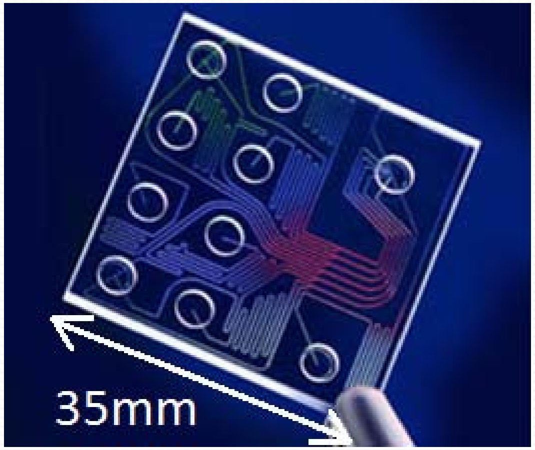
Free Surface Microfluidics Based on Electrowetting

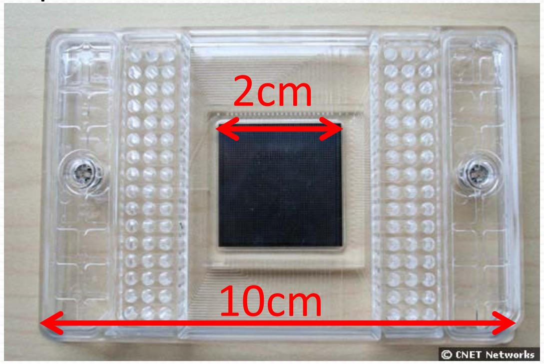
Juan David Gutierrez-Franco
Mechanical Engineering
Allan Hancock College
Mentor: Meysam R. Barmi
Advisor: Prof. Carl Meinhart
Mechanical Engineering

Why is microfluidics important?

- Reduction of laboratory size, analysis time, and sample needed
  - Micro Total Analysis System (µTAS)
    - Lab-on-a-Chip (LOC)
    - Microarrays
- Portable and easily controllable devices for chemical and biological applications



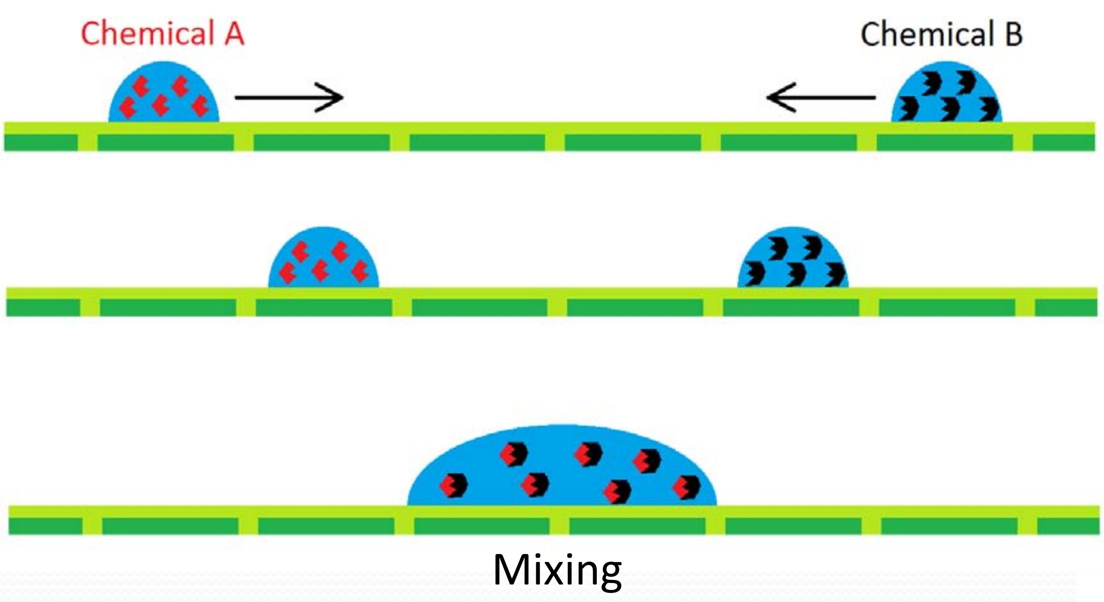
Lab-on-a-Chip (LOC)
http://gigaomized-green-demo.blogspot.com/2011/02/lab-on-chip-what-is-this.html



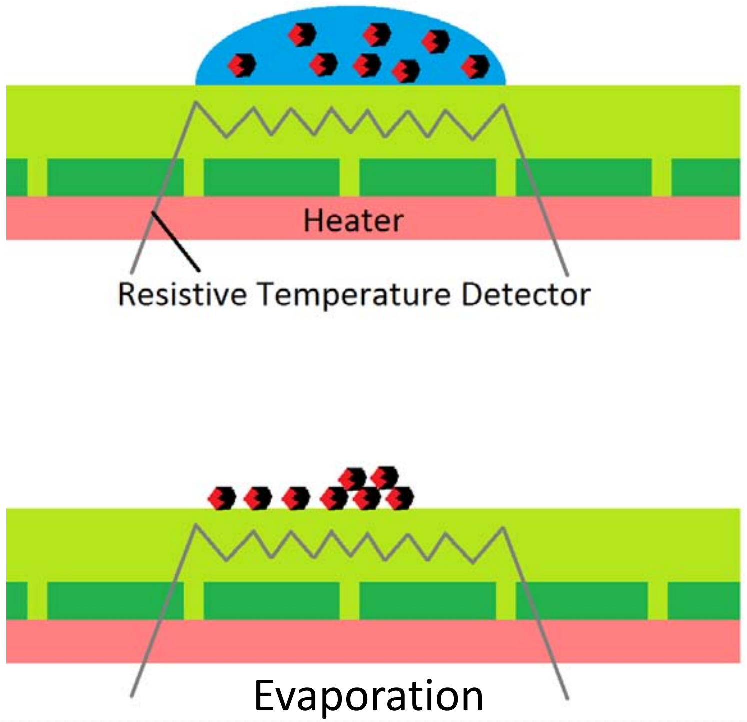
Microarray
http://i.i.com.com/cnwk.1d/i/ne/p/2007/fluidigm-007_550x367.jpg

The Big Picture

- Mixing chemicals to perform experiments

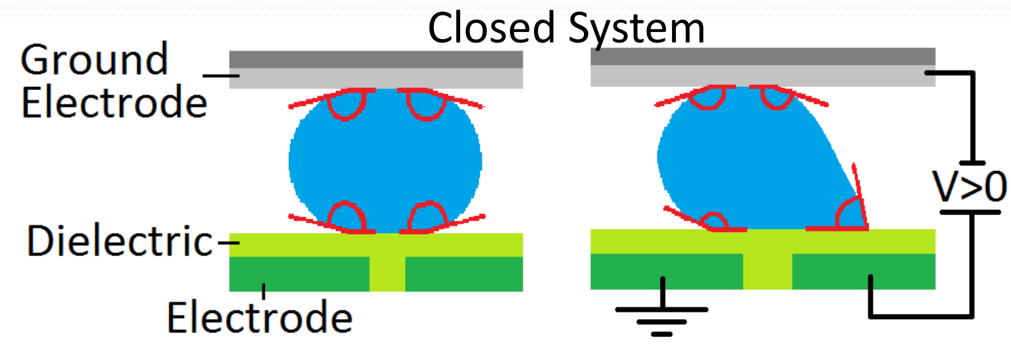


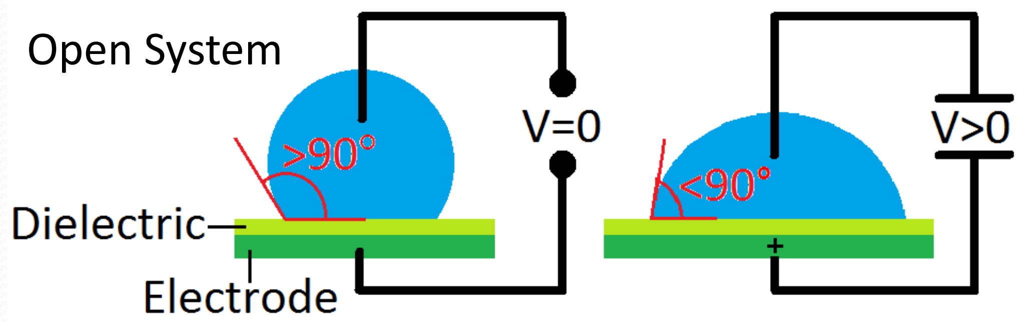
Evaporation of solvent

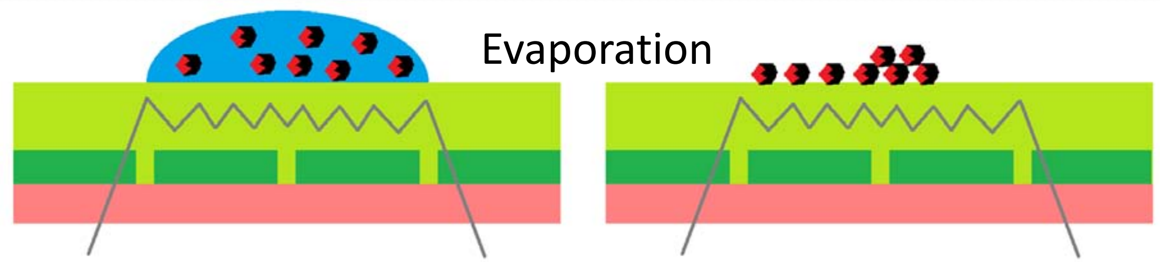


Goals of the Project

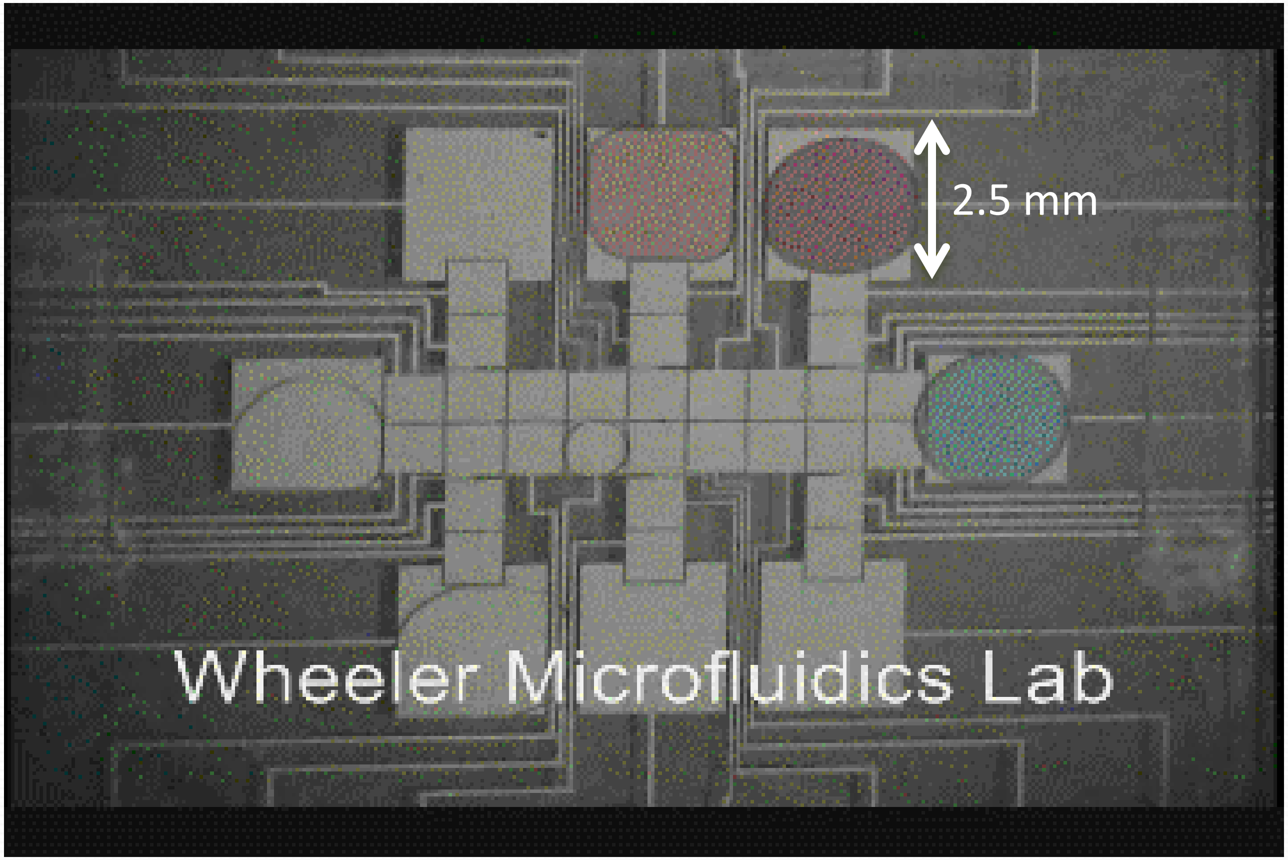
- To understand the physics of electrowetting on open and closed systems
- To create and test open surface electrowetting devices
- To lower required voltage to move droplet
- To control the evaporation rate of the droplet







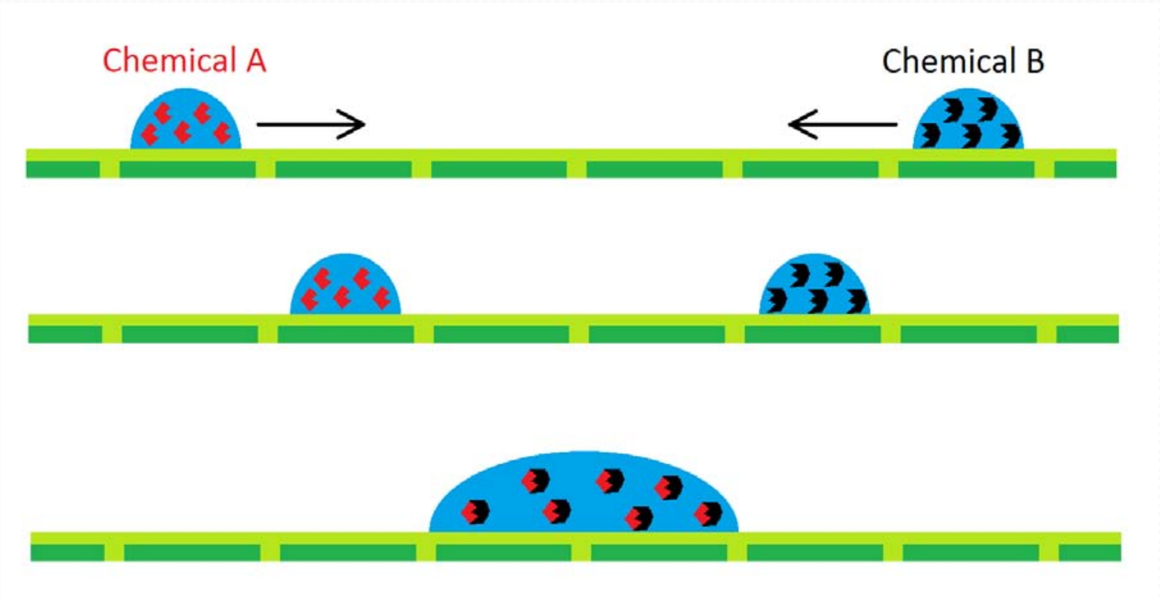
Lab-on-a-Chip mixing chemicals



Lab-on-a-Chip performing chemical reactions

http://www.chem.utoronto.ca/staff/WHEELER/html/Main.htm

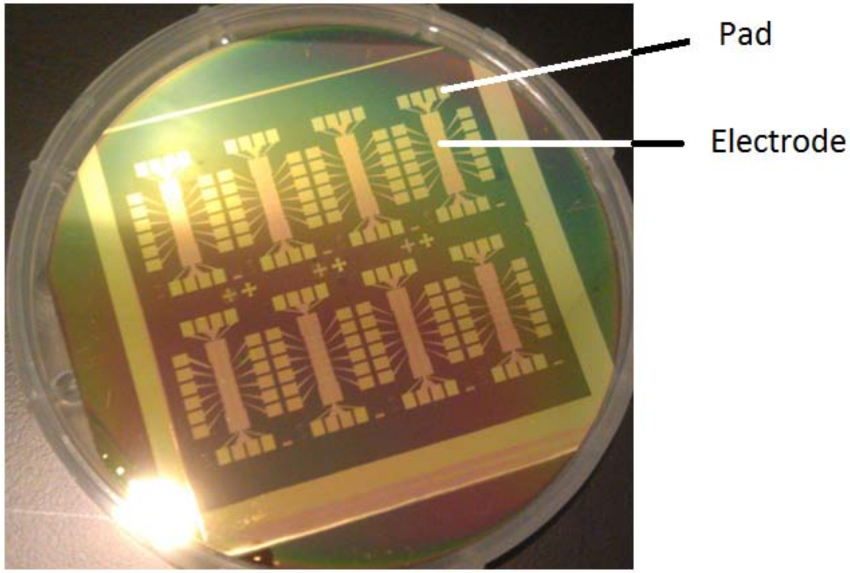
Electrowetting

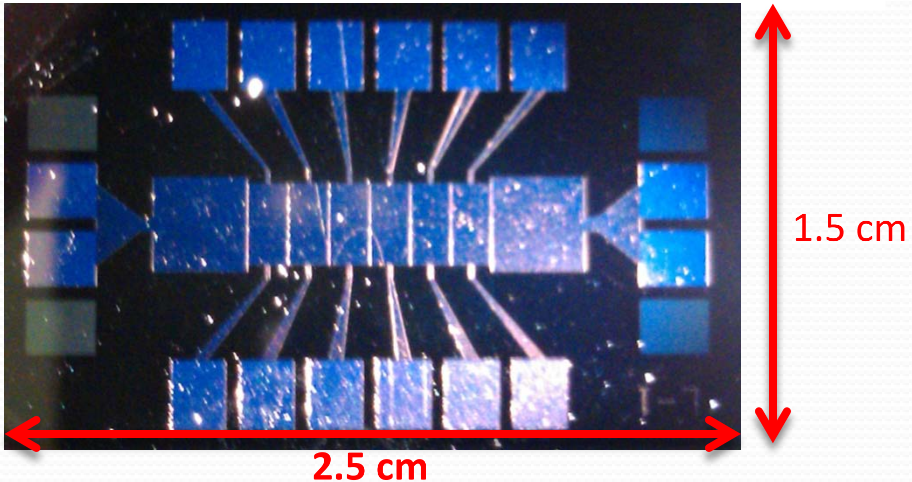


Droplets containing different chemicals need to be mixed. The movement is done with electrowetting.

Research Method: Electrowetting

- Apply voltage to droplets on chips to achieve electrowetting without electrolysis.
- Try different solution concentrations, dielectrics, voltages and frequencies.

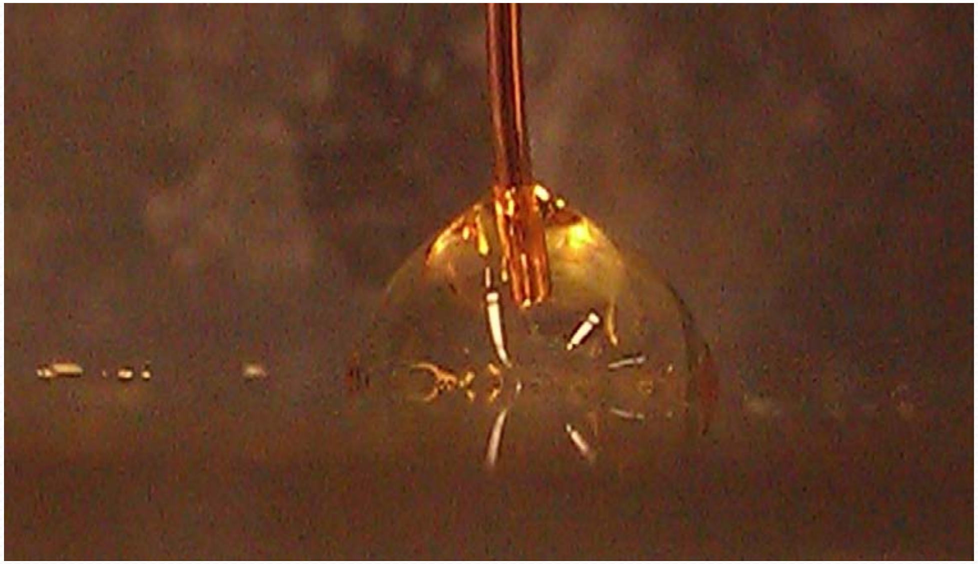


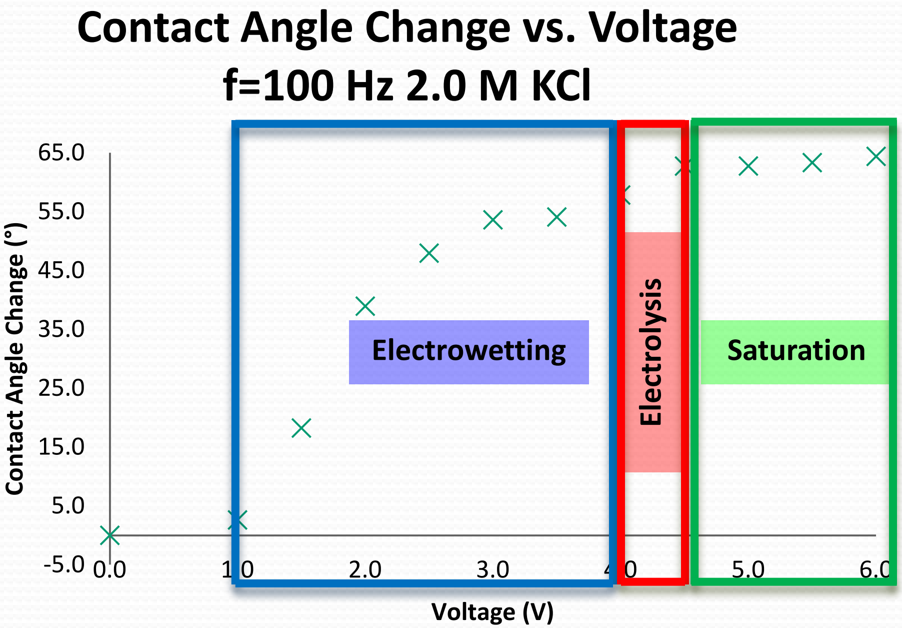


Research Method: Electrowetting

1M KCl solution 4V 1kHz gold electrode

Research Method: Electrowetting





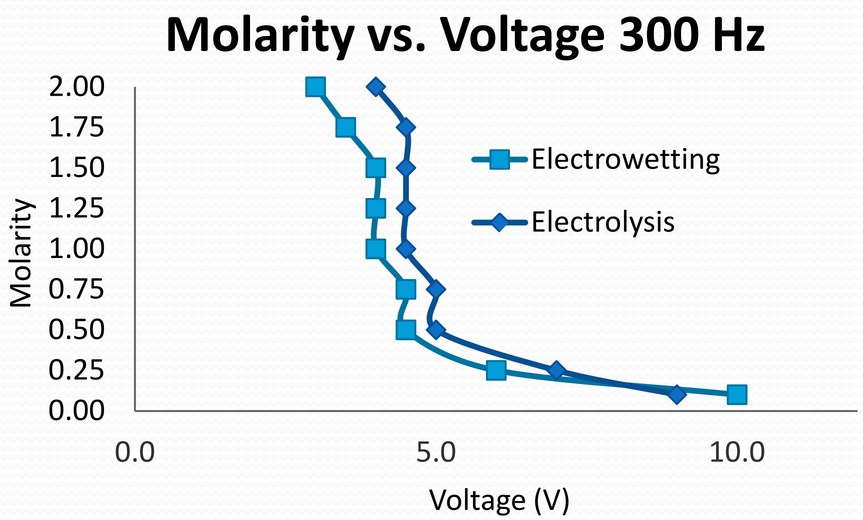
Saturation is seen once the contact angle does not change while increasing voltage.

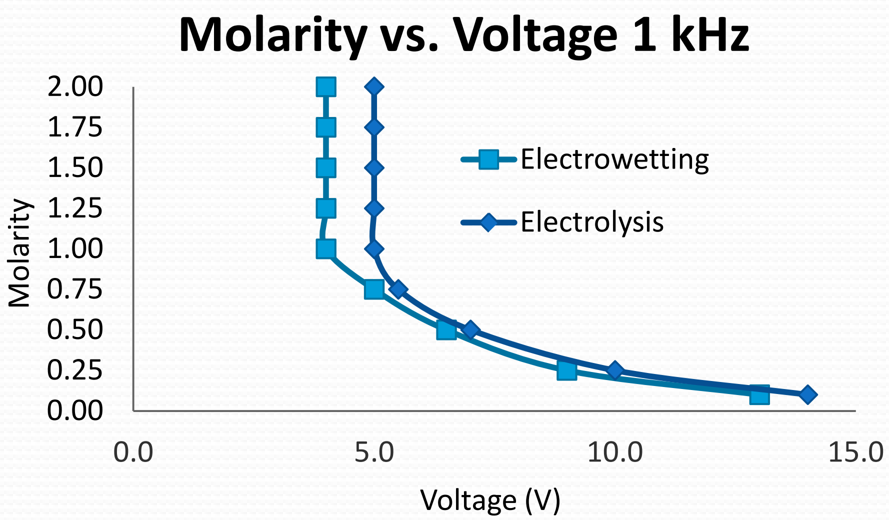
Higher molarity solutions show better response to voltage at 1 kHz

Concentration	Electrowetting	Electrolysis
1 M KCl	4 V	6 V
0.1 M KCl	24 V	16 V
0.01 M KCl	120 V	90 V

- 1 M KCl solution showed the lower voltage needed to cause electrowetting.
- As molarity dropped, electrolysis occurred sooner than electrowetting.

Effect of Molarity on Electrowetting and Electrolysis

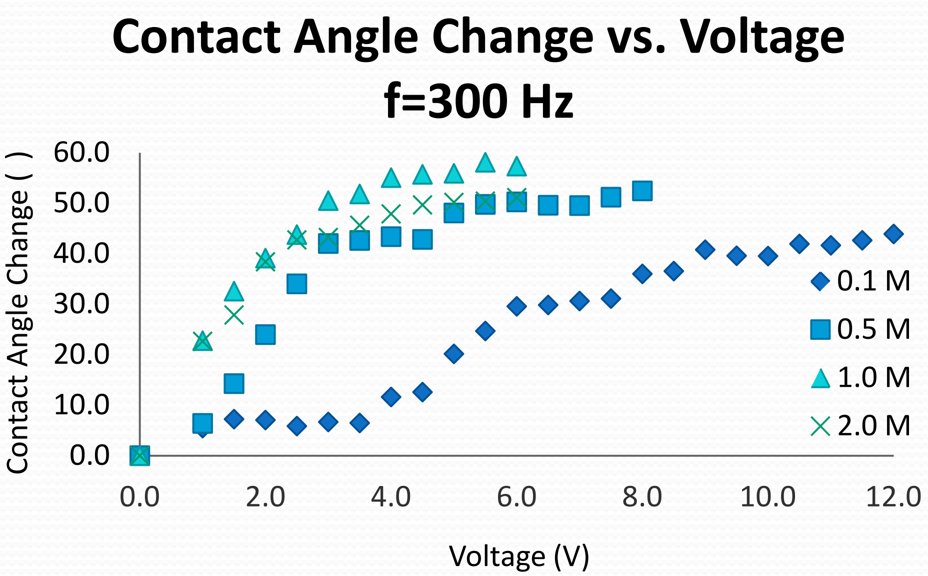


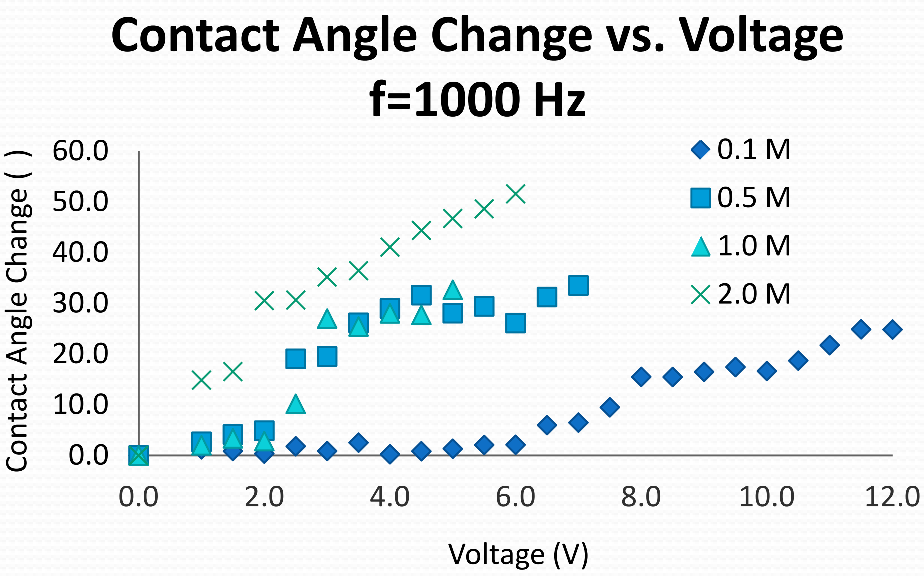


KCl solution on gold electrode with no dielectric.

- As molarity and frequency drop, electrolysis occurs sooner.

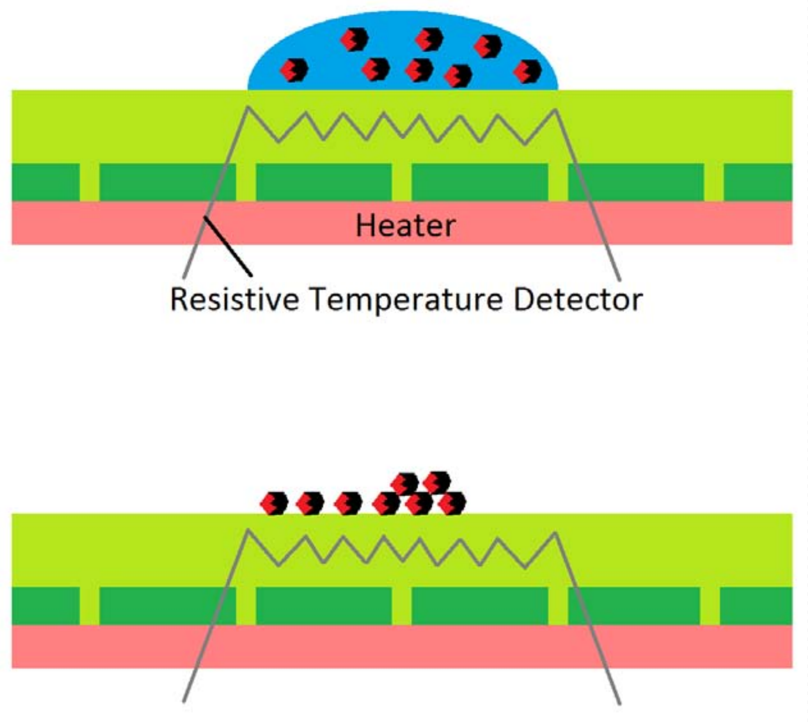
Molarity Effect on Contact Angle Change





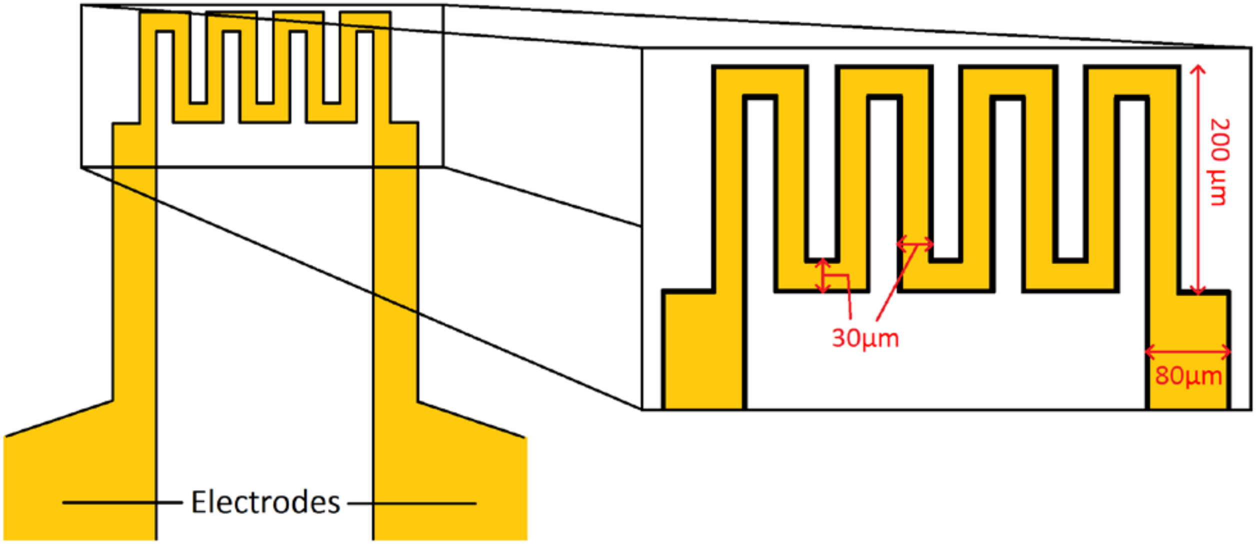
- Actuation voltage is same for all cases.
- Saturation is reached sooner by the higher molarity solutions.

Evaporation



Once the droplets are mixed, the solvent needs to be evaporated.

Research Method: Evaporation



Resistive Temperature Detector (RTD)

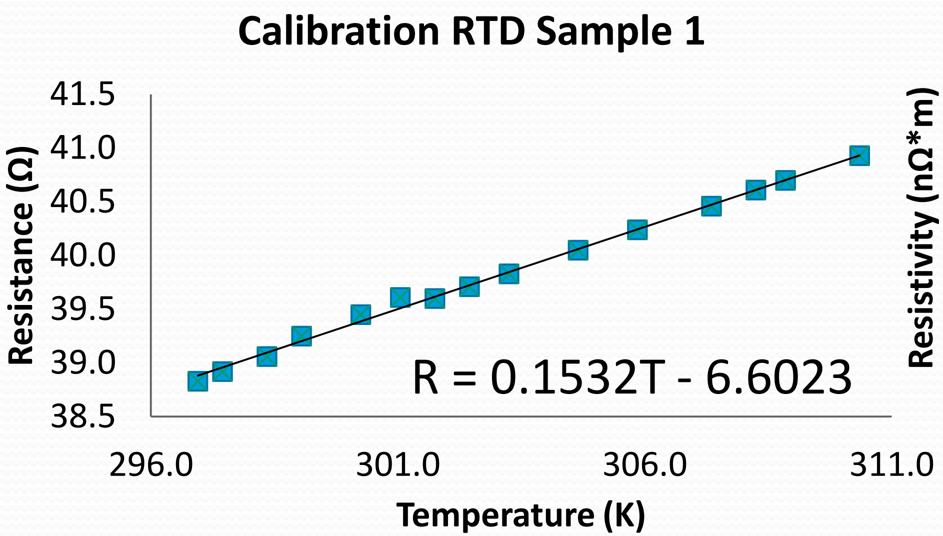
- Made of two layers: Ti/Pt (200/2500Å)
- Resistance is measured
- Resistance relates linearly to temperature

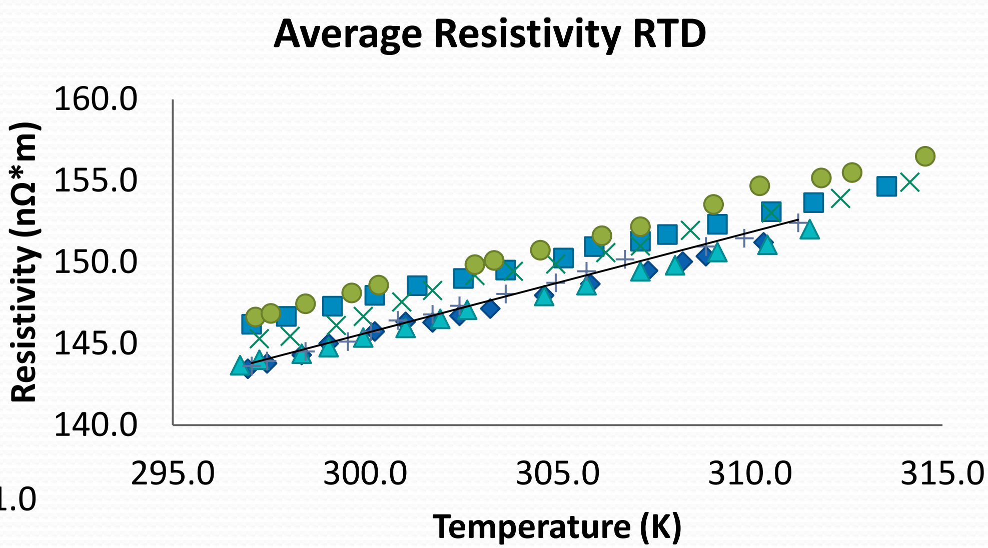
Calibration of RTD

- Fabrication can alter properties of the RTD
  - Calibration is needed for each chip
- Readings of resistance at known temperature used for calibration of RTD.

$$\boldsymbol{\rho = \rho_{ref}[1 + \alpha(T - T_{ref})]}$$

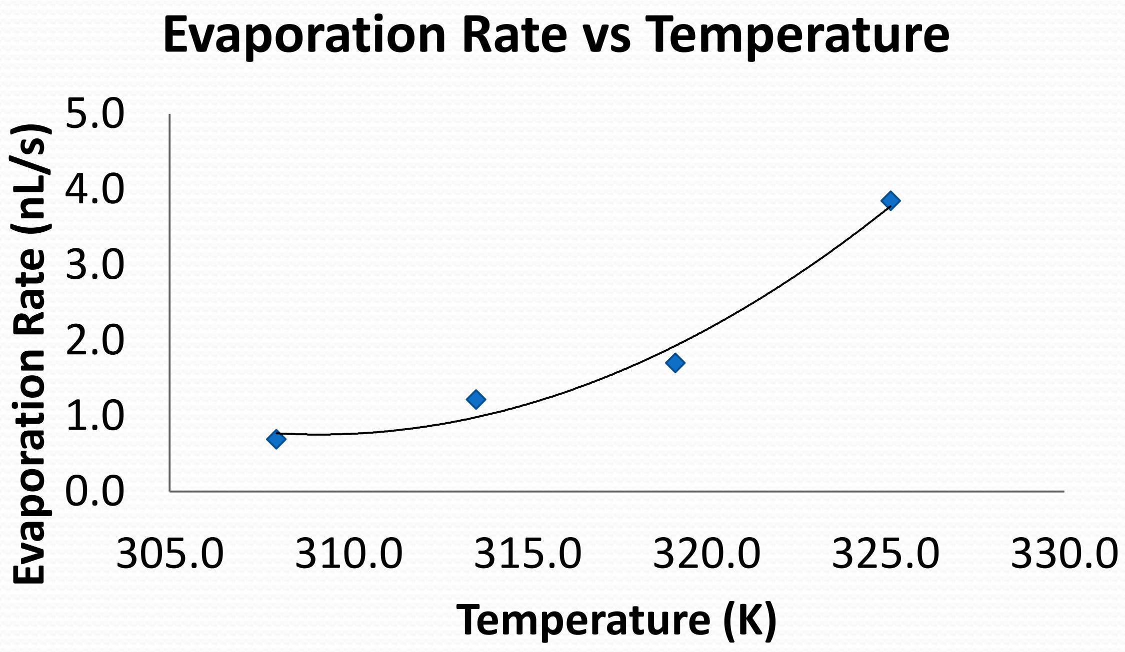
Theoretical Value	***Experimental Value***
$\boldsymbol{\rho} = 105n\Omega * m$	$\boldsymbol{\rho} = 144n\Omega * m$
$\boldsymbol{\alpha} = 0.00393K^{-1}$	$\boldsymbol{\alpha} = 0.00395K^{-1}$
$T = 20°C$	$T = 25°C$





Evaporation Time

- Evaporation rate was measured and plotted vs. temperature



- As temperature increases, the rate of evaporation of droplets increases.

Summary

- Best electrowetting seen with 1 M KCl solution with applied potential of 4V at 300 Hz.

- Manual movement of droplets has been achieved using electrowetting.

- RTD resistance increases linearly with temperature.

- Resistivity follows the equation

$$\boldsymbol{\rho} = \boldsymbol{\rho}_{ref}[\mathbf{1} + \boldsymbol{\alpha}(\boldsymbol{T} - \boldsymbol{T}_{ref})]$$

$\boldsymbol{\rho} = 144 n\Omega * m$

$\boldsymbol{\alpha} = 0.00395 K^{-1}$

$T = 25°C$

Future Plans

- Find dielectric that decreases voltage needed for electrowetting and prevents electrolysis.
- Find way to dewet a droplet after electrowetting occurs.
- Control the evaporation rate of the droplet using a peltier heater and the reading of the resistance of the RTD.
- Combination of electrowetting and evaporation devices.

Acknowledgments

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  - Arica Lubin
- Microfluidics Lab
  - Prof. Carl Meinhart
  - Meysam R. Barmi
  - Irvin Martinez

Thank you for your attention

Back Up Slides

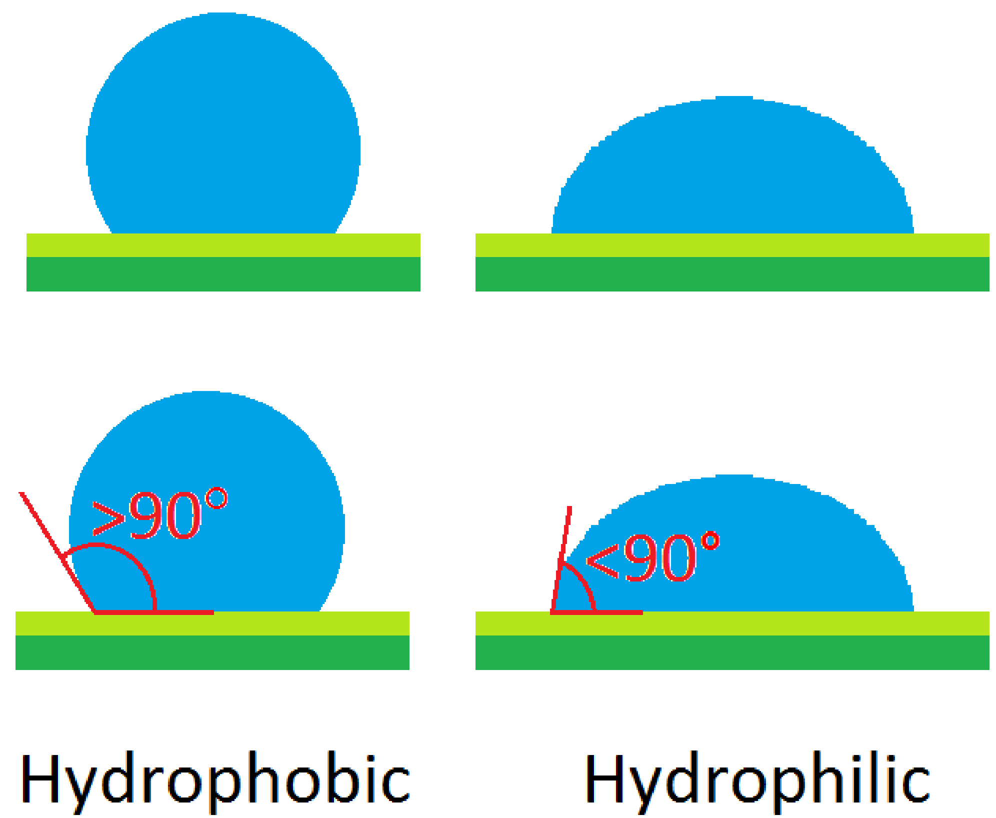
Definitions

- Electrowetting: modification of the properties of the droplet's surface by applying electricity.
  - Modifies contact angle and surface tension.
  - Surface from hydrophobic to hydrophilic
- Microfluidics: use of small volumes of fluid to perform tasks (reactions, movement, mixing)
- Free Surface: system where the droplet is in contact with the air.
- Hydrophobic: repels water
- Hydrophilic: attracts water

Contact Angle

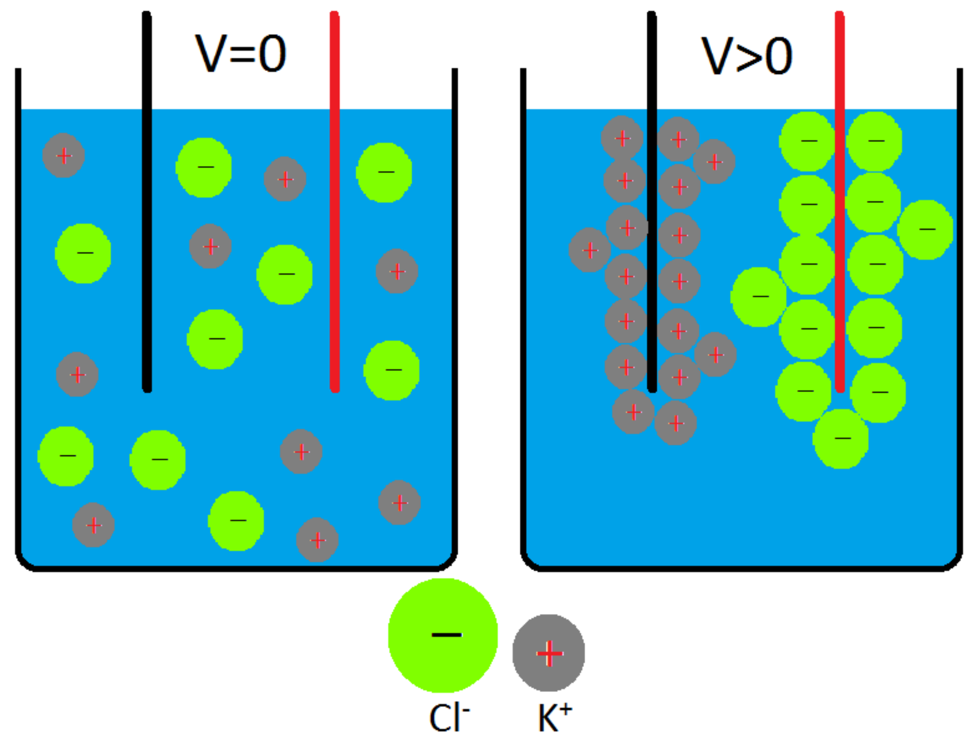
- Distance at which the liquid (droplet) and vapor (air) interface meets a solid surface.

- If the angle is:
  - >90 → surface is hydrophilic
  - <90 → surface is hydrophobic



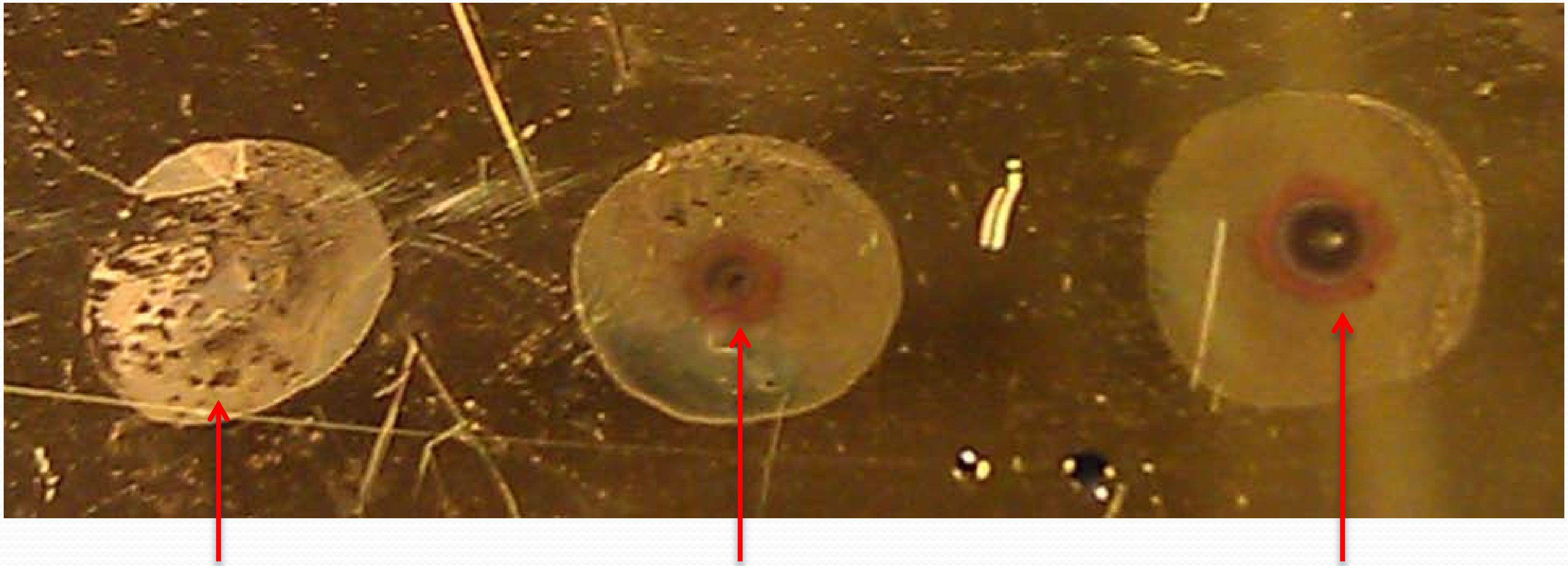
Electrolysis

- KCl is present in solution as ions
- Once voltage is applied, positive ions (K+) go to the negative electrode and negative ions (Cl-) go to the positive electrode
- K gains an electron
  - Forms potassium atoms
- Cl loses an electron
  - Forms chlorine atoms



Electrolysis happening

Residue seen on chips

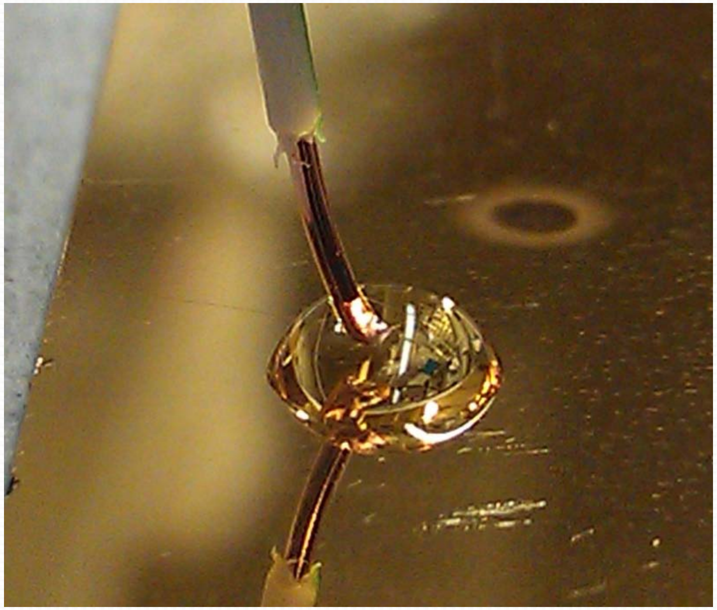


Desired residue after electrowetting

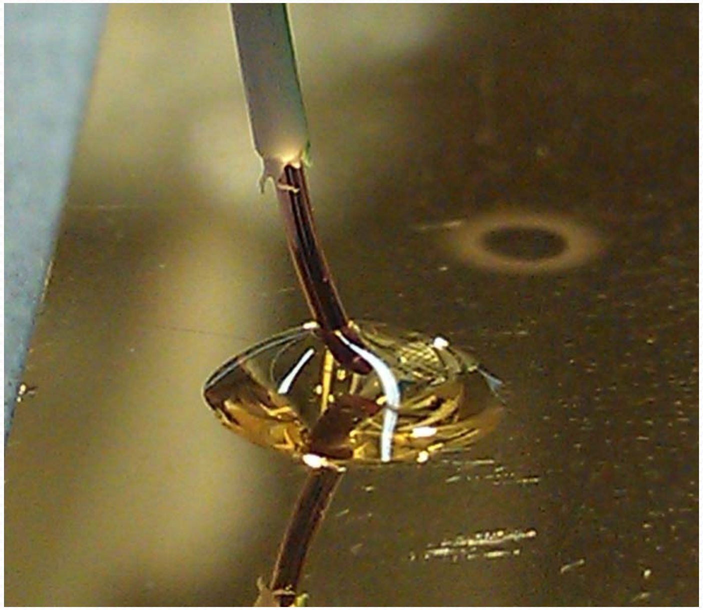
Residue when electrolysis occurs (7V)

Residue when electrolysis occurs (100V)

Electrowetting Effect

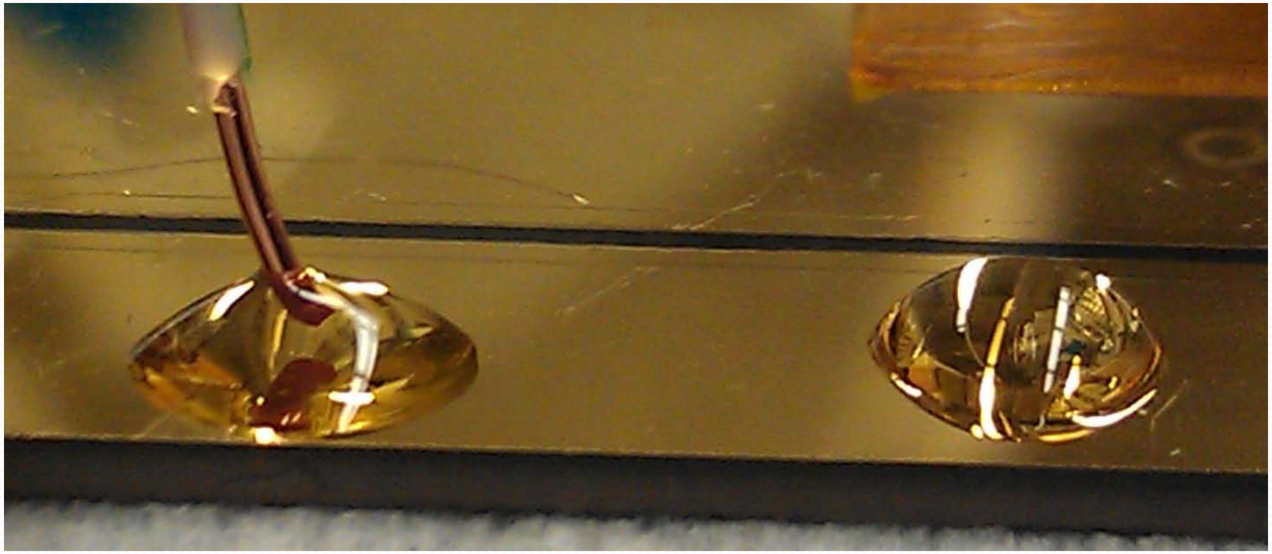


Before



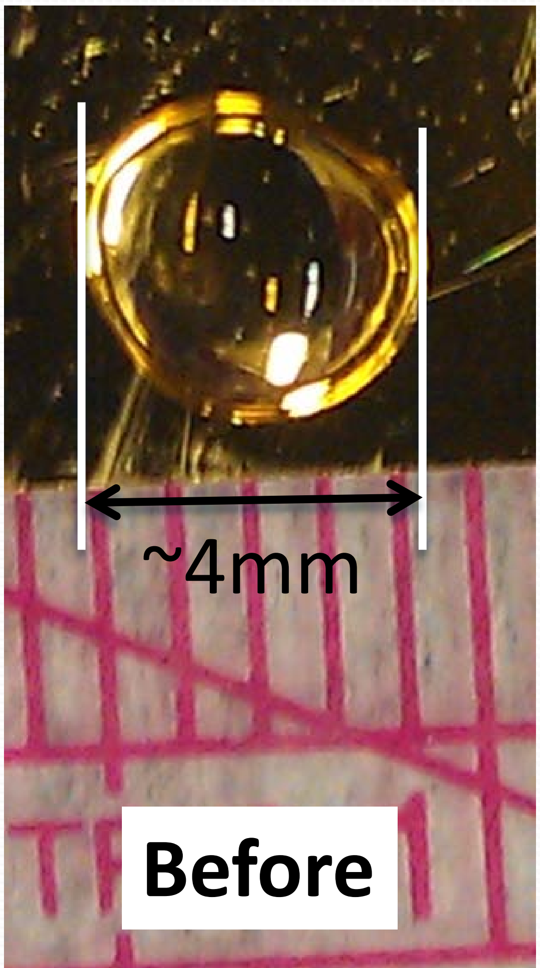
After

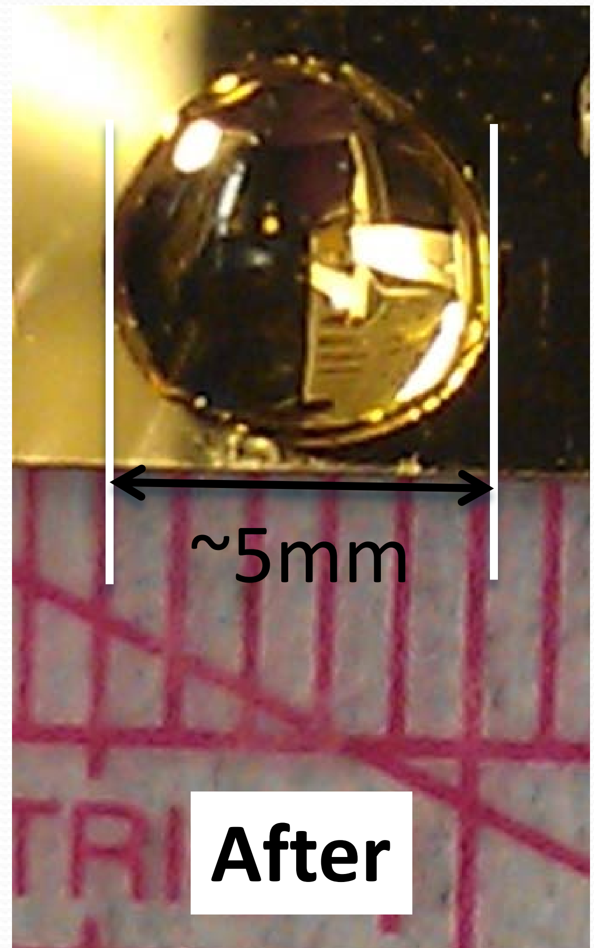
Before



After

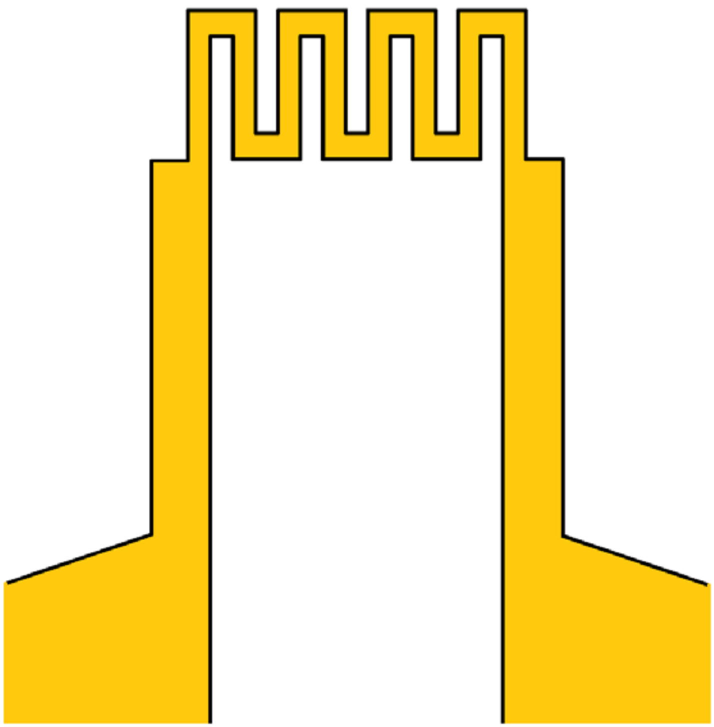
Change in diameter of droplet after electrowetting





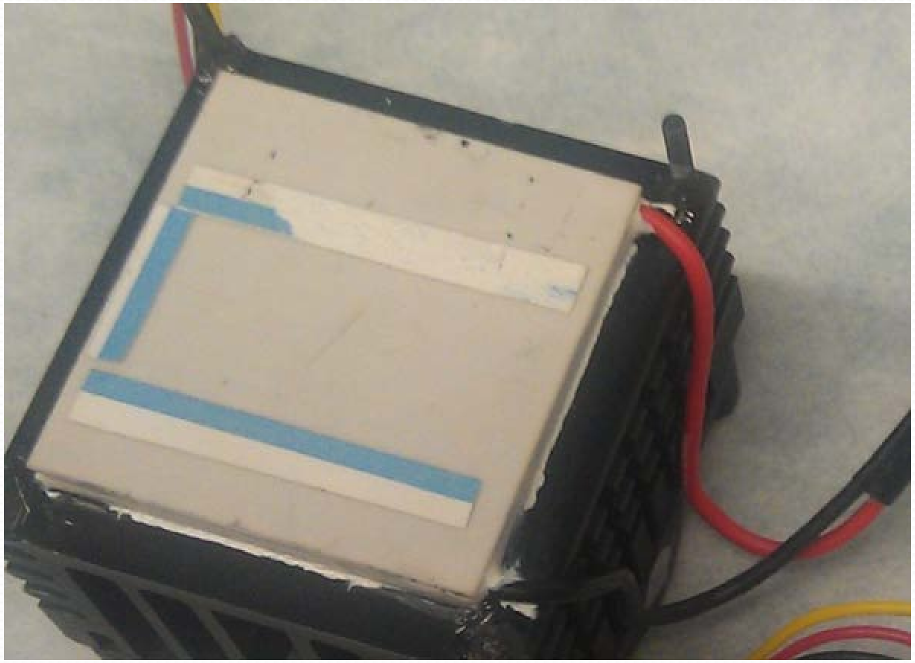
RTD Cross-Section

- Two layers
  - 200 Å Titanium
    - Acts as adhesive
  - 2500 Å Platinum



Peltier Cooler

- Used to cool or heat chips.
- Positive voltage on red cable cools the top surface and heats the bottom surface
- Negative voltage on red cable heats the top surface and cools the bottom surface



Evaporation Rate Curve

- Seem to follow the equation

$$\log J_e = A + \frac{B}{T + C}$$

- T is temperature
- A, B, and C are constants that are affected by
  - Ambient temperature
  - Contact angle
  - Surface area