RAPID FABRICATION OF 3D MICROFLUIDIC STRUCTURES VIA LASER-MACHINING AND VACUUM DEFORMATION

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Flexible and stretchable microsystem platforms have recently garnered significant attention due to their increasing variety of applications ranging from biomedical monitoring systems to soft robotic actuators [1]. Of particular importance to BioMEMS and lab-on-chip applications are those which enable the incorporation of complex microfluidic networks. Many of these systems, however, are expensive to fabricate and remain limited by traditional MEMS fabrication procedures that are optimized for planar architectures. Some systems aim to overcome this latter issue by using positive pressure, which requires a controlled pressure source during device usage [2-3], while others resort to solvent-induced deformation [4].

In this paper we present a novel technique for fabricating auto-deformable soft microfluidic platforms that exhibit out-of-plane deflections. The fabrication features rapid prototyping techniques that reduce production cost and time and enable straightforward customization. The structures are fabricated out of laser-machined PDMS films via a layer-by-layer approach. Embedded microchannels allow fluid flow in the structures, while a logically-designed set of air pockets enables controlled three-dimensional structure deformation when placed in a vacuum. The vacuum-induced deformations are finally locked in place with a Parylene coat.

The platform consists of a network of microchannels formed by bonding together a stack of three thin (100-1000 μm) layers of PDMS, Figure 1. The two outer layers of the structure are solid with the exception of channel ports. The middle layer is laser-machined to define two types of channels: continuous channels for transporting liquid, and isolated channels (pockets) for controlling bending direction. Figure 2 shows the fabrication procedure for the devices. The PDMS layers are formed by casting and curing PDMS on a silanized wafer and transferring them to a more rigid substrate (i.e. 100 μm PET film) for further processing. Laser machining is then used to selectively cut away PDMS regions to define microchannels and ports. The use of a laser engraver system (Universal Laser Systems, Scottsdale, AZ) for microchannel fabrication offers an inexpensive direct-write method for microfluidics with resolutions up to 125 μm and without the need for clean room technology. The layers are then bonded via plasma-induced surface activation, and they are subsequently placed in a Parylene-C deposition chamber. Finally, the channel structures are allowed to degas under vacuum for an hour before a 0.3 um layer of Parylene-C is deposited.

Figure 3 shows a close-up view of a fabricated structure. The design of the sealed pockets behaves like the grain orientation in polymers and thus controls the direction and degree of deformation of the structures. The magnified inset of Figure 3 shows the well-delineated microchannel side walls that are capable by thin PDMS laser-machining. This technique eliminates the need for master mold fabrication for microchannels of similar dimensions.

Two structure implementations are shown in Figure 4 after vacuum and Parylene deposition, showing significant deflection. The deflection is characterized by measuring the average attainable curvature for various PDMS thicknesses. Figure 5 shows an average curvature of 0.04 mm^{-1} for an overall PDMS thickness of 1.17 mm, as well as an inverse relation between deflection and PDMS thickness, in accordance with beam deflection theory. The long-term stability with and without Parylene is plotted in Figure 6, showing a significant improvement when Parylene is used. The final curvature can be further adjusted by the Parylene thickness.These structures serve as a proof of concept of a novel technique for fabricating auto-deflectable soft microfluidic platforms.

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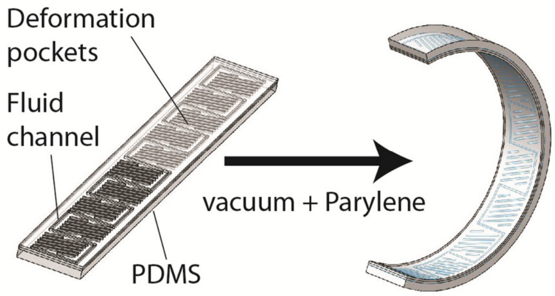

Figure 1 : Conceptual illustration of the vacuum-induced deformation. A thin PDMS structure with embedded microchannels and air pockets is placed in a vacuum and subsequently coated with Parylene-C. Upon removal, the structure deflects in a predetermined orientation.

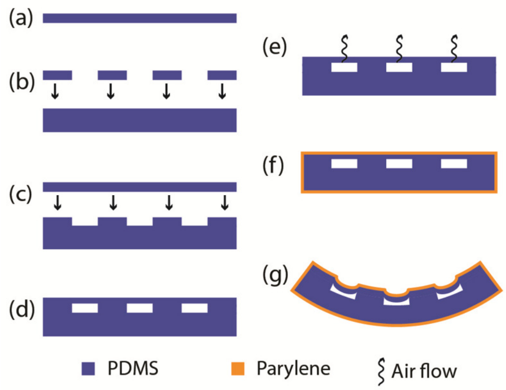

Figure 2: Fabrication procedure of the structures. (a) a thin (~500 µm) PDMS layer is cast; (b) it is laser-cut to define channels and deflection pockets, and subsequently bonded to a thicker (~800 µm) PDMS; (c) a thin (~100 µm) PDMS is bonded to the laser-cut layer, creating closed channels. (e) The structure is placed in vacuum to de-gas the air pockets, and (f) a thin layer of Parylene is then deposited. (g) The structure deflects upon removal from vacuum.

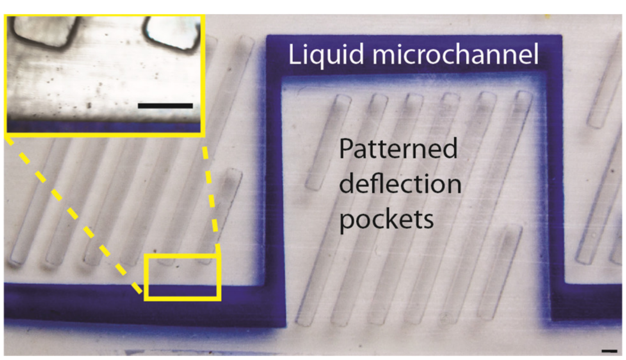

Figure 3: Close-up view of a fabricated deflectable structure showing the deflection-controlling pockets and a liquid-filled microchannel. Microscope inset shows laser-machining detail. Scale bar: 500 µm.

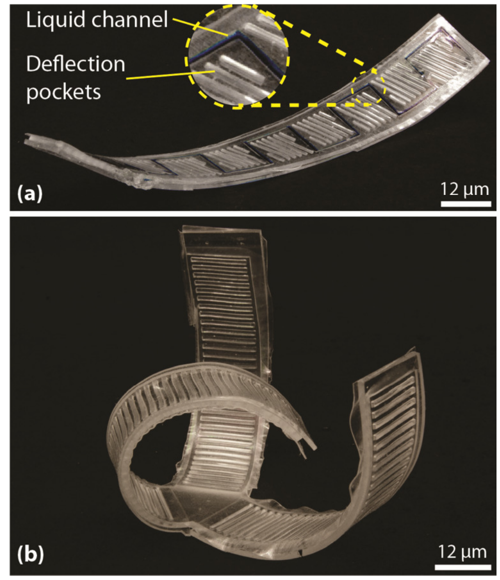

Figure 4: Photographs of deflected, Parylene-coated structures (a) with and (b) without liquid microchannels.

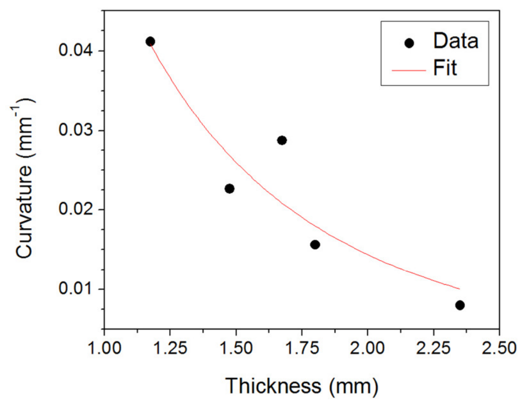

Figure 5: Thicker structures have a lower curvature, as expected from beam deflection theory. The thinnest structures obtained an average curvature of 0.04 mm^{-1}.

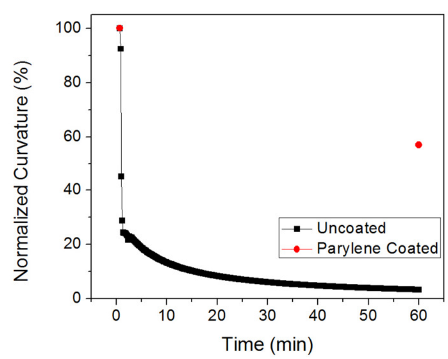

Figure 6: A 1µm layer of Parylene significantly improves deflection stability over time. Final curvature can be adjusted with Parylene thickness.