A COMPARATIVE STUDY OF PAPER-BASED MICROFLUIDIC (µPAD) MINIATURIZATION

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ABSTRACT
In recent years, paper-based analytical devices gained more attention for development of low-cost point-of-care diagnostic tools in many fields, such as environmental testing, point of care diagnosis, and food analysis. In the present study, we introduce a new paper substrate (Xuan paper) and compare to commercial filter paper (whatman) with hydrophobic materials called polydimethylsiloxane (PDMS). The xuan paper can be used for paper-based microfluidics analytical devices (µPAD) and that flow rate is reliant on many factors affecting fluid flow inside the channels. The screen-printing method was used to concocted hydrophobic channels by patterning hydrophobic materials onto paper substrate with the patterned channels reaching a minimum width of 0.2 mm and maximum 5 mm. The fabricated channels were tested by using water with different paper types and different channel widths. The experimental results were compared with commercially available filter paper (11 and 21 µm pore size). The results of this study are raw xuan paper (0.15 mm of thickness) is similar trend with filter paper (0.21 mm of thickness) about 43 mm distance in 140 second and it is higher than three other papers. However, jinghe paper (0.13 mm of thickness) and cotton xuan paper (0.10 mm of thickness) shows the distance of water about 10 mm and 4 mm, respectively in 140 second because of their fiber orientation and water being absorbed by it. Therefore, xuan paper was a good candidate in applied for µPAD application.

Keywords: Channel width, Fluid transport, Microfluidic, Water Flow, Xuan paper.

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INTRODUCTION

Microfluidic paper-based analytical devices (µPADs) emerged as potential tools for development of low-cost point-of-care diagnostic in many fields. µPADs have a number of advantages over conventional microfluidic devices including affordability, low cost, disposable, and usability [1-4]. Currently, many different types of paper such as filter, chromatography paper, bioactive paper have adopted the developing of paper-based analytical devices (µPADs)[5]. Filter and chromatography paper (Whatman) are widely used as paper-based microfluidics due to their characteristics such as pore size, thickness, surface area and porosity, though some investigators also explored other unconventional paper types and their chemically modified grades[6-8]. The first paper-based microfluidic that was patterned using photolithography technique was developed by Martinez et al, 2007 for bioassay application. In fact, it can be used both in biochemical analysis and medical industry as diagnostic devices[9].

This study investigated new kind of paper that have potential as paper-based microfluidics analytical devices (μPAD) and obtained some factors affecting fluid flow inside the channels. To increase the flow rate, high-pore-size papers can be used. However, the relatively large pore size would facilitate both the water and barrier materials (e.g. PDMS, paraffin wax and Nail oil) to flow across pores, and therefore lead to poor patterning resolution[10-12]. The primary goal of this research is to study the properties of paper relevant to microfluidic applications, including fiber characteristics and hydrophilicity. The experimental setup and our proprietary image processing algorithm allow us to analyze the natural spreading patterns of liquid driven by capillary force in all directions with respects to different paper and liquid properties.

MATERIALS AND METHODS

Different types of xuan paper (as shown in figure 1) were obtained from Chang Chuen Cotton Paper Co. Ltd. (Taiwan). For preparation of paper-defined channels, the paper substrates were cut into (2 x 8 cm). Whatman filter paper Grade 1 and 4 were obtained from GE Healthcare part number 1004-070 (Chicago, IL). Polydimethylsiloxane or PDMS (CAS 9006-65-9) was obtained from Alfa Aesar (China). For the fabrication of microfluidic devices, PDMS (liquid) was mixed with a cross-linking agent followed by poured it into a micro structured mold and heated to obtain an elastomeric replica of the mold (PDMS cross-linked). It is thermally stable and does not show significant changes in viscosity upon temperature changes, which makes it a suitable material for use in a wide temperature range from −40°C to 150°C.

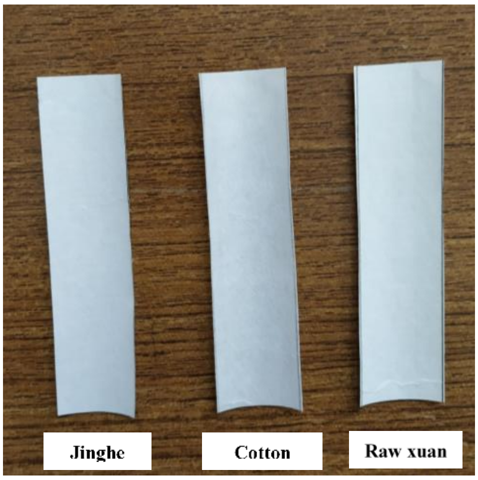

Figure 1. Types of Xuan paper.

Screen printing process was shown in figure 2. For fabricating the channels width, it was exploited screen printing method by 4 different steps of fabrication. A screen stencil that we employed in this research was ordered from Guger Industries Co., Ltd (Taipei, Taiwan). The characteristic of screen is T-420 nylon mesh with ~35 μm pore size on an aluminum frame. The hydrophobic barriers as black zones on a white background were designed using AutoCAD. For experimental purpose, we developed the variation channels width started from 5 mm, 2 mm, 1 mm, 0.8 mm, 0.6 mm. The paper was putted on the patterned screen stencil that placed directly on a piece of paper substrate, the screen frame was forced by hand to be right up next to the paper. Blocking material was rubbed onto the surface of mesh screen using a squeegee, forcing the materials past the pore of the woven mesh to create materials pattern in the paper matrix. After rubbing materials can slowly penetrate into the cellulose paper structure.

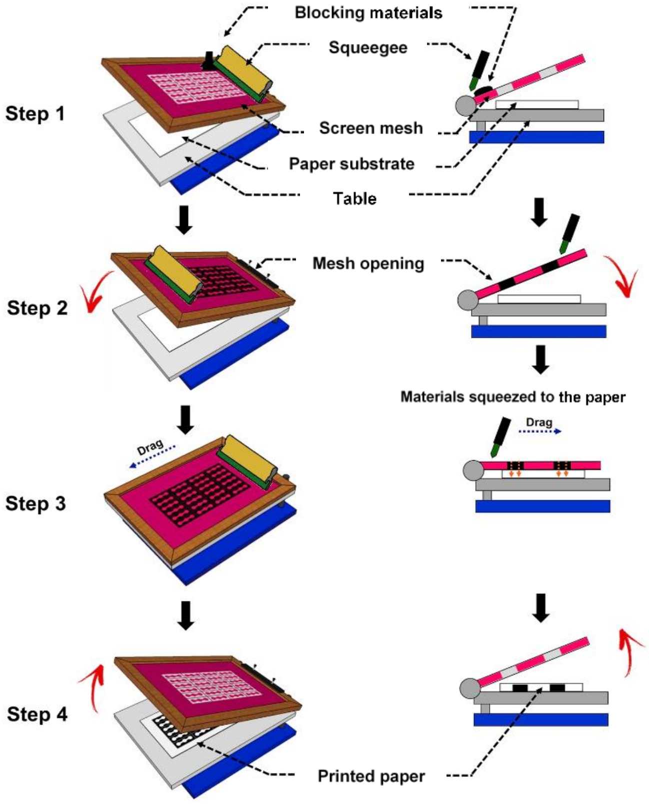

Figure 2. Schematic of screen printing for µPADs fabrication.

RESULTS AND DISCUSSIONS

Surface Morphology of Papers

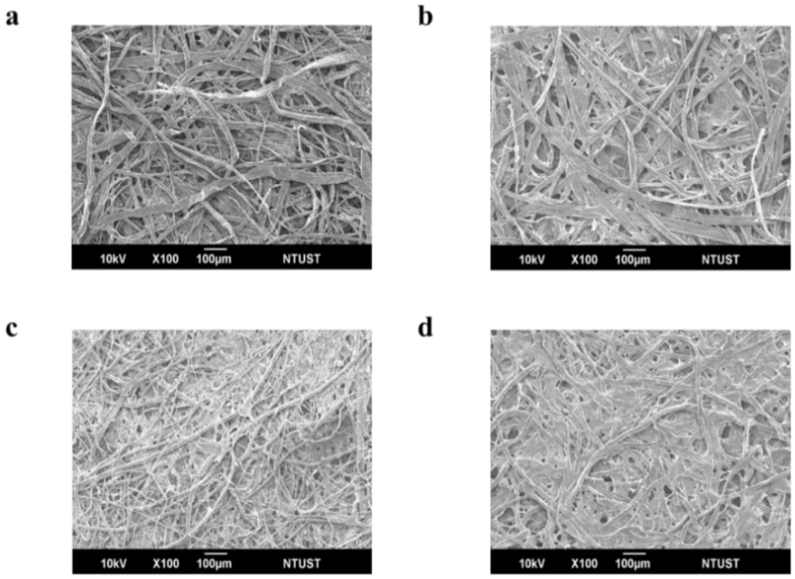

Figure 3. Scanning Electron Microscope (SEM) images of **(a)** Jinghe Paper, **(b)** Cotton Xuan Paper, **(c)** Raw Xuan Paper, and **(d)** Filter Paper.

The morphology of the paper fiber samples was analyzed using a field emission scanning electron microscope (FE-SEM). Figure 3 shows the SEM images of Jinghe, cotton xuan, raw xuan, and filter paper with average diameters of 38.474 ± 5.4, 17.392 ± 4.8, 7.299 ± 2.66, and 10.653 ± 7.38 µm, respectively. As shown in fig. 3 the raw xuan and filter paper fibers were more densed than jinghe and cotton xuan paper fibers.

Water flow comparison of xuan and filter paper

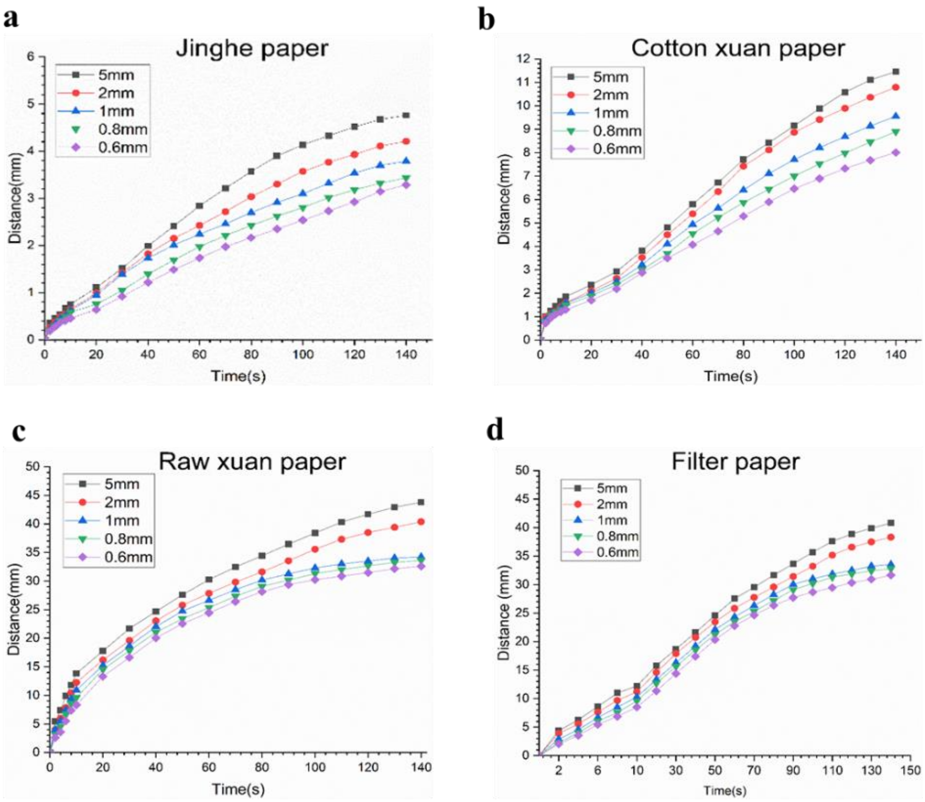

Figure 4. Flow of water using **(a)** Jinghe Paper, **(b)** Cotton Xuan Paper, **(c)** Raw Xuan Paper, and **(d)** Filter Paper with different width.

Figure 4 present the capillary driven-flow of water by different type and width of paper. At the beginning, the water speed is very fast so that the pulling force leads the water to move forward. When the water flows through the flow channel, the resistance to let the water pass will become more larger, so that the flow velocity at the end of trend will become slower. Jinghe paper is the lowest speed of water because of the fiber orientation that confirmed from SEM data and the width of the flow channel also affects to the water speed through the channel[13]. The wide channel has higher flow velocity than the narrow channel because of the resistance effected to the flow rate. There are two main factors that affect the flow rate, they are channel width and distance of water flows pass through the channel[14]. Cotton xuan paper is a little bit higher speed than jinghe paper but both of them are still lower than raw xuan and filter paper. For the comparison of cotton and jinghe paper, it can be seen from the figure 4. The acceleration of cotton xuan paper in 1-2sec increase more than jinghe, which mainly depends on the type of paper while the flow rate drops rapidly between 2-10 second. Raw xuan and filter paper (0.21 thickness) get similarity number of water flow and acceleration by different channels width. The acceleration of those paper approximately 1.4 m/s^2, 1.0 m/s^2, 0.9 m/s^2, 0.8 m/s^2 and 0.7 m/s^2 for 5 mm, 2 mm, 1 mm, 0.8 mm and 0.6 mm channel width respectively and the speed decrease dramatically at 4 sec. On the other hand, filter paper (0.18 mm thickness) shows the acceleration of water flow about 1.1 m/s^2, in 2 sec for 5 mm channel width and decline for others channels width.

Water flow comparison of xuan and filter paper using PDMS as blocking material

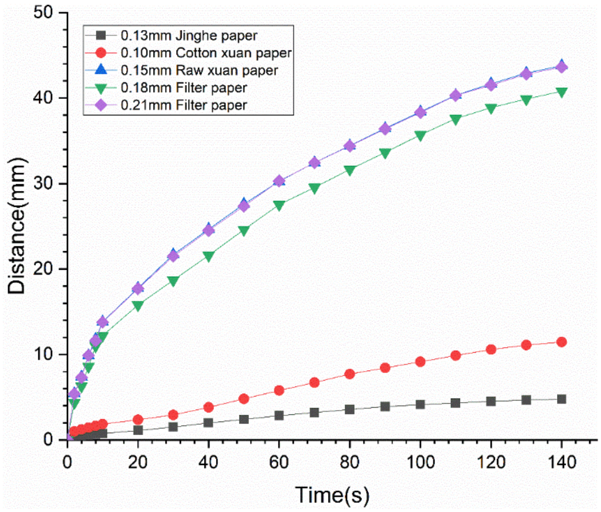

Figure 5. Flow of water with different paper types.

Figure 5 provided the comparison of water flow using PDMS as blocking material. The result shows raw xuan paper (0.15 mm of thickness) is similar trend with filter paper (0.21 mm of width) about 43 mm distance in 140 second and higher than three other papers. The second higher speed was filter paper (0.18 mm of width) that reached approximately 40 mm of water distance flow. In contrast, jinghe paper (0.13 mm of width) and cotton xuan paper (0.10 mm of width) are worse xuan paper because their ability to absorb the water and very slow of water speed[15]. It shows the distance of water about 10 mm and 4 mm respectively in 140 second. Therefore, jinghe and cotton xuan paper cannot be applied for paper-based microfluidic.

CONCLUSION

A new types of microfluidic paper was developed in this work. By comparing flow profile for water, raw xuan paper (0.15 mm thickness) is similar trend with filter paper about 43 mm distance in 140 second and higher than three other papers. In contrast, jinghe paper and cotton xuan paper are worse xuan paper because their ability to absorb the water. Futhermore, blocking materials are not influence to water flow but the channel width will give more affect to water transport.

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