Droplet Microfluidics and Dielectrophoretic Levitation: A New Approach to ICF Target Fabrication

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UCLA · CNSI · MCTP Materials Creation Training Program · GENERAL ATOMICS

Introduction

Polymer sphere and shell applications:

- Controlled drug delivery
- Inertial confinement fusion targets
- Photonic crystals
- Catalytic supports
- Sensors

Goals
Use droplet-based and channel microfluidic devices to form polymer spheres or shells with controlled, size, shape and concentricity.

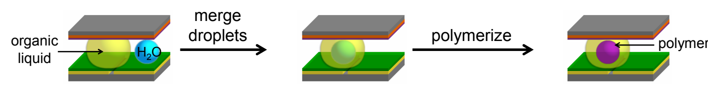
Current polymer sphere and shell formation problems:

- Polydispersity
- Aggregation
- Poor concentricity
- Lack of control over shell wall uniformity

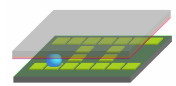
Droplet-Based Microfluidics Approach

Shell Formation

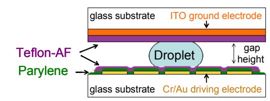
1. Encapsulate water droplet within an immiscible organic droplet between two hydrophobic surfaces
2. Polymerize monomer at the interface



3-D Device Schematic

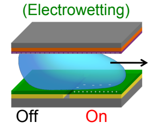


2-D Device Schematic

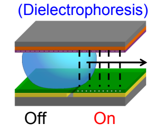


Droplet Driving Mechanisms

EW (Electrowetting)



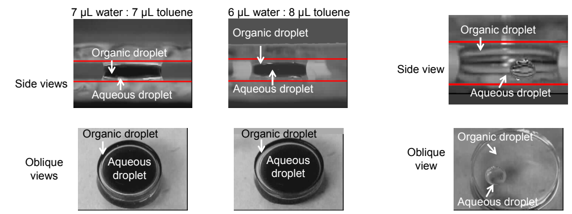
DEP (Dielectrophoresis)



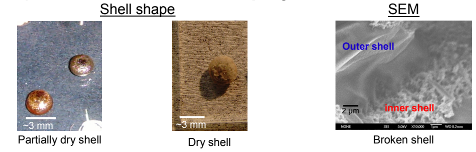
Droplet Entrapment and Polyaniline Beads

Aqueous droplet inserted into organic droplet between two hydrophobic surfaces

- Dyed water droplet encapsulated in toluene between Teflon coated plates
- Smaller embedded water droplet is spherical



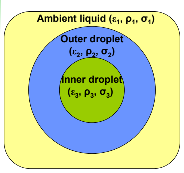
Interfacial polymerization of aniline by ammonium persulfate (APS) leads to hollow oblate polymer shells.



Double Emulsion Droplet Levitation and Centering

Project Objectives

1) Use dielectrophoresis (DEP) to levitate double emulsion (droplet in a droplet)
2) Use DEP to center inner droplet (The concentric outer droplet can be polymerized to form a shell)



- Levitation counteracts gravity, lifting sessile droplet into ambient liquid
- Suspended droplet becomes spherical to minimize liquid-liquid interfacial area
- DEP centers inner droplet forming concentric outer liquid shell

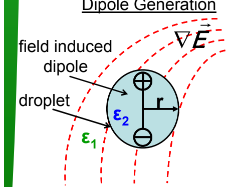
Introduction to Dielectrophoresis

Dielectrophoresis- Response of a dielectric liquid, particle, or droplet to the force resulting from a non-uniform electric field ($\nabla\vec{E}$).

How DEP works:

- Field induces a dipole, which in turn generates a force along the field gradient
- Force direction depends on ε_1 and ε_2

Dipole Generation



Theoretical DEP Force Equation

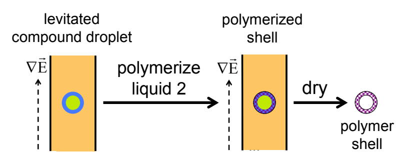
$$F_{DEP} \approx 2\pi r^3 \varepsilon_1 \left(\frac{\varepsilon_2-\varepsilon_1}{\varepsilon_2+2\varepsilon_1}\right)\nabla\vec{E}^2$$

$\nabla\vec{E}$ - Non-uniform electric field
ε_1 - liquid 1 dielectric constant
ε_2 - liquid 2 dielectric constant
r - droplet radius

Droplet Levitation

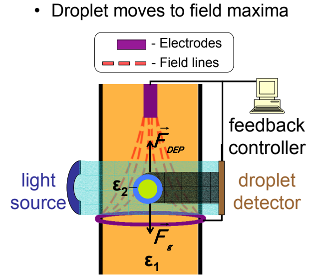
Liquids and Symbols Legend

Liquid 1 · Liquid 2 · Liquid 3 · $\nabla\vec{E}$ Non-uniform electric field · Double emulsion droplet



+DEP Levitation Apparatus

- Feedback controlled levitation
- Droplet moves to field maxima



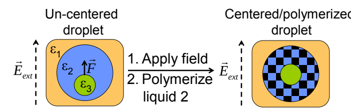
+DEP Limitations

- $\varepsilon_2 > \varepsilon_1$
- Liquid 2 immiscible with liquid1 and 3
- Liquid 1 conductivity <10^{-4} S/m
- Densities of liquid 1,2, and 3 must be very similar
- Monomer must dissolve only in liquid 2

DEP Centering

Centering approach

1. Apply uniform electric field to center inner droplet
2. Polymerize monomer in liquid 2

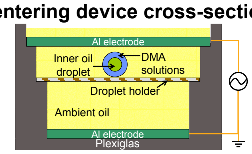


Criteria for Stable Droplet Centering

1. Liquid 2 (outer droplet) *must be immiscible* in liquid 1 (ambient liquid) and liquid 3 (inner droplet)
   - Liquid 1 and 3 may be the same
2. $\varepsilon_2 > \varepsilon_1$ (No constraint on ε_3)
3. ρ_1, ρ_2, ρ_3 must be very similar
4. Applied electric field must be uniform

Proof of Principle

Centering device cross-section

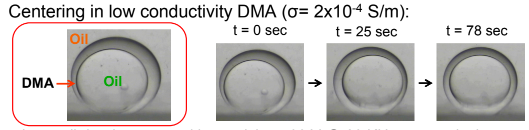


Liquids and Densities

Liquid 1- Mixed silicone oils
Liquid 2- N,N-dimethylacetamide (DMA)
Liquid 3- Mixed silicon oils
Densities slightly offset so $\rho_1 < \rho_2 < \rho_3$

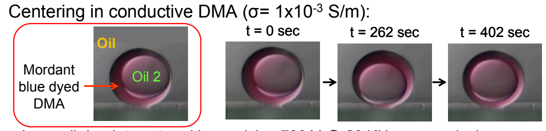
Successful Droplet Centering

Centering in low conductivity DMA (σ= 2×10^{-4} S/m):



Inner oil droplet centered by applying 700 V @ 20 KHz across device

Centering in conductive DMA (σ= 1×10^{-3} S/m):



Inner oil droplet centered by applying 700 V @ 20 KHz across device

Future Work

- Levitate double emulsions
- Test centering of different double emulsions
- Polymerize outer liquid in centered double emulsions
- Increase centering speed

Acknowledgments

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