A PHOTOPATTERNABLE SILICONE FOR BIOMEMS APPLICATIONS

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ABSTRACT

Here we show the application of a commercially available photopatternable silicone (PPS) that combines advantages of both PDMS and SU-8 to address a critical need in material building blocks for bioMEMS. Using PPS we have demonstrated the ability to pattern free-standing mechanically isolated elastomeric structures on a silicon substrate, a feat challenging to approach using soft lithography-based fabrication. PPS can be readily integrated in cell-based bioMEMS since it exhibits low-autofluorescence and cells can attach and proliferate on PPS-coated substrates. PPS is compatible with standard microfabrication processes and can be easily aligned to complex featured substrates on a wafer-scale. By leveraging PPS's unique properties we demonstrate the design of a simple dielectrophoresis-based bioMEMS device for patterning mammalian cells.

Keywords: Silicone, bioMEMS, photolithography

1. INTRODUCTION

Polydimethlysiloxane (PDMS) has emerged as one of the most commonly used bioMEMS materials because it displays low autofluorescence, excellent biocompatibility, and can be molded with reasonably high resolution. Because PDMS is formed by relief casting, it can be challenging to create mechanically isolated structures. Further, its flexible nature makes alignment with pre-existing substrate features challenging. SU-8, meanwhile can easily make isolated structural features and can leverage conventional photolithographic alignment for multi-level patterning [1]. However, SU-8 is highly autofluorescent and thus poorly suited for high-contrast fluorescence imaging. Here we show the application of a commercially available photopatternable silicone (WL-5150, Dow Corning Corporation) [2] that combines advantageous features of both PDMS and SU-8 to address a critical need in the microTAS community.

Prior work with photopatternable silicones has involved either custom synthesis [3] and thus was not readily available, or was aimed at bench-top rapid prototyping, and thus had poor resolution (50-75 μm) and incompatibility with conventional lithography [4, 5]. PPS consists of siloxane precursors that form a densely crosslinked elastomer on exposure to UV light. It was originally developed for electronics packaging applications. In this abstract we show its first application for cell-based bioMEMS.

2. METHODS

PPS coatings and free-standing structures were fabricated using standard photolithographic techniques. Briefly, silicon wafers were oxygen plasma-cleaned for 5 minutes. Next, PPS films were spun for 10 seconds at 500 rpm followed by 1500 rpm for 30 seconds. Two-minute prebakes at 120 ºC were performed followed by UV exposure of the samples and subsequent postbake for 3 minutes at 150 ºC. Samples were developed for 6 minutes in mesitylene and finally cure baked at 150 ºC for 2 hours. PDMS thin films

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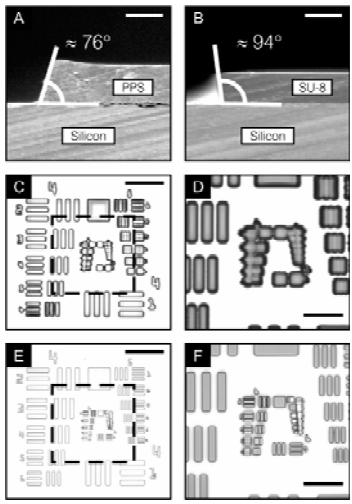

Figure 1: Resolution tests. (A) & (B) show scanning electron micrographs (SEMs) of sidewall angles in a direct comparison between patterns formed using PPS and SU-8. Scale bar 25 μm. (C) and (E) show bright-field microscopy images of the standard USAF 1951 resolution test pattern for the case of PPS and SU-8 respectively. Scale bar 50 μm. (D) examines the outlined region in (C) and (F) surveys the outlined region in (E) in closer detail. Scale bar 25 μm.

were obtained using a similar spin protocol. All SU-8 processing was performed according to established guidelines provided in the associated product datasheets. Standard cell culture techniques were used for growing NIH 3T3, HeLa and BA/F3 cells. Dielectrophoresis (DEP) devices were fabricated on silicon by depositing aluminium and subsequently dry etching to form interdigitated electrodes. Laser-cut silicone gaskets with a coverslip cap functioned as flow channels to sequester cells over the active electrode regions.

3. RESULTS AND DISCUSSION

We obtained PPS in a formulation suitable for creating ~20-μm-thick films that are processed as conventional photoresists. Using traditional contact lithography, we determined that the material patterns with feature resolution down to ~10 μm, and exhibits sidewalls of ~75º (Figure 1). Our primary motivation in using this material was to create low-autofluorescent isolated structures. In Figure 2 we show the creation of free-standing mechanically isolated posts on a silicon substrate, which would be challenging to create using conventional PDMS casting. As an initial demonstration of the biocompatibility of PPS, we grew NIH3T3 and HeLa cells on PPS-coated silicon substrates. As a control, cells were also grown on a standard tissue culture dish. Both cell types proliferated and displayed normal morphology. One of the primary drawbacks of SU-8 for cell-based bioMEMS is its high autofluorescence. Figure 3 shows quantitative measures of fluorescence of PPS as compared to other materials, clearly showing that PPS has fluorescence intensity levels comparable to those of PDMS, whereas SU-8 is highly

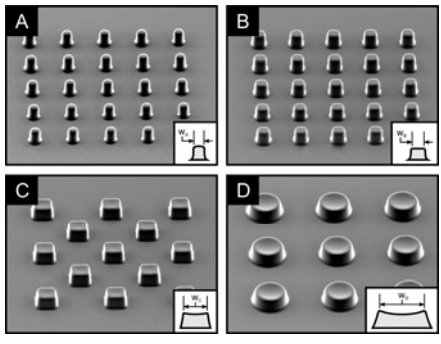

Figure 2: Free-standing PPS microstructures. SEM images of free-standing circular, (A) and (D), and square, (B) and (C), pillars patterned on a silicon substrate. Inset schematics portray the basic cross-sectional geometry of each feature ($w_A \approx 15$ μm, $w_B \approx 20$ μm, $w_C \approx 45$ μm, and $w_D \approx 80$ μm). This type of isolated feature is difficult to realize using conventional soft lithographic fabrication techniques. Based on the SEM images, shapes with smaller footprints show slightly convex tops while features with larger footprints exhibit concave geometries.

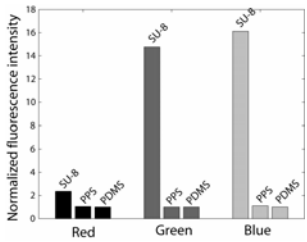

Figure 4: Auto-fluorescence. Quantitative comparison of fluorescence intensities of SU-8, PPS, and PDMS (normalized to PDMS), indicating high auto-fluorescence of SU-8 in green and blue channels.

autofluorescent. Finally, we created devices where PPS is aligned to patterned features. Such structures are difficult to realize using PDMS because of the difficulty in aligning PDMS to substrates and the limited bonding capabilities of PDMS with substrate patterned metals such as gold and aluminium. As a simple test, we created a dielectrophoretic trap where PPS was aligned to interdigitated electrodes. Figure 4 shows that murine BA/F3 cells are levitated and patterned in the regions without PPS, whereas they remain unpatterned in regions covered with PPS.

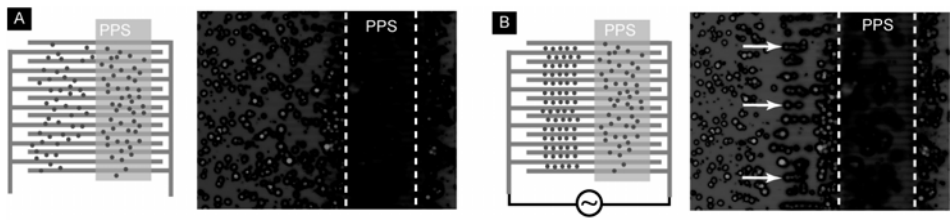

Figure 5: Cell patterning. (A) Schematic of top-down view of bioMEMS device architecture with PPS aligned to interdigitated electrode array where cells (gray circles) are randomly seeded on device. Left panel shows fluorescence image of randomly seeded cells. Cells seeded on PPS (dashed line) appear out-of-focus. (B) On application of 500 kHz waveform, cells are levitated and patterned above the electrodes (indicated by arrows). Scale bar 50 μm.

4. CONCLUSIONS

We believe that PPS's unique properties frame it as an ideal candidate material for integration in many bioMEMS applications. Its combination of low autofluorescence, biocompatibility, alignment capabilities for patterned substrates, and moderately high resolution (~10 μm) position it as a complement to SU-8 and PDMS. The key material properties and integration capabilities explored in this work should present new avenues for exploring elastomeric microstructures for the design and implementation of increasingly complex bioMEMS architectures.

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