Engineering Surfaces to Investigate Cell-Material Interactions

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Primary CNF Tools Used: Heidelberg Mask Writer - DWL2000, ABM High Resolution Mask Aligner, Hamatech-Steag Wafer Processors, Hamatech-Steag HMP900 Mask Processing System, Unaxis SLR 770 Etcher, SC4500 Cryopumped Evaporator, DISCO Dicing Saw, MVD-100 Molecular Vapor Deposition System, Westbond 7400A Ultrasonic Wire Bonder

Abstract:

Microscale fabrication technique was employed to create master wafers for polydimethylsiloxane devices including microfluidic devices, micropillar arrays, and micro patterning. These devices were used to study bacterial response to active topography with micropillar arrays loaded with magnetic nanoparticles. The microfluidic devices were used to construct a model to simulate protein aggregation in kidney arterioles that is superior to traditional models. A valid protocol to produce a Giant Magnetoimpedance (GMI) sensor was also explored. Several iterations of the protocol were performed to troubleshoot and find a valid protocol. These platforms are useful for understanding the mechanism of cell-material interactions and complex biological processes.

Summary of Research:

Several fluid transport microfluidic devices with smallest feature size of 20 μm were fabricated by writing patterns onto masks with 1 to 1 feature ratio. The patterns were then transferred onto wafers by contact aligning and exposing photoresist coated silicon wafers, which were subsequently etched to create master wafers for soft lithography peel off process. The final microfluidic devices have channels from tens of microns to as large as millimeters in diameter mimicking capillary structure in typical human kidney vascular system. The implementation of microfluidic devices eliminates air liquid interface and intense fluidic shear force present in current laboratory protein aggregation protocols, which involves aggressive stirring of protein solution by magnetic stir bar in beakers.

Micropillar array has also been fabricated according to previously published protocol [1], where briefly, patterns of different sizes and spacing between patterns were exposed onto silicon wafer with photoresist, and etched to create high aspect ratio pillars (50:1) micro hole arrays with hole diameter as small as 2 μm. The master wafer was then used in soft lithography to create micropillar arrays with magnetic nanoparticle loaded polydimethylsiloxane. The pillars are finally placed under actuated magnetic field at different field densities for either biofilm removal or biofilm formation prevention.

A protocol for the fabrication of a GMI sensor is currently under development. This sensor consists of a sandwich structure with multiple sub-micron thick metal layers on a fused-silica wafer. The thin films were deposited with electron beam deposition and exposed several times using different masks to create three layers of different patterns on top of the substrate. A final lift-off process was done to remove photoresist and preserve the sensor structure. This sensor can be used to study cell-material interactions.

Conclusions and Future Steps:

Both microfluidic device and micropillar array master wafers were successfully fabricated with desired polydimethylsiloxane structures and excellent performance in experimental setups. For the micropillar arrays, the 50:1 aspect ratio pillar was fully achieved

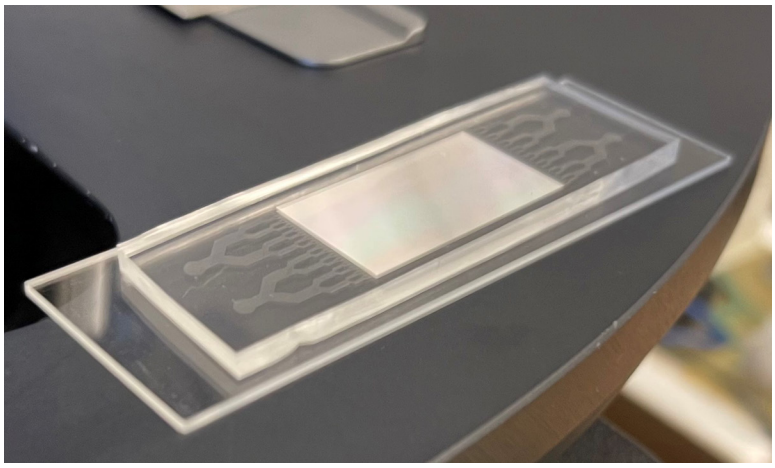

Figure 1: A picture of a microfluidic device plasma bonded to glass slide, with the channels visualized by artificial red dye.

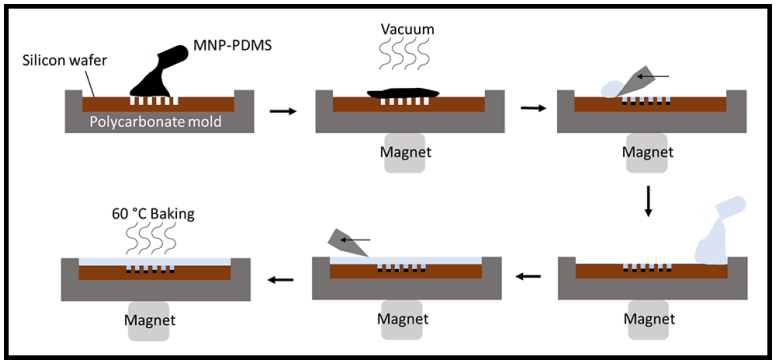

Figure 2: Illustration of fabrication process for micropillar array loaded with magnetic nanoparticles, using the master wafers.

even at the theoretical lower limit of soft lithography process (2 μm features). Future plan for these devices includes varying the dimensions or design, as well as fabricating extra master wafers for higher throughput device fabrication.

For the GMI sensor protocol, several challenges were met in the lift-off process, where the edge of the metal layers have a tendency to peel off when stripping the photoresist, resulting in partially incomplete or completely destroyed patterns. The future plan for this protocol includes optimization of pattern design to protect the layers.

References:

[1] Gu, H.; Lee, S. W.; Carnicelli, J.; Zhang, T.; Ren, D., Magnetically driven active topography for long-term biofilm control. Nature Communications 2020, 11 (1), 2211.