METHOD FOR CONTROLLING WATER EVAPORATION IN PDMS-BASED MICROFLUIDIC DEVICES

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ABSTRACT

Applications of droplet-based microfluidics have been expanded to agriculture and personalized medicine in recent years. However, evaporation of droplet contents during biological screening reactions remains an obstacle. In this paper, we present a method for ultra-thin fabrication of PDMS-based microfluidic devices to limit water evaporation.

KEYWORDS: Microfluidics, Droplets, Amplification, Evaporation

INTRODUCTION

Droplet-based microfluidics has many applications in fields ranging the gamut, from agriculture [1] to personalized medicine [2]. One of the most successful uses of droplet microfluidics in commercial applications to date has been the polymerase chain reaction (PCR). To execute PCR, samples need to be repeatedly heated and cooled during thermocycling. Most platforms available for droplet-based PCR require off-chip thermal cycling to prevent evaporation of droplets [3]. PDMS is a common material used in microfluidics due to its low cost and ease of fabrication. However, due to the permeability of PDMS, evaporation of droplets at elevated temperatures occurs. Another significant problem is the interaction between the droplet contents and microchannel surfaces. As droplets flow through the channels, overall surface and time of contact with channel walls is increased which may lead to adsorption of biomolecules on to channel walls. We hypothesize that a thin PDMS fluidic layer fluidic layer bonded with a coverslip will significantly limit water vapor transport and thus minimize evaporation of samples (droplets) during thermocycling. The top glass coverslip will function as a hermetic vapor barrier for the static droplet array, thereby restricting vapor transport to the thin 30 μm slab of PDMS. We hypothesize that the thin PDMS slab will become saturated with vapor after only a small fraction of the reagent volume on the device pervaporates.

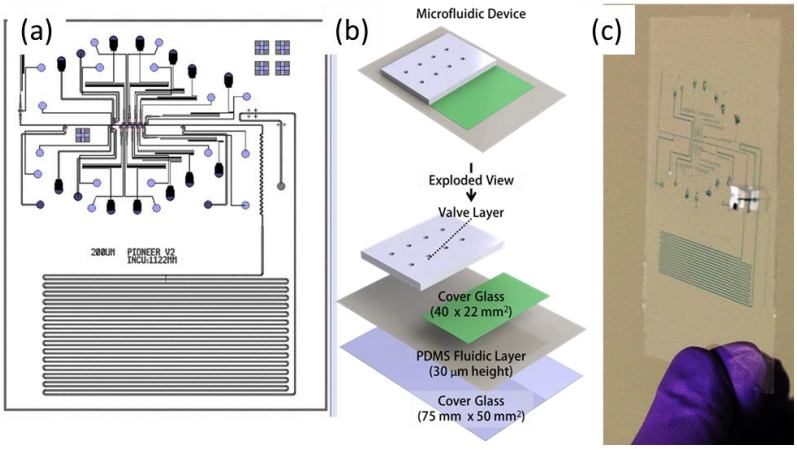

Figure 1: (a) Layout of fluidic chip. Fluidic layer shown in black, valve layer shown in blue. (b) Schematic of microfluidic device assembly. The exploded view shows the valve layer (top), cover glass (which covers the incubation channels), PDMS fluidic layer (30 μm height), and cover glass which functions as the substrate for the chip. (c) Picture of the microfluidic device with only the fluidic layer bonded to a cover glass. The fluidic channels have been injected with blue food dye for visualization. As visible from the picture, the thin PDMS fluidic limits the volume available for water vapor transport.

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EXPERIMENTAL

The device shown in Figure 1 was fabricated using a modified soft lithography technique. The fabrication method presented here (Figure 2) requires only glass and PDMS and overcomes the need for complicated processes such as vapor deposition of Parylene C. Parylene C currently is the material of choice to seal PDMS-based devices with pervaporation boundaries but requires expensive equipment and is not commonly available in research settings [4]. We propose fabrication of ultrathin PDMS devices placed between two glass coverslips. These devices feature a 9 μm PDMS membrane separating the top of the fluidic channels containing nanoliter drops and the bottom of the glass coverslip. A schematic of our prototype device is shown in Figure 1. Fabricating such thin PDMS membranes with through-holes required us to develop a new fabrication technique which is outlined in Figure 2.

After PDMS devices were fabricated using the modified soft lithography technique, the channels were treated with Aquapel (PPG Industries) to render the sidewalls hydrophobic and fluorophilic. Aquapel was pushed through the channels using compressed air. Devices were then baked at 80°C for at least 20 minutes.

A mixture of FC40:PFO (4:1 ratio, v/v) was used as the carrier phase. Mixtures of Alexa 488 (20 nM, 100 nM) were prepared for the aqueous phase. A dual laser (ex 488 nm, 552 nm) confocal fluorescence spectroscopy platform was used for detection. Droplet volumes and fluorescence data were measured and collected at the beginning of the incubation channels and the exit. Droplet volumes were calculated by determining the area of the droplets (ImageJ) and multiplying by the height of the channels.

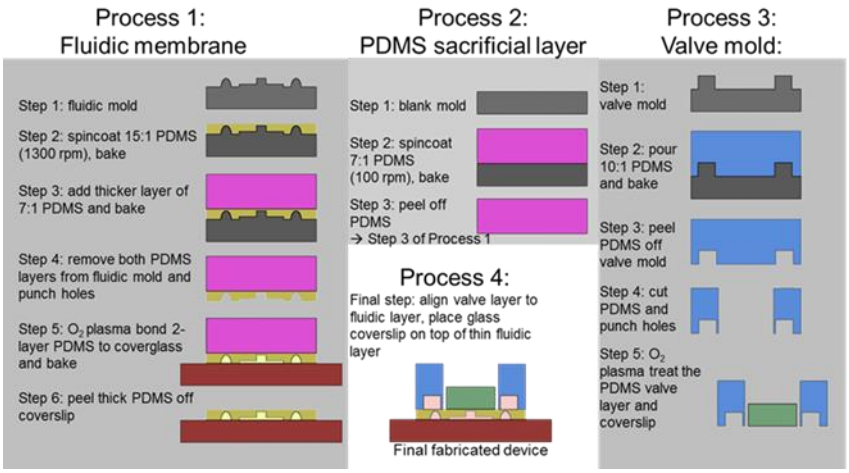

Figure 2: Fabrication scheme of ultra-thin PDMS membrane-based chips. The fabrication process involves three parallel steps: Process 1 – Fabrication of fluidic membrane, Process 2 – Fabrication of the PDMS sacrificial layer which serves to transfer the fluidic PDMS membrane to a glass slide and Process 3 – Fabrication of the valve layer. These three processes culminate in the final assembly of the PDMS microfluidic device (Process 4). This method is simple, inexpensive and robust. Perhaps most importantly, the materials required for the fabrication of these devices should be available in most research labs.

RESULTS AND DISCUSSION

For proof-of-concept, we conducted initial experiments at room temperature. In conventional 3 mm-thick PDMS chips we observed droplet volume reductions of ~66% in ~30 minutes at room temperature. In contrast, in the hybrid glass-PDMS microfluidic devices produced by the technique presented in this work, droplet volume reduction was observed to be ~26% (Figure 3a). Figure 3b shows confocal fluorescence spectroscopy traces of droplets entering and exiting the incubation region. Sequences of droplets containing Alexa 488 at two different concentrations (20 and 100 nM). The droplet data (Figure 3) suggests that adsorption of fluorophores onto the sidewalls of the channels is exacerbated at higher concentration (100

nM) of fluorophore. In future work, we plan to explore this effectiveness of this technique to prevent evaporation during thermocycling.

CONCLUSION

In summary, the technique presented in this paper allowed us to reduce the evaporation by limiting the volume of elastomer accessible to water diffusion in the device while maintaining ease of fabrication and low cost.

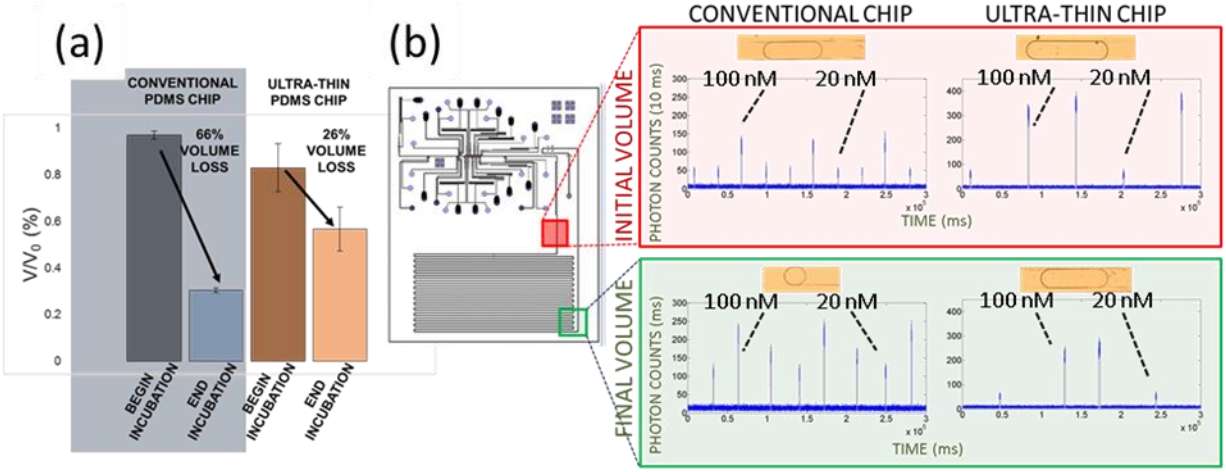

Figure 3: (a) Volume loss in conventional PDMS-based chips was measured to be 66%. In contrast, ultra-thin PDMS chips only exhibited 26% volume loss. (b) Confocal fluorescent spectroscopy data of droplets (20 and 100 nM of Alexa 488) entering and exiting the droplet incubation region. Interestingly, at lower concentration of fluorophore (20 nM Alexa 488) evaporation seemed to dominate. Namely, in the conventional chip for the 20 nM sample, the fluorescence intensity increased 3x. For the 100 nM sample, the signal intensity increased only by 1.9x despite volume reduction of 66%. In the ultra-thin chip, again for the 20 nM sample, fluorescence signal dropped by 11%. For the 100 nM sample, fluorescence signal dropped by 28% again indicating more adsorption of fluorophores onto the surface of the channels for droplets containing higher concentrations of fluorophores.

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