PROCESSING OF PMMA FOR MICROFLUIDIC APPLICATIONS

Application notes

Issue № AN1012IL02

Material: PMMA

Application: DNA, amino acids, peptides and protein analysis, profiling saccharides, pollutants, nerve agents, and explosives screening, electrophoretic separation of ions, and detection of purines

Current methods of fabrication: hot embossing, room temperature imprinting, injection molding, laser ablation, *in situ* polymerization and solvent etching. Chen et al. [Eletrophoresis. Fabrication, modification, and application of poly(methyl methacrylate) microfluidic chips, **29**: 1801-1814 (2008)] gives an overview of applications and fabrication techniques.

Specifically, Sun et at. [J. Micromech. Microeng. Low-pressure, high-temperature thermal bonding of polymeric microfluidic devices and their applications for electrophoretic separation, **16**: 1681-1688 (2006)] use a CO_2 laser with varying power and scan speeds. Showcased is a trench cut at 0.75 W average power and a scan speed of 32 mm/s giving a volumetric removal rate of 120 μm^3/µsec. Feature size, heat affected zone and processing speed are all important considerations for the application.

Laser tested: Ekspla PL10100 (centre wavelength: 1064 nm, repetition rate: 50 kHz). Patterning done with galvo scanning.

***In situ* imaging:** white light interferometer centred at 800 nm ("OCT M mode") with image line rates up to 312 kHz (axial image).

***Ex situ* imaging:** bright field microscopy.

EKSPLA note: *due to the continuous product improvements, laser PL10100/SH was renamed to Atlantic series.*

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Case 1: CORNROWS PATTERN

Microscopy images show clean cutting with some melting near edges *(Fig. 1)* at an average power of 4.83 W. Melting is more evident when the number of passes is doubled, though there is no significant difference. However the presence of melt and large varied trench width (50 – 110 µm) suggest that thermal ablation is the dominant mechanism. A rough estimate of average volumetric removal rate is: 62.2 μm^3/µsec and 31.1 μm^3/µsec for 4 and 8 passes respectively (final depth of 350 µm for both). This shows that there is a saturation depth where more passes would not drill deeper but only increase heat affects. A faster scan speed and lower average power would limit the thermal effects.

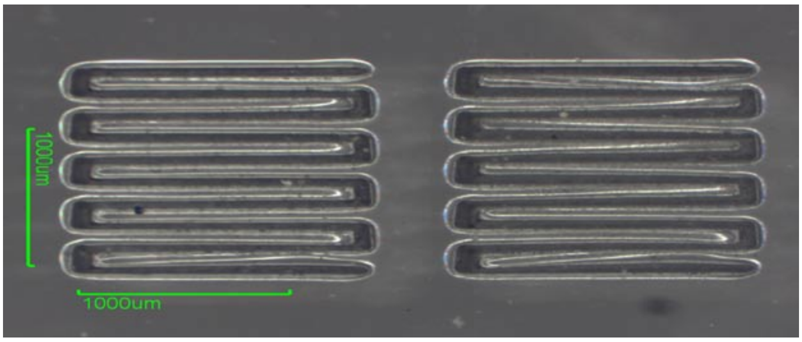

Fig. 1. Bright field microscopy image of cornrows pattern cut in PMMA. Specifications: galvo scan speed 14 mm/s, laser spot 18 µm FWHM, pulse energy 96.6 µJ/pulse on the sample, 500 pulses, 50 kHz repetition rate, final depth 350 µm for both, 4 passes of machining beam (left pattern) and 8 passes of machining beam (right pattern).

Case 2: SQUARES

The relatively slow scan speed was found to be the main reason for the thermal ablation process.

Fig. 2 gives a top view of a square with no visible heat affected zones, consistent with nonlinear ablation. Multiple passes do not appear to affect the ablation mechanism and leads only to lower depths. A rough estimate of average volumetric removal rate is 217 $\mu m^3/\mu sec$, which is faster than CO_2 ablation conducted by Sun. Sun also mentions the limitations that were encountered by thermal ablation, which did not allow creation of sub 100 µm channels. This would not be a problem with a nonlinear process. Though not mentioned as essential, nonlinear ablation would lead to more rectangular trenches (low/nonexistent taper) with a flat bottom.

By moving to a faster scan speed the effects of plasma etching is reduced and a much faster removal rate can be achieved. The average power is also reduced to 1.45 W giving better photon efficiency. The large surface area also allows for refocusing to a new depth to cut deeper without diffraction limitations that arise from high aspect ratio cuts. It should be noted that the edges of the square are slightly deeper due to acceleration affects from the galvo.

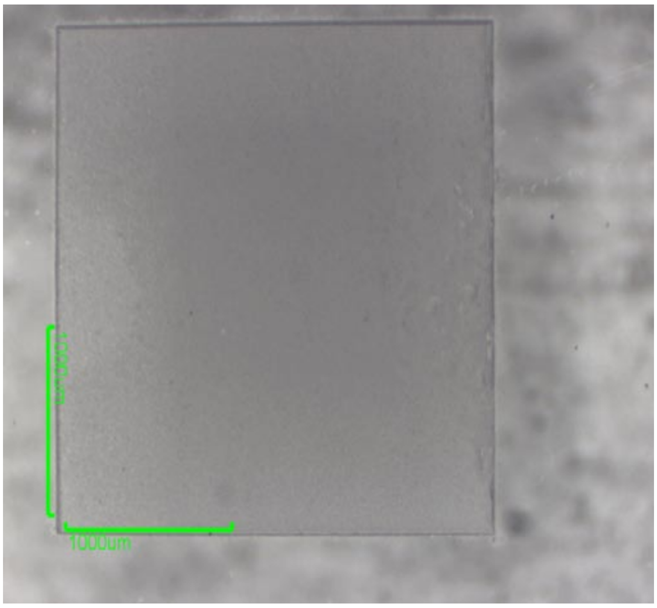

Fig. 2. Bright field microscope image of a square. Specifications: x-axis galvo speed 537 mm/s, y-axis galvo speed 5.37 mm/s, laser spot 18µm FWHM, pulse energy 29 µJ/pulse on the sample, 50 kHz repetition rate, 20 passes on slow axis, final depth 300 µm.

Case 3: TRENCHES

For microfluidic specific applications, trenches were cut as specified by collaborators in the chemistry department.

Between square and trench cutting, the fast and slow axis scans maintained a frequency ratio of 100:1, reducing the effective processing speed of the slow axis. However, the lack of thermal effects seen in *Fig. 3* reasonably suggests the onset of nonlinear ablation is determined by the faster motion. There is an area of overlap in the 2 trenches resulting in a slightly deeper depth. This can be better controlled with feedback or more accurate galvo movement given a deterministic etch rate as evidenced so far.

Fig. 4 shows trenches cut in a cross formation. Except for the overlap region the depth is consistent with that of *Fig. 3* showing remarkable repeatability given the same settings, characteristic of nonlinear ablation.

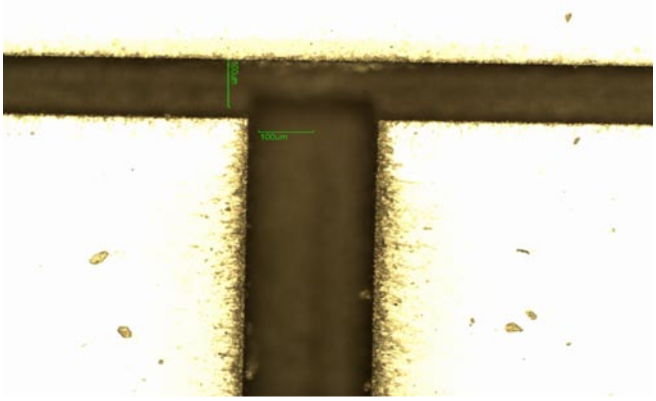

Fig. 3. Bright field microscope image of trenches. Debris along the edges appear to be recast of removed material. Specifications: laser spot 18 µm FWHM, pulse energy 29 µJ/pulse on the sample, 50 kHz repetition rate, 10 passes on slow axis, final depth 145 µm. For horizontal trench: x-axis galvo speed 537 mm/s, y-axis galvo speed 0.24 mm/s. For vertical trench: x-axis galvo speed 0.48 mm/s, y-axis galvo speed 537 mm/s.

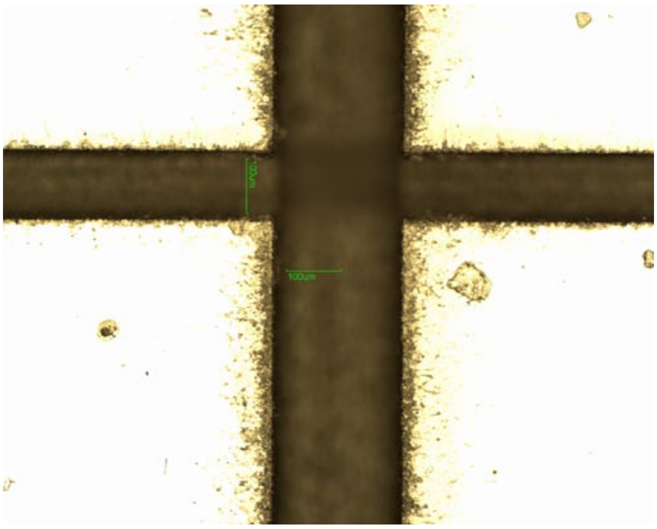

Fig. 4. Trenches were cut with same specifications as *Fig. 3.* The final depth for these 2 trenches is also 145 µm.

CONCLUSIONS

Reduction of thermal effects can be obtained by decreasing the average power hitting the sample and increasing the scan speed. It is speculated that this reduces plasma etching and heat build up at a single spot, and thus is better suited for trench/slot cutting than blind hole drilling (though optimization for blind hole cutting is possible). The trenches show very clean edges with high removal rates (up to 217 µm^3/µsec) and repeatable etch rates. The nonlinear process would be able to create sub 100 µm wide trenches, which is a limitation encountered by thermal ablation processes.

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Revision number – 101210