FABRICATION OF PAPER-BASED MICROFLUIDIC DEVICES BY OCTADECYLTRICHLOROSILANE SELF-ASSEMBLING AND UV-PATTERNING

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ABSTRACT

Paper-based microfluidic devices are emerging as a new technology for simple, low-cost, portable, and disposable diagnostic and monitoring platform. This article presents a novel method for fabricating microfluidic devices on paper by means of octadecyltrichlorosilane self-assembling and UV/O_3-patterning. The hydrophilic filter paper was uniformly coated with a hydrophobic layer of octadecyltrichlorosilane (OTS) by dipping the paper into an OTS-hexane solution. The coated OTS layer was then treated with UV/O_3 through a patterned quartz mask, generating hydrophobic barriers that define hydrophilic fluid channels, reservoirs and reaction zones. Contact angle measurements, XPS and ATR-FT-IR spectra confirmed that OTS self-assembled layer (OTS-SAL) was chemically immobilized on the filter paper surface and that the monolayer was degraded after UV/O_3 treatment. The widths of the prepared hydrophilic channels and hydrophobic barriers could be as small as 80 μm and 130 μm, respectively. Colorimetric assays of nitrite ions were demonstrated with the developed paper-based microfluidic devices.

KEYWORDS:

Paper-based microfluidics, self-assembling, UV patterning.

INTRODUCTION

Paper-based microfluidic analytical devices (μPADs) have recently attracted great interests due to its easy-to-use, low cost, portable and easy-to-dispose. Since Whitesides' group first reported a simple method for patterning paper in 2007 [1], a variety of methods for fabrication of paper-based assay devices have been reported [1-4]. Thus, various hydrophobic substances such as SU-8 photoresist, wax, alkylketene dimmer, polydimethylsiloxane, etc. have been utilized to create well-defined, millimeter-sized hydrophilic channels on paper, and different techniques such as wax printing, screen printing, plasma treatment, laser treatment, iCVD-UV-photolithography and so on have been applied to pattern hydrophilic-hydrophobic contrast on a sheet of paper. Here we present a novel and facile method for the fabrication of paper-based microfluidic devices based on the hydrophobilization of the filter paper by formation of a hydrophobic OTS-SAL, followed by UV/O_3-patterning via region-selective degradation of the OTS-SAL.

EXPERIMENTAL

Whatman No.1 paper was cut into appropriate size. The paper sheets were immersed in 0.1% (v/v) OTS solution in n-hexane at room temperature for 5 min to hydrophobilize their surfaces. After removed out of the solution, the sheets were put in nitrogen-based atmosphere to have the hexane evaporated. A quartz mask with designed microfluidic channel pattern was placed directly on the OTS-coated paper. The assembly was then exposed to the UV/O_3 generated by PL16-110 UV-cleaner (Sen Lights Corporation, Osaka, Japan) for 90 min to produce the designed hydrophilic channels. The UV-light power was measured 35 mW/cm^2 at 254 nm.

A μPAD for NO_2^- assay was fabricated. The device possessed flower-shaped designs with one central sample dosing zone, six channels and detection zones. During assay, 5 μL of indicator solution (consisted of 50 mM sulfanilamide, 330 mM citric acid and 10 mM n-(1-napthyl)ethylenediamine in 80% methanol) was first pipetted onto the central sample dosing zone, and penetrated through channels to the detection zones in ca 5 min. Then, 0.2 μL of standard sample solutions containing different nitrite concentrations were pipetted onto the detection areas, each area for one standard. The detection areas soon changed their colors from slightly yellow to pink or red, depending on the nitrite ion concentration in the dropped solutions. After the spots dried in air (ca 5 min), the μPAD was placed on a desktop scanner for image collection. The images were converted to grayscale in Adobe Photoshop ® CS3. Calibration curve was made according to the measured gray intensities of the standards.

RESULTS AND DISCUSSION

SU-8 photoresist was used as a hydrophobic substance to define hydrophilic microchannels on paper in previous works [1]. However, it is expensive and needs to be processed in special clean room. In contrast, silanizing reagents such OTS are not so expensive as the photoresist, and the silanization can be conducted in ordinary chemical laboratories. OTS-SAL has been used to pattern surface hydrophobic and hydrophilic contrast of various silica-based materials [5]. However, it has not been exploited to pattern the hydrophobic and hydrophilic contrast on paper surface.

We observed that after treated with OTS solution the filter paper became highly-hydrophobic. The measured water contact angles (WCAs) were in the range of 125–130°, indicating that a dense OTS-SAL was formed on the surface of the

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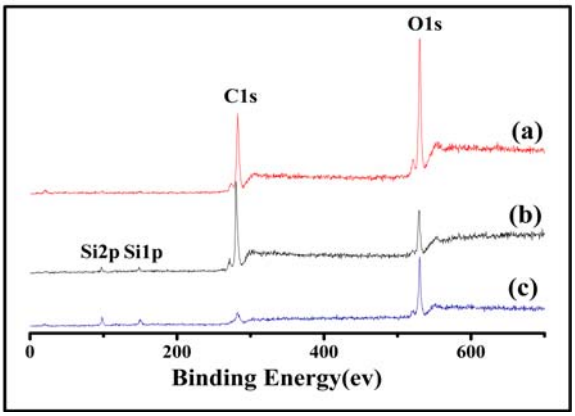
paper. The hydrophobicity of the OTS-coated paper was very stable. The measured WCAs kept unchanged during storage at ambient temperature for 6 months or immersion in different organic solvents such as ethanol, acetone, n-hexane and methylene chloride for 24 h. The formed SAL can be degraded with UV/O_3 treatment. The UV/O_3-treated, OTS-coated paper (abbreviated as UV/O_3-treated-OTS-paper) showed its hydrophilicity as the native paper had (water spread out quickly on the UV/O_3-treated-OTS-paper surface). Fig.1 shows the XPS spectra of native filter paper, OTS-coated paper and UV/O_3-treated-OTS-paper. The spectrum of native paper only contains the carbon and oxygen peaks. The appearance of silicon peak in the OTS-coated paper indicates the presence of OTS-SAL layer. C/O ratios of 2.2, 9.5 and 1 were observed for native paper, OTS-coated paper and the UV/O3-treated-OTS-paper, respectively. This confirms the chemistry changes in the paper surfaces due to the silanization and degradation of ODTA-SAL. The ATR-FT-IR spectra (Fig.2) also show the chemistry changes in the paper surfaces of native filter paper, OTS-coated paper, UV/O_3-treated native paper and UV/O_3-treated-OTS-paper.



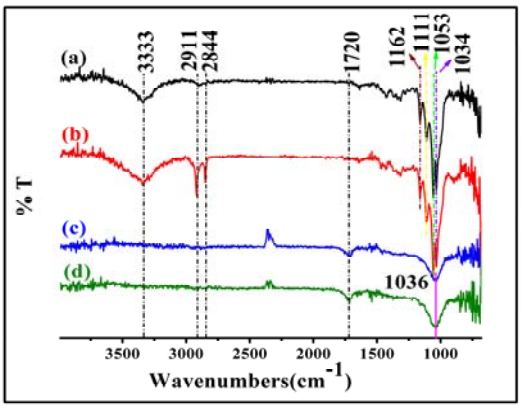
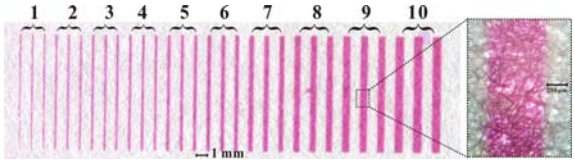


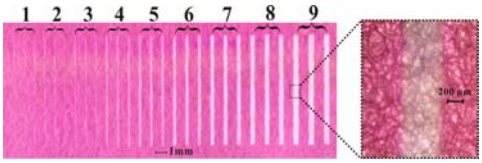
Fig.1 (Left) XPS spectra of native filter paper(a), OTS-coated paper(b) and UV/O3-treated OTS-paper(c).

Fig.2 (Right) ATR-FT-IR spectra of native filter paper(a), OTS-coated paper(b), UV/O3-treated native paper(c) and UV/O3-treated-OTS-paper(d).

By using a UV-photomask, patterning of hydrophilic-hydrophobic contrast on the OTS-coated filter paper can be realized. Fig. 3 shows the resolution of hydrophilic-hydrophobic contrast on filter paper provided by the developed method. The minimum widths of the prepared hydrophilic channels and hydrophobic barriers were 80 μm and 130 μm, respectively.



(a)



(b)

Fig.3 (a) The scanned image of straight hydrophilic channels on hydrophobic paper with different widths penetrated with Rhodamine B solution. (1~10, from left to right, each group containing 3 channels of identical width of 80 μm, 125 μm, 165 μm, 215 μm, 250 μm, 300 μm, 420 μm, 510 μm, 590 μm, 680 μm). (b) The scanned image of straight hydrophobic barriers on hydrophilic paper penetrated with Rhodamine B solution. (1~9, from the fourth of left to right, each group containing 3 channels of identical width of 130 μm, 170 μm, 250 μm, 350 μm, 440μm, 520μm).

A paper-based microfluidic device with flower-shaped layout for colorimetric assay of nitrite ions was prepared. Based on on-chip Griess color-reaction, a typical calibration curve for nitrite ion is shown in Fig.4.

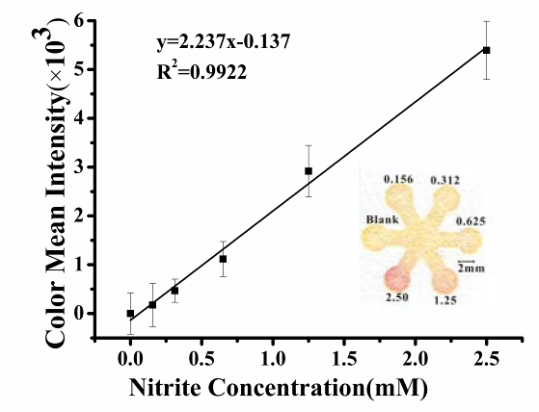


Fig.4 Colorimetric assay of nitrite anions via Griess color-reaction by using the prepared microfluidic paper device

CONCLUSION

Filter paper can be patterned with highly hydrophobic and hydrophilic contrast by means of OTS self-assembling and UV/O_3-degradation of OTS-SAL through a photomask. With this approach, paper-based microfluidic devices with hydrophilic channels and hydrophobic OTS barriers can be prepared in ordinary chemical laboratories. The developed method features simple in operation, low in cost and no needs in clean room and expensive equipments herein. Further work on developing paper-based test strips for pesticides and contaminants residuals in foods and vegetables is undergoing in our laboratory.

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