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MICRODROPLET ELECTROWETTING ACTUATION ON FLEXIBLE PAPER-BASED PLATFORM CHIP

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ABSTRACT

This paper presents the microdroplets electrowetting causing by the voltage actuation on the flexible platform chip. A 5µl of Potassium Chloride (KCl) microdroplet is pipetted on top of two separated electrodes fabricated on this flexible platform chip. The electrode is made of a thin Aluminium (Al) film while the platform substrate is made from the cellulose paper, which is flexible. The voltage is supplied between the two separated planar electrodes to actuate the microdroplet motion. In this experiment, the best point of low voltage to move the microdroplet between the two planar electrodes is 12Vpp where the microdroplet is observed to move far and give higher displacement from its origin under the frequency of 10Hz.

Keywords: Microdroplet; Electrowetting; Flexible device;Aluminium electrode; Paper-based chip.

INTRODUCTION

The development of the microfluidic manipulation on chemical or biological encourages for manipulation on smaller volume of particles or droplet with great efficiency. The electrowetting (EW) in one of the microfluidic techniques used to manipulate droplet using the electrical potential, which induced force from the electrical field [1]. Sample dilution or mixing is a common procedure in biological and chemical analysis. There are many methods that have been conducted for moving, mixing, splitting operation of droplet manipulation such as fluid flow, multilayer PDMS technology, double heart chamber, etc. However those methods take a complex and extreme sensitivity of the device. Some of them are not suitable for cell analysis. Thus, we came out with EW technique on paper based platform chip, and it is only controlled by voltage and frequency as the parameter.

Basically, when two separated conductive plates are put together and connected with electrical supply, it will create a medium of electric field in the middle, known as the capacitance effect. The illustration is shown in Figure 1.

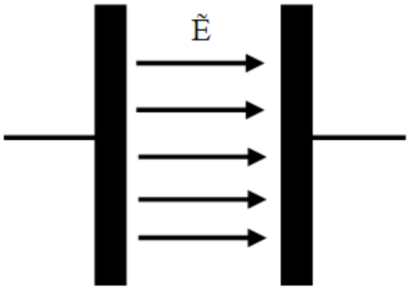


Figure 1: Electric field formed between two charged separated plates[2]

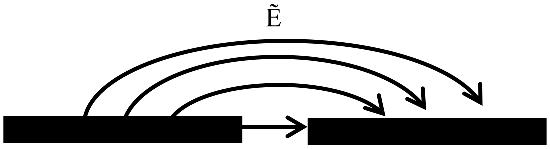


Figure 2: Electrical field formed when the plate is modified

In electrowetting technique, the plate is modified by rotating it 180° and the electrical field also will change due to the distance between two points as shown in Figure 2.The direction of electric field is radially outward from a positive charge plate and inward a negative charge plate. The position of negative and positive is important in order to identify the direction of electric field. The direction of the field is dominated as direction of force. In electrowetting application, the droplet will become the medium of electric field and it will penetrate through it. So, the force of electric field will disturb the atom of liquid and push it towards negative charge plate. The amount of force dependent on value of capacitance, C where the formula of capacitance is given in Equation 1;

$$C = \frac{\varepsilon A}{d} \qquad \text{Eq.1}$$

The ε, A and d is permittivity of dielectric, area of plate in square meters and distance between two plates in meter, respectively.

$$F = \frac{\varepsilon_0 A V^2}{2d^2} \qquad \text{Eq. 2}$$

The attraction force, F is defined as in Equation 2, where the existence of voltage plays big role for magnitude of force. This force leads to physical attraction of droplet and it can move based on the direction of electric field.

The voltage applied across the liquid interphase influence the contact angle (C.A.) of a droplet. Cahill et al. conducted a simulation using COMSOL software to test the contact angle reaction for sessile droplet and for droplet in microchannel [3]. Both types of simulations show a positive result where there are decreasing of contact angle. At some certain limitation, the contact angle will achieve saturation mode where the droplet will start to evaporate due to over voltage supply and heat generated too much.

On the other hand, the limiting contact angle is calculated mathematically by using the equation known as Young's equation shown in Equation 3[4];

$$\gamma_{SV} = \gamma_{SL} + \gamma_{LV} \cos\theta \qquad \text{Eq. 3}$$

where γ_{SV}, γ_{SL} and γ_{LV} denoted to surface tension energy between solid to vapour, solid to liquid and liquid to vapour respectively. Large contact angle denoted the saturation of droplet. Figure 3 shows the position of surface tension energy and position of contact angle.

Most common factors make people want to solve for electrowetting issue is on the voltage consumption. Electrical potential is the main source to turn ON the system. Low consumption of power becomes main target of study and research in this field. Many development on parameter such as type of fabrication method [5], type of electrode shape [6, 7] and type of electrode material [8, 9] have been done to get the ideal voltage consumption without wasting power consumption and get effective result.

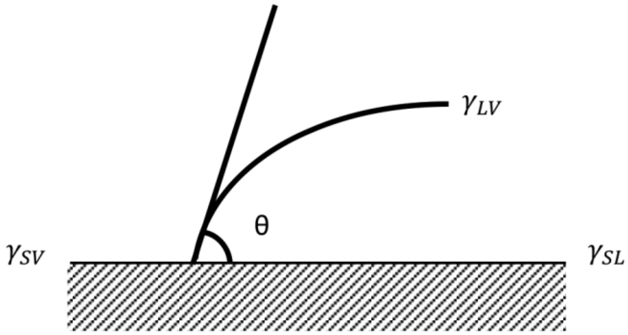


Figure 3: Contact angle and surface tension configuration

a) Droplet at zero voltage *b) Droplet with voltage effect*

Figure 4: Illustration of microdroplet on top of substrate from side-view.

Based on chronology, it starts from voltage supply connected to both plates, then there will be two accumulations of charges. Next when it induced the line of electric field, this will create a force based on direction and magnitude of electric field. This force will move the atom of liquid and physically the droplet will actuate. The actuation will decrease the surface tension of liquid as shown on Figure 4.

In paper [10], the Al foil is used as electrode in flexible substrate. The work can be used for the light control in video-rate operation. Other than that are in displays, optics, chip cooling, particle science and engineering and energy harvesting. This has inspired authors to examine the new electrowetting microfluidic chip using the same electrode material but for different application such as in chemical and biomedical fields. For example, the study in particle science and engineering, the droplet based microreactor displacement or coalescences is important under the induction of electrical signal [11]. Therefore, the focus of this paper will be on the interfacial tension as major parameter in electrowetting and droplet displacement under voltage actuation on the new flexible paper-based platform chip.

METHODOLOGY AND FABRICATION

Electrowetting is a technique for a manipulation of a droplet of liquid by using effect of voltage supply. The droplet manipulations are such as splitting, moving, transporting, mixing and generating. There are two reasons of why electrowetting can make those reactions towards water droplet. Firstly, Rajabi et al.[6] said and proved that when the conductive material that is electrode fabricated underneath the droplet with a dielectric layer in between and connected to the potential supply, there is existence of electric field from two close charging plates. Furthermore, when the electrode underneath the droplet is charged with potential supply, there are layers of ion accumulated at the interface of droplet and electrode.

It formed two different layers of ions, thus it makes the attraction between the droplet and electrode due to the electrical force generated from electrical field. This attraction reduced the interfacial tension energy between droplet and electrode.

One challenge in EW is to manipulate the droplet with a low voltage, since many EW devices require tens to hundreds of volts while most electronics operate at much lower voltages. Microfluidic device and Lab-on-a Chip devices can reduce power consumption. In view of microfluidic device to move small amount of liquid, the EW microfluidic device is fabricated using a few materials of thin films. A cellulose-flexible film has been chosen with a thickness of 106.5µm, and it is cut into a small size of 1.5cm x 6cm (width x length). After that, it is covered by a thin-transparent adhesive sheet with thickness of 58µm to protect the cellulose-flexible film from wetting and it is a water-proof substrate. This acrylic-made-of adhesive sheet is ready to be used material, thus it did not require any special fabrication method to apply it on flexible film. Next, the prepared electrode is applied on top of it. The preparation of electrode is by using a thin layer of Aluminium, Al film that is cut into small size about 2.5cm of length and 0.1cm of width by using a scissor. After transformed the Al film into a desired shape, it is placed on top of water-resist flexible film by using a double-sided pressure-adhesive sheet with thickness of 320µm. The adhesive also comes from acrylic adhesive. The Al film has been tested where its resistance amount is only about 0.2Ω-

0.5Ω. The entire device on the flexible paper substrate is illustrated in Figure 5.

In between third and fifth layer, there is a very thin layer of lubricant oil works as dielectric medium and also can reduce the drag force of the Al surface. Cooking oil is used in this experiment.

For the sample preparation, the droplet used is made from KCl powder diluted with distilled water. The concentration of KCl is adjusted until we get the desired conductivity. The conductivity used in this experiment is about 1400µS/cm and it is a good range for tested a live cell. After the KCl solution is prepared, it is ready to be tested on the electrowetting chip. The eppendorf pipette apparatus with volume range of 10-1µm is used to transfer the droplet onto the electrowetting chip.

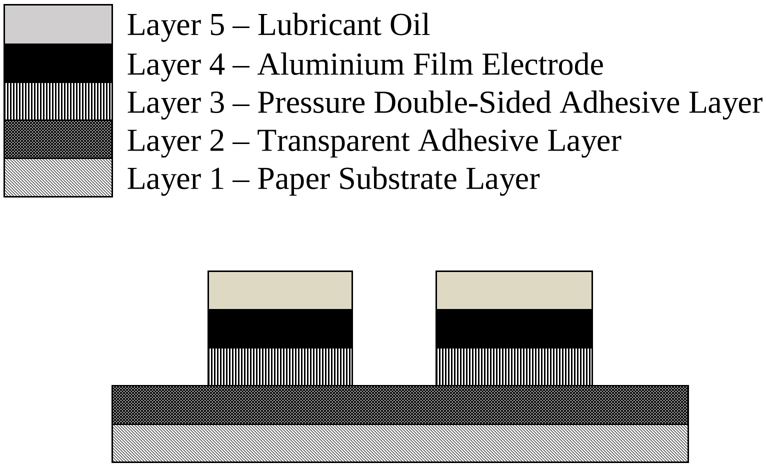


Figure 5: Crossed-view from the side of electrowetting (EW) chip

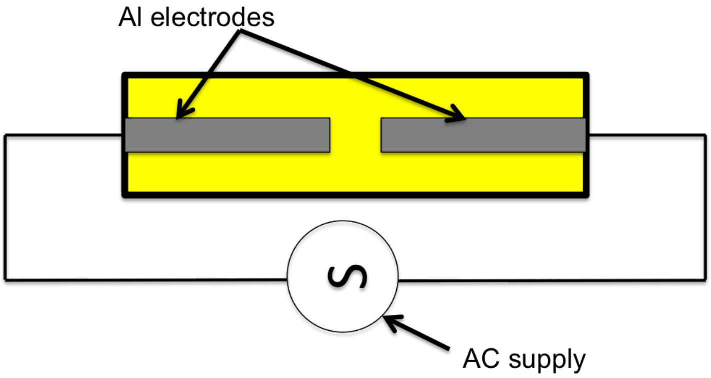


Figure 6: Top-view of electrowetting (EW) chip connected to the voltage supply

RESULTS AND DISCUSSION

Interfacial tension is one major parameter in electrowetting. It is a force that holds the surface of a particular phase together and makes the surface become static. By using the Matlab software, a simulation has been done using Lippmann's equationas in Equation 4 and 5 [12].

$$\gamma_{SL} = \gamma_{SL}^{0} - \frac{\varepsilon V^2}{2d} \qquad \text{Eq. 4}$$

$$\gamma_{SL}^{0} = \gamma_S - \gamma_L \cos\theta \qquad \text{Eq. 5}$$

where γ_{SL} is interfacial tension of solid and liquid after connected with voltage, γ_{SL}^{0} is interfacial tension of solid and liquid at zero voltage, ε is dielectric constant of dielectric, V is connected voltage, d is thickness of dielectric and θ is contact angle between solid and liquid. Table 1 is the value used for the simulation and calculation. Equation 4 is used to calculate the interfacial between solid and liquid before voltage is connected. Some of the values are referred from published journals and some from the experiment, are then inserted in Equation 4, while voltage V works as manipulation variable as the software calculates the value for γ_{SL}.

Table 1: Value used for simulation of Eq. 4

Symbol	Value
γ_{SL}^{0}	40.18 mNm^{-1}
ε	2.79 x 10^{-11} Fm^{-1}[13]
d	400nm (approximate)
θ	132.7° (experimental data)
γ_S	41.2 mNm^{-1}

Theoretically, Equation 4 is proven and shown in Figure 7. The higher the voltage supply, the interfacial tension of liquid or droplet will be lesser. This happened because the energy from voltage supply break the energy wall of the droplet and when the particle become less tension, it will have loose particle inside. Thus, it is easier for the droplet to move. The voltage acts as the electromotive force supply the energy to move the positive and negative ions.

In the experiment procedure, a droplet was initially placed in the middle between two separated planar electrodes as shown in Figure 8 a) when the droplet is in static mode; the voltage is connected with the desired voltage and frequency using AC REALTEK Power Generator. When the voltage is increased, the droplet starts to flow forward and the displacement is measured as x shown in Figure 8 b). The voltage is measured starting from 1Vpp to observe any motion, however only at $8V_{pp}$ the droplet starts to have a change and it is observed until the voltage reaches $13.5V_{pp}$. The distance of droplet movement is recorded and plotted in the graph. The droplet is trailing forward follow the electrode path when the electrode is activated by the voltage supply.

This happened due to the effect of electromotive force induced from electrical field [14]. The value is averaged from repeated experiment. For every repetition, new droplet is used and electrowetting (EW) chip is only used three times maximum because the layer became swollen on flexible paper-based platform chip when too long exposed to liquid medium. The chip is designated to be disposable chip to avoid any contaminated when different sample is used.

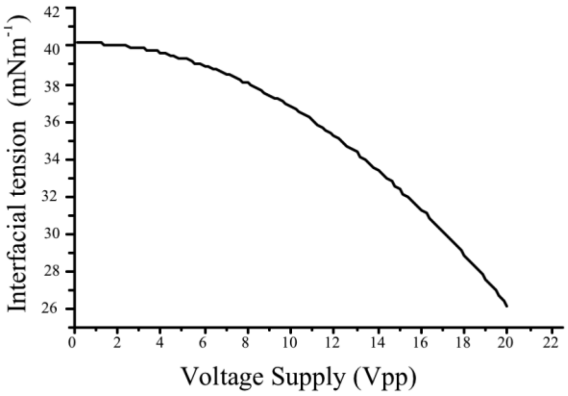
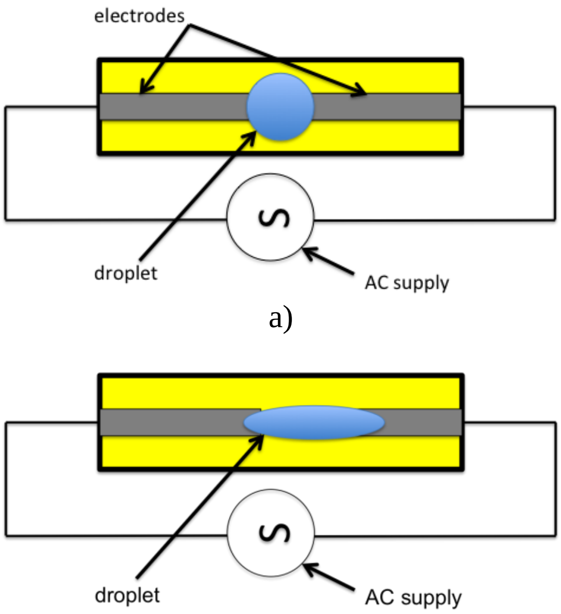


Figure 7: Graph of simulation interfacial tension vs voltage supply



a)

b)

Figure 8: Electrowetting experiment from top view a) At V=0V b) At V=Vpp

In the experimental result which taken from average value of thirty repetition data, it gives the observation in Figure 9 that further increasing of voltage supply will produce a movement travel or called as displacement for the droplet. It is the same reaction occurred in [15].As shown in Figure 9, the result proved that high charge will create more energy and move further along the electrode track longer. Moreover, as the voltage gets higher the motion of the droplet increase.

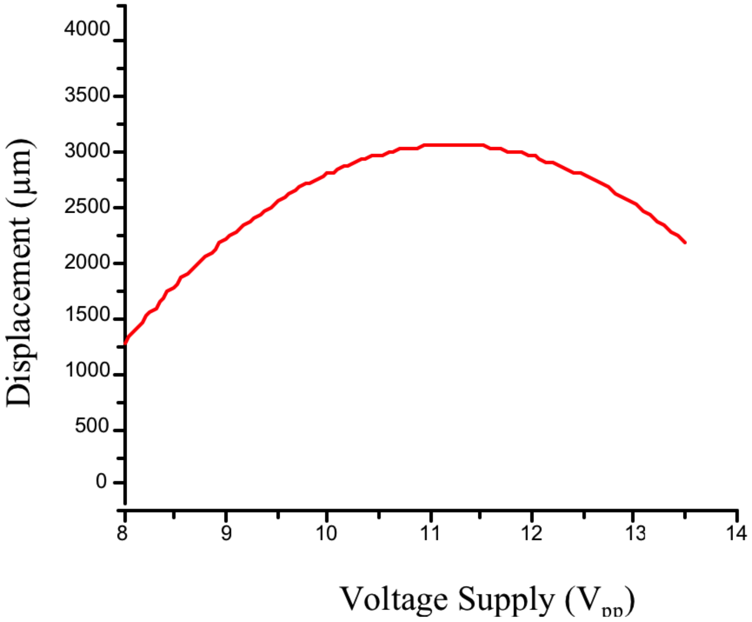


Figure 9: Graph of displacement vs. voltage supply

But, after the peak point, the energy is over limit and transfers it into heat and causes the liquid to evaporate. Thus, the voltage and frequency supply which causing the production of charge must be controlled properly. The measurement is done using software Olympus Stream. From this experiment, the maximum range displacement reading is at voltage between10V$_{pp}$to 13V$_{pp}$. Further than that, the displacement is seemed to be static or saturated. This behavior leads to a decrease of contact angle where it is one important character in EW to justify the efficiency of droplet reaction.

Based on the motion observation at 10Hz, the droplet seems move in inch-worm mechanism which is similar like reported in [14, 16]. The droplet moves in unidirectional due to the AC sinusoidal wave of reaction where it always switches ON and OFF frequently. At the earlier cycle, the droplet seems struggling to start moving either right side or left side, until either one side is succeeded to move further and the other side will just stay static at the original point. When the frequency is applied above 100Hz until Mega Hertz, the droplet seems static like no motion, but when closely observed, there was a vibration at both corner sides of the droplet.

CONCLUSION

This research is conducted to have a simple, low-cost, low voltage and conducive EW to be manufactured since it is a disposable chip. The flexible paper based platform EW chip has fulfilled the Lippmann's equation where the higher the voltage supply, the interfacial tension of liquid or droplet becomes lesser. Moreover, the droplet able to trail along the track of activated electrode on this flexible paper-based platform EW chip. This has shown that the new electrowetting microfluidic chip can be used in the study of particle science and engineering, since the droplet has shown a promising displacement under low voltage 12Vpp and low frequency of 10Hzelectrical signal. Hence due to the positive result on voltage actuation variation, next step would be focused on concentration and conductivity of droplet.

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REFERENCES

[1] Samad, M., A. Kouzani, and M. Samad. Design and analysis of a low actuation voltage electrowetting-on-dielectric device. in 2013 ICME International Conference onComplex Medical Engineering (CME), (2013)
[2] Boser, B.E., Capacitive Sensor Interfaces. Univ. of Berkeley, 1996: p. 1-41
[3] Cahill, B.P., et al., A dynamic electrowetting simulation using the level-set method. Proc. of the COMSOL conference.(2008)
[4] Navascues, G., *Reports on Progress in Physics*, **42** (7) 1131 (1979)
[5] Tröls, A., H. Enser, and B. Jakoby. Modeling and fabrication of low-cost electrowetting actuators for flexible microfluidic display applications. in 2016 IEEE SENSORS.(2016)
[6] Rajabi, N. and A. Dolatabadi, *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* **365** (1) 230-236 (2010)
[7] Jin, H. An improved crescent electrode in electrowetting-based microfludic. in IEEE International Conference on Manipulation, Manufacturing and Measurement on the Nanoscale (3M-NANO), (2016).
[8] Pu, J., et al., *Journal of Materials Chemistry A.* **1** (4) 1254-1260 (2013)
[9] Tan, X., Z. Zhou, and M.M.-C. Cheng, *Nanotechnology.* **23** (37) 375501 (2012)
[10] You, H. and A. Steckl, *Journal of Adhesion Science and Technology.* **26** (12-17) 1931-1939 (2012)
[11] Jung, Y.-M., et al., *Biomicrofluidics.* **3** (2) 022402 (2009)
[12] Pollack, M., A. Shenderov, and R. Fair, *Lab Chip.* **2** (2) 96-101 (2002)

[13] Rangacharyulu, M.,et al., *Journal of International Academic Research For Multidisciplinary.* **3** (12) 87-96 (2016)

[14] Gunji, M. and M. Washizu, *Journal of Physics D: Applied Physics.* **38** (14) 2417 (2005)

[15] Yunus, N.A.M., et al., *Journal of Engineering Science and Technology. Special Issue on Applied Engineering and Sciences.* 115-124. (2014)

[16] Gunji, M., H. Nakanishi, and M. Washizu, *Special Publication-Royal Society of Chemistry.* **296** 168-170 (2004)