A DOUBLE-SIDED MICROMOULDING PROCESS FOR REPRODUCIBLE MANUFACTURING OF THIN LAYERS AND 3D MICROCHANNELS IN PDMS

J. Mikael Karlsson, Tommy Haraldsson, Carl Fredrik Carlborg and Wouter van der Wijngaart
Microsystem Technology Lab, KTH Royal Institute of Technology, Sweden

ABSTRACT

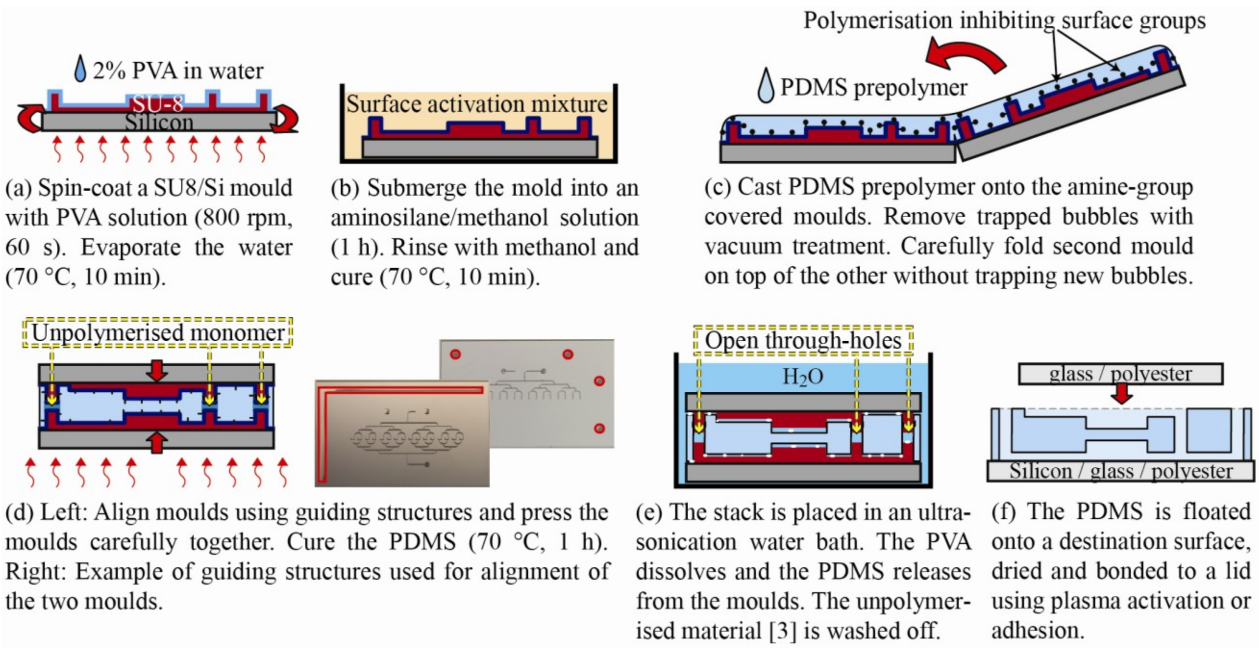
To fabricate complex microfluidic devices in a rapid manner, we have developed a novel method for simultaneous patterning of two sides of a single layer of PDMS using double-sided micromoulding. A mould surface coating containing aminosilanised poly(vinyl alcohol) (PVA) provides low-stress release of fragile polymer structures from the mould as well as inhibition of PDMS polymerisation at through-hole locations, thus enabling fabrication of membranes and 3D microfluidic networks in a single step. Alignment of the top and bottom patterns is achieved already during the moulding step using guiding structures in the mould halves, leading to a procedure with a minimum number of alignment and bonding steps needed to fabricate fragile 3D microfluidic devices.

KEYWORDS

Double-sided moulding, 3D microfluidic networks, poly(vinyl alcohol) release layer, poly(dimethylsiloxane), microfabrication

INTRODUCTION

Lab-on-chip systems requiring 3D microfluidic networks, e.g. for laminar mixing [1] and valving [2], need vertical interconnects to join channels in different layers. Such interconnects (vias) are difficult to manufacture in soft lithography due to squeeze films on raised mold features that define vias locations, resulting in residual thin membranes that block the vias [3]. Also, large area thin PDMS layers, e.g. used as membranes [4], are difficult to fabricate due to stress-inducing manual process steps of soft lithography that tend to rupture the membranes [5]. Furthermore, assembly of microstructured layers requires careful alignment, which is difficult to achieve when performed manually due to straining of the thin PDMS structures. These challenges have previously been addressed through double-sided moulding to obtain patterns on two sides of a single PDMS layer using high-precision instruments. However, these processes require complex moulds [6, 7] and either high clamping pressure [6] or post-processing [7] to achieve through-holes. We recently presented alternative methods for 3D through-hole fabrication, using polymerisation inhibition [3] and low-stress fabrication of fragile structures using a water-dissolvable mould coating [8]. However, our previous methods require assembly and alignment of several PDMS layers to create 3D microfluidic networks. Here, we present a novel, generic variant of PDMS soft lithography for rapid prototyping of advanced microchips in which a “monolithic” block of micropatterned polymer is created in a single cure process using an uncomplicated double-sided moulding technique, in which we combine our previously reported polymerisation inhibition [3] and water-dissolvable film [8] methods.



(a) Spin-coat a SU8/Si mould with PVA solution (800 rpm, 60 s). Evaporate the water (70 °C, 10 min).

(b) Submerge the mold into an aminosilane/methanol solution (1 h). Rinse with methanol and cure (70 °C, 10 min).

(c) Cast PDMS prepolymer onto the amine-group covered moulds. Remove trapped bubbles with vacuum treatment. Carefully fold second mould on top of the other without trapping new bubbles.

(d) Left: Align moulds using guiding structures and press the moulds carefully together. Cure the PDMS (70 °C, 1 h). Right: Example of guiding structures used for alignment of the two moulds.

(e) The stack is placed in an ultra-sonication water bath. The PVA dissolves and the PDMS releases from the moulds. The unpolymer-ised material [3] is washed off.

(f) The PDMS is floated onto a destination surface, dried and bonded to a lid using plasma activation or adhesion.

Figure 1: Process steps of the double-sided moulding method.

EXPERIMENTAL

Figure 1 shows the detailed fabrication sequence. SU-8/silicon moulds were designed and fabricated to consist of two layers, in order to achieve polymerisation inhibition [3] and guiding structures for alignment. The moulds were then spin-coated with a layer of PVA solution (2% PVA in water, 60 s at 800 rpm) and dried on a hotplate (70 ºC, 10 min). The moulds were thereafter immersed into a solution of 2% (w/w) aminosilane AEAPS (Z-6020, Dow Corning, USA) / methanol for 1 h and dried (70 ºC, 10 min). PDMS was casted onto the two moulds, which were then folded onto each other and aligned using the guiding structures. The moulds were pressed in close contact and placed in an oven (1 h at 70 ºC). The cured polymer layer was released from the moulds through dissolution of the PVA in an ultrasonication water bath, thus providing low-stress release demoulding of the PDMS. The polymerisation inhibitory function of the aminosilane groups prevents solidification of the polymer at the via positions by binding the PDMS polymerisation platinum catalyst [3]. The unpolymerised material at the via positions was flushed away during demoulding, thus resulting in well-defined microfluidic connections between the two structured sides. The moulds were thereafter removed and the PDMS was floated onto a destination substrate (silicon, glass, polyester film) and dried. Silanisation used during the floatation [8], plasma activation (15 s at 40 W, FEMTO A, Diener electronic GmbH) and adhesion were used for bonding of top and bottom substrates onto the PDMS to seal off the channels, resulting in a contained cartridge with two structured sides. The top lid had a smaller footprint than the bottom substrate to allow fluidic access on the top side of the cartridge.

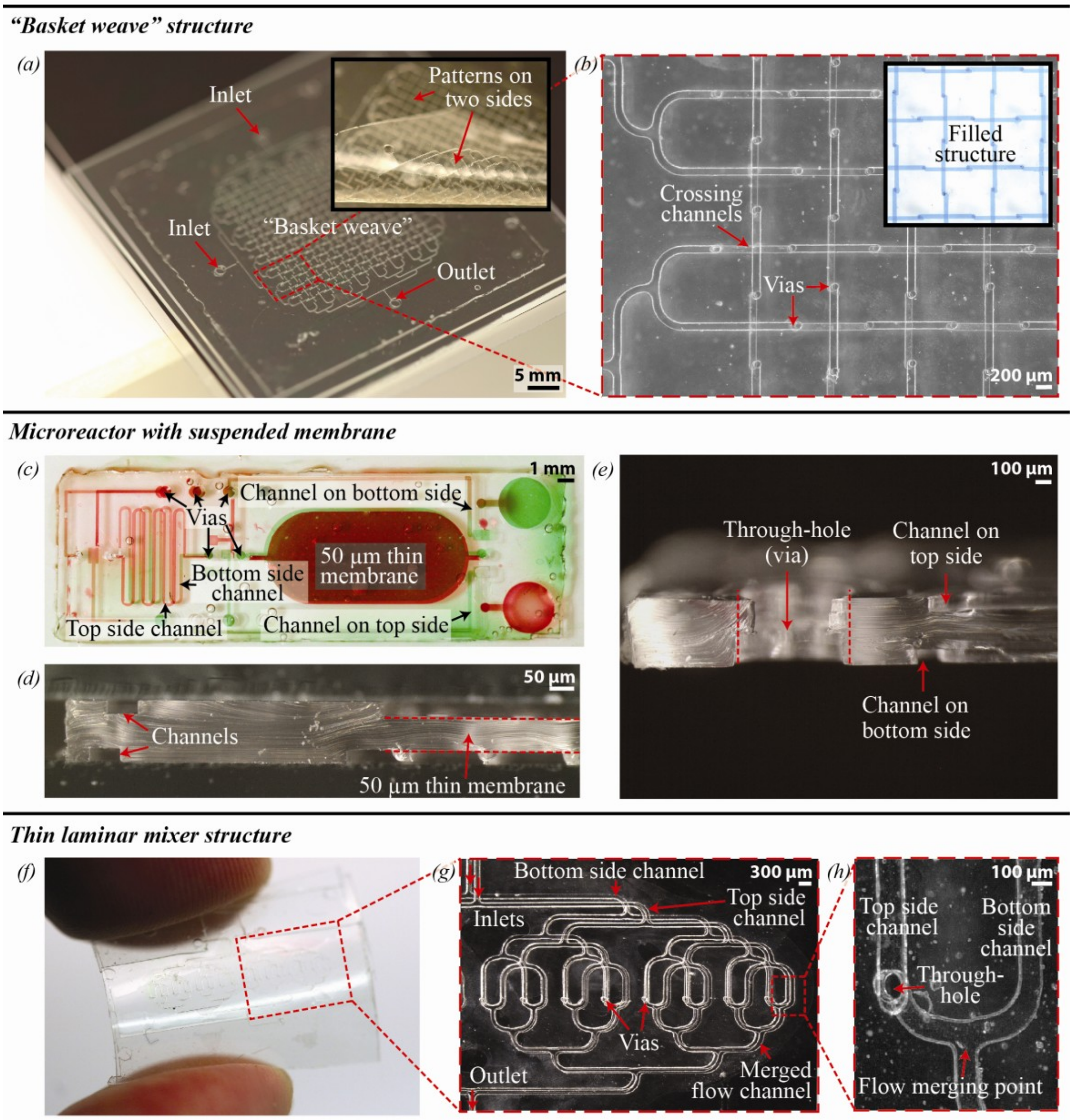


Figure 2: Structures made using the double-sided moulding process. a) Photograph of a 160 µm "basket weave" structure, with b) channels moving from one layer side to the other through vias, with a density of 512 vias on 250 mm^2, defined by the inhibition technique. c) Photograph of a microreactor structure, containing a fragile, 50 µm thin and 1 cm^2 footprint suspended membrane. Water with candy dye was introduced to both sides for visualisation. d-e) Cross section photographs showing d) channels and a membrane and e) a through-hole of the microreactor structure. f) A 330 µm thin laminar mixer chip with two separate liquid inlets and a common outlet for mixed liquid.

RESULTS AND DISCUSSION

The double-sided moulding method was successfully used for fabricating 3D microfluidic structures in a single moulding step, as shown in Figure 2. First, a 160 µm thin basket weave structure bonded between a silicon substrate and a microscope cover glass, with 32 crossing channels & 512 trough-holes on 250 mm^2, was successfully produced (Figure 2.a-b). It was observed that careful alignment was crucial to achieve a 100 % yield of open holes, and the floatation transfer was needed to achieve wrinkle- and bubble free contact and avoid structure damage. Second, a layer forming a microreactor structure, containing a 50 µm thin and 1 cm^2 area integrated membrane, suspended between two reaction chambers, was covalently bonded to a glass slide using plasma activation (2.c-e). Finally, a polyester-PDMS-polyester laminar flow micromixer stack, with a total thickness of 330 µm, based on a previous design [1] that combines flows from the two sides of the layer into one stream, was fabricated (2.f-h).

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CONCLUSION

We introduce a novel method for fabrication of advanced microchips made in one PDMS piece, containing microstructures on two sides connected with through-holes of high density. A pin-guided mould alignment allows for downscaling of feature sizes and reduced dead volumes on-chip. Lab-on-chips containing 3D microfluidic networks and fragile structures were successfully fabricated. This constitutes an easy and scalable method to achieve thin, advanced microstructures for production of microfluidic lab-on-chips.

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CONTACT

* J.M. Karlsson, tel: +46(0)87909059; jmkarl@kth.se