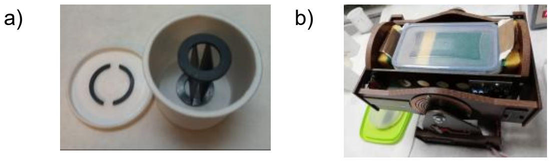

Fig. 2. Stand designed for the etching on RPM and RWV: a) stand at a glance, b) set-up for wet chemical etching of the glass substrate.

Results and discussion

To evaluate changes in etching effectiveness, etching rates were determined for all samples using a micrometer screw gauge, followed by statistical analysis including mean, standard deviation, and minimum/maximum values (Tab. 1, Fig. 3). As the same etching solution was reused for all samples, a gradual decrease in etching rate was noted, suggesting potential aging of the solution. The experiment was carried out using a 40% HF : 65% HNO_3 solution (10:1, v/v) at room temperature. Rotation speeds were set to 10 RPM for both RPM and RWV simulators, and 1000 RPM for the magnetic stirrer [4].

Tab. 1: Wet chemical etching of glass substrates in RPM and RWV compared with reference.

	RPM etching rate [µm/min]	RWV etching rate [µm/min]	Reference etching rate (no stirrer) [µm/min]	Reference etching rate (with stirrer) [µm/min]
Mean value	2.85	1.54	1.26	1.69
Standard deviation	0.13	0.14	0.09	0.21
Maximum value	3.06	1.71	1.39	2.01
Minimum value	2.74	1.52	1.18	1.52
Min/max × 100%	89.54	88.89	84.89	75.62

The results clearly indicate that the use of the RPM simulator led to the highest etching rates among all tested methods. The average etching rate achieved with RPM was 2.85 µm/min, which is approximately 40% higher than that of the reference process using a magnetic stirrer. The RWV simulator showed a slightly lower etching rate than the stirred reference (by about 9%) but still outperformed the unstirred reference by around 18%.

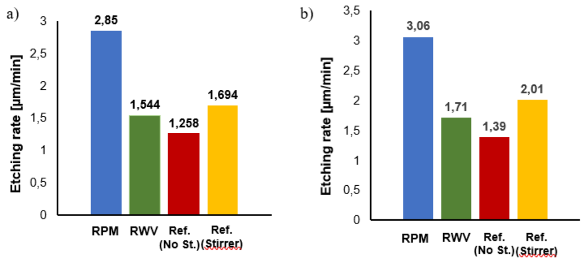

Fig. 3. Graph representing etching rates of the samples depending on the etching method: a) mean values, b) maximum values.

Microscopic inspection of the etched microchannels showed isotropic etching across all samples, with the best surface quality observed for RPM, RWV, and the reference with stirring. The deepest and most uniform channels were achieved using RPM, while RWV produced the sharpest edges—valuable for precise microstructures. SEM analysis showed no significant surface defects in any microgravity-processed samples (Fig. 4).

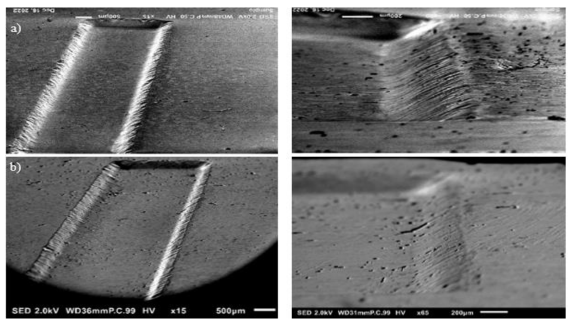

Fig. 4. SEM images of the etched microchannels with the use of: a) RPM, b) RWV. On the left – microchannel view, on the right – magnified edge profile.

Conclusion

In conclusion, results presented in these studies have showed that microgravity environment provided by microgravity simulators can constitute interesting research tools. Further investigation in this field, especially in the area of chemical reaction dynamics could be done to verify other application ideas.

References

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