Electronic Supplementary Information

Acoustothermal tweezer for droplet sorting in a disposable microfluidic chip

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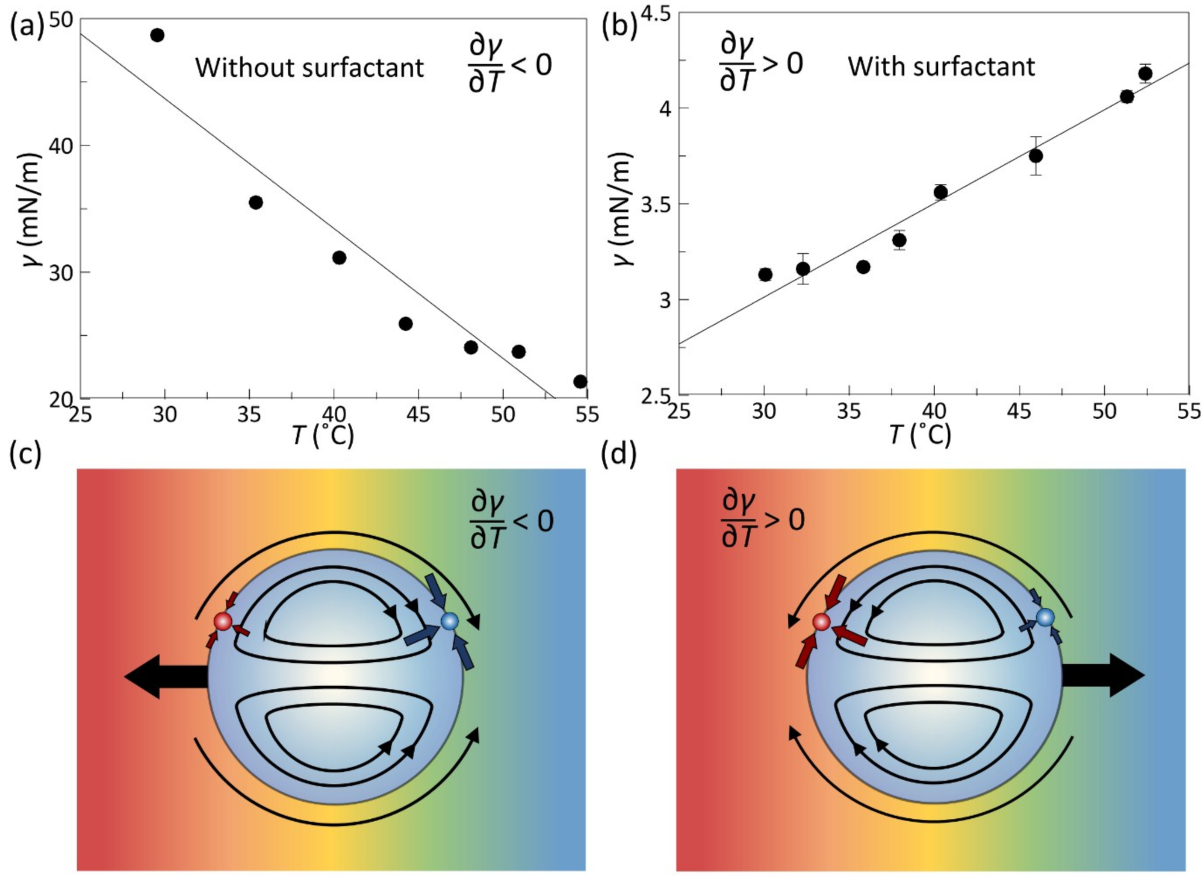

Fig. S1 Plots showing the dependence of the interfacial tension as a function of temperature **(a)** without and **(b)** a non-ionic surfactant. Schematic illustrations of thermocapillary droplet

Interfacial tension measurements

For the water-in-oil droplet production, the continuous (Novec^{TM} 7500, 3M, USA) and disperse (deionized water, Sinhan Science Tech, Korea) phase fluids were used with a 2 wt% of non-ionic surfactant (Pico-Surf^{TM} 1, Dolomite Microfluidics, UK) added to the fluids to stabilize the produced droplets and prevent droplet merging. The interfacial tension of the water-in-oil droplets were measured by an optical tensiometer (Theta Optical Tensiometer, Attension, Sweden) using a pendant drop method. In the range of approximately from 30 to 55°C, the first derivative of the interfacial tension with respect to temperature $\partial\gamma/\partial T$ was measured to be -1.0391 and 0.0557 (mN/m)/°C for without (Fig. S1(a)) and with (Fig. S1(b)) the non-ionic surfactant, respectively. Under a linear temperature gradient, Marangoni microvortices in and outside of the droplet are formed due to the interfacial tension gradient caused by the temperature gradient. The corresponding thermocapillary droplet migration is shown in Figs. S1(c) and (d).Without the surfactant, a droplet under a linear temperature gradient migrates from cold to hot temperature regions. Conversely, the droplet moves from hot to cold temperature regions.

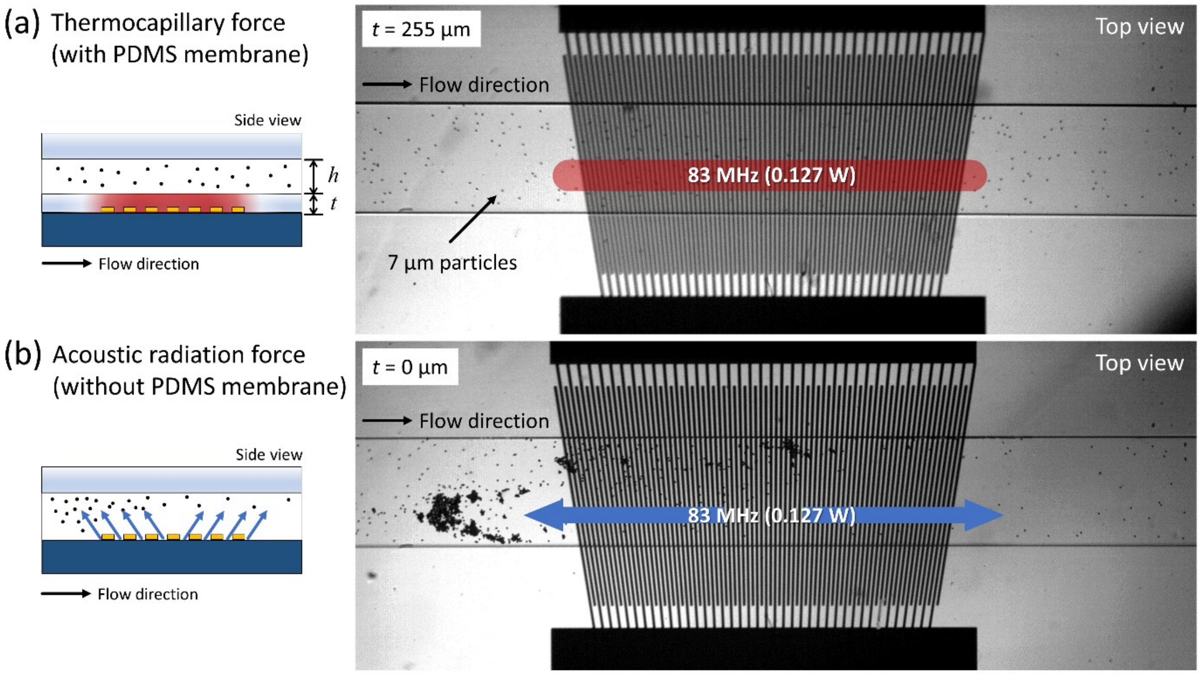

Fig. S2 A comparison between **(a)** thermocapillary force (with a thin PDMS membrane) and **(b)** acoustic radiation force (without a thin PDMS membrane) effects.

Comparison between thermocapillary force and acoustic radiation force effects

As seen in Fig. S2, two devices were fabricated for distinction between thermocapillary force and acoustic radiation force (ARF) effects. In Fig. S2(a), the device consisted of a closed microfluidic chip bonded reversibly to a SFIT deposited on a piezoelectric LiNbO3 substrate. The closed microfluidic chip was composed of microstructured PDMS with a channel height of h = 55 µm sealed with a thin PDMS membrane with a thickness of t = 255 µm. The SFIT used in the experiments had linearly varying electrode spacing ($\lambda/4$ = 10–12 µm), the resultant working frequency bandwidth of f = 76–90 MHz, 40 electrode finger pairs, and a total aperture of 1000 µm was used. The sample fluid carrying micro-particles with a diameter of 7 µm in DI water was injected into the microchannel. On applying an AC signal with f = 83 MHz (0.127 W) to the SIFT, the thin PDMS membrane absorbed acoustic energy, and thus acoustothermal heating phenomenon occurred. As a result, the particles flowing in the microchannel were not disturbed. On the contrary, in Fig. S2(b), the only difference in the device from that in Fig. S2(a) was that the microstructure PDMS was irreversibly bonded to the substrate by oxygen plasma bonding. In other words, the thin PDMS membrane was absent in the device. On applying the same AC signal, the micro-particles were disturbed and pushed by ARF acting on the particles, as seen in the figure. These results confirmed that the presence of the PDMS membrane can decouple thermocapillary force and ARF effects. As a consequence, the dominant working mechanism in the acoustothermal tweezer system is thermocapillary force induced by acoustothermal heating.

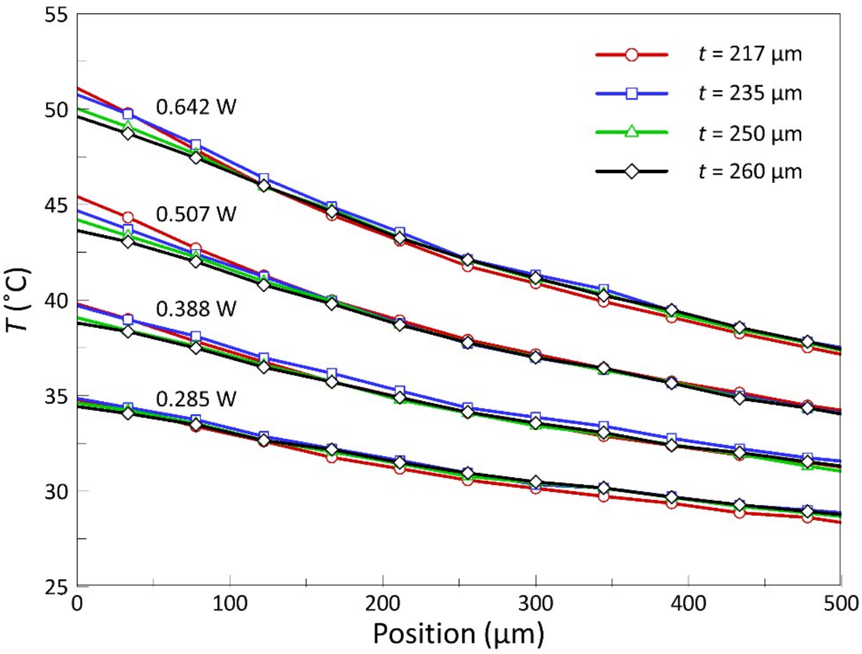

Fig. S3 The effect of varying thickness of the thin PDMS membrane on acoustothermal heating. The red circle, blue square, green triangle, and black diamond symbols indicate the various PDMS thicknesses of *t* = 217, 235, 250 and 260 µm, respectively.

PDMS thickness effect on acoustothermal heating

The thin PDMS layer used in the acoustothermal droplet sorting system has two important functions. First, it seals the microstructured PDMS to form a closed microfluidic chip. Second, it serves as an acoustic absorbing layer that converts acoustic energy into thermal energy. The effect of varying thickness of the thin PDMS membrane (t) on acoustothermal heating was investigated in the range of t = 217, 235, 250 and 260 µm (red circle, blue square, green triangle, and black diamond symbols in Fig. S3, respectively). For the experiments, a slanted finger interdigital tansducer (SIFT) with linearly varying electrode spacing ($\lambda/4$ = 10–12 µm), 40 electrode finger pairs, and a total aperture of 1000 µm was used. An AC signal with the frequency of 95 MHz was applied with varying electrical power W = 0.285, 0.388, 0.507, and 0.642 W. As a result, linear temperature gradients were constructed in the region of interest (width = 500 µm). As shown in Fig. S3, the varying PDMS thickness does not have a noticeable effect on the temperature gardients produced by acoustothermal heating.

Movie captions:

Movie I: Acoustothermal heating: spatiotemporal temperature control, dynamic generation of temperature gradients (linear and double-peak), and heating and cooling rates.

Movie II: Bidirectional droplet sorting in the acoustothermal tweezer system.

Movie III: Multichannel droplet sorting in the acoustothermal tweezer system.