Electrowetting on screen printed paper based substrate

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ABSTRACT

In this work, electrowetting on dielectric (EWOD) is performed on a paper based substrate. Electrode patterns are fabricated on a paper substrate using screen printing. Conventional photolithography fabrication techniques are replaced by screen printing conductive ink directly on the paper substrate instead of using subtractive and sacrificial etching processes. On the other hand, screen printing fabrication technique is an additive process that has several advantages over conventional photolithography techniques such as mass production capability, reduced production time, simplicity in fabrication steps and equipment used,. Moreover, Paper based substrates offer additional advantages such as material flexibility, low cost and disposability. The integration between printed electronics and microfluidics facilitates the production of the chips needed in microfluidics applications. This integration can have a great impact on the microfluidics research and commercialization as several applications has gained a lot of benefits when it became able to be manufactured by printed electronics techniques such as Radio Frequency Identification (RFID) applications.

Keywords: Digital microfluidics, Screen printing, Electrowetting, Paper substrates

1 INTRODUCTION

Electrowetting is the phenomena of modifying the contact angle of the liquid by applying an electric field. The electrowetting phenomena was first noticed by G. Lippman in 1875 [1]. Electrowetting on dielectric (EWOD) was later studied by B. Berge [2]. The change of the contact angle will generate a difference in the pressure of the droplet. Therefore, the modification of the surface tension of the droplets can be used to transport droplets. Digital microfluidic systems (DMF) has taken advantage of the electrowetting phenomena in manipulating the droplets independently on arrays of electrodes.

2 LITERATURE REVIEW

Modifying the contact angle by electrowetting has been used in many applications [3], [4]. Electrowetting technology has been used in fabricating flexible electronic display screens [5]. Electrowetting has been studied when it occurs on curved surfaces [6].

Reverse electrowetting has been introduced for energy harvesting [7]. A model to differentiate between electrowetting and reverse electrowetting has been introduced by Klarman et al.[8]

Electrowetting has been mainly used to transport droplets on array of electrodes. Digital microfluidics platform is used to manipulate the droplets independently for performing different chemical and biological applications [9]–[11]. Digital microfluidics systems is categorized under two main types. The first one is the single plate DMF system where the droplets are sitting on an array of electrodes without being covered or surrounded by anything. The array of the electrodes are located on the bottom plate as shown in fig. 1. The second type is called closed DMF system where the droplets are sandwiched between upper and lower plates.

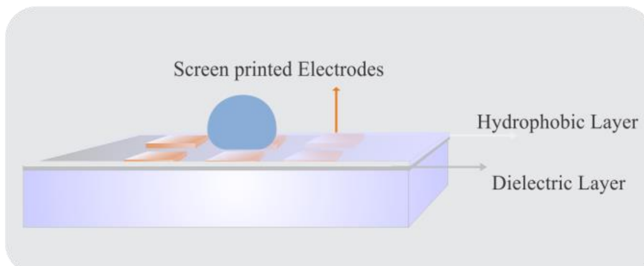

Figure 1: Single plate (open) digital microfluidics system.

Screen printing is a printing technique is well known for being capable of generating the required patterns with large amounts at low cost. Textile and clothes industry are using this technique for generating their designs and patterns on the clothes. Screen printing has been also used in several applications such as the printed electronics industry. Radio frequency identification devices (RFID) is one example of the devices that were fabricated by screen printing technique [12]. In this work, electrowetting on dielectric is going to be tested on a screen printed electrode.

3 EXPERIMENTAL SETUP

Screen printing technique mainly utilizes a screen that has the required designs on it which is patterned by an emulsion layer. A stainless steel screen mesh was purchased from Sefar inc. Silver and carbon based inks were purchased from Dupont® and Bare Conductive®. The screens were stretched on an aluminum frame and then covered by emulsion according to the required patterns as shown in fig 2.

The emulsion is then exposed for curing and the excess emulsion can be removed by water spraying.

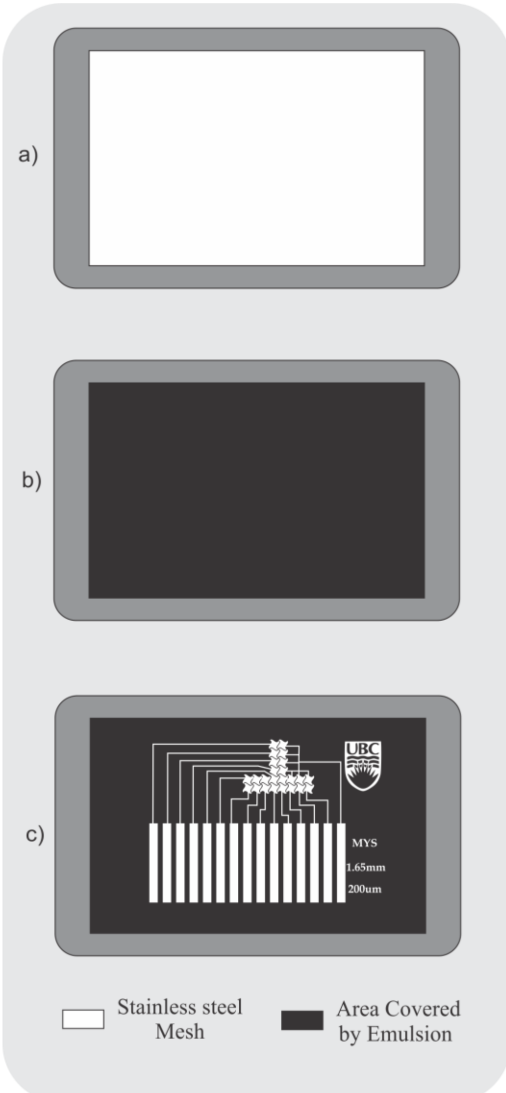

Figure 2: Steps of the screen preparation and patterning the emulsion.

4 RESULTS AND DISCUSSIONS

The screen printing process was performed manually were the squeegee was pushed on the ink to force it to go through the areas on the screen where there is no emulsion covering it. The screen printed patterns shown in fig. 3 can be used to transport the droplets in an open digital microfluidic system.

After printing the required patterns a sheet of parafilm layer was stretched and gently pressed on top of the electrodes to act as a dielectric layer. A hydrophobic layer is needed to increase the initial contact angle between the water droplet and the surface. A water repellant (Rain-X®) was sprayed on top of the dielectric layer.

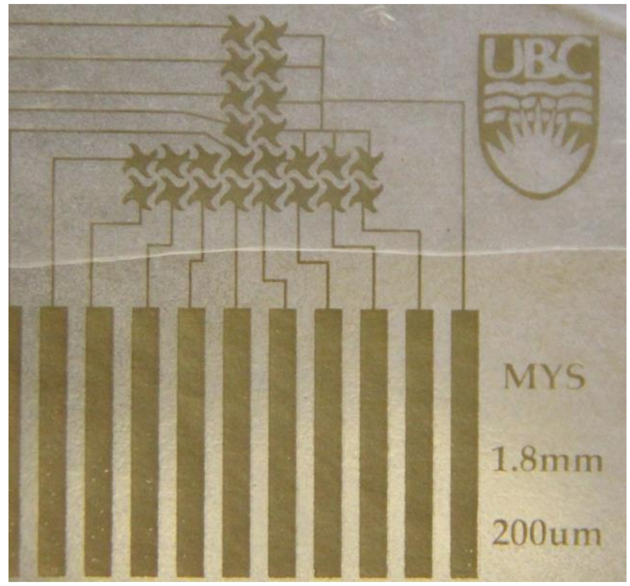

Figure 3: Screen printed DMF chip on wax paper covered by parafilm as a dielectric layer.

The change in the contact angle can be demonstrated by the following equation:

$$\cos\theta_v = \cos\theta_0 + \frac{\varepsilon_d \varepsilon_0 V^2}{2d\gamma_{\mathrm{lg}}} \quad (1)$$

Where θ_v is the contact angle when voltage V is applied, θ_0 is the contact angle at zero voltage, ε_d is the dielectric constant of the dielectric layer and ε_0 is the vacuum permittivity, d is the insulator thickness and γ_{lg} is the liquid gas interfacial surface tension

The setup shown in fig. 4 was constructed for modulating the contact angle. A 10 µl droplet was dispensed on top of the hydrophobic layer. A grounded wire was inserted on the top of the droplet and the electrode beneath the droplet was activated. The electrical signal used for actuation was an AC square wave signal with frequency of 1 kHz. The voltage was varied from 0 to 375 V_{rms}.

The contact angle measurement was measured by a software called ImageJ [13]. A microscopic lens (12X zoom lens assembly, Navitar) coupled with a digital camera was used to capture the contact angle measurement images from the horizontal direction. The change of the contact angle when the voltage applied is varied can be noticed in fig. 5. As the applied voltage increases, the contact angle decreases. This decrease in the contact angle continue till a certain angle where the contact angle does not decrease furthermore even if the applied voltage has been increased. This happens because of the contact angle saturation effect [14], [15].

The theoretical model for the electrowetting extracted from eqn. 1 is then compared to the experimental results as shown in fig.6. The theoretical model extracted from eqn.1 cannot predict the contact angle saturation. Therefore, there

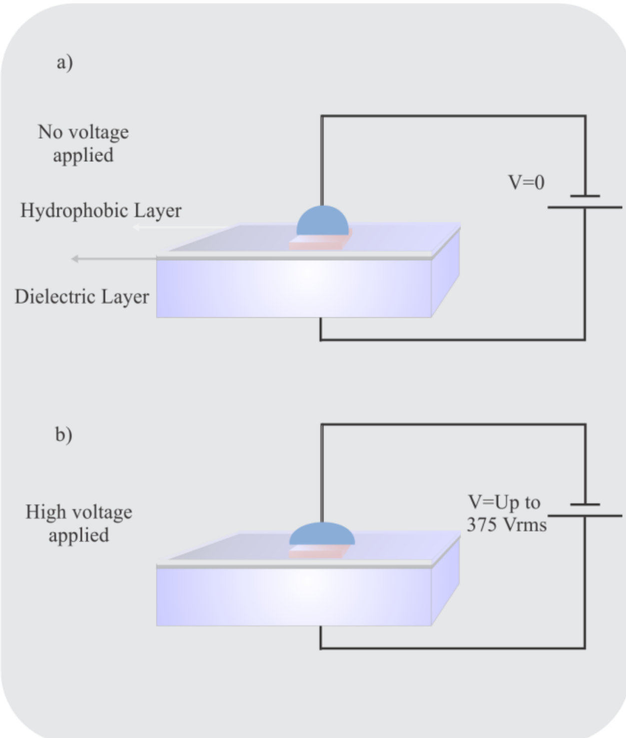

Figure 4: The setup required for changing the contact angle when the voltage is applied.

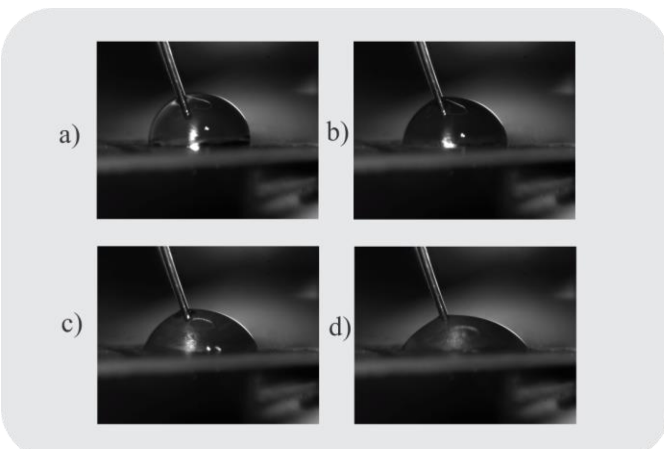

Figure 5: The change in the contact angle that happens when the voltage equals to a) 0 volts, b) 150 volts, c) 225 volts and d) 350 volts.

is a mismatch between the experimental and the theoretical results that start to occur at around 325 volts.

Finally, the screen printed platform was capable of modifying and manipulating the contact angle of the droplets as shown in the experimental results

Further work is going to be performed to evaluate the performance of this system in moving the droplets on a digital microfluidic system.

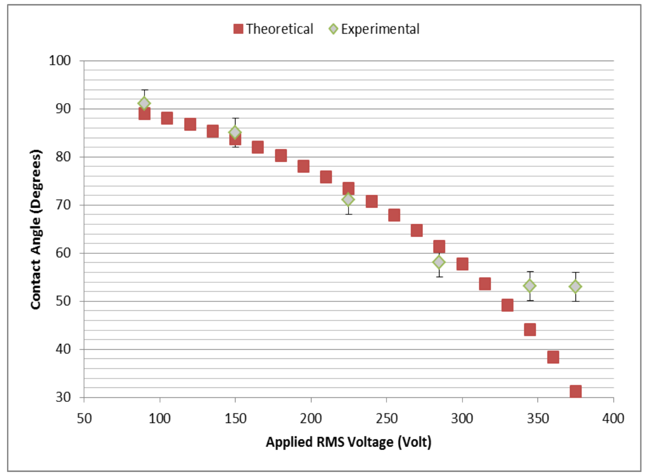

Figure 6: The change in the contact angle versus the applied voltage (experimental and theoretical result).

5 CONCLUSIONS

Screen printing has been introduced to fabricate the electrodes required for the electrowetting process and digital microfluidic operations. Electrowetting has been demonstrated successfully on the screen printed electrodes where the contact angle of the droplet was manipulated by changing the applied voltage. The experimental results nearly matched the theoretical results until contact angle saturation occurred when the voltage level reached 325 volts. Finally, screen printing conductive inks on different substrates can offer a cost effective fabrication technique for electrowetting and digital microfluidics platforms.

6 ACKNOWLDGEMENT

We would like to thank Professor Briar Craig from Faculty of Creative and Critical Studies at the University of British Columbia, Okanagan Campus for his help, support and sharing his experience throughout the screen printing design process. We would like also to thank Dana Tosic, sessional lecturer in print making, for her effort and guidance in the screen printing process.

REFERENCES

[1] G. Lippmann, “Relations entre les phénomenes électriques et capillaires,” *Ann. Chim. Phys.*, vol. 5, pp. 494–549, 1875.

[2] B. Berge, “Électrocapillarité et mouillage de films isolants par l’eau,” *Comptes rendus l’Académie des Sci. Série 2, Mécanique, Phys. Chim. Sci. l'univers, Sci. la Terre*, vol. 317, no. 2, pp. 157–163, 1993.

[3] F. Mugele and J. J.-C. Baret, “Electrowetting: from basics to applications,” *J. Phys. Condens. Matter*, vol. 17, no. 28, pp. R705–R774, Jul. 2005.

[4] Y.-P. Zhao and Y. Wang, “Fundamentals and Applications of Electrowetting,” *Rev. Adhes. Adhes.*, vol. 1, no. 1, pp. 114–174, Feb. 2013.

[5] R. a Hayes and B. J. Feenstra, “Video-speed electronic paper based on electrowetting.,” *Nature*, vol. 425, no. 6956, pp. 383–5, Sep. 2003.

[6] Y. Wang and Y.-P. Zhao, “Electrowetting on curved surfaces,” *Soft Matter*, vol. 8, no. 9, p. 2599, 2012.

[7] T. Krupenkin and J. A. Taylor, “Reverse electrowetting as a new approach to high-power energy harvesting.,” *Nat. Commun.*, vol. 2, no. May, p. 448, Jan. 2011.

[8] D. Klarman, D. Andelman, and M. Urbakh, “A Model of Electrowetting, Reversed Electrowetting and Contact Angle Saturation,” vol. 2, pp. 1–13, 2011.

[9] H.-H. Shen, S.-K. Fan, C.-J. Kim, and D.-J. Yao, “EWOD microfluidic systems for biomedical applications,” *Microfluid. Nanofluidics*, Mar. 2014.

[10] M. Abdelgawad and A. R. Wheeler, “The Digital Revolution: A New Paradigm for Microfluidics,” *Adv. Mater.*, vol. 21, no. 8, pp. 920–925, Feb. 2009.

[11] M. J. Jebrail, M. S. Bartsch, and K. D. Patel, “Digital microfluidics: a versatile tool for applications in chemistry, biology and medicine.,” *Lab Chip*, vol. 12, no. 14, pp. 2452–63, Jul. 2012.

[12] N. F. Salmeron, J.F.; Capitan-Vallvey, L.F.; Palma, A.J.; Molina-Lopez, F.; Briand, D.; de Rooij, “Physical and electrical properties of ink-jet and screen printed patterns for RFID HF antennas,” *2012 IEEE Int. Conf. RFID-Technologies Appl.*, pp. 188–192, 2012.

[13] C. A. Schneider, W. S. Rasband, and K. W. Eliceiri, “NIH Image to ImageJ: 25 years of image analysis,” *Nat. Methods*, vol. 9, no. 7, pp. 671–675, Jun. 2012.

[14] V. Peykov, a. Quinn, and J. Ralston, “Electrowetting: a model for contact-angle saturation,” *Colloid Polym. Sci.*, vol. 278, no. 8, pp. 789–793, Aug. 2000.

[15] A. G. Papathanasiou, A. T. Papaioannou, and A. G. Boudouvis, “Illuminating the connection between contact angle saturation and dielectric breakdown in electrowetting through leakage current measurements,” *J. Appl. Phys.*, vol. 103, no. 3, p. 034901, 2008.