Fabrication of paper-based microfluidic devices via local deposition of photo-polymer followed by UV curing

P. J. W. He, P. P. Galanis, I. N. Katis, R. W. Eason, C. L. Sones

Optoelectronics Research Centre, University of Southampton, Highfield, Southampton, UK

Abstract: We report a paper-patterning technique that improvises the previously reported laser-based direct-write approach through the introduction of local deposition of photo-polymer. We believe this modified technique should establish a route for routine commercial-scale fabrication of paper-based microfluidic devices with applications in clinical diagnostics and analytical chemistry.

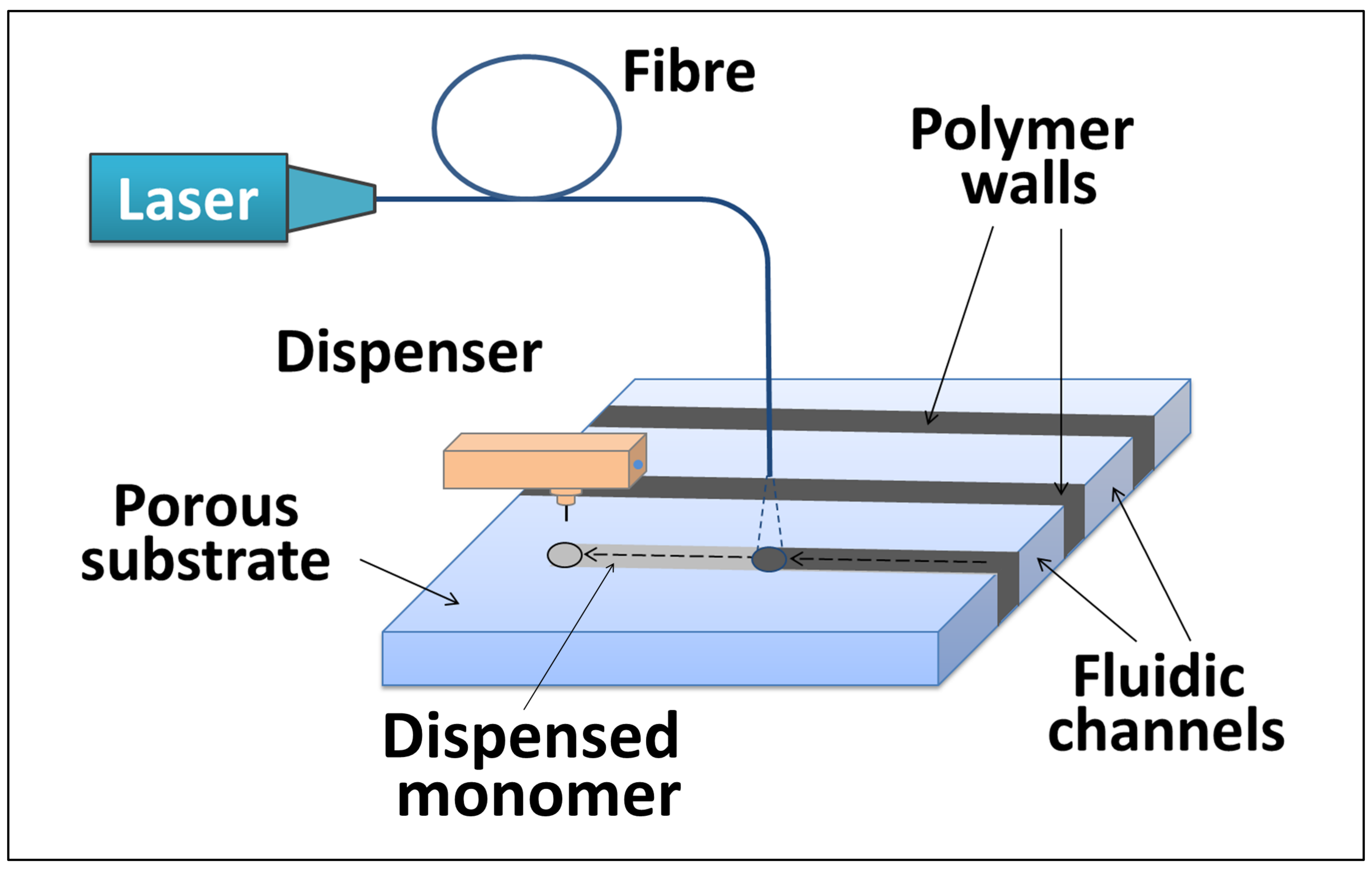
Introduction

Demand for low-cost alternatives to conventional medical diagnostic tools has been the driving force that has spurred significant developments in the diagnostics field. Paper-based fluidic devices, proposed by the Whitesides' group in 2007 have been regarded as one such low-cost alternative [1], and consequently, this field of paper-based diagnostics has been progressing rapidly [2]. Several methods such as photolithography, inkjet printing, printing of wax etc. have already been reported for creating fluidic patterns in porous substrates. [3]

In our previous publications, we have demonstrated the usefulness and versatility of a laser direct-write (LDW) approach in the patterning of fluidic devices in porous materials for the development of diagnostic devices . The LDW technique has the potential to be up-scaled for mass-production of paper-based devices at affordable cost [4-7], and to further improve, optimise and simplify this approach for such large-scale manufacture, we propose the inclusion of a local deposition procedure that allows the deposition of a photo-polymer at user-specific locations.

Here, we present our results that show the successful patterning of nitrocellulose membranes using the local-deposition-assisted LDW technique.

Local-deposition-assisted laser- direct-write (LDW) patterning procedure



The LDW setup that allows the implementation of this improvised methodology is described in the schematic:

Step 1. The photopolymer is locally deposited onto the paper substrate with a deposition nozzle at locations pre-defined by the user's device design.

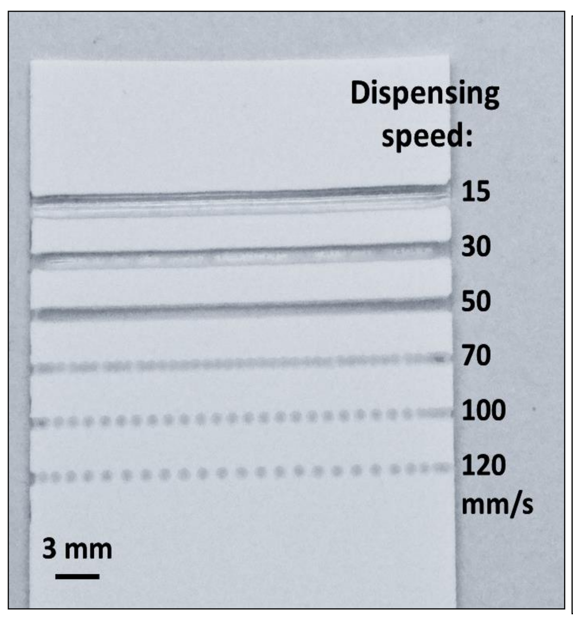
Step 2. A laser beam subsequently follows the deposition head and illuminates the deposited patterns thereby inducing photo-polymerisation or curing of the photo-polymer.

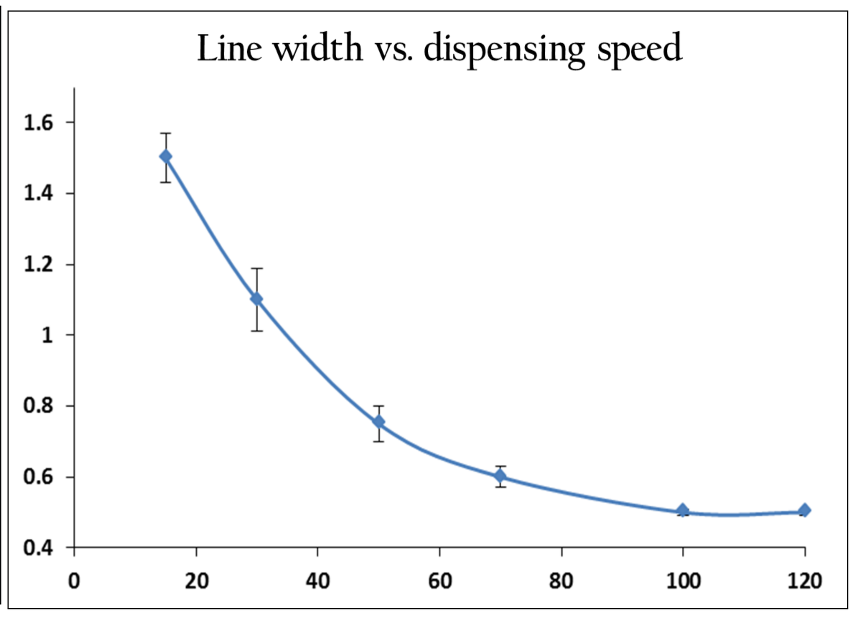
The cured or solidified polymerised patterns define the fluidic walls that serve as barriers that confine and transport the liquids within the paper device.

- Non-contact and hence a non-contaminating procedure that leaves the paper material 'untouched'.
- The width, depth and quality of the photo-polymerised structures depends on the deposition parameters.
- Fabrication speeds can be as fast as m/s; well-suited for rapid fabrication.
- Laser powers required can be as small as a few mW.
- Surface-relief structures with different heights can also be designed to contain large liquid volumes.

Local-deposition-assisted laser-direct-write patterning of fluidic devices in nitrocellulose membranes

Parametric study - results





* Error bars indicate the standard deviation for 5 measurements along each line

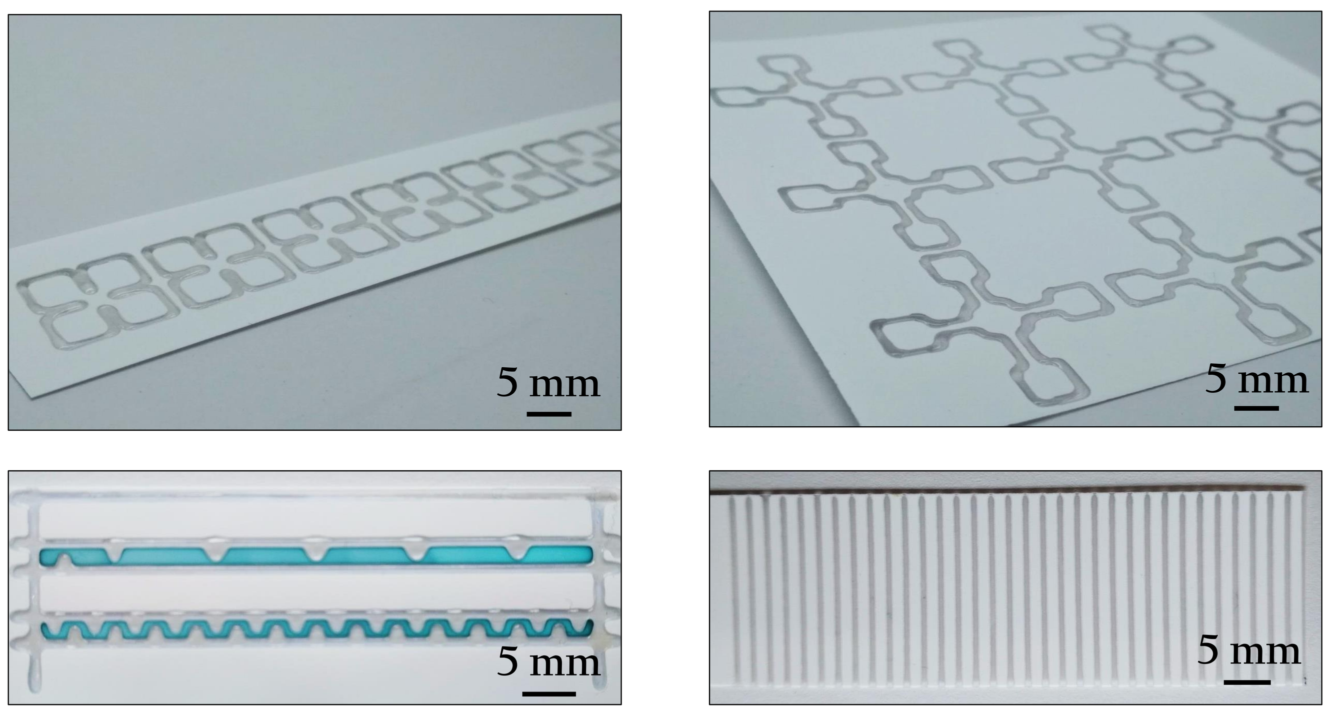
Experimental parameters

- Polymer dispensing speeds
  - ranges from 20 to 120 mm/s
- Laser - 405 nm continuous wave
  - output power fixed at 30 mW

Results

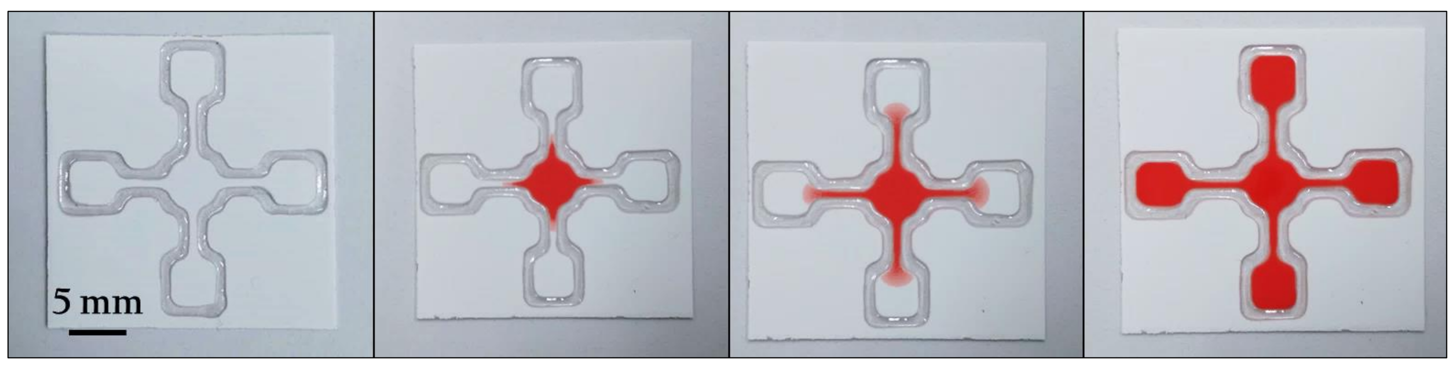
1. Polymer line-width increases with decreasing dispensing speed
2. Smallest line-width that contains and guides fluids: ~ 600 µm

Example devices



Example applications of patterned devices

Simultaneous/multiplexed detection of BSA and nitrite in water

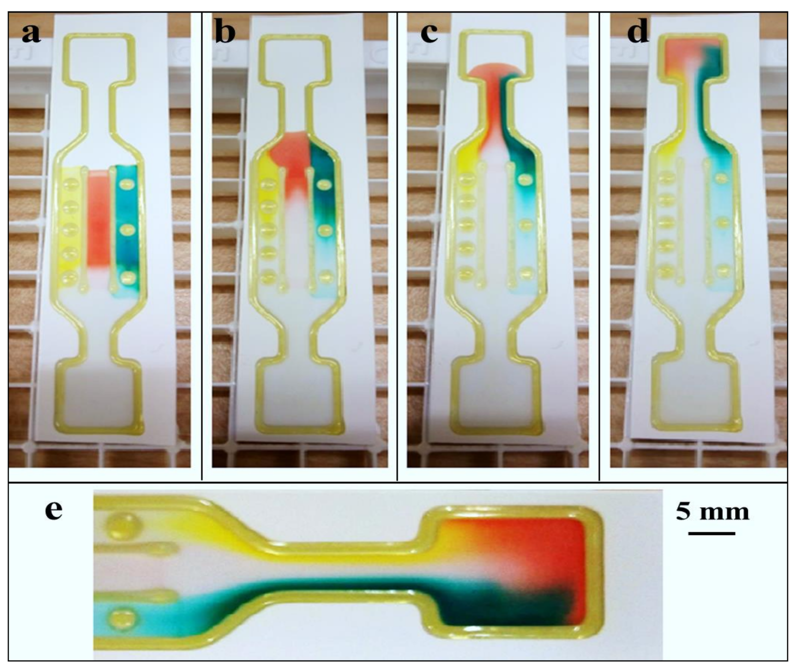


Device patterned in nitrocellulose membranes with one central input/distributor equally feeding four individual wells.

Device allows simultaneous detection of four different bio-markers from within a common fluidic 'sample'.

- Yellow-green indicates the presence of BSA in the sample
- Purple-red indicated the presence of nitrite in the sample

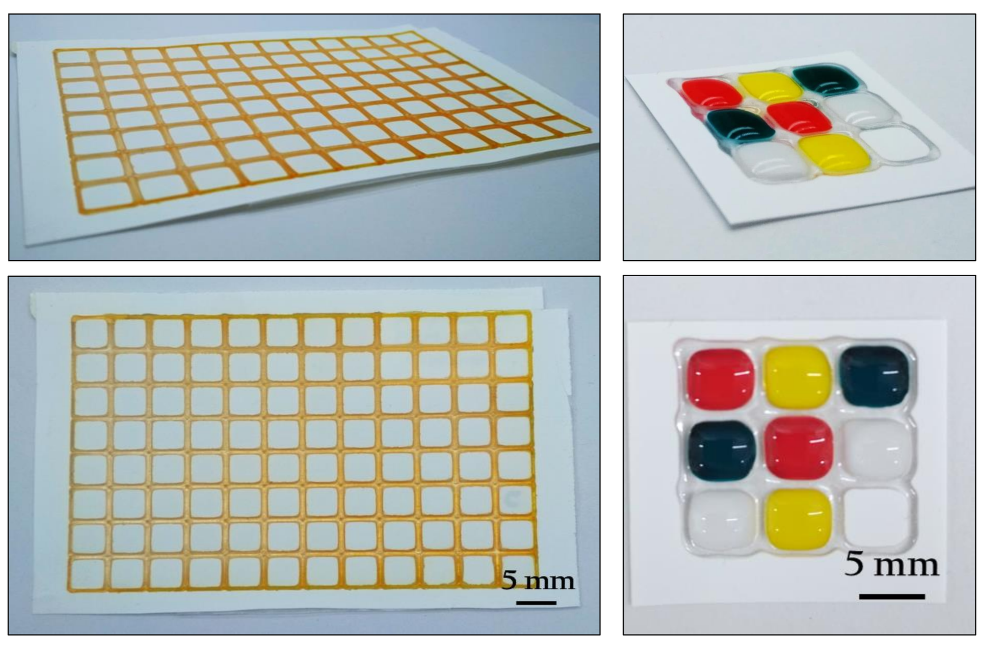
Applications in flow-control



Laminar-flow and diffusion in a three-channel paper device.

- Flow rate in each channel is determined by the size and number of the pillars within each channels
- The laminar-flow of the three sub-streams in the common channel is determined by the individual flow-rates

Application as paper-based microtiter plate



Advantages presented via the patterning technique and the inherent properties of paper:

- Surface raised structures with controllable heights
  - Avoid cross-contamination
  - No overflow even with large or excessive volumes
- Smaller well-dimension and small paper bed-volume
  - Smaller sample volumes, ~ 2 µL per well
  - Smaller assay operation times

Conclusions:

In conclusion, we believe that the above presented preliminary results convincingly indicate that the LDW technique, when compared to the improvised local-deposition-assisted LDW technique, is better suited for roll-to-roll manufacture of paper-based microfluidic devices that can be used for a variety of diagnostics-related applications.

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