Electronic Supplementary Material (ESI) for Lab on a Chip.

Supporting Information

Pinch-off Droplets Generator Using Microscale Gigahertz Acoustics

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Section 1 Droplet extracting method

A micro syringe can be used to suck up the droplets staying at the oil-water interface. As shown is in Figure S1A, the cavity is inclined by approximately 20° respect to the horizontal. Since the density of water is greater than that of mineral oil, the generated droplets will roll down to the corner of the cavity along with the oil-water interface. This design can avoid the contact between the pipette and the oil-water interface, which may produce satellite droplets. Thus, the generated droplets can be completely sucked into the micro-syringe.

After completing the suction of the droplets, the pipette is placed in the cavity filled with mineral oil (Figure S1B). And the droplets are slowly discharged onto the PDMS substrate through a computer-controlled micro-syringe pump. By installing a three-dimensional position system on the pipette, the droplets can be well patterned on the substrate. As shown in Figure S1C, we pattern "TJU" characters on the PDMS substrate using droplets. This result proves the ability of system to complete different patterns and broadens the potential applications of micro-droplets.

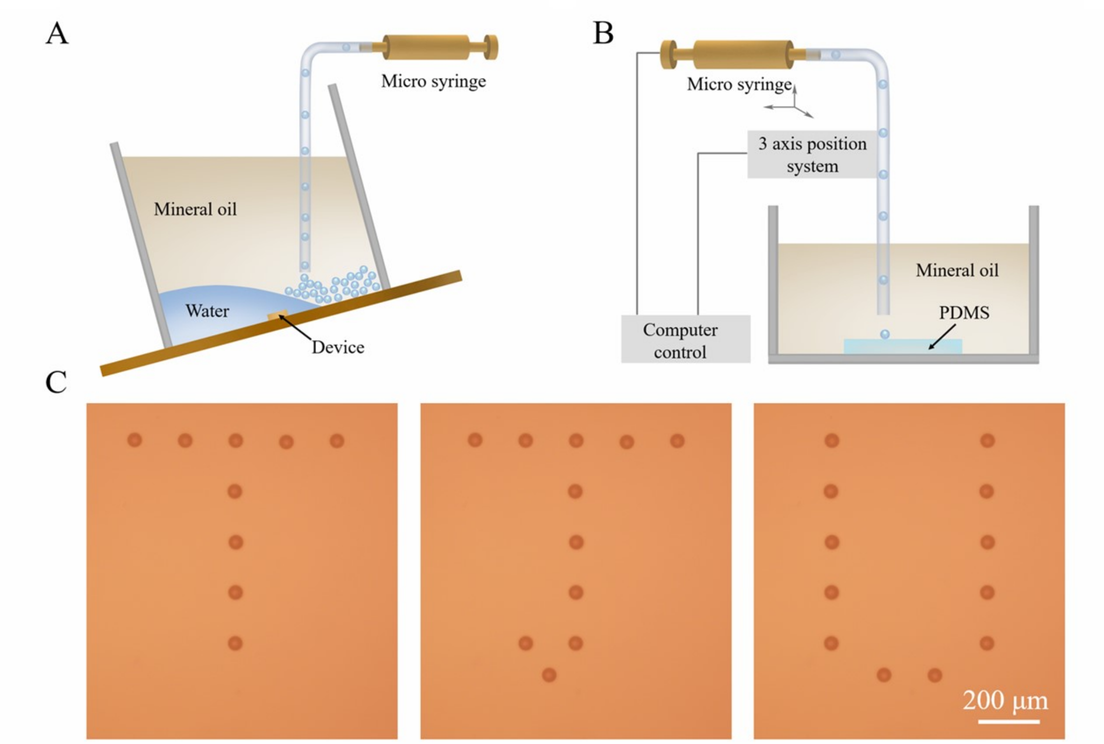

Figure S1. (A) Sucking up droplets through a micro syringe. (B) Patterning droplets on the PDMS substrate. (C) A "TJU" pattern on the PDMS substrate.

Section 2 Finite Element simulation

The process of droplet pinch-off was simulated using the "two-phase flow, phase field" module in COMSOL Multiphysics 5.5. We use the Phase Field Method to calculate the phase trajectories when calculating the transient motion at the interface of two immiscible fluids. The Navier-Stokes equations describe the transport of mass and momentum for fluids of constant density (in equation 1). In this experiment of droplet generation, the low Bond number (in equation 4) shows that the effect of gravity is weak relative to the interfacial tension. The effect of gravitational force is actually added (however after the calculation, the effect produced by gravitational force is negligible). The surface tension force (F_{st}) is also taken into account in our model, which is the major part of the external mass force f and dominates droplet generation. It can be expressed as:

$$F_{st} = G\nabla\phi$$

where ϕ is the phase field parameter, and G is the chemical potential (J/m3).

$$G = \lambda\left[-\nabla^2\phi + \frac{\phi(\phi^2 - 1)}{\varepsilon^2}\right] = \frac{\lambda}{\varepsilon^2}\psi$$

where λ is the mixing energy density (N) and ε is the interface thickness parameter. The ψ variable is referred to as the phase field help variable. As seen above, the phase field surface tension is computed as a distributed force over the interface using only ψ and the gradient of the phase field variable. This computation avoids using the surface normal and the surface curvature, which are troublesome to represent numerically. And the direction of F_{st} is normal to the interface.

The model input parameters based on experimental results were listed in Table S1.

Input parameters	Numerical value	Unit
Liquid column bottom diameter	400	μm
Liquid column top diameter	200	μm
Liquid column height	900	μm
Water viscosity	1	mPa·s
Water density	1000	kg/m^3
Mineral oil viscosity	10	mPa·s
Mineral oil density	840	kg/m^3

Table S1. The model input parameters based on experimental results.

Section 3 Discussion about two non-dimensional numbers

The Reynolds number is one of the most important dimensionless quantities in microfluidics which correlates the inertia forces to the viscous forces. The low Reynolds numbers typical of microfluidic flows indicate highly laminar flow profiles in our droplet generation system. Here, it is defined as

$$Re = \frac{\rho v D}{\mu}$$

where ρ is the fluid density, μ is the fluid dynamic viscosity, v is the velocity of the liquid column fallback, and D is the diameter of the liquid column.

The Weber number relates the inertia forces to the forces resulting from the surface tension. It is defined as

$$We = \frac{\rho v^2 D}{\gamma}$$

where γ is the interfacial tension at the oil-water interface.