Supplementary Information

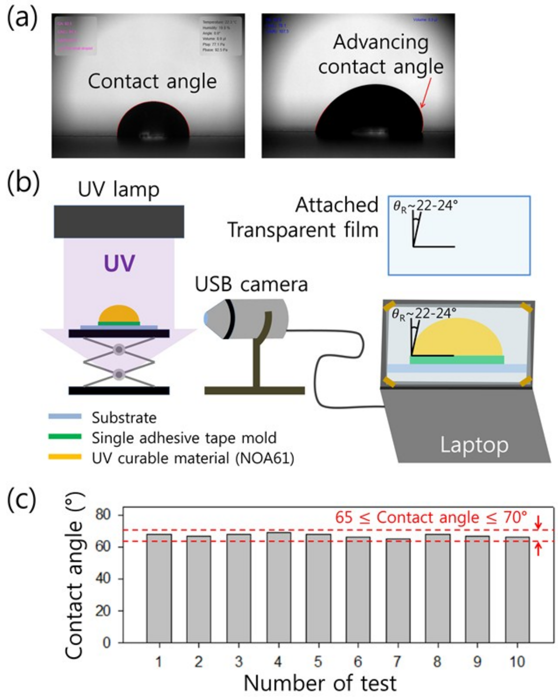

Figure S1. (a) Characterization of the surface of a single adhesive tape using DI water. The contact angle and advancing contact angle by tilting were measured using a contact angle analyzer. (b) Experimental set-up for fabricating the dome-shaped chamber mold using a UV-curable material, comprising of a UV lamp for UV exposure, USB camera and laptop for real-time visualization. A transparent film marked with the Rayleigh angle is attached to the laptop monitor. (c) Measured contact angles from 10 different dome-shaped chamber molds, which show contact angles between 65 and 70°. Using this experimental setup, the dome-shaped chamber with Rayleigh angle (~22–23°) could be fabricated.

Determination of volume of UV-curable material

To achieve a desirable contact angle in the dome-shaped chamber device, the surface energy of the single adhesive tape was measured with a contact angle analyzer (SmartDrop, Femtobiomed Inc., Korea). For the measurement, a droplet of deionized water was dispensed on the surface, and the contact angle and advancing contact angle by tilting were measured, as shown in Figure S1 (a). From the results, the surface energy of the single adhesive tape can be calculated using the equation below[1,2]:

$$\cos\theta = -1 + 2\sqrt{\frac{\gamma_{sv}}{\gamma_{lv}}}e^{-\beta(\gamma_{lv}-\gamma_{sv})^2}, \quad (1)$$

$$\beta = 0.0001247\ (m^2/mJ)^2, \quad (2)$$

where θ, γ_{sv}, and γ_{lv} indicate the contact angle, surface tension of the single adhesive tape, and surface tension of water (71.8 J/m^2), respectively. The contact angle of the DI water droplet was measured as ~91.5 $\pm$ 0.9°, whereas the advancing contact angle was measured as 107.51°. Therefore, the surface energy of the single adhesive tape was calculated as 18.04 J/m^2. The surface tension of NOA 61 (γ_{lv}) was measured as 0.039 J/m^2, which is similar to the known value of 0.04 J/m^2, and the advancing contact angle was confirmed as 73.88°. Therefore, the contact angle of the NOA 61 droplet that was lower than 73.88° could be achieved by real-time visualization of the droplet and UV curing.

Figure S1(b) shows the fabrication set-up for the dome-shaped chamber mold. To visualize the real-time process of dispensing UV curable material on a 3-mm diameter circle in the tape mold, a USB camera (800 × Digital microscope, DMicroscope Inc.) was placed on the side. The volume of UV curable material ranging between 1 and 6 µL at 1-µL intervals was used to achieve the desired contact angle (~68°) by real-time monitoring with a transparent film marked with the Rayleigh angle (~22–23°), attached to the laptop. Additionally, a UV lamp was located above the droplet to enable UV exposure starting at the moment of the droplet reaching the contact angle marked on the transparent film. In the previous report, the crosslinking time was only 1 or 2 s for full curing[3]. It can be said that the time for UV curing is shorter than the time for the droplet to spread further to have a small contact angle. Therefore, the dome-shaped chamber mold with contact angle of ~68° can be successfully fabricated with 5 µL of NOA 61.

Figure S1(c) shows the measured contact angles from the dome-shaped chamber mold fabricated in the setup shown in Figure S1(b). 10 different molds fabricated by 5 µL of NOA 61 dispensed on a 3-mm diameter circular tape mold were used. The contact angles were measured as 67.2 ± 1.2°, which were suitable for the fabrication of the dome-shaped chamber with the Rayleigh angle (22–23°)

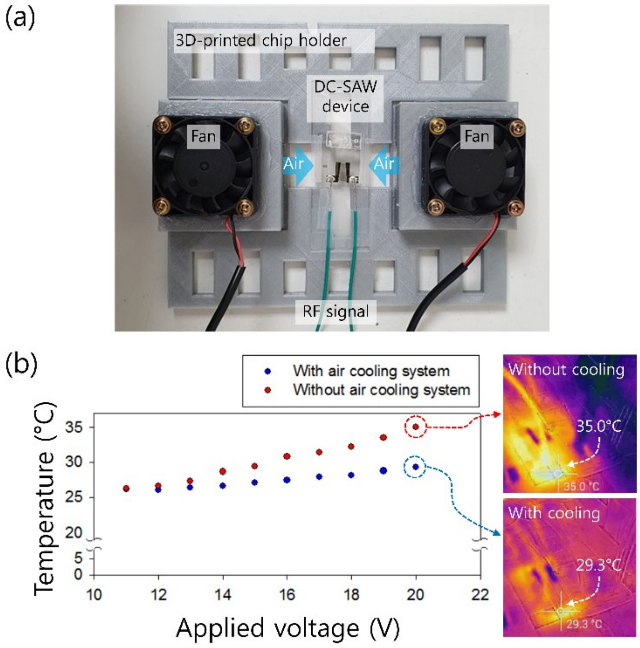

Figure S2. (a) Air cooling system for temperature control of the DC-SAW device (b) Measured temperature depending on the applied voltage with and without the air cooling system

Temperature control using air-cooling unit

Temperature control is important to apply our DC-SAW device to biological applications. In this study, an air cooling system was used to prevent the temperature from increasing higher than 40°C during the acoustic mixing by acoustic actuation[4] (Fig. S2 (a)). The air cooling system was fabricated by 3D-printer contained two open air conduits with two axial fans mounted and the DC-SAW device was placed in the center open slit for visualization using a microscope and open air vents.

Figure S2 (b) shows the measured temperature at the dome-shaped chamber at Q_{total} = 100 µl/min depending on the applied voltage with and without the air cooling system. Digitalized value of the temperature was reported from the thermal imaging camera at the thermal saturation 2 min after applying the voltage. Measured temperature with the applied voltage ranging from 11 to 20 V_{pp} showed 26-29.3°C with the air cooling system, so that our DC-SAW device can be applied to biological sample analysis without protein denaturation and physiological damage to cells[5].

Effect of the contact angle of the dome-shaped chamber on the mixing performance

Effect of contact angle on the mixing performance is critical to characterize the DC-SAW device for acoustic mixing. To evaluate the mixing performance depending on the contact angle, the cylindrical chamber with the dome-shaped chamber with the contact angle less than 5° and the dome-shaped chamber with the contact angle of ~ 24° were used. At Q_{total} = 100 µl/min and the applied voltage of 20 V_{pp}, 300-nm fluorescent particles showed the patterns indicated by black arrows, which was parallel to the transmitted F-SAW in the cylindrical chamber with dome-shaped chamber (contact angle < 5°) due to lower channel height compared to the wavelength of FSAW (100 µm) (Fig. S3 (a)). This is consistent with the results reported in the previous research[6]. On the other hand, in the dome-shaped chamber with 24° contact angle, the acoustic mixing was achieved at the separation efficiency of 17 % (Fig. S3 (b)). The separation efficiency was lower than that of the DC-SAW device with the contact angle of ~68°, which is due to less effective SAW transmission.

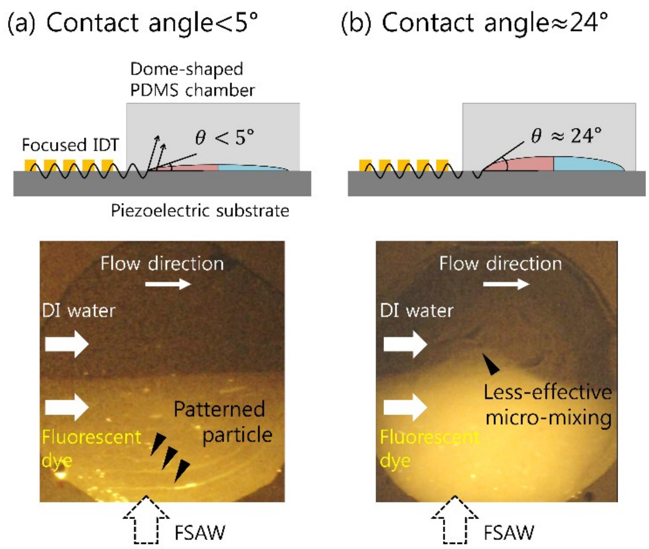

Figure S3. Effect of the contact angle of the dome-shaped chamber on the mixing performance (a) in the cylindrical chamber with the dome-shaped chamber with the contact angle less than 5° and (b) the dome-shaped chamber with the contact angle of ~ 24°.

References

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