3-Dimensional Paper-based Fluidic Devices Using Parafilm-infused Paper

Yeong-Beom Cho[1], Yong Shin Kim[1] and C. S. Henry[2]
[1]*Hanyang University, South Korea and*
[2]*Colorado State University, USA*

ABSTRACT

Here, we have presented novel paper-based fluidic devices (PFDs) that can provide cheap systems in fluid manipulation for a variety of applications including medical diagnosis, environmental monitoring and food quality testing. One example of PFDs is a 3D time-gated flow device fabricated by using parafilm-based papers. In this device, an aqueous sample was divided into four branches, and then reached detection zones at different arrival times with passing through grid-patterned paper acting as a time-delay layer. Second PFD is a 2D lateral flow device possible to deliver multiple reagents to a detection zone, sequentially. Furthermore, we have also demonstrated a multiplexing colorimetric sensor chip with a new PFD channel structure based on hollow paper, providing a spontaneous and very fast flow rate.

KEYWORDS: Paper-based fluidic device, Microfludics, Parafilm-infused paper

INTRODUCTION

Paper-based fluidic controls and detections have proven to be convenient and low-cost platforms for running assays with small volumes of fluids [1,2]. Typically, paper-based fluidic devices (PFDs) utilize spontaneous 2D lateral flow in porous paper channel owing to the capillary action. PFDs are exceedingly inexpensive, easily fabricated for rapid prototyping of new designs, and stand-alone devices that do not require external pumps to move fluids. Recently, they have evolved into advanced fluidic devices that permit fluid movement in 3D directions and accommodate more assays on a smaller area. These platform technologies are exciting for developing low-cost, high-performance point-of-care diagnostic devices that eventually may surpass polymer-based microfluidic devices.

Here, we have presented a novel 3D time-gated PFD fabricated by using patterned parafilm-infused paper, prepared by staking and hot-pressing the commercial parafilm M sheet and chromatography paper (see figure 1). The use of adhesive parafilm material resulted in efficient and easy fabrication of 3D PFDs. In the time-gated device, an aqueous sample was divided into four branches, and then reached detection zones at different arrival times with passing through grid-patterned paper acting as a time-delay layer.

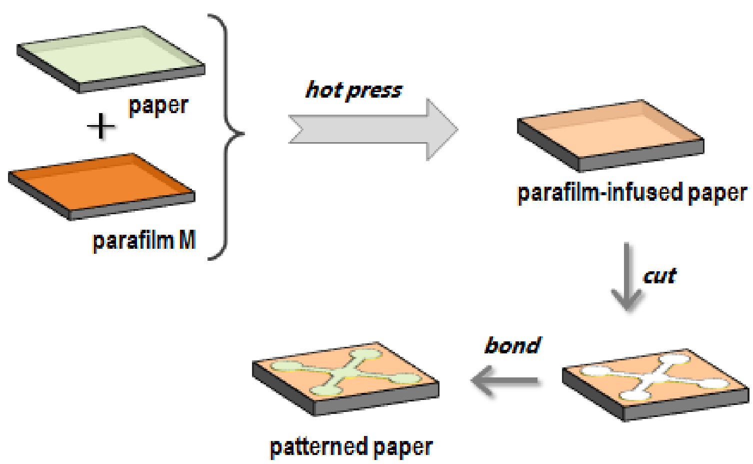
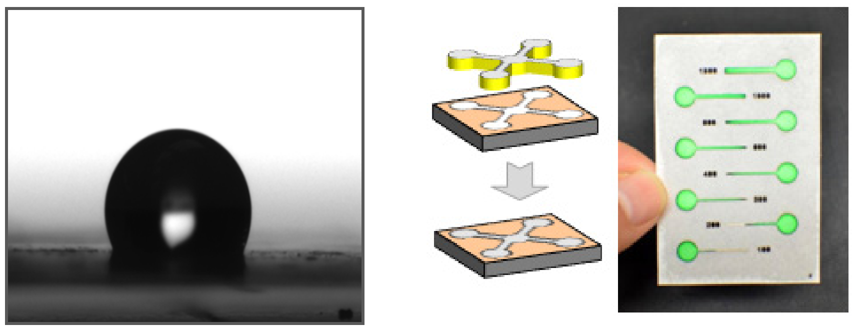


Figure 1: Schematic diagram of fabricating patterned parafilm-infused paper

FABRICATION OF 3D TIME-GATED PFD

The parafilm-infused paper was prepared by hot-pressing chromatographic paper (Whatman Chr grade 1) and parafilm sheet (Parafilm® M). Figure 2A shows water-wetting behavior on the parafilm-infused paper prepared under the conditions of 65°C and 0.5 ton. The contact angle of 115° was measured on the surface of paper side before the pressing, indicating the penetration of parafilm wax through the paper. The patterning process was achieved by laser cutting the infused paper and then inserting paper with identical shape at the cut-off position. Figure 2B demonstrates a process schematic to prepare patterned paper using the parafilm-infused paper. And, figure 2C shows a fabricated test sample with different paper channel widths within 0.1 – 1.5 mm. The cut-and-fit patterning method had confirmed to fabricate a paper channel approximately up to 200 μm. This patterned paper layer was used to fabricate 3D fluidic paper devices.



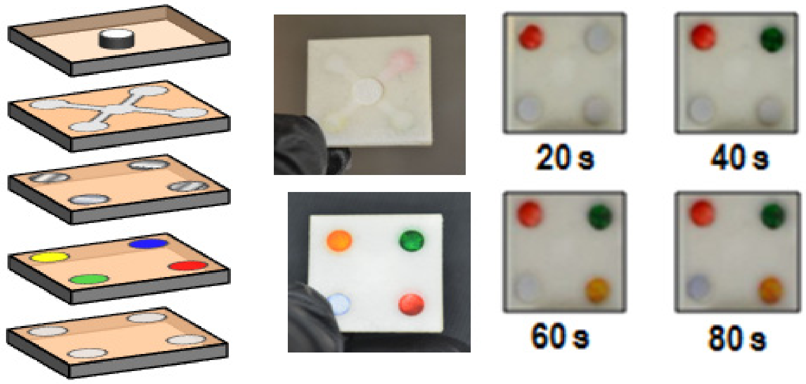
(A) (B) (C)

Figure 2: (A) Picture showing contact angle of parafilm-infused paper, (B) a schematic layer structure of the time-gated 3D PFD, and (C) a picture of the patterned sample using the parafilm-infused paper and normal paper.

Figure 3A shows a schematic layer structure of the 3D time-gated PFD, consisting of 5 sheets. All layers were prepared by using the parafilm-infused paper. The 2nd 3rd and 4th layers were patterned by the cut-and-fit method. The 2nd and 4th layers provided fluidic channels made of normal and dye-impregnated chromatography papers, respectively. However, the circle holes of the 3rd layer were fitted with the wax-printed copy paper in grid shape having a different hole size. Finally, all five layers were aligned and softly bonded by hot-pressing to fabricate 3D PFDs.

PERFORMANCE OF 3D TIME-GATED PFD

The two images of figure 3B show front and back side images of the fabricated time-gated 3D device, respectively, after flow testing. The device was well worked as followings: 1) 50 μL H_2O sample was dropped on the inlet of 1st layer; 2) the sample was branched off 4 ports on 2nd paper layer; 3) each flow had a different passing time through the wax-printed grid pattern on 3rd layer, 4) the passing flow dissolves the pre-deposited dye from the 4th paper layer and then transfer to 5th paper. The measured color display time were approximately 20 s for no grid paper (red), 40 s for spare grid pattern (green), 60s for medium pattern (blue), and 80s for dense pattern (yellow) as observed in figure 3C. These results indicate that the flow passing time can be controlled simply by modulating a grid line density of the circular paper installed on the 3rd layer. This method can reduce the total number of layers in fabricating 3D PFDs because the parafilm-infused layers were bonded each other without additional adhesive layers in addition to providing fluidic channels in the layer. The layer number will be reduced to half time of the conventional paper-and-tape method used to fabricate 3D PFDs.



(A) (B) (C)

Figure 3: (A) A schematic layer structure of the time-gated 3D PFD, (B) front-side (up) and back-side (bottom) images of the fabricated device, and (C) flow-testing images.

CONCLUSION

In this work, we have presented novel parafilm-infused paper and its cut-and-fit patterning method. For illustrating usefulness of the new material and patterning method, the 3D time-gated PFD has been fabricated with using the patterned parafilm paper. A use of the infused-paper can provide a simple way to fabricate 3D paper devices, and simplify a device structure due to the reduction in layer number. This methodology could be applied to other paper-based devices.

ACKNOWLEDGEMENTS

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (NRF-2012R1A1A2005473).

REFERENCES

[1] A. W. Martinez, S. T. Phillips, and G. M. Whitesides, “Diagnostics for the developing world: microfluidic paper-based analytical devices”, Anal. Chem. 82, 3 (2010).

[2] A. K. Yetisen, M. S. Akram, and C. R. Lowe, “Paper-based microfluidic point-of-care diagnostic devices”, Lab Chip, 13, 2210 (2013).

[3] E. Carrilho, A. W. Martinez, G. M. Whitesides, “Understanding wax printing: a simple micropatterning process for paper-based microfluidics”, Anal. Chem. 81, 7091 (2009).