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Control the Poly-Dispersed Droplet Breakup Mode in a Droplet-based Microfluidic Device by External Electric Field

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Introduction:

- Electric field has been proposed to be an additional handle to manipulate the droplet-based microfluidic systems (Link, 2006).
- Due to the different electric properties, *i.e.*, permittivity and conductivity, between the two phases, electric charges are induced on the fluid interface. The interaction between the electric field with these charges creates Maxwell stresses, which help to control droplet breakup, coalescence, sorting, etc.
- Poly-dispersed droplet breakup modes have been observed in droplet-based microfluidics. Secondary droplets of sizes much smaller than the primary ones are pinched off due to the combined effects of capillary instabilities and end-pinching effect (Stone, 1989).
- By introducing the electric force to system, the squeezing process can be accelerated; in other words, the capillary instability has less time to develop. Therefore, the poly-dispersed breakup mode can be eliminated.
- The conservative level-set method coupled with electric static model has used to study the droplet breakup dynamics controlled by an external DC electric field.
- The dispersed phase properties: ρ_d=960 kg/m^3, μ_d= 10/20 cp, $\varepsilon_{r,d}$= 2.8;
  The continuous phase properties: ρ_c=1000 kg/m^3, μ_c= 1 cp, $\varepsilon_{r,c}$= 78.

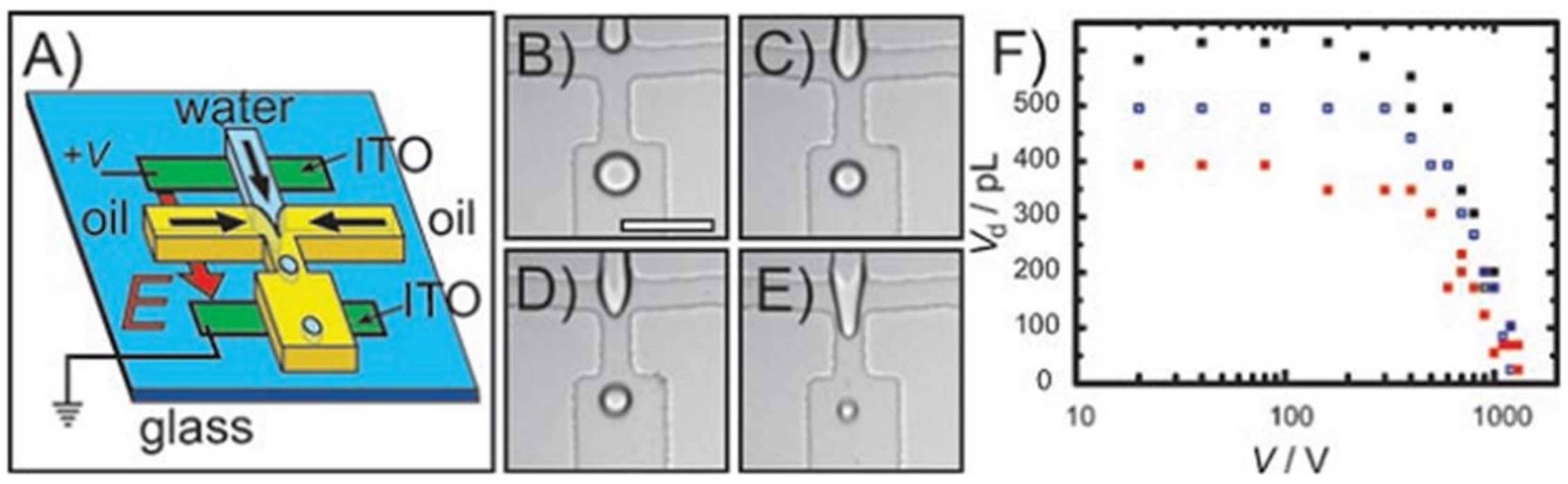

Figure 1. Using electric field as an effective tool to control droplet sizes (Link, 2006)

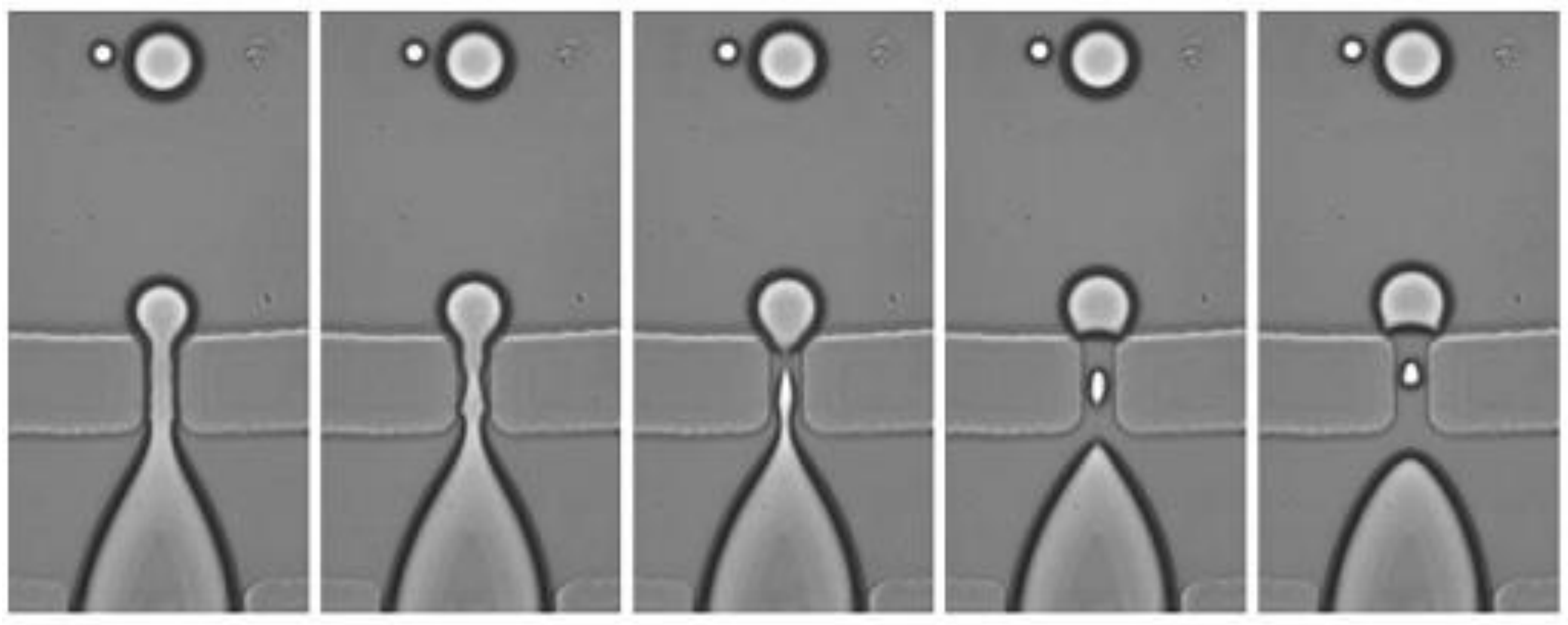

Figure 2. A typical poly-dispersed droplet breakup mode observed in a hydrodynamic flow-focusing device. The operating conditions are: Q_c/Q_d=40; Q_c=4.2x10^{-4}mL/s. (Anna, 2003)

Computational methods

(1) Poisson Equation (Electrostatics, AC/DC module): predicts the electric field inside the continuous and dispersed phases;
(2) Conservative level-set method: tracks the motion of the fluid interface. Additional volumetric force terms are added to the momentum equations to describe the electric force on the fluid interface.

Simulation setup

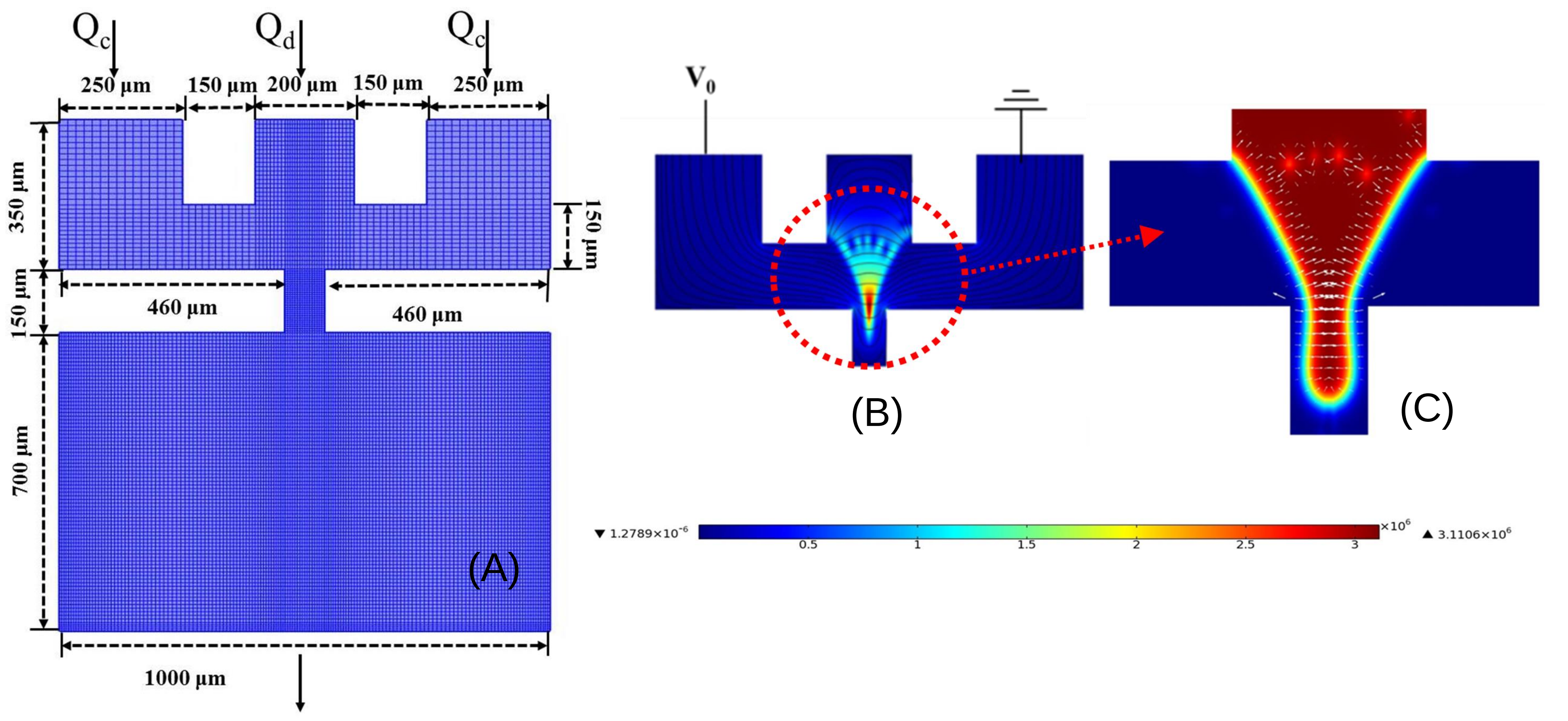

Figure 3 (A) The geometry of the microfluidic flow-focusing device and the computational grids used by numerical simulations. (B) The distributions of electric field in the flow-focusing region. The color bar indicates the electric field strength. (C) The contour plot of the phase evolution during the droplet breakup process. The white arrows indicate the electric force on the fluid interface.

Simulation results

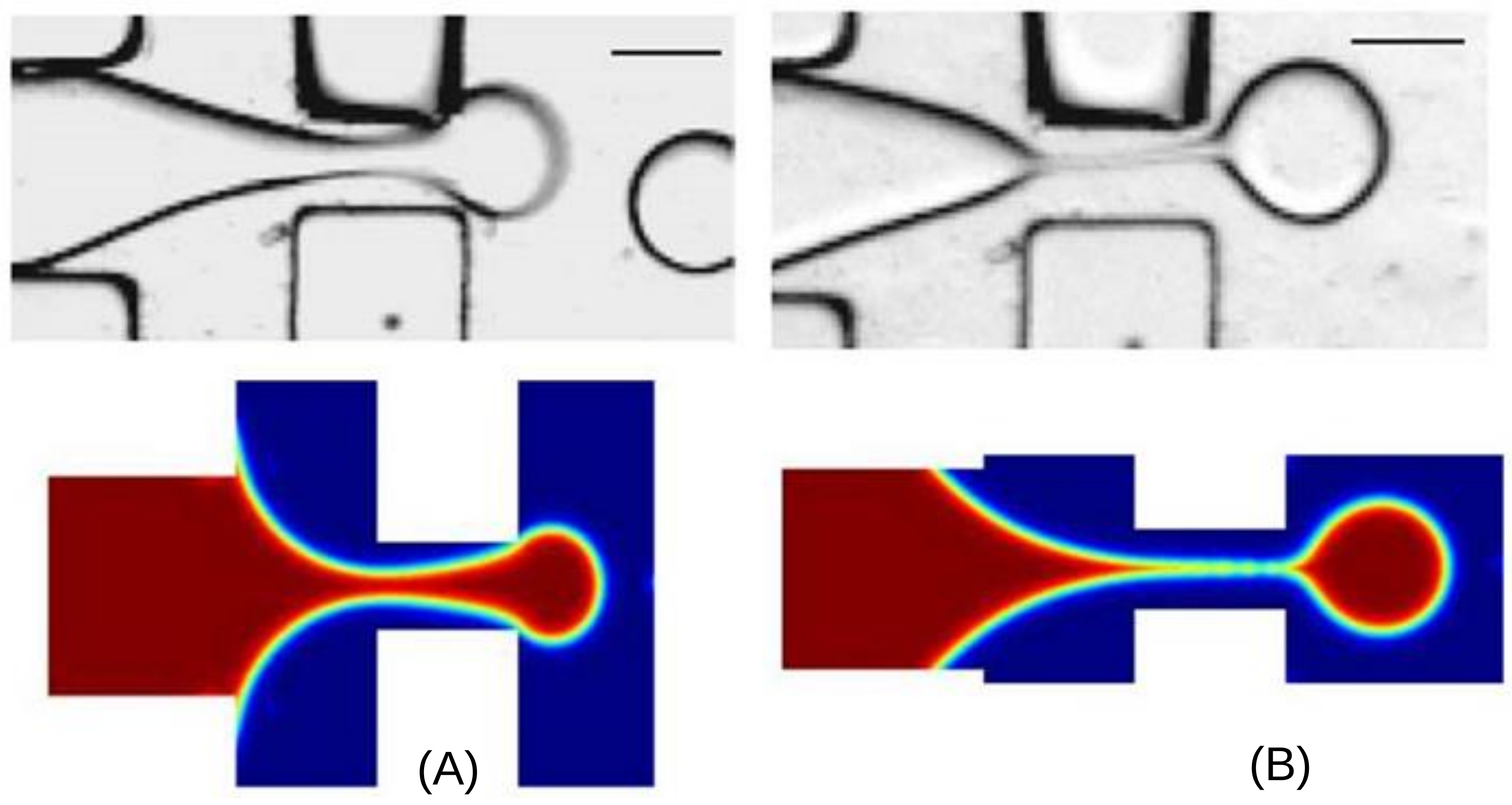

Figure 4 Snapshots of the droplet breakup process with different viscosity values of the dispersed phase. (a) μ_d / μ_c = 20; (b) μ_d / μ_c = 100. The flow ratio of these two cases are: Q_c / Q_d = 20, and the corresponding Ca_c = 0.0067. The top pictures are cited from the experimental results (Nie, 2008); the bottom pictures are taken from the simulations.

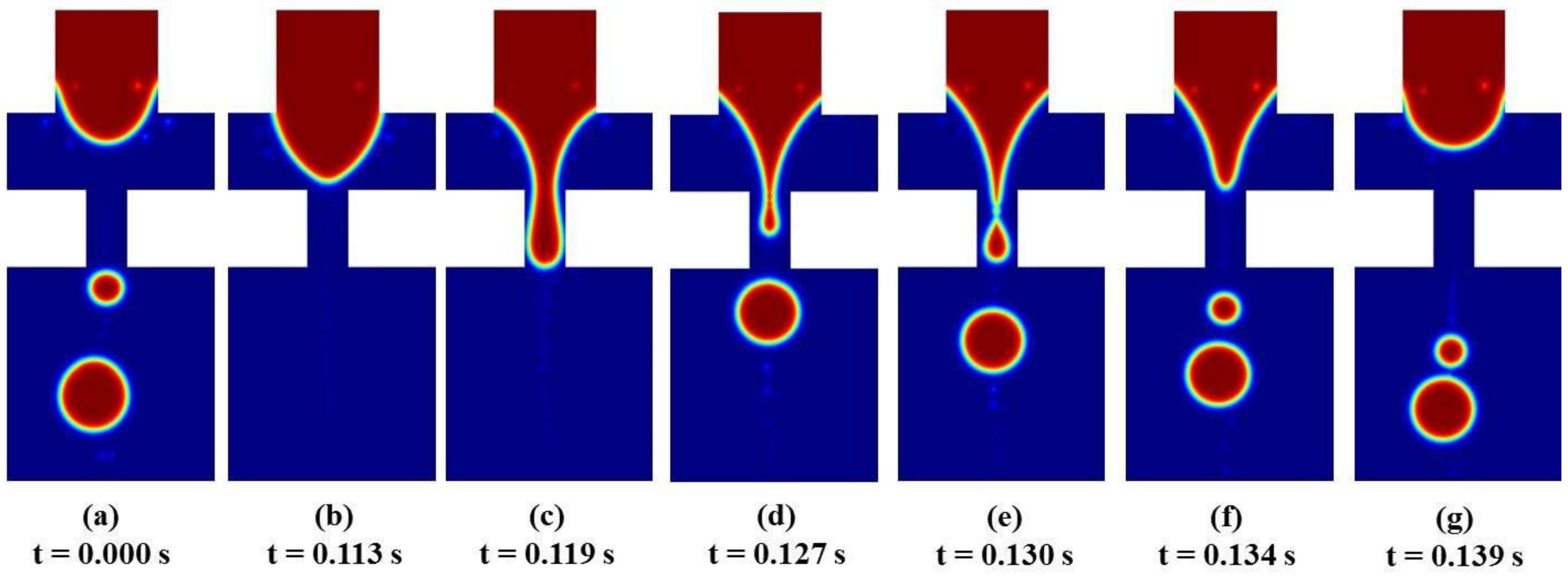

Figure 5 A typical droplet breakup process of the poly-dispersed breakup mode in the dripping regime.

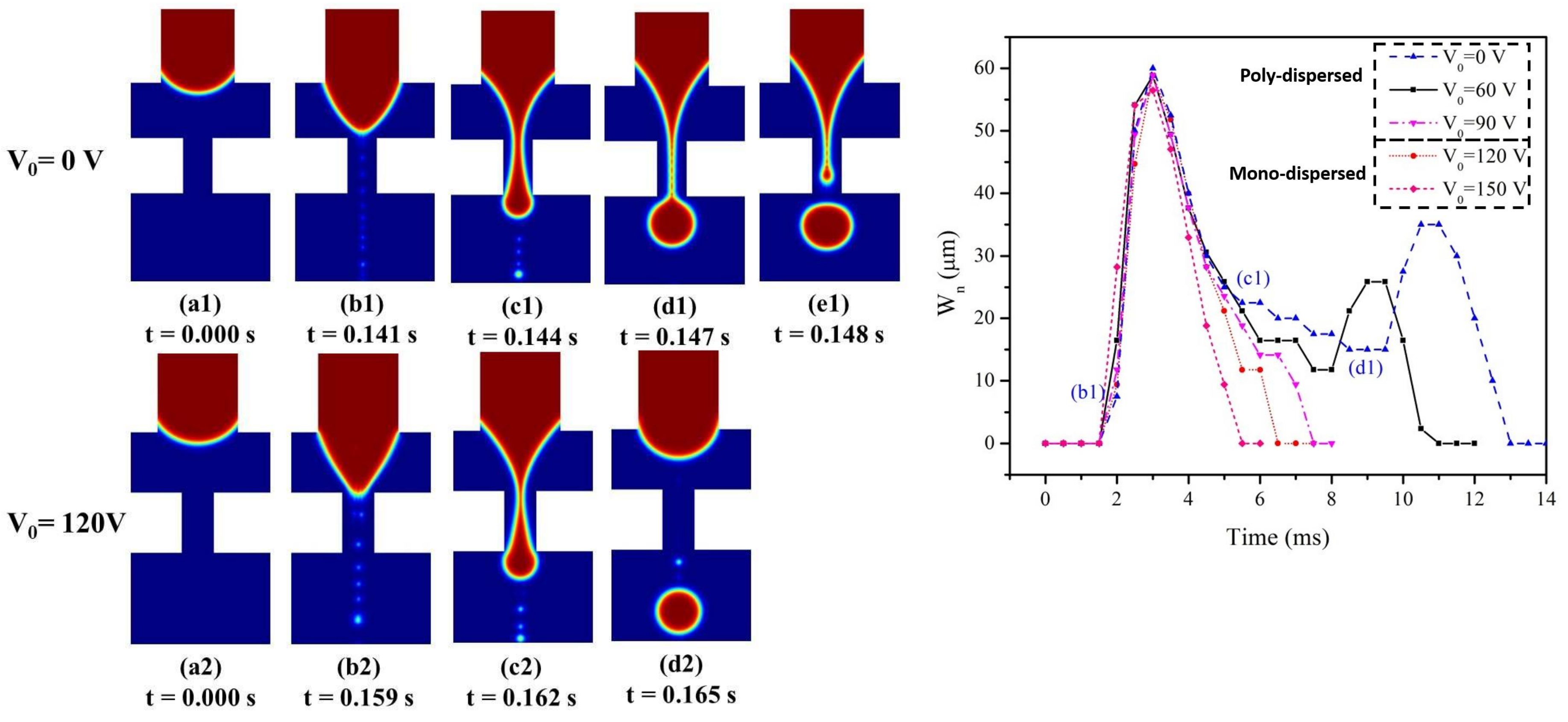

Figure 6 Left: (a1) ~ (e1): no electric field is applied, and poly-dispersed breakup mode is observed. (a2) ~ (d2): V_0 = 120 V is applied to the system, resulting in mono-dispersed droplet breakup mode. Right: the effect of applied voltages on squeezing the fluid neck. As the applied exceeds 120 V, the developing time of the capillary instability is suppressed, thus mono-dispersed breakup mode is obtained.

Conclusions:

- The electric field can be used to eliminate the “poly-dispersed breakup mode”.
- The “poly-dispersed” breakup mode is governed by the capillary instabilities.
- By exerting an electric force to squeeze the fluid neck, the droplet formation time can be reduced, thus the development of capillary instability is suppressed.
- As the applied voltage exceeds the certain threshold value, the poly-dispersed breakup mode can shift to the mono-dispersed breakup mode.

References:

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Excerpt from the Proceedings of the 2015 COMSOL Conference in Boston