Understanding The Physics Of Droplet Electrocoalescence In A Microtrap

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Abstract

Droplet-based microfluidic systems are emerging as an ideal platform for the high-throughput screening of eukaryotic cells aimed to understand the complex, multidimensional, and dynamic biological processes [1]. Here, two aqueous droplets - each containing a eukaryotic cell - suspended in oil media are captured in a hydrodynamic microtrap and then merged with one another using the well-known electrocoalescence process for conducting downstream cell-based analyses such as studying biological cell-cell interactions.

In this work, through extensive COMSOL Multiphysics® simulations, we conducted a parametric study to analyze the effect of fluid (FC-40 oil/water) surface tension γ and the minimum droplet gap d on the droplet behavior in the hydrodynamic microtraps (Fig. 1). Specifically, the parametric study ranged over an order of magnitude on the surface tension, γ ϵ (0.0025-0.04) N/m and minimum droplet gap, d ϵ (0.4-1.6) microns. This study resulted in the generation of a preliminary design chart - a plot of the droplet fate (merged or failed to merge) vs minimum droplet gap d - for a fixed supply voltage (8 V) and fixed electrode gap (10 microns). Our microfluidic system comprises of two aqueous droplets suspended in oil media with a set of electrodes (Fig. 1a, b). To study and track the progression of the droplet behavior, we utilized the COMSOL® Microfluidics Module, modeled the system as a two-phase flow, employed the phase-field method, implemented extremely fine mesh, and assumed a hydrophobic channel wall (contact angle is 180°, [2]) (Fig. 1b, c).

As a first step, we validated our model with an experiment data available in the literature (Fig. 1d,e) [3]. Importantly, two observations are reported. (1) For a successful merging of the aqueous droplets, a higher fluid (oil/water) surface tension γ necessitates a lower droplet gap d (Fig. 1f). (2) For a successful merging of the aqueous droplets, the magnitude of the electric field strength E=V/d must be about 4.45 MV/m for γ =0.0025 N/m and about 17.8 MV/m for γ =0.04 N/m. These observations are in good agreement with the existing literature [3].

Reference

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[2] N. S. Suteria et al., “Microfluidic bypass manometry: highly parallelized measurement of flow resistance of complex channel geometries and trapped droplets,” Lab Chip, 18, 343 (2018)
[3] C. Priest, S. Herminghaus, and R. Seemann, “Controlled electrocoalescence in microfluidics: Targeting a single lamella,” Appl. Phys. Lett. 89, 134101 (2006)

Figures used in the abstract

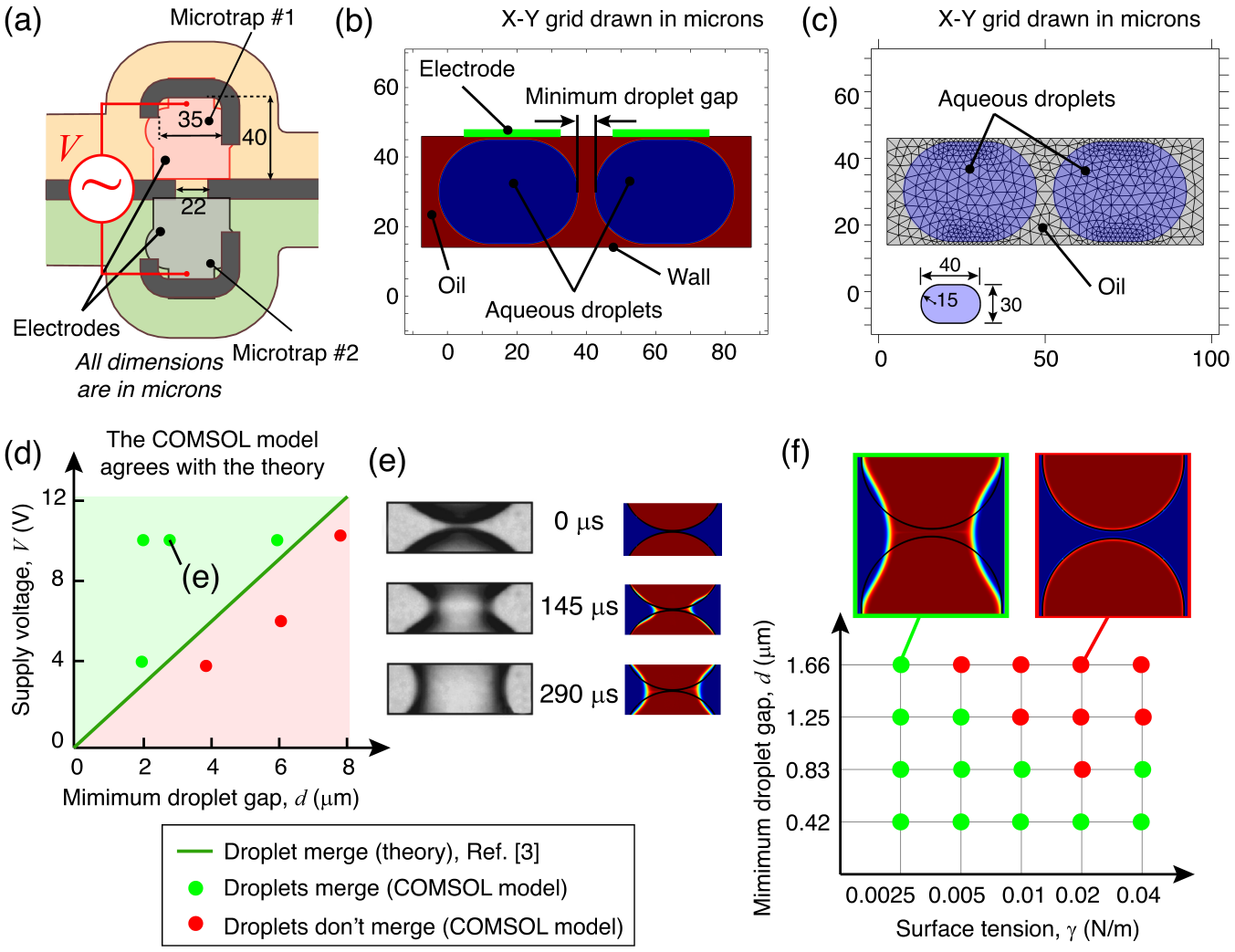

Figure 1 : (a) Microtrap with embedded electrodes (b) Sketch of the aqueous droplets suspended in oil media (c) Representative mesh (d, e) Model validation. (f) A preliminary design chart