Voltage and Capacitance Analysis of EWOD System Using COMSOL

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Nov 05, 2011
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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 $\theta$ 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.
The equivalent capacitance in each measurement volume:

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

- \( \varepsilon \) 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
  - 94.6% voltage drop across the gap

- Water filling 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
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

Capacitance Analysis

droplet position (m)
measured capacitance (F)

theoretical
simulated

COMSOL Conference Bangalore 2011
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 \( \rightarrow \varepsilon_{F1} \) 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


Thank you