Fabrication of paper-based lab-on-a-chip by printing SU-8 polymer

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Abstract

Nowadays, lab-on-a-chip which integrates the functions of laboratory into a compact chip is attracting a lot of interest from scientific community, since it can perform chemical detection or disease diagnostics at the point of care. Generally, it consists of several micro-channels and wells that contain detection agents such as chemicals or biological molecules (i.e. protein and DNA). When the fluid sample flows into micro-channels, the target substance mixes with the detection agents causing some physical changes, for instance, color change. Therefore, type of the target substance (i.e. chemical or disease) can be identified. Generally, lab-on-a-chip is often fabricated on glass or plastic templates. Recently, filter paper has been employed as the template for reducing cost resulting in a more widespread usage of the lab-on-a-chip especially in developing countries. Previously, several methods have been proposed to fabricate the micro-channels and wells in the production of the paper-based lab-on-a-chip such as photolithography using SU-8 polymer [1], wax printing in a laser printer [2], polydimethylsiloxane (PDMS) printing in a modified plotter [3], inkjet printing of hydrophobization agent [4] etc. In this work, we studied the fabrication process of paper-based lab-on-a-chip using the inkjet printing technology of SU-8 polymer. The advantages of the proposed method are inexpensive equipment and its simple procedures. This study aims to determine the suitable conditions in the fabrication process and test the developed prototypes.

In the fabrication process, a piezoelectric inkjet printer (Epson, T13) was used to print the pattern of micro-channels and wells on a filter paper (Whatman, Grade 1) using SU-8 (Microchem, SU-8 2010) as ink. SU-8 is a polymer that can be hardened when exposed to UV light. In this work, three key conditions in the fabrication process: the concentration of SU-8 in cyclopentanone solvent, the width of the micro-channel wall and the printing time, are determined in order to fabricate micro-channels and wells that can prevent the water leakage. According to the experimental results, the three suitable conditions are as follows; the concentration of SU-8 in solvent: 1 to 10, the width of the micro-channel wall: at least 3 mm and the printing time: 3 times and more. The micro-channels and wells fabricated with these conditions were found to transport the water without leakage. This proposed scheme provides an alternative to low cost and simple manufacturing of the paper-based lab-on-a-chip.

Keywords*:* lab-on-a-chip, micro-channel, inkjet printer, SU-8

1. Introduction

At present, most of chemical detections and disease diagnostics are performed in laboratories that require expensive equipment, complicated procedures and long processing time. Recently, lab-on-a-chip (LOC) technology has emerged as a new route to circumvent these obstacles. LOC devices integrate the functions of laboratory into compact chips which enable chemical detection and disease diagnostics at the point of care. It consists of several micro-channels and wells that contain detection agents such as chemicals or biological molecules (i.e. protein and DNA). These detection agents can react or bind with the target substances or target molecules causing some physical changes, for instance, color change. Therefore, type of the target substance (i.e. chemical or disease) can be identified. The LOC devices are often fabricated on glass or plastic templates. Recently, filter paper has been employed as the template to reduce cost resulting in a more widespread usage of the LOC, especially in developing countries.

Paper-based LOC is increasingly of interest as it is expected to revolutionize the point-of-care healthcare system. It requires the network of micro-channels and micro-wells that can prevent the fluid leakage. Previously, several methods have been proposed to fabricate the micro-channels and micro-wells in the production of the paper-based LOC including,

Photolithography method [1]: This method employs a photo-sensitive polymer to construct the network of micro-channels and wells. The polymer such as SU-8 is cross-linked when exposed to UV light through a designed mask that includes the pattern of micro-channel network. However, this method requires expensive equipment and generates a lot of polymer waste.

Printing polydimethylsiloxane (PDMS) using a modified plotter [2]: This method utilizes a modified plotter that is equipped with a special holder for PDMS. Then the PDMS solution is plotted onto a filter paper to form the network of micro-channels. The pattern of the micro-channel network can be easily changed by changing the pattern image to be plotted in the computer program. However, this method has some drawbacks such as the slow production speed, and the deteriorated quality of plotted patterns due to excessive PDMS penetration.

Thermal wax printing technology [3]: This method utilizes a laser printer to print wax onto a filter paper. After that, the patterned paper is put on a high temperature hotplate to allow wax to diffuse into the paper. This method can easily change the patterns of the network and has a high throughput. Nevertheless, it requires the thermal diffusion process which degrades the resolution of the micro-channel network.

Inkjet printing of hydrophobization agent of alkenyl ketene dimer [4]: This method utilizes an inkjet printer to print alkenyl ketene dimer to create a hydrophilic-hydrophobic contrast onto the paper surface. This method is simple, fast and low cost. Furthermore, it can also print other agents that are necessary for the LOC devices with a precise alignment. Therefore, LOC devices can be fabricated in a single device.

In this work, we studied the fabrication process of paper-based LOC using the inkjet printing technology to pattern micro-channels using SU-8 polymer as ink. This study aims to determine the suitable conditions in the fabrication process of a micro-channel network and investigate the quality of the patterned micro-channels in the water leakage test.

2. Experimental

In the fabrication process, a piezoelectric inkjet printer (Epson, T13) was chosen to print a polymer solution onto a paper. This piezoelectric technique has an advantage over the thermal inkjet printer, since it does not generate heat during the printing. Filter paper (Whatman, Grade 1) with a pore size of 11 microns and a thickness of 180 micrometers was used as a paper substrate. SU-8 (Microchem, SU-8 2010) in cyclopentanone solution was used as ink which can be hardened when exposed to UV light or high temperature.

In the experiment, three key conditions in the fabrication process: the concentration of SU-8 in cyclopentanone solvent, the width of the micro-channel wall and the printing time, are determined in order to fabricate micro-channels and wells that can prevent the water leakage. The solutions of SU-8 polymer in cyclopentanone solvent with three different concentrations (1:10, 2:10, and 3:10) were used as printing inks. The width of the micro-channel wall was varied from 0.5 – 5.0 mm (the increment of 0.5 mm) and the printing time of 1, 2, 3, 5, and 10 times were used in the experiment. After the printing, the patterned paper was baked at 100˚C for 5 minutes on a hotplate to dry and harden the SU-8. Finally, the specimens were tested by dipping in deionized water to determine the suitable conditions.

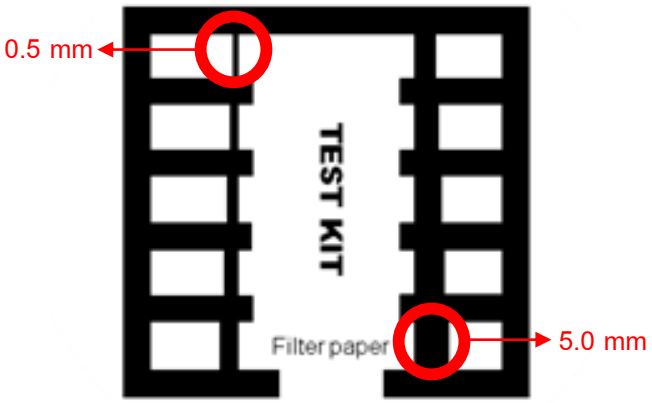

Fig. 1 Schematic illustration of the specimen that consists of a set of micro-channels with thewidth of channel wall varied from 0.5 to 5.0 mm (the increment of 0.5 mm).

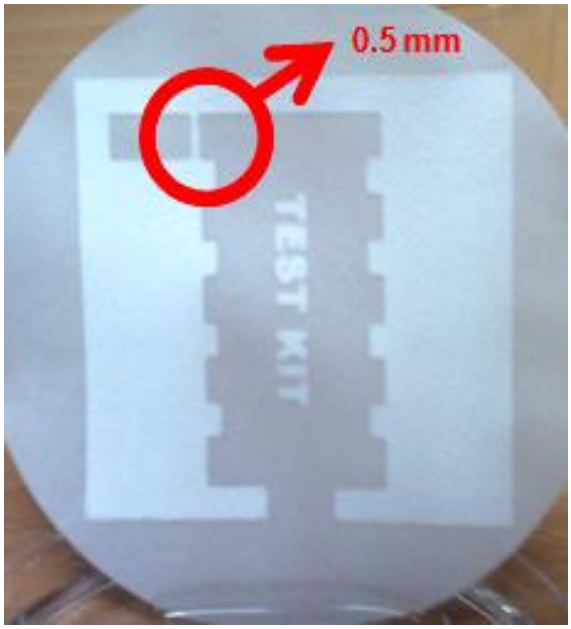

Fig. 2 Result of the leakage test of the specimen fabricated with the following conditions: the SU-8 concentration in cyclopentanone of 1:10 and the printing time of 3.

3. Results and Discussion

Figure 2 shows the result of the leak test of the specimen that fabricated by the following conditions: the SU-8 concentration in cyclopentanone solvent of 1:10, and the printing time of 3. It was found that the width of micro-channel wall of 0.5 mm could not prevent the water leakage. The results from all experiments were summarized in table 1. According to the results, the micro-channels fabricated using the SU-8 concentration of 3:10 could not prevent the water leakage because the polymer solution could not penetrate through the paper in order to form complete micro-channels and wells. Moreover, the increase of the printing time in this case could not help the polymer solution to penetrate through the paper either, since the previously printed polymer blocked further penetration of the subsequently printed polymer solutions. The experimental results can be summarized as follows:

1. The excessive SU-8 concentration might prevent the successful fabrication of the micro-channels. On the other hand, the fabrication using low concentration of SU-8 requires more number of the printing time to successfully fabricate the micro-channels.

2. For the appropriate SU-8 concentrations, more number of reprints could lead to the successful fabrication of micro-channels because of the amount of the polymer increases with the printing time, but this could induce the overlay positioning errors which degrade the resolution of the pattern. Therefore, the printing time should be kept at minimum.

3. Although, the large width of the channel wall might help preventing the water leakage, it requires larger amount of polymer solution and longer fabrication time.

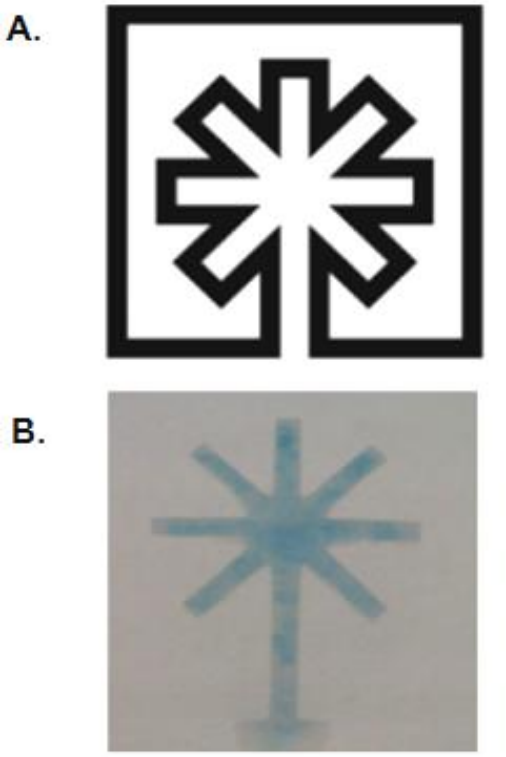

Fig. 3 LOC design (A) and the fabricated prototype that consists of seven channels after dipping into colored water (B).

According to the experimental results, the suitable conditions are as follows; the concentration of SU-8 in solvent of 1:10, the width of the micro-channel wall of at least 3 mm and the printing time of 3 times or more. The micro-channels network fabricated with these conditions were found to transport colored water without leakage as shown in fig. 3. Interestingly, the results also suggested that the fabrication condition using the SU-8 concentration of 2:20, and the width of channel wall larger than 4 mm allows the successful fabrication of the micro-

channels with the printing time of 2. This condition is useful, if the overlay error is a critical concern.

TEST TABLE (Filter papers Whatman No.1)											
concentration SU-8 1:10	times \ width	0.5 mm	1 mm	1.5 mm	2 mm	2.5 mm	3 mm	3.5 mm	4 mm	4.5 mm	5 mm
	1	X	X	X	X	X	X	X	X	X	X
	2	X	X	X	X	Y	Y	Y	Y	Y	Y
	3	X	X	X	Y	Y	O	O	O	O	O
	5	X	O	O	O	O	O	O	O	O	O
	10	X	O	O	O	O	O	O	O	O	O
concentration SU-8 2:10	times \ width	0.5 mm	1 mm	1.5 mm	2 mm	2.5 mm	3 mm	3.5 mm	4 mm	4.5 mm	5 mm
	1	X	X	X	X	X	X	Y	Y	Y	Y
	2	X	X	X	X	X	Y	Y	O	O	O
	3	X	X	X	X	X	Y	O	O	O	O
	5	X	X	X	X	X	Y	O	O	O	O
	10	X	X	X	X	X	O	O	O	O	O
concentration SU-8 3:10	times \ width	0.5 mm	1 mm	1.5 mm	2 mm	2.5 mm	3 mm	3.5 mm	4 mm	4.5 mm	5 mm
	1	X	X	X	X	X	X	X	X	X	X
	2	X	X	X	X	X	X	X	X	X	X
	3	X	X	X	X	X	X	X	X	X	X
	5	X	X	X	X	X	X	X	X	X	X
	10	X	X	X	X	X	X	X	X	X	X

Table. 1 The summary of the experimental results. X: Water leakage after dipping the specimen into water, Y: Water leakage after a period of time, O: No water leakage.

4. Conclusions

In this work, we studied the fabrication process of paper-based LOC by printing SU-8 polymer on a filter paper to form micro-channels and micro-wells. We focused on the three fabrication conditions: the concentration of SU-8 in cyclopentanone, the width of the wall and the printing time in order to fabricate the network of micro-channels and wells that can transport liquid without leakage. According to the experimental results, the three suitable conditions are as follows: the concentration of SU-8 in solvent of 1:10, the width of the micro-channel wall of at least 3 mm and the printing time of 3 times or more. The micro-channels network fabricated under these conditions were found to transport the water without leakage. This proposed scheme provides an alternative to low cost and simple manufacturing of paper-based LOC.

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6. References

[1] Martinez, A. W., Phillips, S. T., Butte, M. J., and Whitesides, G. M., "Patterned paper as a platform for inexpensive, low-volume, portable bioassays," Angew. Chem., Int. Ed. 2007, 46, 1318– 1320.

[2] Lu, Y., Shi, W., Jiang, L., Qin, J., and Lin, B., "Rapid prototyping of paper-based microfluidics with wax for low-cost, portable bioassay," Electrophoresis 2009, 30, 1497– 1500.

[3] Bruzewicz, D. A., Reches, M., and Whitesides, G. M., "Paper-Based Microfluidic Devices by Plasma Treatment," Anal. Chem. 2008, 80, 3387– 3392.

[4] Li, X., Tian, J., and Shen, W., "Progress in patterned paper sizing for fabrication of paper-based microfluidic sensors," Cellulose 2010, 17, 649– 659.

[5] Abe, K., Suzuki, K., and Citterio, D., "Inkjet-Printed Microfluidic Multianalyte Chemical Sensing Paper," Anal. Chem. 2008, 80, 6928– 6934.