SOLVING THE SHRINKAGE-INDUCED PDMS REGISTRATION PROBLEM IN MULTILAYER SOFT LITHOGRAPHY

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ABSTRACT

Curing-induced shrinkage of PDMS films causes alignment registration problems in multilayer microdevices. Standard solutions involve shrinkage characterization and master optimization, which is time consuming and can often result in low device yield. 'Sandwich mold fabrication' is a previously developed technique to produce thin patterned films of PDMS. This paper demonstrates the use of that technique as a simple, robust, and scalable method to eliminate the alignment registration issue in multilayer soft lithography, significantly reducing the trial and error time required to fabricate large, dense arrays of well-aligned PDMS devices.

KEYWORDS: multilayer soft lithography, PDMS, shrinkage, alignment

INTRODUCTION

A challenge in using PDMS to construct multilayer devices is that alignment registration across a large area is made difficult by polymer shrinkage during curing [1]. Curing can shrink PDMS by 0.5-2.5%, depending on curing temperature, PDMS component ratios, and layer thickness [2]. For larger device areas, displacement of peripheral features prevents accurate registration between multiple layers. The most common solution to this has been to experimentally determine the shrinkage for specific curing conditions and scale the master features up accordingly [2]. However, empirical shrinkage characterization results are not perfectly repeatable, since maintaining precise curing conditions in a nonspecialized, multi-user facility is challenging. Thus, this approach can often result in low device yield. Furthermore, this technique requires additional characterization for each layer thickness and composition, and becomes difficult and time-consuming to accurately implement for larger device areas. This paper demonstrates the application of a well-established technique as a method to solve this issue.

METHOD

Thin PDMS films can be formed either by spin-coating onto a master or by 'sandwich mold fabrication' [3], in which liquid PDMS is squeezed between a polyethylene sheet and a patterned mold master, clamped, and cured to produce a patterned PDMS thin film. This film preferentially sticks to the polyethylene sheet (Figure 1). The PDMS film can then be transferred and permanently bonded to glass or another PDMS layer, before peeling away the polyethylene. The technique was originally developed specifically for multilayer devices to obtain repeatable layer

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thicknesses; however, an important aspect has not been recognized: throughout the process, the PDMS film is never released from a high-modulus material (either polyethylene or the substrate to which it is bonded), and is hence never allowed to shrink. Shrink-free standard casts can thus be replicated by bonding a patterned film to a slab of pre-shrunk PDMS. Using these sandwich molded films for multilayer soft lithography eliminates the shrinkage-induced registration issue in large devices.

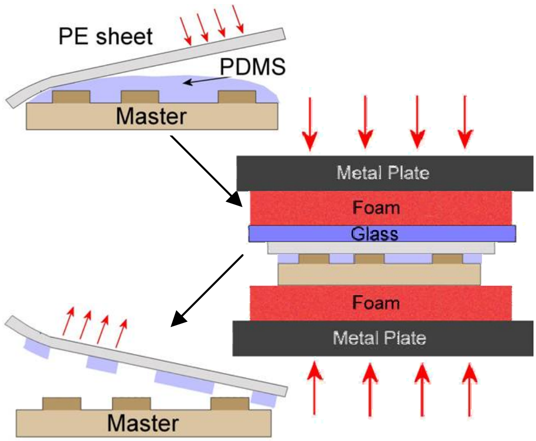

Figure 1. Sandwich mold fabrication process (adapted from [3]).

EXPERIMENTAL

To demonstrate the utility and efficacy of this technique, a microfabricated "Braille display" was constructed using the sandwich mold fabrication process for each patterned layer. An array of posts on a membrane is raised by applying a positive pressure beneath the membrane. A 12×9 array of these posts was fabricated using three sandwich-processed layers, and actuated (Figure 2). Alignment was accurate within 10μm across the array, as shown in Figure 3.

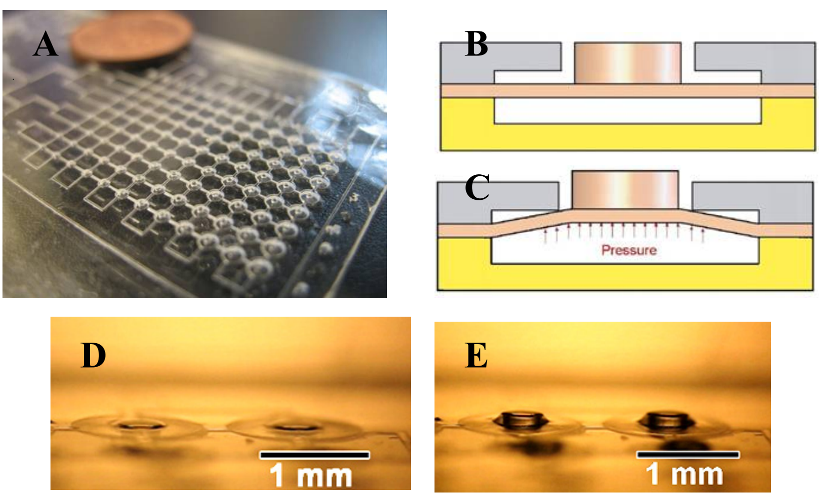

Figure 2. (A) 9×12 array of microfabricated Braille actuators. (B) & (C) Cross-sectional schematic of the three-layer structure at rest and undergoing pneumatic actuation. (D) & (E) Images of actuated post structures.

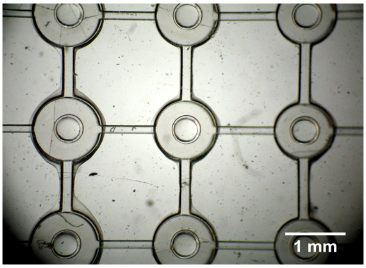

Figure 3. Top-down view of the braille array.

To better illustrate the registration advantage of sandwich fabrication, multilayered wells were formed using both the sandwich fabrication method and the conventional method, in which a casting step is used. The results (Figure 4) indicate zero registration error across the 1”×2” device area for the sandwich process.

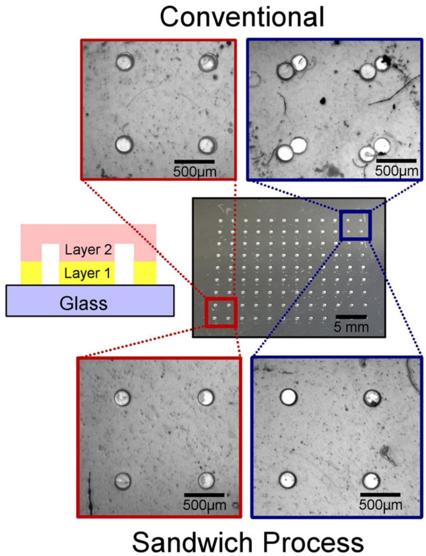

Figure 4. A demonstration array of cylinders. Results for the conventional cast-and-peel vs. the sandwich mold fabrication process are shown.

DISCUSSION

Besides solving the shrinkage issue, the polyethylene sheets act as support structures for the PDMS layers during alignment, eliminating problems caused by the deformability and thermal expansion of PDMS. The technique is robust and easily integrated into the infrastructure required for multilayer soft lithography. Future work will demonstrate this technique for even larger devices, necessary for high-throughput array-based research.

CONCLUSIONS

A technique has been utilized by which, at the cost of a few fabrication steps, large-scale devices with stringent alignment tolerances can be produced at high success rates, without time-consuming trial-and-error experimentation. These methods should significantly reduce the time and cost required during the concept-to-prototype turnaround cycle for the development of large-scale devices.

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