Supplemental Document

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Few pulses femtosecond laser exposure for high efficiency 3D glass micromachining: supplement

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1. Overview of the etched sets of lines

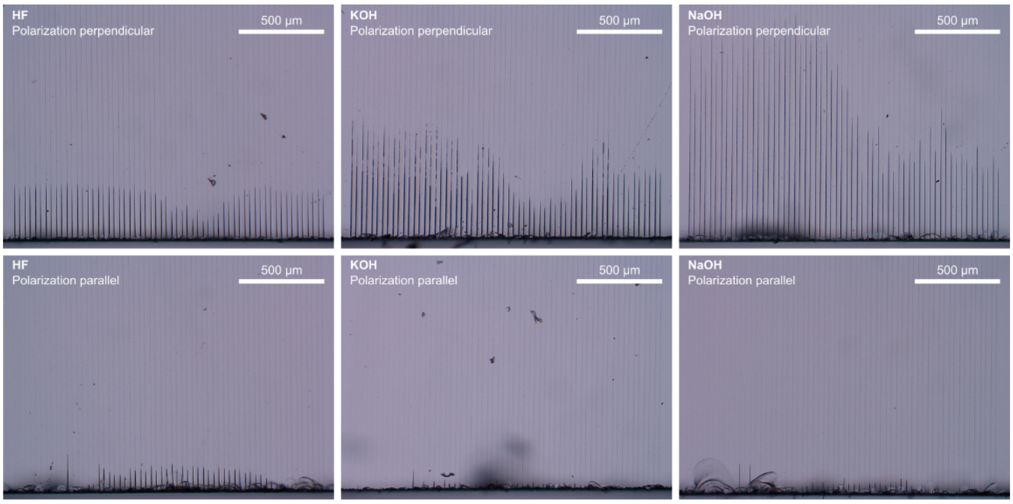

Figure S1. Optical microscope image of the sets of lines written with 260 nJ of pulse energy for both polarizations after 4 hours of etching with HF, KOH, and NaOH. For each image, the exposure dose increases from left to right.

2. Surface quality

A comparative study on the surface quality after etching of both pristine and machined glass is performed (Figure S1). An atomic force microscope (easyScan 2 AFM, from nanoSurf) is used to measure the average surface roughness (R_{avg}) on areas of 25x25 µm^2. After 15 hours, the pristine glass roughness degrades from below 5 nm to around 20 nm with HF and KOH, and to 35 nm with NaOH. On the other hand, under the same etching conditions, a laser-patterned vertical wall shows a R_{avg} ~ 80 nm after HF etching and ~ 125 nm after either KOH or NaOH etching. These results suggest that although leading to higher selectivity and etching speed, the alkali bases produce parts with larger roughness compared to HF. In order to take the best from each etchant, one can for example think of etching a structure with NaOH and then put it in HF for a quick bath to improve the surface quality.

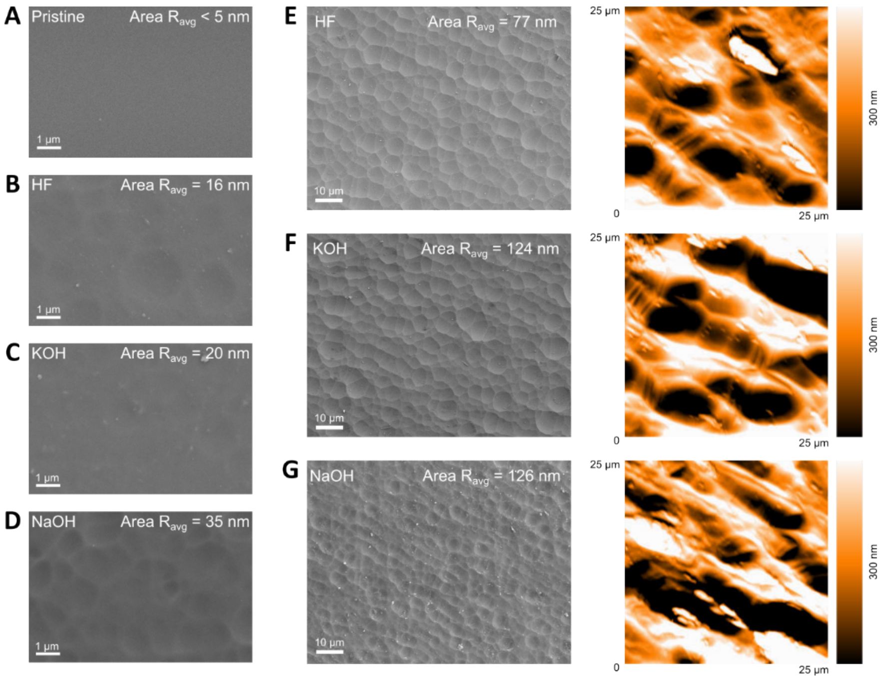

Figure S2. Scanning electron micrographs of pristine fused silica (A) before etching, and after 15 hours in HF (B), KOH (C), and NaOH (D). Micrographs and related average surface roughness measurements of a vertical wall laser-machined and etched for 15 hours in HF (E), KOH (F), and NaOH (G).

3. Effect of writing-direction

The writing direction should in theory not impact the laser induced material modifications if we assume an ideal optical beam. However, it was noticed during the experiments that it does influence the etching rate. In particular, the writing direction differential remains between +/- 25 µm/h for HF, but reaches up to 100 µm/h for KOH and 150 µm/h for NaOH. This effect decreases for increasing deposited energy. We propose the pulse front tilt to be the main reason behind the existence of such a differential.

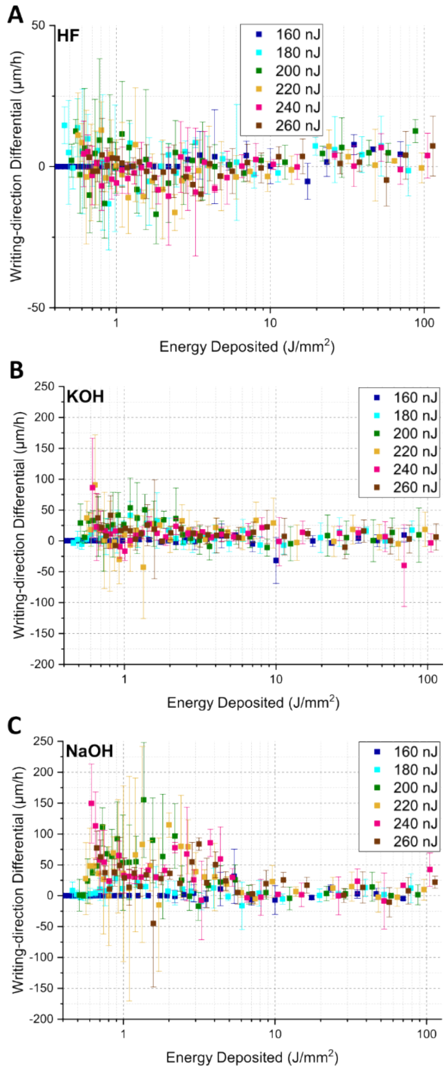

Figure S3. Etching contrast between opposite writing directions (along the same axis) versus exposure dose for different pulse energies and three etchants: (A) HF, (B) KOH, and (C) NaOH. The polarization is constantly kept perpendicular to the writing direction. In each graph, the squares represent the mean and the bars the standard deviation of the two measurements performed.