Voltage and Capacitance Analysis of EWOD System Using COMSOL

Debanjan Das[1], Shiraz Sohail[1], Soumen Das[2], Karabi Biswas[1]

[1]Department of Electrical Engineering
[2]School of Medical Science and Technology

IIT Kharagpur, Kharagpur

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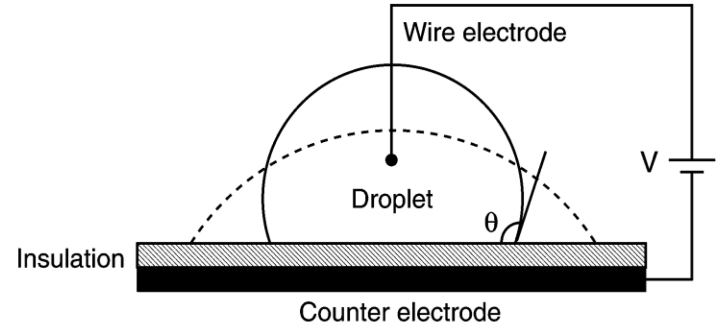
Digital Microfluidic: State of the Art…

- Manipulation of discrete droplets on an electrode array using electric fields-"Droplet processors"
- ElectroWetting On Dielectric (EWOD) has now become one of the best way to manipulate the droplet in DMS
- What is EWOD?
  - Electrical control of wettability of liquids on a dielectric material

- Application of V reduces θ due to lowering of the effective solid–liquid interfacial energy

$$\cos\theta = \cos\theta_0 + \frac{\varepsilon_0 \varepsilon_r}{2d\gamma_{LV}} V^2$$

- Main physics behind EWOD phenomenon is electrostatic energy



Schematic of Traditional EWOD system

- Advantages of EWOD:
  - Has no mechanical part
  - Control parameters are in electrical domain
  - Can perform all operations on same device by programming
  - Easy to fabricate

- Applications:
  - Lab-on-a-chip systems
  - MEMS-based fluidic devices
  - Biomedical devices
  - Chip cooling
  - Variable focal length lenses

PCR, Enzyme Assays, Proteomics, DNA Hybridization

Motivation

- Idea: Lab-on-a-Chip for clinical diagnoses
  - Use EWOD phenomenon

- Problem with EWOD system:
  - May damage the cells with high applied
  - Very often droplet loses its track

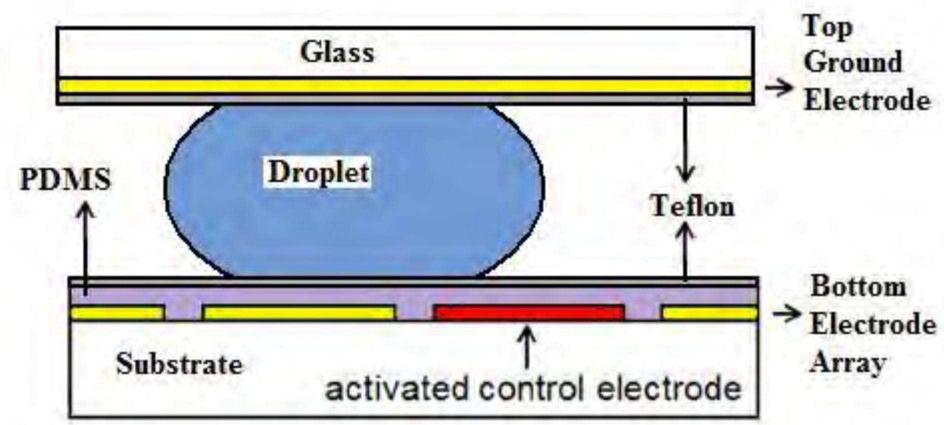
- Understanding of the electrostatic properties
  - Voltage distribution
  - Capacitance

Objective

- Analysis of voltage distribution in EWOD system
  - Applied voltage across test sample
- Modeling and analysis of capacitance
  - Current position of droplet
  - Composition of the sample

Modeling of EWOD System

- EWOD system is very similar to a parallel plate capacitor



- Each addressable position can be modeled as a number of parallel plate capacitors connected in series

Cross section of EWOD system and equivalent electrical circuit

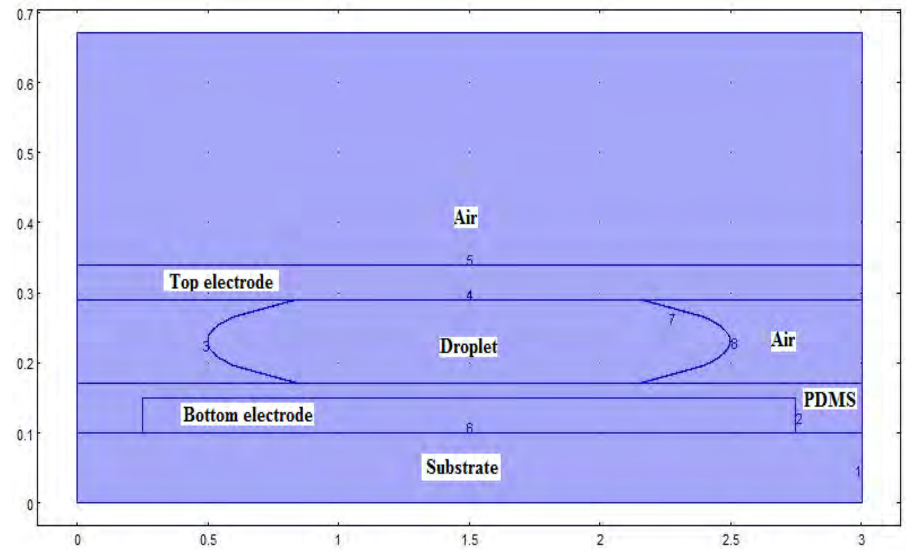
Cont……

- The equivalent capacitance in each measurement volume:

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

  - ε is a dielectric constant
  - A is the area of the electrode
  - t is the thickness
  - 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

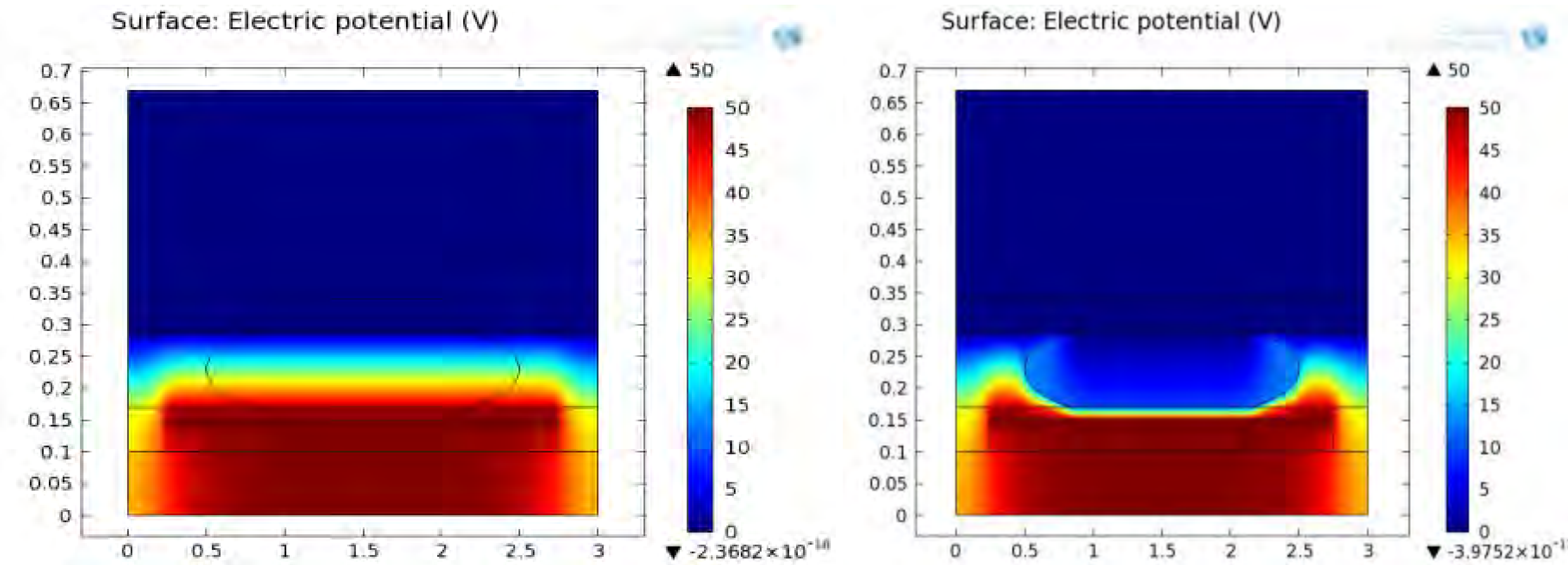
Model Definition



- DC Electrostatic physics under AC/ DC module
- Electrode dimension
  - 2 mm x 50 µm.
- Height between top and bottom electrode is 80 µm.
- PDMS thickness 20 µm
- Dielectric constant
  - Water- 80, Air-1, PDMS- 3
- Boundary condition
  - Ground- Top electrode, Terminal- Bottom electrode

Voltage Distribution

- Voltage distribution in EWOD system



Air filling the gap

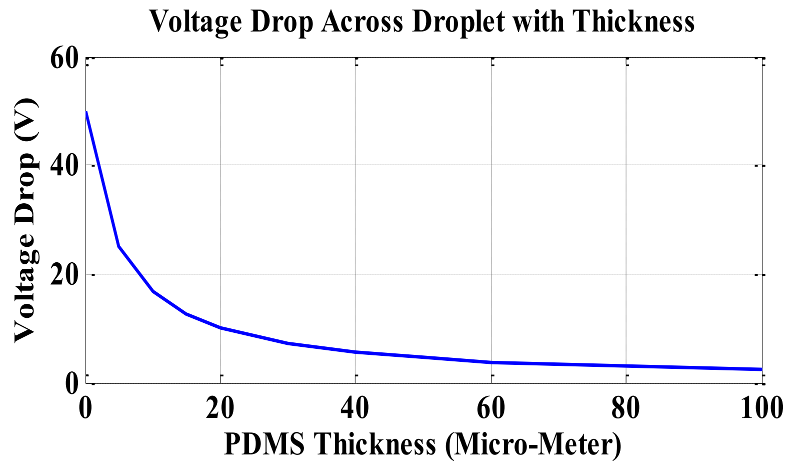
Water filling the gap

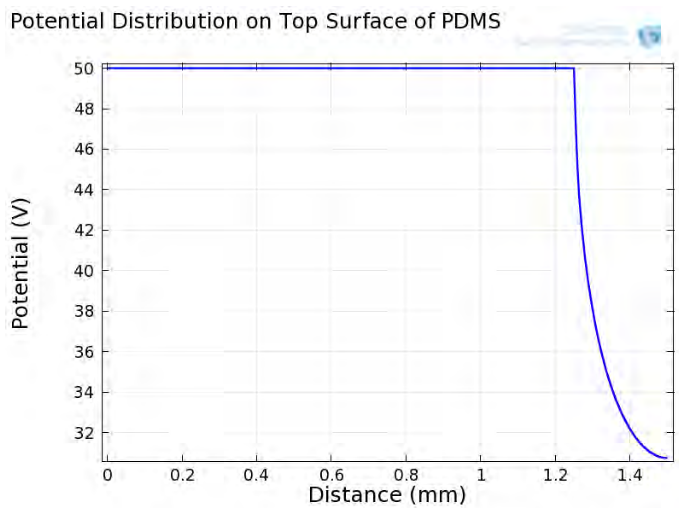
❖94.6% voltage drop across the gap

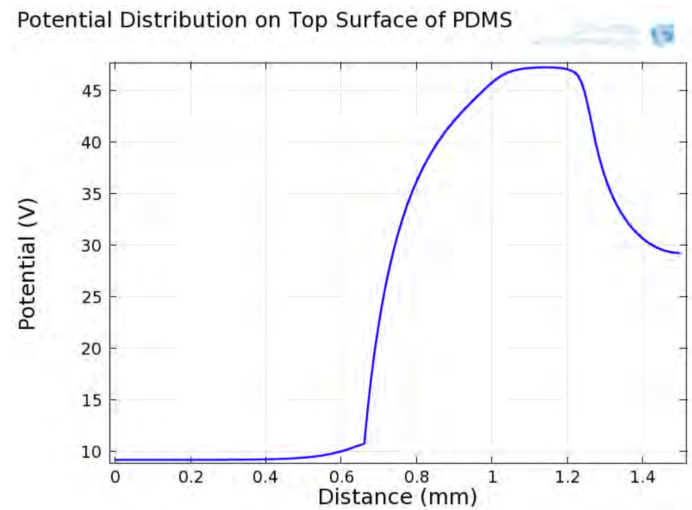
❖18%voltage drop of total applied potential

Effect of Dielectric layer

- Voltage drop decreases with increasing thickness of PDMS



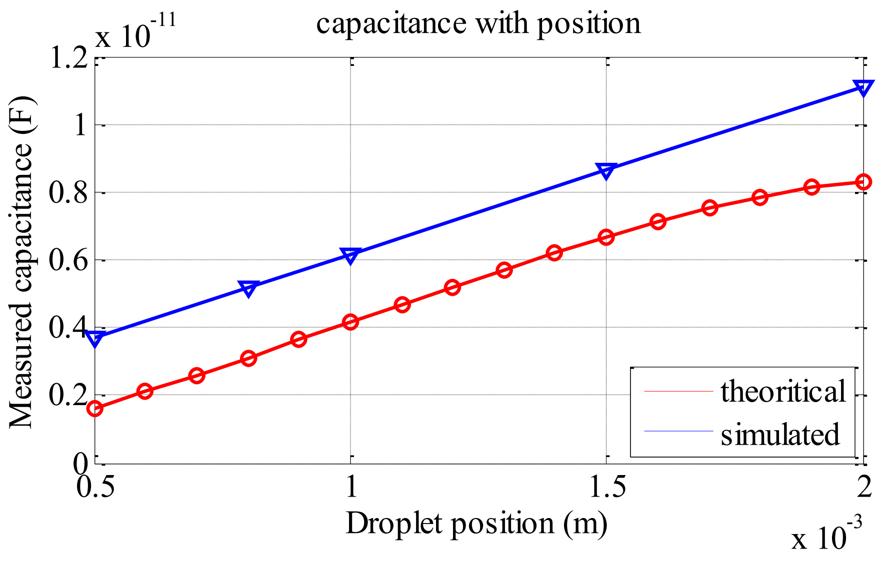




- A constant voltage drop until the edge of the electrode
- Maximum voltage drops across the PDMS at the edge of droplet

Capacitance Analysis

- Monitoring Droplet's Position
  - In each position system forms a parallel plate capacitor
  - Capacitance value is simulated by changing the droplet's position
  - A linear relationship between the capacitance value and droplet position
  - By developing a capacitance measurement system its position can be monitored



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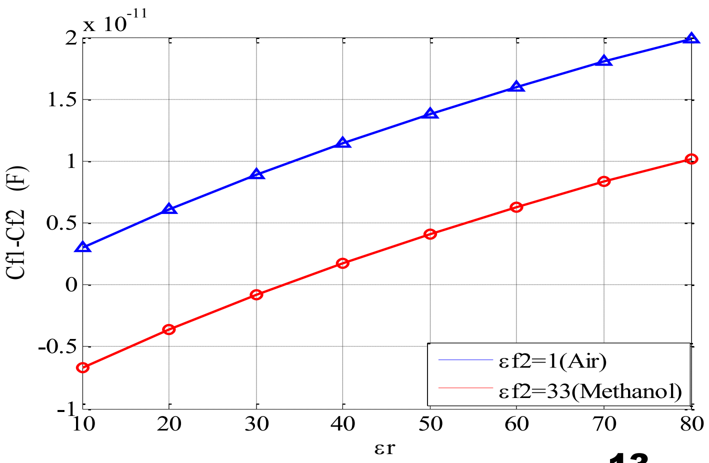
Capacitance Analysis

- Identifying Droplet's Composition
  - Capacitance value differs between fluids and their composition
  - Difference between the measured and a reference capacitance

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

  - F1 and F2- fluid being examined and a reference fluid
  - Changing of F1 $\Rightarrow$ ε_{F1} changes $\Rightarrow$ $C_{F1} - C_{F2}$ changes
  - Difference gives information of droplet composition or percentage of mixing.



Conclusion

- Voltage distributions studied with respect to dielectric layer thickness and the position of the droplet
- Voltage drop observed across the dielectric layer can be reduced by increasing dielectric thickness
- Lower voltage may protect cells from damage
- Both simulation and theoretical results show that capacitance value changes linearly with the droplet position
- Accurate capacitance measurement will give indication about droplet's proper position and idea about percentage of mixing
- 3-D modeling and inclusion of cell itself in the model are required

Reference

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Thank you