Laser Engineering of Three-dimensional (3D) Structures in Paper-Based Microfluidic Devices

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Microfluidic engineering technology has been widely used for implementing lab-on-chip (LOC) type point of care (POC) devices since its origins in the 1990s. LOC devices offer some distinct advantages such as the possibility of reducing the quantity of valuable samples or reagents needed and the shortening of the detection times, both of which result from their compact structure [1]. Paper-based microfluidic devices, which are regarded as a low-cost alternative to conventional POC diagnostics tools, have also been popularly studied in the last few decades, and a huge number of advantages have been explored, such as low-cost, mass production, disposability, being equipment free etc. [2] However, some disadvantages or limitations are also apparent, such as issues with the control of flow rate, multiplexed detection on the same device footprint and further reduction of size [2]. As a result, 3D microfluidic paper analytical devices, as an alternative solution, have been proposed in recent years, which enable distribution of fluids in both lateral and vertical directions.

Compared with traditional 2D devices, 3D devices introduce a number of unique characteristics which are advantageous for certain applications such as that they enable multiple assays on the same device footprint, introduce a potential capacity for implementation of multi-step assays in a compact device and help to further decrease the volume required for performing an assay, hence they help to hugely reduce the reagent distribution times. Several methods have already been reported for creating 3D structures in paper-based devices, including using double-sided tape or hydrophilic spray adhesive to physically attach individual 2D devices, by folding a single piece of pre-patterned paper based on the principle of origami etc. [3] However, as these methods normally require manual stacking and sealing of multiple layers, they cause issues of reproducibility and also potential contaminations. Meanwhile, another key issue/challenge is to ensure contact between hydrophilic features in each layer of the paper [2].

In this report, we present a new approach for fabrication of 3D devices using the same laser-based direct-write (LDW) technique based on light-induced photo-polymerisation, which we have previously proposed for fabrication of 2D paper-based devices [4]. The 3D structures in this report are created using the same principle. In brief, through controlling the patterning conditions, we could produce solid hydrophobic structures either partially inside a single layer of paper (Fig. 1a) or all the way through a few layers of paper (Fig. 2a). Thus by selectively patterning from both sides of the paper we could fabricate 3D devices based on both a single layer of paper and a stack of multi-layers. Some example devices are shown in Fig. 1b and Fig. 2b&c respectively. Unlike other 3D device fabrication methods, the approach presented here does not require any additional processing equipment or alignment/assembling steps.

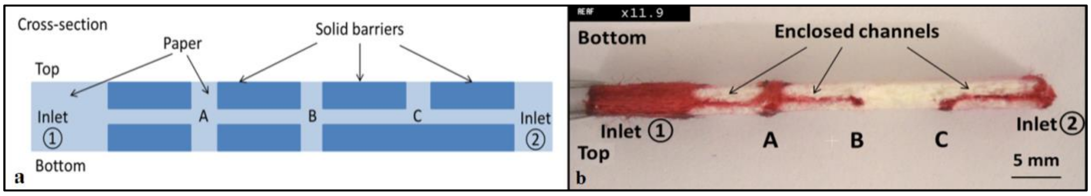

Fig. 1 a) Schematic representation of the cross-section of a 3D fluidic device with two inlets (①②) from either end. b) Image showing the device described in a) after the introduction of red ink from both inlets.

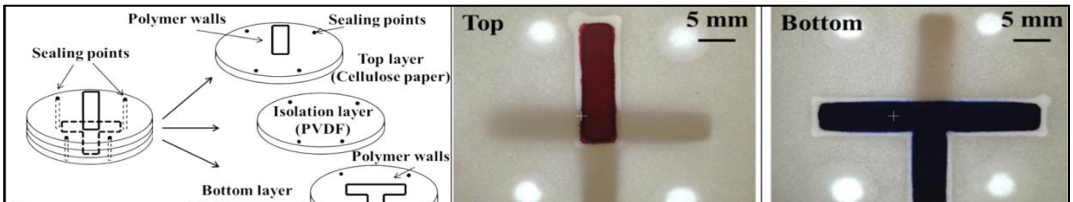

Fig. 2 a) Schematic image showing the arrangement of a stacked device with different structures in top and bottom layers, which are isolated with a hydrophobic film in between. b) Top and c) bottom images showing the device described in a) after the introduction of different inks.

References

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