Numerical Simulation of Electrostatic Charging Droplets in Microfluidic Devices

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Introduction: Precharged droplets can facilitate manipulation and control of low-volume liquids in droplet-based microfluidics. However, the working principle and charge quantification of the non-contact charging system (Fig.1) remains elusive for precise control of droplets in practical systems. In this paper, the mechanism was simulated and analyzed. The simulation was conducted using COMSOL Multiphysics®, based on the laminar two-phase flow level-set interface coupling with the electrostatic interface. The simulation agreed well with the experimental results.

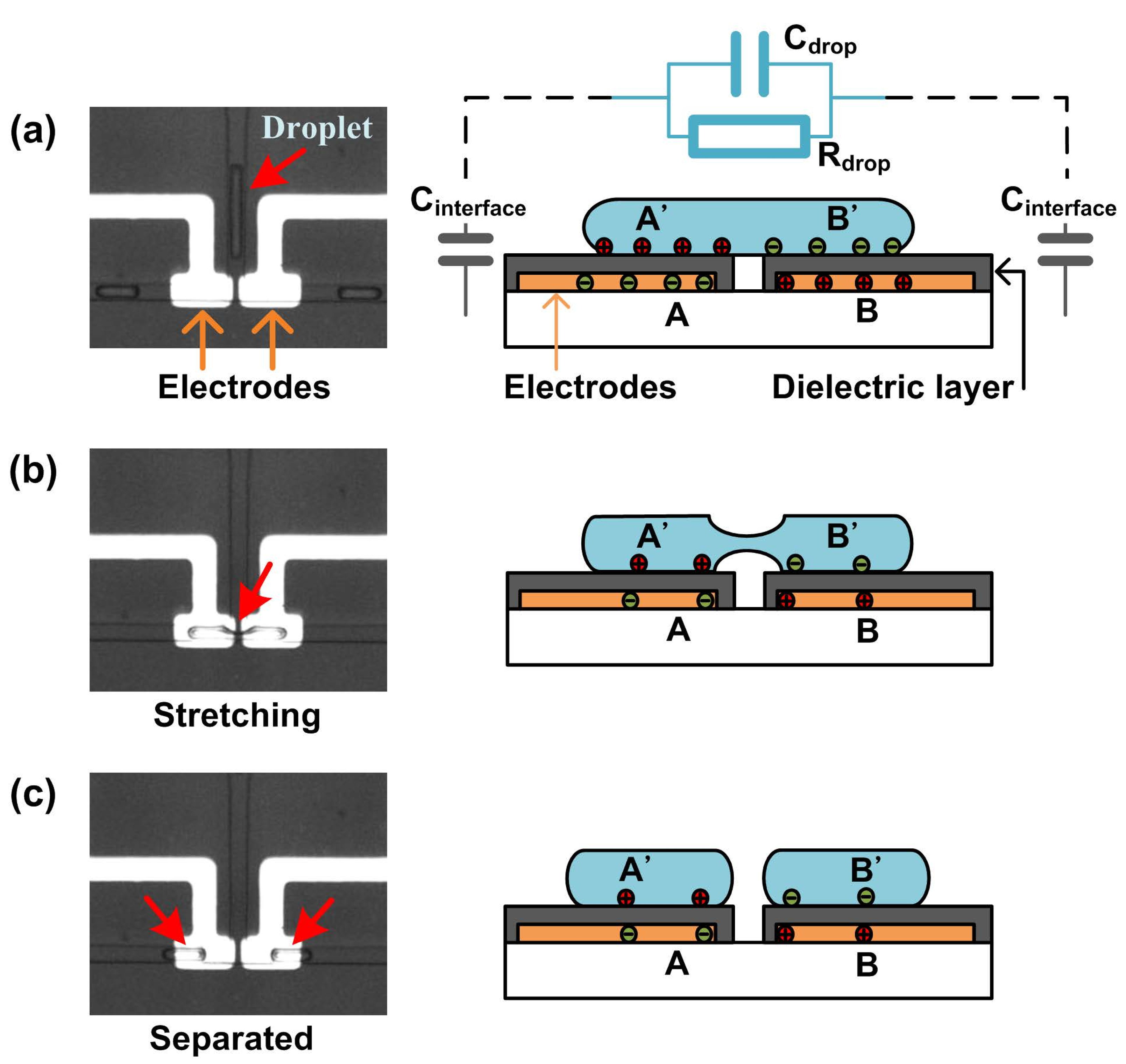

Fig.1 Principle of the charging process. The left column is the top view and the right column is the side view.

Numerical simulation

First, the interface is tracked using the level set method.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{u}) = 0$$

$$\rho \frac{\partial \vec{u}}{\partial t} + \rho(\vec{u} \cdot \nabla)\vec{u} = -\nabla p + \nabla \cdot (\mu \nabla \vec{u}) + \vec{F}_{st}$$

$$\frac{\partial \phi}{\partial t} + u \cdot \nabla \phi = \gamma \nabla \cdot \left(\varepsilon \nabla \phi - \phi(1-\phi)\frac{\nabla \phi}{|\nabla \phi|}\right)$$

The electric field in the system is calculated :

$$\nabla \cdot (\varepsilon_o \varepsilon_r \nabla \varphi) = \rho_f$$

The system capacitance is calculated :

$$C = \frac{2U_e}{V^2} \quad \text{and} \quad U_e = \frac{1}{2}\varepsilon_0 \varepsilon_r \int_\Omega |E|^2 d\Omega$$

Results and discussion

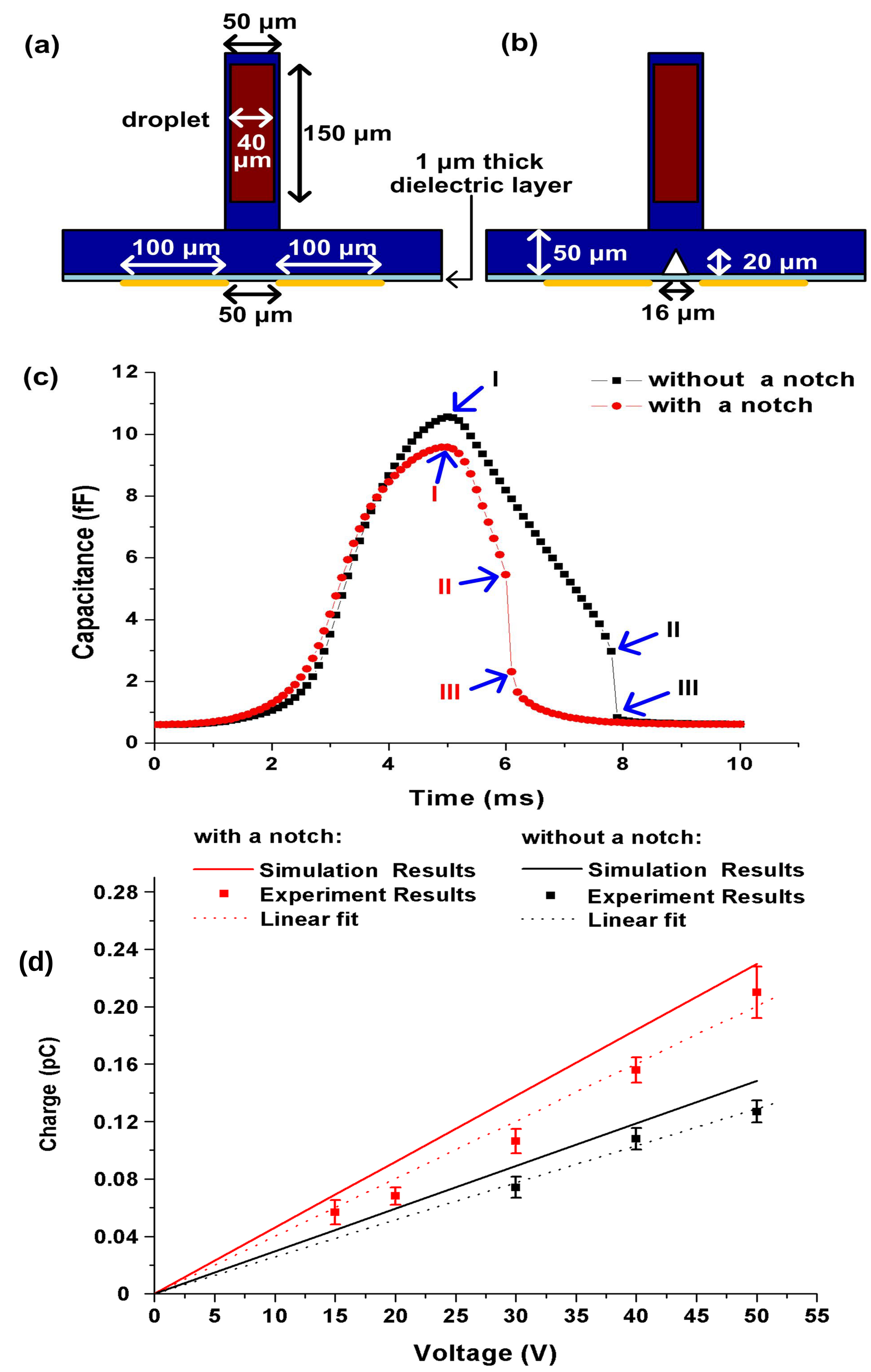

Fig. 2 Simulation of the charging process. (a) and (b) 2D computational domain. (c) The capacitance of the whole system during the splitting process. (d) Comparison of simulation and experimental results.

Conclusion

Both simulation and experimental methods matched well with each other. We expect our work could enable precision manipulation of droplets for more complex liquid handling in microfluidics and promote electric-force based manipulation in 'lab-on-a-chip' systems.

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