Rapid Fabrication of Close-Typed Electrowetting on Dielectric Devices

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Abstract

Electrowetting on Dielectric (EWOD) devices have become a common device for manipulating liquid droplets in chemical, electrochemical, disease diagnosis and biomaterial detection processes. EWOD devices are prefect platform for Lab-on-a-Chip devices due to their simplicity with no moving parts and high manoeuvrability precision. In this paper, the rapid fabrication procedure of close-type EWOD devices is proposed. The EWOD electrodes was designed to manipulate droplets as small as 8 microlitre. The experimental test reveals that the droplet velocity increases with the magnitude of applied voltage. The further experiment also confirms the capability of the fabricated EWOD on droplet dispersion, which is common requirement for Lab-on-a-chip applications.

1. Introduction

Electrowetting on dielectric devices are a microfluidic device that can be designed specifically for transport, disperse and mixing of liquid droplets. EWOD devices can be used to manipulate small droplets in the vicinity of microlitre [1] to nanolitre [2]. With their precise manipulation of small droplets, EWOD devices are widely used in biomaterial detection such as electrochemical property detection [3], and polymerase chain reaction PCR [4]. Recently, EWOD devices have become common platform for Lab-on-a-Chip devices [5]–[7]. EWOD devices utilize the induced electromotive force to disturb the equilibrium of droplet surface tension, thus causing the droplet to move in order to sustain the equilibrium state.

In this paper, the focus is on proposing the rapid fabrication technique of closed-type EWOD devices. The configuration of typical closed-type EWOD devices in Figure 1 are composed of bottom plate, lower electro layer, hydrophobic layers, dielectric layer, and top electrode layer. The bottom plates or substrates must be rigid, stiff, durable to heat, non-electroconductive, and well-adhesive to metal such as SiO2 plate [7] and glass slide [8]. The lower electrode must be fabricated with high conductive materials. The high conductive electrode allows precise manipulation of droplet movement.
on EWOD devices [9]. The common materials for electrode layer are gold [10], silver [10], and copper [12]. The dielectric layer must be fabricated with high dielectric constant materials such as PDMS [13], and Parylene C [14]. Both hydrophobic layers are important to the magnitude of surface tension and droplet contact angles. The common hydrophobic layers are fabricated by Teflon spin coating [15]. The top layer is normally made of IOT glasses or FOT glasses to allow visual possibility, rigidity and electricity conduction. The top layer then also acts as the top electrode layer. Medium layer sandwiched between the hydrophobic layers are left for material tested. Sometimes the medium layer is filled with mineral oils in order to control the droplet size and to prevent the outside chemical interference on tested droplets.

Normally, fabrication of EWOD devices are complex and requires sophisticated equipment in order to create precise layers of EWOD devices. In this paper, the rapid fabrication technique is proposed with the objective of providing common accessibility to microfluidic and biomaterial detection research on EWOD devices to the Lab-on-a-chip platform. The responsive velocity of droplet movement in EWOD devices fabricated by proposed rapid technique due to applied voltage is also reported in this paper. Further dispersion behaviour of droplets in EWOD device is also mentioned in this paper.

![Figure 1](image)

**Figure 1.** Configuration of a closed type EWOD device

### 2. Bottom Electrode Design

The fabrication of closed type electrowetting on dielectric devices started from imprinting lower electrode layer on the substrates. The size of each electrode is important and directly related to the volume of controlled droplets. The smaller droplet requires the smaller size of electrode. The relation of droplet volume and the geometry of electrodes and void space in Figure 2 [16] is described in Equation (1)

\[
V_{full} = \frac{2L}{3} \pi (3w^2 + 2L^2)
\]  

where

- \(2w\) is the width of each electrode [m]
- \(2L\) is the width of the void space of EWOD device [m]

In this paper, the size of bottom electrodes is fixed at 3 mm. x 3 mm. and the width of the void space of medium space is 1 mm. When considering the corresponding droplet volume according to relation in Equation (1) and the width of medium space at 1 mm, the suitable volume of droplets for
3 mm. x 3 mm. electrodes is about 7.59 microlitres. In this design in Figure 3, the gap space between two adjacent electrodes is 0.15 mm.

![Figure 2. Geometry of Droplets and Closed Type EWOD devices](image)

![Figure 3. Bottom electrode geometry](image)

### Table 1
The droplet volume according to electrode size at the width of medium space equal to 1 mm

| w (mm) | Volume of Droplet (microliter) |
|--------|--------------------------------|
| 1.00   | 3.67                           |
| 1.25   | 5.43                           |
| 1.50   | 7.59                           |
| 1.75   | 10.14                          |
| 2.00   | 13.09                          |

### 3. Proposed Rapid Fabrication Procedure
This paper is aimed to propose the rapid fabrication procedure of EWOD devices with low fabrication cost and requiring less complex equipment. This work will be benefit in providing the accessibility to public and educational institutes for acquiring EWOD and Lab-on-a-chip technology. Materials was carefully selected in this work to provide common usage in fabricating each EWOD layer. The main materials in this work are included of:

1. Printed Circuit Board (PCB), which is used as substrate and imprinted bottom electrode layer,
2. Teflon Film, which can be used to fabricate both dielectric and hydrophobic layers simultaneously,
3. Mineral Oil, which is used to fill the void or medium space for controlling droplet size and contact angles of testing droplets.
4. Conductive coat glass (FTO), which is used as the top electrode layer and rid of the EWOD devices.

3.1 Fabrication of the bottom plate and bottom electrode layer by utilizing PCB
The photolithography technique using photo-responsive dried film in Figure 4 is applied to imprint electrode layout on Printed Circuit Board (PCB). The fabrication in this step is included of

3.1.1 Preparation of photo-responsive dried film
The photo-responsive dried film must be cut with similar size of printed circuit board (PCB). The hot roll process with the rolling temperature of 150°C by heat plate is used to strict the dried film on to the PCB as in Figure 5.

![Figure 4. The photo-responsive dried film](image1)

![Figure 5. The photo-responsive dried film on PCB after hot rolling process](image2)

3.1.2 Fabrication of negative film mask
Negative dried film mask is used to create the electrode layout on the photo-responsive film. For simplicity, the transparent paper was used to create the negative film mask. The typical laser print with high dot per inch (dpi) is used to print the electrode layout on the transparent paper as in Figure 6.
3.1.3 Imprinting Electrode Layout on PCB by Applying UV Light
The chemical substance coated on the photo-responsive film will be solidified under ultraviolet light. After covering the photo-responsive dried film rolled on PCB in Figure 5 with the negative film mask in Figure 6, the typical UV lighting as in Figure 7 was then applied for 8 seconds to form the electrode layout on the PCB.

3.1.3 Etching process
This etching process is a common electronic circuit fabrication technique. The part of copper coated on PCB that is not covered with the solidified film on top of the PCB can be removed under etching process. During the etching process, the PCB was soaked with aqueous acid solution at 60–70°C for 15 minutes. After the uncovered copper was removed from PCB in Figure 8 (a), the PCB was then soaked in aqueous sodium hydroxide to remove the photo-responsive chemical substance. In the end, the clear bottom electrode layer was successfully imprinted on PCB as in Figure 8 (b).
3.2 Fabrication of Both Dielectric and Hydrophobic Layers by Applying Teflon Film

Instead of coating the dielectric materials on PCB to create the dielectric layer and then coating Teflon-AF on the dielectric layer to create the hydrophobic layer, Teflon film with thickness of 40 micron as in Fig. 9 was applied to create directly on the PCB to create both dielectric and hydrophobic layers. The mineral oil film was applied on the PCB to prevent air bubbles prior to applying the Teflon film. The surface tension of mineral oil also adheres the Teflon film to the PCB and prevent the peeling off between the film and the PCB surface.

3.3 Mineral Oil Filling For Droplet Protection

Mineral Oil has very low chemical activity and low viscosity comparing to other oils. Mineral oil was applied to fill the void space or the medium space between the top and bottom plates of closed-type EWOD devices for protecting the tested droplets from excessive heat that may cause evaporation, for improving droplet contact angles, and for protecting droplets from chemical contamination.

3.4 Conductive FTO Glass As the Top Plate

FTO glasses normally coated with conductive materials such as Fluorine-doped Tin Oxide was used as the top plate of the closed-type EWOD device in this work. The light transparent characteristics of FTO glasses also allows the visibility of droplet movement in the medium layer. Thus, the FTO glasses are perfect for fabricating EWOD devices for Lab-on-a-chip application.
4. Experimental Set-Up
The experimental test was set-up to study the droplet movement in the EWOD devices fabricated by the proposed method. The equipment for controlling experimental test conditions in Fig. 10 are composed of
1. A step-up transformer with the discharge voltages in the range of 450 – 750 Volts,
2. A function generator for controlling the frequency of applied electrical field,
3. A power amplifier for controlling applied voltages,
4. A sequential controller for controlling the sequence of applying voltage on each electrode.

![Diagram of control equipment set-up and power supply for EWOD devices](image)

**Figure 10.** Diagram of control equipment set-up and power supply for EWOD devices

5. Experimental Results
The experimental test was done of the droplet with the controlled volume of 8 microlitre, which is slightly bigger than the 7.56 mm limit reported in Table 1. The electrical control was connected to the EWOD device fabricated following the guideline in this paper as in Figure 10.

![Responsive velocity graph](image)

**Figure 11.** The responsive velocity according the magnitude of applied voltages at 1,000 Hz

The frequency of the applied electrical field was fixed at 1,000 Hz, while the applied voltage was in the range between 450 – 750 Volts. The responsive velocity of droplets was determined based on the minimum of switching time for applying voltage on each EWOD electrode. The responsive velocity is reported in Figure 11, in which the droplets move faster as the voltage increases.
Further study on dispersion behaviour of droplets in the EWOD devices is shown in Figure 12, where the droplet volume was successfully split into half on the EWOD device fabricated following the guideline in this paper.

![Figure 12. the dispersion behaviour of droplet in the fabricated EWOD devices](image)

6. Conclusion
In this paper, the new rapid fabrication procedure of EWOD was proposed in order to provide accessibility of such devices to public and educational institute, who are interested on microfluidic and Lab-on-a-chip technology. The responsive velocity on EWOD fabricated following the guideline of this paper are collected and reported, in which the responsive velocity increases with parabolic relation with the magnitude of applied voltages. In this case, the empirical relation between the responsive velocity \( v \) and the applied voltage \( V \) at fixed frequency of 1,000 Hz can be described as Eq. (2) for the applied voltage in the range between 450 - 750 Hz. The maximum responsive velocity is 8.57 mm/s at the applied voltage of 750 Volt.

\[
v = 6 \times 10^{-5} V^2 - 0.0482 V + 11.078
\]

The further experiment also confirms the capability of such devices for droplet manipulation, -i.e. in this case, the dispersion capability, thus allowing such devices as the perfect platform for microfluidic and Lab-on-a-chip technology.

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