

SIMPLE AND LOW-COST FABRICATION PROTOCOL FOR PRODUCING 100'S OF PNEUMATIC MICROVALVES IN ALL-PDMS SUBSTRATES FOR MICROFLUIDICS RESEARCH

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ABSTRACT

This work reports a unique fabrication protocol that would enable microfluidic researchers to prototype complex microfluidic circuits that require 100s (or less) of pneumatic microvalves in all-Polydimethylsiloxane (PDMS) substrates. The protocol is simple, facilitates rapid prototyping, avoids some drawbacks of corona/plasma bonding, does not require cleanroom use and can be used for high or low-aspect ratio microchannels of any channel cross-section profile. Furthermore an application of this protocol is demonstrated in the fabrication of a microfluidic device for high-throughput genetic screening of *Caenorhabditis elegans* (*C.elegans*).

KEYWORDS: PDMS membranes, Soft lithography, Microvalves, Multiplexing, High-throughput

INTRODUCTION

There are two types of pneumatic-actuated microvalves for PDMS substrates: normally-open microvalves [1] and normally-closed microvalves [1]. Popular normally-open microvalves are Quake microvalves [1]. These can be fabricated in high densities, but only work with low aspect-ratio channels with rounded/semicircular cross-sectional profile [1]. This necessitates cleanroom facilities for soft lithographic molds. A cheaper alternative to these are the doormat-style microvalves [1] (a popular type of normally-closed microvalves) and their functionality is independent of channel aspect-ratio and channel cross-section profile. Therefore soft lithographic molds for them can be made outside the cleanroom by xurography of adhesive vinyl films [2].

Doormat-style microvalves have two subcomponents. These two subcomponents are called Flow-layer and Valve-layer. The Flow-layer includes all microchannels with valve-seats in which the analyte is manipulated. The Valve-layer contains all valve-chambers with microchannels for pneumatically pressurizing the valve-chambers, thereby controlling the ON/OFF function of the microvalves. However, as doormat-style microvalves have valve-seats in their design, it makes alignment between the Flow-layer and Valve-layer critical. Consequently, doormat-style microvalves are difficult to produce in high densities as compared to Quake microvalves.

Mosadegh et. al. have fabricated doormat-style microvalves in high densities in a all-PDMS device [3], but used corona bonding to bond the Valve-layer to the Flow-layer. However, efficient repeatable alignment in corona bonding requires trained hands or alignment hardware, as good quality corona-induced irreversible bonding is instantaneous with less room for correcting misaligned layers. Furthermore, Mosadegh et al used precisely aligned stamping of PDMS residual oligomers to deactivate the bonding properties selectively for valve-seats [3]. Therefore repeatable use of the same PDMS stamp for many identical prototypes is questionable, as the stamp may gradually lose its ability to deposit sufficient oligomers for deactivation.

Our new fabrication protocol (described in Figure 1) for PDMS-based microvalve arrays avoids these limitations of instantaneous irreversible bonding, oligomer stamps and cleanroom costs (both monetary and time) to fully utilize the benefit of soft lithography for rapid, easy and cost-effective prototyping. The key innovative feature of the protocol is exploitation of the tendency of the partially-cured actuating PDMS membrane to stick to the valve-chamber's top-wall

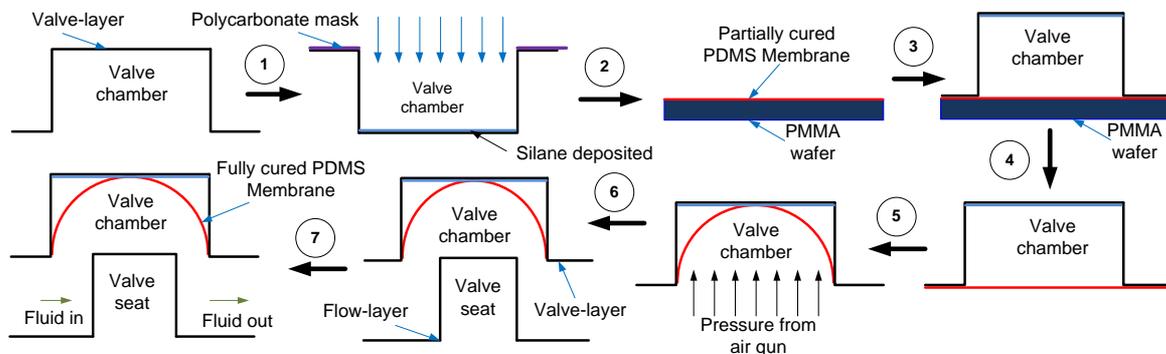


Figure 1. Schematic of the fabrication process with each major process designated by a number

(which has been pre-silanized) and create a Valve-membrane overlap. This helps the membrane to avoid being irreversibly bonded to the valve-seat during the final assembly process (a major drawback of doormat-style microvalves [3]), but irreversibly bond everywhere else for robust microvalve arrays. Furthermore, since partially-cured bonding is utilized (which is not instantaneous and has good bonding quality as compared to corona bonding [4]) good manual

alignment can be easily achieved, as an alignment-error can be corrected by safely separating the misaligned layers and re-align.

EXPERIMENTAL

All PDMS used in this work has a base to curing agent ratio of 10:1. Molds for replica molding of PDMS devices were made by Laser Xurography of adhesive vinyl tape [2]. Thickness of a single layer of vinyl tape is $\sim 110 \mu\text{m}$.

Figure 1 shows the new fabrication protocol for making the microvalve array, which is made by combining two sub-components: Flow-layer and Valve-layer. For the Valve-layer, PDMS is poured in the mold and fully cured. Then the molding is separated from the mold. Using a hole-punch, access holes for the pneumatic pressurization of valve-chambers in the Valve-layer are cored in. Valve-layer is turned upside-down and a patterned polycarbonate masking layer ($\sim 0.12 \text{ mm}$ thick) is placed on top of it (step 1 of Figure 1). Patterning (selectively cutting) of the masking polycar-

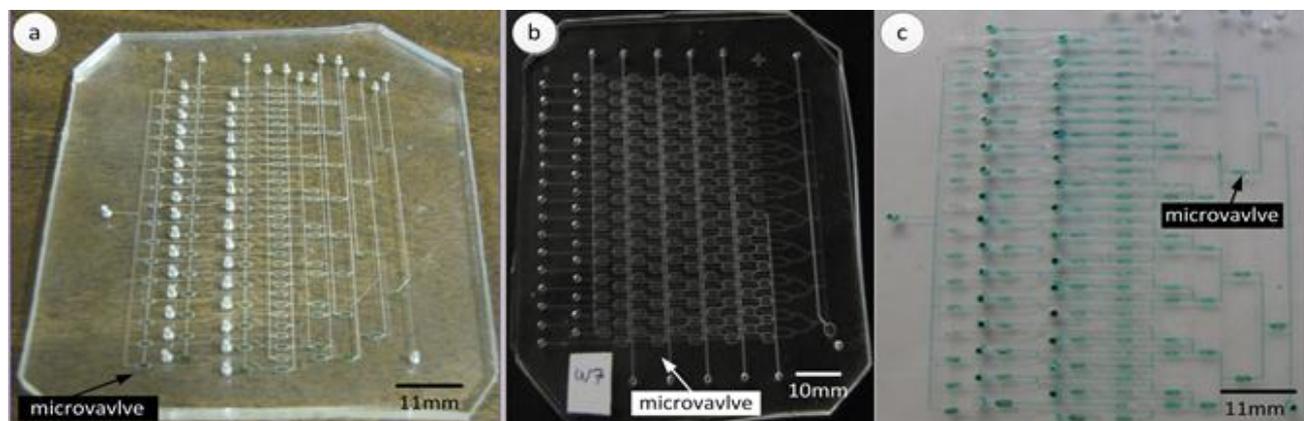


Figure 2. All microfluidic circuits above contain microchannels of $110 \mu\text{m}$ depth with widths ranging from $320 \mu\text{m}$ to $120 \mu\text{m}$. (a) Circuit-I containing 110 microvalves (capsule-shaped $2.6 \text{ mm} \times 1 \text{ mm}$). (b) Circuit-II containing 160 microvalves (capsule-shaped $3.3 \text{ mm} \times 2.4 \text{ mm}$). (c) Microvalve test for Circuit-I in which the channels were filled with green colored water soluble dye, for microvalve leaks and microvalve performance.

bonate layer is done by a CO_2 laser. This patterning is done so as to protect all parts of the inverted Valve-layer, except the valve chambers from silane deposition later. The placement of polycarbonate layer is done without any aid of alignment hardware. The Valve-layer with the polycarbonate masking layer on top, is placed in a vacuum chamber at -26 inHg for vacuum deposition of silane (step 1 of Figure 1). Silane inhibits irreversible bonding of the actuating valve membrane (bonded to the Valve-layer later). A PDMS layer is spin-coated on a PMMA (Poly-methyl methacrylate) wafer at 2800 rpm and partially cured (step 2 of Figure 1).

After vacuum deposition of silane the polycarbonate masking layer is removed and the bottom of the Valve-layer is corona-bonded to the partially-cured PDMS layer on the PMMA wafer (step 3 of Figure 1). Both contacted pieces are placed in an oven at $62 \text{ }^\circ\text{C}$ for 30 minutes to deactivate the membrane for any further corona bonding and increase the strength of the corona bond. After cooling the Valve-layer and membrane at room temperature, the Valve-layer is peel-off against the PMMA wafer (step 4 of Figure 1). This peels-off the bonded membrane (partially-cured) as well. Then the membrane is pushed-up against the valve chamber by the help of an air gun (step 5 of Figure 1). The partially-cured membrane will have a tendency to stick to the valve's ceiling due to the presence of un-crosslinked oligomers [5]. This produces a Valve-membrane overlap between the valve-chamber's top wall and membrane. Thru-holes are cored in the Valve-layer with hole-punches for inlets/outlets of the microfluidic flow circuit in the Flow-layer.

The Flow-layer is molded by Xurographic molds in the same way as the Valve-layer, except that it is partially-cured. Then the Flow-layer and the Valve-layer are brought together to make the microvalve array. The bonding arrangement for these two layers is shown in Figure 1 step 6. Trapped air bubbles are manually squeezed out.

Once proper alignment is achieved and air bubbles have been squeezed-out, the assembly is placed in the oven at $62 \text{ }^\circ\text{C}$ to convert the reversible bond between Valve-layer and Flow-layer to a irreversible bond and fully cure the membrane. In the end the microvalve array is tested for any non-functional valves or valve-leaks (step 7 of Figure 1) by flowing colored water through the microchannels in Flow-layer and Valve-layer.

RESULTS

Figure 2 parts (a) and (b) show two microfluidic circuit designs for a microfluidic 32 well-plate designed for high-throughput manipulation of *C.elegans* in genetic screening. The circuits contain an array of microvalves: 110 microvalves in Circuit-I and 160 microvalves in Circuit-II. Figure 2 part (c) shows flow tests carried on Circuit-I. The tests revealed 2 valves non-functional in Circuit-I and 1 valve non-functional in Circuit-II.

CONCLUSION

A simple and cost-effective fabrication protocol for fabricating 100s of microvalves in all-PDMS substrates has been presented. The protocol is specifically designed to aid microfluidic researchers to fully utilize the benefits of rapid prototyping provided by PDMS-based soft lithography to test their research ideas.

However the protocol could be characterized further so that it could be easily utilized by the microfluidic research community.

ACKNOWLEDGEMENTS

Authors would like to thank Erik Liddiard for his contribution in this work.

REFERENCES

- [1] Au A K, Lai H, Utela B R and Folch A 2011 *Micromachines* 2 179-220
- [2] Bartholomeusz D A, Boute R W and Andrade J D 2005 *J. Microelectromechanical Systems* 14(6) 1364-74
- [3] Mosadegh B, Tavana H, Leshner-Perez S C and Takayama S 2011 *Lab-on-a-Chip* 11 738-42
- [4] Eddings M A, Johnson M A and Gale B K 2008 *J. Micromech. Microeng.* 18(6) 1-4
- [5] Kroner E, Maboudian R, Arzt E 2010 *Advanced Engineering Materials* 12(5) 398–404

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