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# Voltage and Capacitance Analysis of EWOD System Using COMSOL

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**Abstract:** Electrowetting on Dielectric (EWOD) is widely practiced digital microfluidic technique, used in Lab-on-a-Chip (LoC) system for biomedical application. The problems with EWOD device for biological sample are the damages of the cells with high applied voltage across it and very often droplet loses its track in the system. Understanding of the electrostatic properties of digital microfluidics, like voltage distribution and capacitance is somewhat limited. Therefore, information about the exact applied voltage across test sample, its current position on the device is required for effective analysis. In this work voltage analysis will provide the behaviour of the voltage distribution around the droplet, while capacitance analysis will allow for the ability to indicate the current position of droplet and to identify the composition of the fluid.

**Keywords:** EWOD, micofluidics, voltage distribution, capacitance, COMSOL.

## 1. Introduction

Electrowetting on Dielectric (EWOD) has now become one of the best ways to manipulate the liquid droplet in digital microfluidic system [1]. The principle of EWOD process is based on control of surface tension of a liquid-solid interface by applying electrical potential at the interface. Figure 1 shows the basic mechanism of open channel EWOD technique.

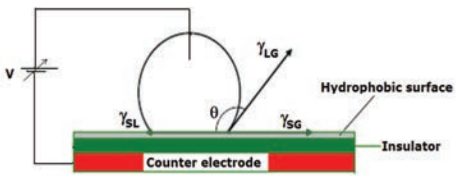



**Figure 1.** Schematic of EWOD system

A polarizable and conducting liquid droplet is placed on a substrate with a dielectric-hydrophobic layer on top of the electrode. By applying an electric potential between the droplet and counter electrode, contact angle reduces due to effective changes of solid-liquid interface energy [2]. This change in contact angle creates a pressure gradient across the droplet which drives the droplet toward the actuated electrode.

EWOD has recently emerged as a widely practiced digital microfluidic technique in biomedical applications such as Polymer Chain Reaction (PCR) [3], enzyme assays [4], proteomics [5], DNA hybridization and soft printing [6]. Now, in biomedical field this EWOD device suffers from mainly two problems- it will damage the cells if the applied voltage across the droplet is large and very often droplet loses its track in the system. Therefore, information about the exact applied voltage across test sample, droplet's current position on the device is required for effective analysis.

In this work, EWOD system is modelled as a parallel plate capacitor using COMSOL Multiphysics and analysis of voltage and capacitance have been performed. Voltage analysis will provide the behaviour of the voltage distribution in the system when a droplet is stationary over the charged electrode, or when a droplet is moving between electrodes. Capacitance analysis will allow for the ability to track the current position of droplet and to identify the composition of the mixed fluid.

## 2. Background

The EWOD system is very similar to a parallel plate capacitor [7]. In this system, a series of small electrodes are placed on the bottom plate, while a large, continuous grounding electrode is placed on the top plate. Both the surfaces are coated with a hydrophobic material, like Teflon, that will repel the water droplet and produce a high contact angle. The bottom plate is coated with a dielectric material, PDMS [7] to prevent from short circuiting, and to increase the range of applied voltage. Due to the presence of dielectric layer, the system will have an electrostatic potential difference distributed around it when the system is charged.

If the cross section of the EWOD system is observed then each addressable position in the

EWOD device can be modeled as a number of parallel plate capacitors connected in series [8].

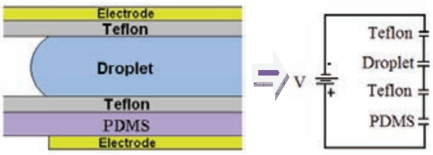



**Figure 2.** Cross section of EWOD system and equivalent electrical circuit

The equivalent capacitance in each measurement volume can be calculated as:

$$C_{Fi} = \frac{\varepsilon_0 \varepsilon_T \varepsilon_P \varepsilon_{Fi} A}{\varepsilon_{Fi}(2\varepsilon_P t_T + \varepsilon_T t_P) + \varepsilon_T \varepsilon_P t_G} \quad (1)$$

Where ε is a dielectric constant, A is the area of the electrode, t is the thickness, and the subscripts T, P, G and $F_i$ denote the Teflon layer, the PDMS layer, the gap between the substrates, and the fluid in the measurement volume respectively. If a fluid droplet moves onto this electrode the capacitance value changes. This gives a proper indication about the droplet location.

## 3. Use of COMSOL Multiphysics

One of the main physics behind EWOD phenomenon is electrostatic energy stored in the capacitors formed in the system. Because of the system's similarities with a parallel plate capacitor, it can be modelled using COMSOL Multiphysics under DC Electrostatic physics. Using COMSOL Multiphysics, the total electrical charge on the surface of one of the electrodes can be determined. The capacitance can then be calculated between the electrodes by using definition of capacitance:

$$C = \frac{Q}{V} \quad (2)$$

Where C is the capacitance between the electrodes, Q is the surface charge on one of the electrodes, and V is the potential difference.

In this work COMSOL Multiphysics' Electrostatics model under AC-DC Model is used, which allows to calculate the electric field of the system in the presence of dielectric materials, using finite element analysis.

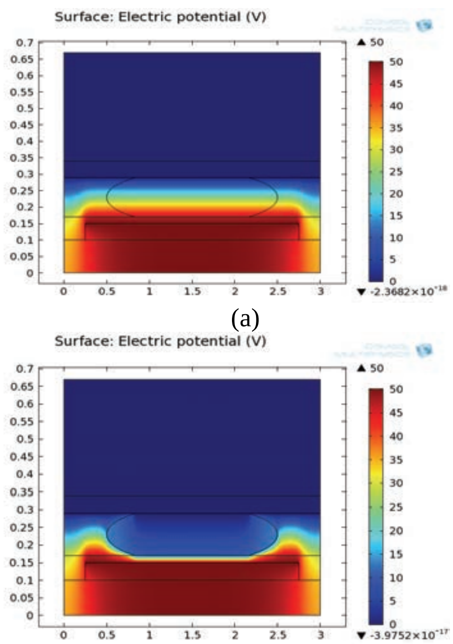
For the Material settings, the relative permittivity (dielectric constant) of the dielectric material in the model is set at $\varepsilon_r = 80$ for water, $\varepsilon_r = 3.0$ for PDMS, and $\varepsilon_r = 1$ for air. 'Ground' boundary condition is applied to all of the faces of the ground plates and 'Terminal' boundary condition (Voltage) is applied to the faces of the bottom plate. For all the other boundaries of the model, the default 'Zero Charge' boundary condition is selected as free space.

## 4. Results and Discussions

For the analysis, a typical EWOD system is modeled as 2D system with the electrode dimension of 2 mm × 50 μm. The height between top and bottom electrode is 80 μm. Depending on the scenario, water, air, and/or other dielectrics will be placed in between and/or surrounding the electrodes to understand the effect of droplet property. At first, for investigating the effect of dielectric layer and voltage distribution in the system thickness of the PDMS layer is varied.

### 4.1. Effect of Dielectric layer

Figure 3 shows the voltage distribution for a 20 μm PDMS layer with the gap between the top and bottom electrodes filled with water and air.




(a)

(b)

**Figure 3.** Voltage distribution in EWOD system for (a) air, (b) water filling the gap

If there is only air in the gap between the top and bottom surfaces, PDMS has a negligible effect on the voltage, giving a 94.6% voltage drop across the gap with respect to ground. For water filling the gap, voltage drop across the droplet is 18% of total applied potential. This voltage drop decreases with increasing thickness of PDMS as shown in Figure 4.

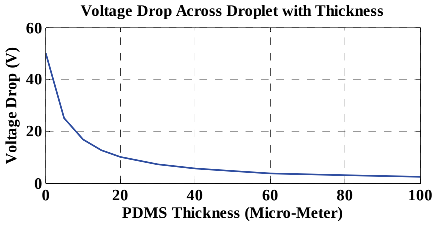
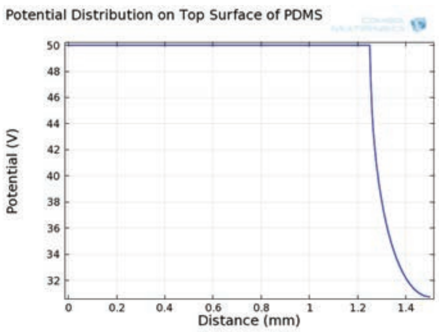
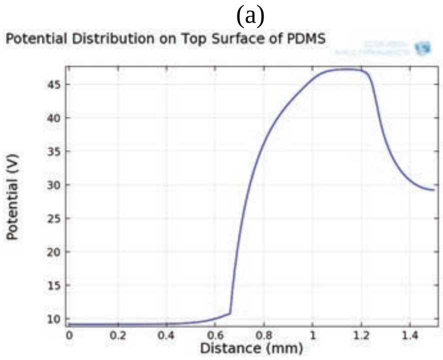



**Figure 4.** Voltage drop across droplet versus PDMS thickness




(a)




(b)

**Figure 5.** Voltage distribution on (a) bottom (b) top surface of PDMS

For the water case, because of the large voltage drop across the PDMS, it is interesting to see the behaviour of the voltage at the edge of the electrode. Figure 5 shows the voltage distribution at the bottom surface of the PDMS, which represents the case with no PDMS, against the voltage at the top surface of the PDMS. Comparing the voltage with respect to the distance from the centre, there is a constant voltage drop across the PDMS up until the edge of the electrode at 1mm. The maximum voltage drops across the PDMS appears at the edge of droplet, which supports the Maxwell stress tensor at the solid-liquid contact line in EWOD [7].

Thus depending upon application and biological sample thickness of dielectric layer is changed to keep the applied potential across the droplet under the maximum allowable potential.

### 4.2. Voltage distribution during droplet covering half of the gap

It is useful to understand how the voltage behaves at the interface between air and water over an active electrode, such in the case when the water droplet is moving. This is done by filling half the gap with air and the other half with water, as shown in Figure 6.

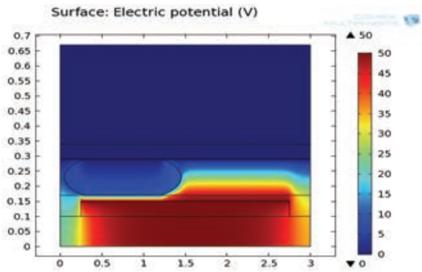



**Figure 6.** Water droplet covering half of the charged electrode

With half water and half air model, there is a bit of a shift in electric potential at the interface, but their values are the same as above far away from the interface. This indicates that although there is a shift in voltage at the interface due to continuity, the overall voltage distribution is not affected too much.

### 4.3. Capacitance variation

Using COMSOL Multiphysics, the capacitance between the parallel electrodes is found by modelling the system. COMSOL solve for the surface charge densities on the surfaces of the electrodes, then integrating over the surface area of the electrodes to determine the overall charge.

Now, to investigate the variation of capacitance value with droplet's position model is simulated by changing the droplet's position in the gap. Figure 7 shows the capacitance value variation with droplet position for both simulation and theoretical case. It shows there is a linear relationship between the capacitance value and droplet position. Therefore, by measuring the capacitance value and continuous monitoring this value one can get the track of the droplet on the device.

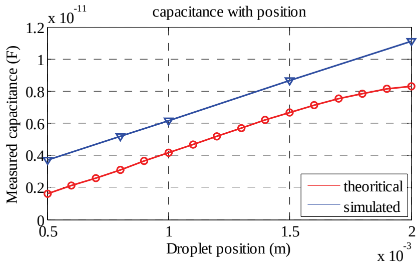



**Figure 7.** Capacitance variation with droplet position

Capacitance measurement also allows for the ability to identify the composition of the fluid, as the capacitance value differs between fluids and their composition. Using (1), it can be shown that the difference between the measured capacitance and a reference capacitance is

$$C_{F1} - C_{F2} = \frac{\varepsilon_0 A}{t_G} \phi(\varepsilon_{F1} - \varepsilon_{F2}) \qquad (3)$$

Where $\phi$ is constant for fixed thickness and area. The subscripts F1 and F2 denote the fluid being examined and a reference fluid, respectively.

Now, as the fluid within the measurement volume (F1) changes, $\varepsilon_{F1}$ changes as well as value of $C_{F1} - C_{F2}$ changes. Figure 8 shows the predicted difference in capacitance for reference fluid as air and methanol. Both cases, the increase in the difference between the capacitance and the reference capacitance with $\varepsilon_{F1}$ is approximately linear. Thus the difference between two capacitances gives the measurement of droplet composition.

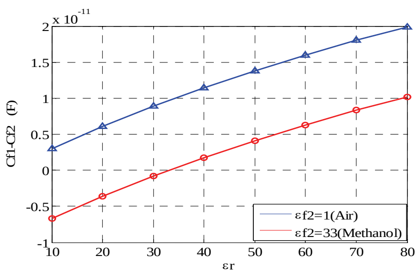



**Figure 8.** Capacitance variation with dielectric change

## 5. Conclusions

In this work, the voltage distributions of the EWOD system were studied with respect to thickness of dielectric layer, droplet's nature, and the position of the droplet with respect to the charged electrode. The voltage drop observed across the PDMS layer can be reduced by increasing dielectric thickness. Both simulation and theoretical results show that capacitance value changes linearly with the droplet position. Thus, capacitance measurement using some sensors arrangement will give indication about droplet's proper position and idea about whether droplets of different compositions have been properly mixed, or if chemical reactions have taken place.

## 6. References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