Geometrical Characterization of a Micro-Channel in Electro-Wetting Application

Mehrdad Shokoohi[1], Mohammad Khorsand Ahmadi[2], Mohammad Passandideh-Fard[3]
Department of Mechanical Engineering, Ferdowsi University of Mashhad, Mashhad, Iran

Abstract
This article investigates the effect of a micro-channel width and height on the threshold voltage for the movement of a liquid metal droplet in the electrowetting on dielectric (EWOD) phenomenon. For this purpose, a PCB (printed circuit board) board composed of an electrode array with a crescent shape is used. The micro-channel is covered from the top with a glass which is made conductive of electricity using the FTO technique. The results show that increasing the height and width of the micro-channel reduces the threshold voltage. The same trend is observed using an electrode curved with an opposite curvature. It is found that for an electrode shape curved with a curvature in the same direction of the droplet meniscus, the threshold voltage is lower.

Keywords: *Microchannel - Threshold Voltage - Droplet – Electrowetting.*

Introduction

In the past decade, fabricating high-tech instruments including many kinds of devices in a tiny chip set has become popular. A famous example is a Lab-On-chip device with the aim of replacing the room-sized laboratory. A large number of microfluidic constituents such as channels, pumps, valves, mixers and dispensers have been designed and manufactured in recent years. Microfluidics is generally used in biomedical analysis where liquids contain blood, DNA, protein, etc. There are various methods to move droplet in a micro scale such as electrophoresis, thermo-capillary, and electro-wetting actuations. Each of these methods has its own advantages but in overall, electro-wetting is the best choice because of the rapid switching response, low power consumption, absence of heat generation, and having no mechanical instrument. Electro-wetting consists of two words: electro and wetting that means changing wettability of a liquid by applying an electrical field.

Lippmann [1] was the first who reported this phenomenon in 1875. He changed the wettability of mercury by applying an electric potential difference. In equilibrium condition when a droplet is on the solid surface, the external forces are balanced and surface energy is minimum (Fig. 1). Now, if an electrical field is applied, the equilibrium situation will be terminated and the droplet will change its contact angle according to the Young – Lippmann mathematical equation:

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

where θ_0 is the contact angle of droplet in absence of voltage, θ_v is the droplet contact angle when applying voltage, $\varepsilon_0 \varepsilon_d$ is the dielectric constant of insulated layer, d is thickness of this layer, γ_{lv} is surface energy of droplet in vapor-gas interface and V refers to the electrical potential. In the beginning of 1990's, Berge [2] gave a new concept of electrowetting; he used a thin dielectric layer between a droplet and electrode and found that by increasing the electrical voltage, the contact angle was reduced.

This study was the introduction of a new category in electrowetting field called "Electrowetting On Dielectric " (EWOD). As shown in Fig. 1a, in equilibrium situation $\theta_a = \theta_b$. If for any reason, one of these two angles become larger than the other, droplet starts to move from the higher contact angle towards the side with a lower angle. (Fig. 1b)

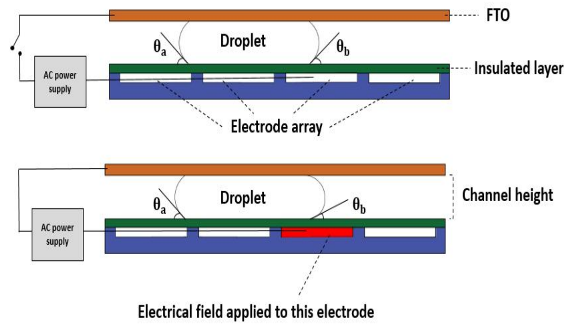

Fig. 1: Droplet configuration in (a) equilibrium where no voltage is applied and (b) after voltage is applied at the right electrode which leads to a resultant force to the right on the droplet.

In recent years, many studies have been performed to investigate different parameters that can affect the droplet's movement. Lienemann et al. [3] studied the effect of the electrodes shape on the process. He showed by two distinct methods that a sinusoidal interdigital shape works better than a simple-edge and a zigzag shape. The interdigital electrode shape, however, is difficult to fabricate. In addition, because of its shape, the risk of break down will be increased. Rajabi et al. [4] presented a new shape called "crescent". They found numerically and experimentally that this new kind of electrode leads to a velocity increase and acceleration of micro-droplet in comparison to other electrode shapes. Xu et al. [5] investigated the electrode shape on another application of electrowetting namely droplet dispensing. They noticed that the reverse-crescent electrode (RCE) shape leads to a lower voltage compared to that of the direct-crescent electrode (DCE) (see Fig. 2). The jagged and square shapes required more voltage compared to the crescent shape.

In this paper, the effect of micro-channel geometry on the threshold voltage for moving the droplet in two configurations of RCE and DCE is studied.

Experimental setup

A major part of this study is focused on the size of the micro channel. Therefore, channels are produced from PVC sheets with three thicknesses (200, 300 and 400µm). In fact, when the setup is assembled, this thickness will be the channel height. By a laser cutting operation, the grooves in two sizes (1500 and 1800 µm) are made on the sheets. An important part of this setup is the PCB, which is mechanically supports and electrically connects electronic components using conductive tracks, pads and other features etched from copper sheets laminated onto a non-conductive substrate. The thickness of copper coated on the board as electrodes is 30 µm. As shown in Fig. 2, the crescent-shaped electrodes

1,2. Graduate Student of Mechanical Engineering
3. Professor, mpfard@um.ac.ir (corresponding author)

are sequentially set on the board with a distance of 100 µm with a crescent radius of 1000 µm. According to electro-wetting on dielectric, a layer of BOPP (Biaxially Oriented Polypropylene) with a thickness of 25 µm on the PCB acts as the dielectric. To complete the electrical field, on top of the droplet, conductive glasses are needed; therefore, the FTO is a good choice which not only can pass the electrical current and complete the field but also allows taking photos of the droplets. The FTO (Fluorine Tin Oxide [SnO_2: F]) is a transparent conducting film typically used as electrodes when a situation calls for low resistance electrical contacts without blocking light.

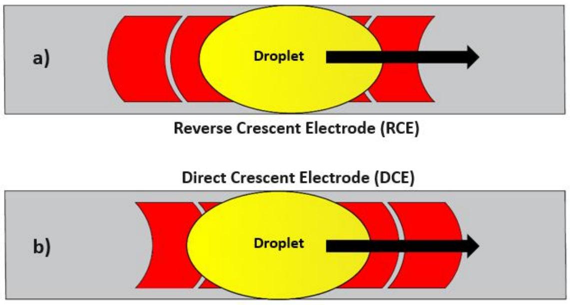

Fig. 2: Two different electrodes array studied in this paper

The volume of the mercury droplet was 1l. As shown in Fig.3, this droplet covered at least more than one ccrescent-shaped electrode depending on the channel height and width. A variable voltage supplier is connected to the PCB electrodes and the FTO. The voltage is applied on the electrode located in the side where the droplet is going to be moved. The voltage is increased gradually until the droplet starts to move. This voltage is then recorded as the threshold voltage.

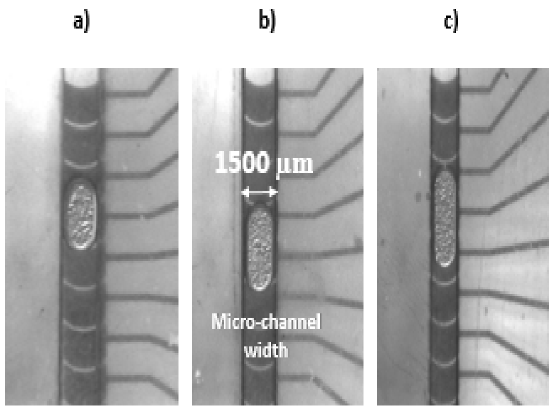

Fig. 3: Position of mercury droplet in a 1500-width micro-channel with a height of (a) 400µm, (b) 300µm, and (c) 200µm

Result and Conclusion:

In order to assess the effect of channel dimensions on the threshold voltage of mercury droplet, six micro channels consisting of a combination of two different widths and three different heights are fabricated and tested. Furthermore, for evaluating the effect of electrodes shape, all of these testes are repeated in two configurations of RCE and DCE as shown in Fig.2

As Fig.4 and Fig.5 show when the width of a micro channel is constant, by increasing the channel's height the threshold voltage is decreased and this trend is observed in both RCE and DCE. It is clear, however, that the RCE leads to a lower threshold voltage compared to the DCE. The other point inferred from these figures, is that for a constant micro-channel height, increasing the width of the channel decreases threshold voltage. By analyzing the sensitivity of the mean threshold voltage to the channel height and width, it is shown that, this voltage is more sensitive to the channel height than the channel width

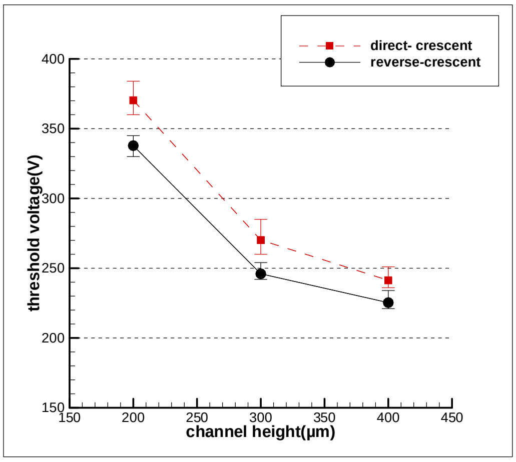

Fig. 4: The effect of channel's height on the threshold voltage in a 1500µm-width microchannel

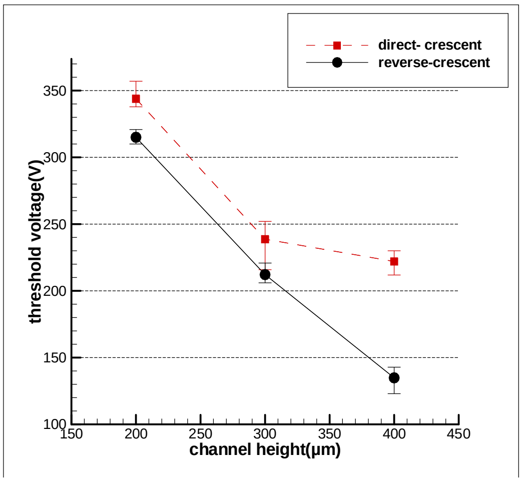

Fig. 5: The effect of channel's height on the threshold voltage in an 1800µm-width microchannel

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