Plasma-Etch Modification of Polymethylhydrosiloxane (PMHS) for Enhanced Surface Area in Microfluidic Devices

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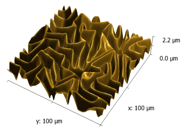
Abstract

Polymethylhydrosiloxane (PMHS) has unique functional merits in terms of chemical modifiability and UV transparency, motivating the study of this material as a candidate for fabrication of microfluidic devices that are used in bioseparation processes. The surface modifications are more effective when there is a large surface-to-volume ratio, which can be achieved by increasing wall roughness.

Wall roughness is an important parameter that affects not only surface area for stationary-phase attachment, but also electrokinetic flow behavior within the fluidic device. In this work the effect of oxygen plasma treatment on surface roughness is examined by varying plasma power, chamber pressure, and exposure time as the input factors. After plasma treatment, the surface roughness increased from 20-30 nm to 84-227 nm for the ranges of inputs that were studied. It was also observed that changes to the surface topography were maintained as high as 100 °C, making the substrate viable for subsequent chemical modifications that require elevated temperature.

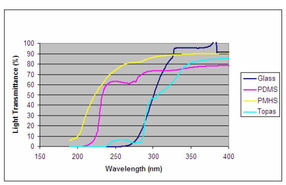


Objectives

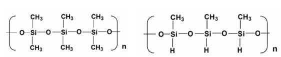
- Perform oxygen-plasma treatment to alter the surface roughness of PMHS.
- Determine relative magnitudes of the effects of process parameters on surface topography.
- Examine repeatability, spatial uniformity, and temperature stability of the process.

Background and Motivation

- PMHS has better optical transparency in ultraviolet range (200-250nm)
- Chemical modification can be readily done on PMHS by hydrosilation



Comparing the UV optical transparency of PMHS with the materials commonly in use for microfluidic devices.

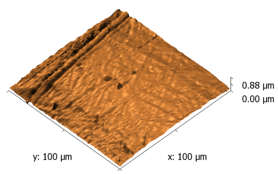


PDMS (left) has wide-spread usage as a substrate material for microfluidic devices. Instead of a methyl group in PDMS, PMHS (right) has a hydride group, making it well-suited for chemical modification by hydrosilation.

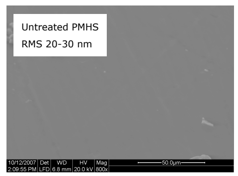
$$\equiv Si{-}H + R{-}CH{=}CH_2 \xrightarrow{cat.} \equiv Si{-}CH_2{-}CH_2{-}R$$

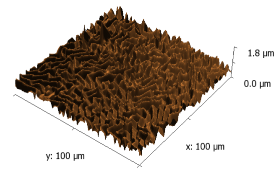
The hydrosilation reaction can be used to alter the surface by attaching functional moieties to the intermediate Si-H bond of PMHS.

Plasma Treatment Results

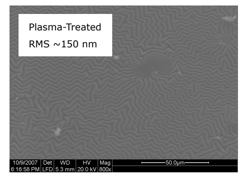


Surface topography of untreated PMHS. The SEM image below confirms the smoothness of the untreated PMHS.

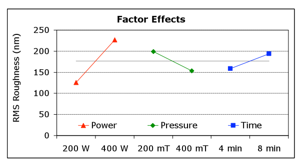




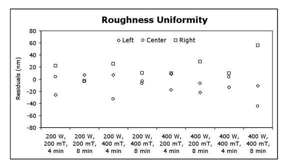
Surface topography of plasma-treated PMHS (400 W, 400 sccm, 4 min), revealing a buckled surface after treatment.



Data Analysis



RMS surface roughness varied between 84 and 277 nm. AFM measurements were performed over a scan area of 100 µm x 100 µm, in three distinct locations separated by approximately 15 mm. Power is observed to be the most dominant factor that affects roughness.

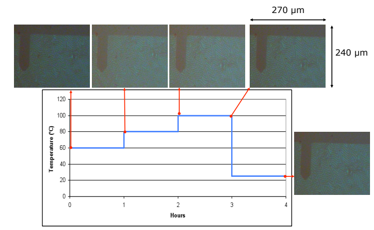


Average magnitude of deviation from the mean (for each set of 3 replicates) was 16 nm. The deviation from the mean was within ±10 nm in the most uniform cases and exceeded ±50 nm in the most non-uniform case.

Run-to-run process repeatability was verified with four identical replicates processed at 300 W, 300 mT, 4 min. The resulting RMS values for these replicates were 132 nm, 125 nm, 128 nm, and 131 nm, corresponding to a standard deviation of 3.2 nm.

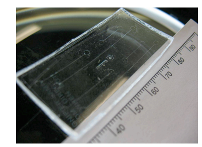
Thermal Stability

The tested thermal cycle is presented in the solid blue line below. All of the images were captured by optical microscope from a common location, and reveal that the PMHS surface topography remained stationary throughout the thermal process.



Future Work

Next steps are to develop spatially selective roughening that is confined to the interior walls of microchannels, and to investigate the effect of increased roughness on electro-osmotic flow in PMHS microfluidic chips.



Conclusions

- Within the range of factors studied, surface roughness can be increased from <30 nm to above 270 nm by oxygen plasma treatment.
- Plasma RF power was observed to have the most dominant effect on increasing surface roughness.
- Within-sample uniformity and run-to-run process repeatability were observed to be smaller than the magnitudes of factor effects, suggesting that the process can be effectively controlled.
- The change to surface topography is stable at moderately elevated temperature, making it viable for subsequent chemical modification processes.

Acknowledgments

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