Supplementary Material

Mechanism and Stability Investigation of a Nozzle-Free Droplet-on-Demand Acoustic Ejector

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1. Electrical Response of LWTA

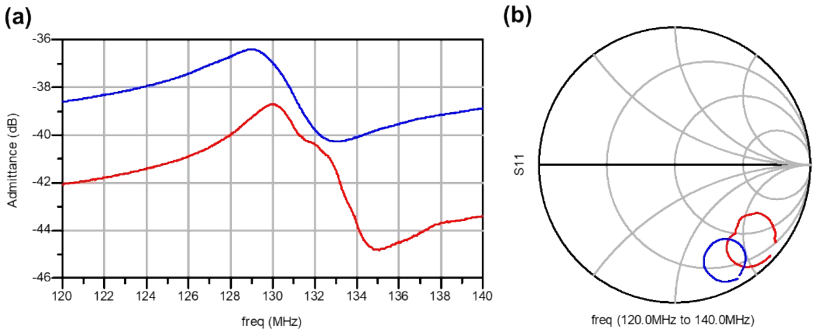

Fig . S1 Comparison of the electrical response of LWTA in air and water. Red curve is measured in air. Blue curve is measured in water. (a) The admittance curves of LWTA. (b) The smith charts of S11 parameter.

2. Estimation and Comparison of Acoustic Radiation Force and Acoustic Streaming

a) Acoustic radiation force: Acoustic radiation force can be obtained using radiation pressure and velocity. Specially, the Lagrangian mean pressure is defined as[1]

$$\langle p_L - p_0 \rangle = \langle E_V \rangle + \langle E_K \rangle + \rho_0 \mathbf{g} \cdot \langle \xi \rangle \quad \text{(S1)}$$

Here, $\langle E_V \rangle = \langle p^2 \rangle / 2\rho_0 c_0^2$, $\langle E_K \rangle = \rho_0 \langle v^2 \rangle / 2$ and $\langle \xi \rangle$ are the time-average potential energy density, kinetic energy density and displacement, respectively. Beads on above equations, the distribution of Acoustic radiation pressure is computed by FEM, as shown in Fig. S2. The boundary conditions are same as the setting in Fig. 3(b). Then, we estimate that the acoustic radiation force ($F_r \approx 4.37 \times 10^{-7}$ N) at the focal point is smaller than the surface tension counterforce.

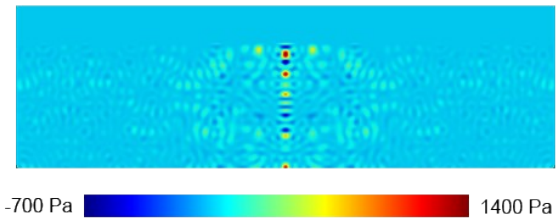

Fig. S2 The distribution of Acoustic radiation pressure.

b) Acoustic streaming: For exploring the effect of acoustic streaming, we have also built the model which computed the body force. Nyborg presented the expression of body force induced from acoustic streaming as[2]

$$\rho_0 \boldsymbol{f}_{10} = -\,\text{real}\,(\boldsymbol{v}_1 \cdot \nabla \boldsymbol{v}_1^* + \boldsymbol{v}_1 \nabla \cdot \boldsymbol{v}_1^*) \quad \text{(S2)}$$

According to this equation, it can be calculated in the simulation model. Fig. S3 depicts the distribution of drag force. Then, we estimate that F_d is around 6.95×10^{-5} N , larger than the surface tension counterforce.

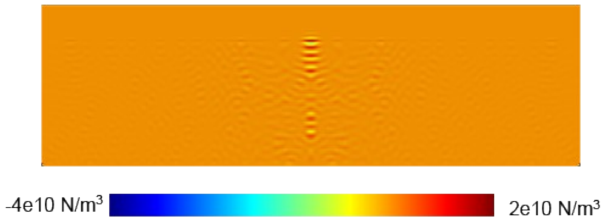

Fig. S3 The distribution of drag force induced from acoustic streaming.

Based on the above, droplet ejection in our work is attributed to the combination of acoustic radiation force and drag force induced from acoustic streaming.

3. Capillary Number and Weber Number

The capillary number is used to characterize the relationship between the viscous force and the surface tension. It is examined as[3]

$$\mathrm{Ca} = \frac{\eta_a v_a}{\sigma} = \frac{\text{viscous forces}}{\text{surface tension}} \tag{S3}$$

where η_a is the outer air viscosity, v_a is the outer air velocity, and σ is the surface tension of liquid, respectively. In general, droplet ejection where the shear stress can overcome surface tension occurs when $\mathrm{Ca} \geq O(1)$.[4] While Ca is small, meaning that surface tension is stronger to oppose break-off, the device will result in non-ejection. In fact, rather than shear stress, the inertia force also can lead to ejection.

Another dimensionless number we should consider is Weber number which relates the inertia forces to the surface tension. It is defined as[3]

$$\mathrm{We} = \frac{\rho v^2 d_f}{\sigma} = \frac{\text{inertia force}}{\text{surface tension}} \tag{S4}$$

where ρ is the density of the fluid, v is the liquid velocity, same as outer air velocity at the surface, and d_f is a characteristic length scale, particularly the diameter of liquid column. Like capillary number, the value of Weber number dedicate if the inertia force can overcome the surface tension. When $\mathrm{We} \geq O(1)$, droplet ejection can be excited because of large inertia force. Oppositely, if the surface tension is dominate, it will be included in non-ejection regime.

Reference

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2. W. L. Nyborg, in Acoustic Streaming, ed. W. P. Mason and R. N. Thurston, Academic Press, New York, 1965, vol. 11, pp. 265–329.
3. B. T. Chu and R. E. Apfel, *The Journal of the Acoustical Society of America*, 1982, **72**, 1673-1687.
4. A. S. Utada, A. Fernandez-Nieves, H. A. Stone and D. A. Weitz, *Phys. Rev. Lett.*, 2007, **99**, 094502.