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Study on mixing and heating of microdroplets by surface acoustic waves

弾性表面波による微小液滴の混合と加熱に関する検討

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1. Introduction

In the medical and biotechnology fields, microfluidic systems (MFS) that can move small amounts of fluid are required because of their advantages such as portability and the need for small amounts of specimens and chemicals. There are several methods to move a small amount of fluid, such as creating a microfluidic channel, controlling the contact angle of a droplet by an electric field, and moving a droplet by exciting a surface acoustic wave (SAW) using a piezoelectric substrate and a comb-shaped electrode (IDT). In the SAW method, a longitudinal pressure wave is continuously emitted into the fluid while the SAW is excited, which causes a flow in the fluid and enables a more efficient mixing of fluids. The attenuation of the longitudinal waves in the fluid causes the temperature of the droplet to rise[1,2]. This is useful for inspections in which the fluid is heated and kept at a constant temperature. **Figure 1** shows a schematic diagram of droplet transport by SAW. In this study, water droplets and glycerin droplets were mixed to simulate a specimen, and the relationship between the temperature rise of the droplets caused by SAW and the mixing location and viscosity of the droplets was investigated.

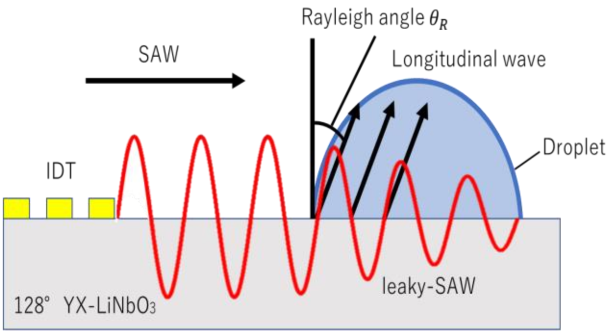

Fig. 1 Schematic diagram of SAW streaming

2. Experimental method

The piezoelectric substrate used in this study is 128°YX-$LiNbO_3$. The experimental system is shown in **Fig. 2**. As shown in Fig. 2, a 5 μL water droplet and a 10 μL glycerin droplet are placed on the piezoelectric substrate. The water droplet is transported to the glycerin droplet by SAW, and the two droplets merge and mix. The temperature of the droplets was measured by a non-contact thermometer from the top of the droplets, and the temperature of the droplets was recorded at 3-second intervals for 60 seconds after the start of mixing. Seven different concentrations of glycerin (0, 10, 30, 50, 70, 90, and 100 wt%) were used for mixing as in the previous study. The same experiment was also conducted when the two droplets were mixed on the IDT instead of on the substrate. Only when the droplets were mixed in a three-layer structure (substrate, water, and glass)[3], glycerin droplets were mixed alone and the temperature was recorded because the water droplets could not be transported at an applied power of 0.8 W.

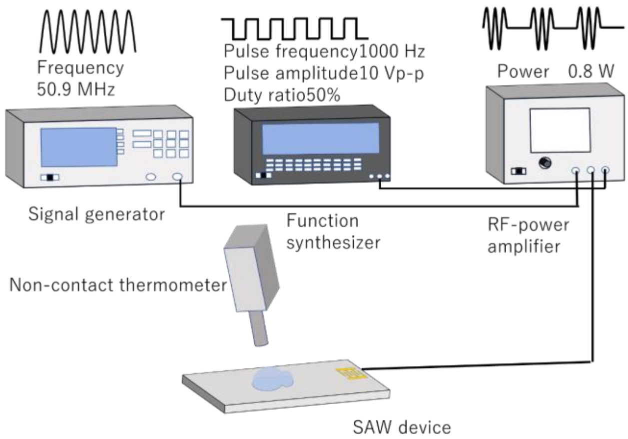

Fig. 2 Experimental system

3. Experimental results and discussion

Figure 3 shows the experimental results when the droplets are mixed on the piezoelectric substrate. It is found that the maximum temperature of the droplet increases with the increase of glycerin concentration. The maximum temperature of the droplet increases with the concentration of glycerin, but the time to saturation is about 10 seconds regardless of the glycerin concentration. The temperature change after the saturation of the temperature rise is larger for higher glycerin concentration.

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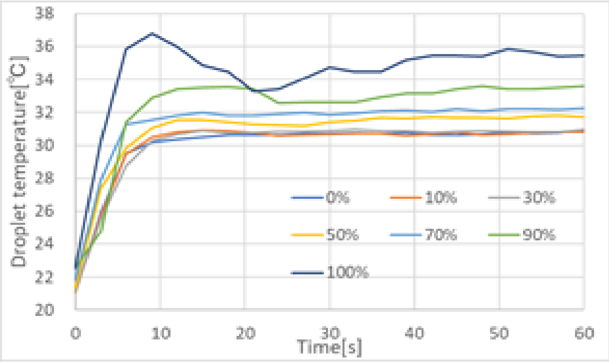

Fig. 3 Relationship between droplet temperature and mixing time on a $LiNbO_3$ substrate.

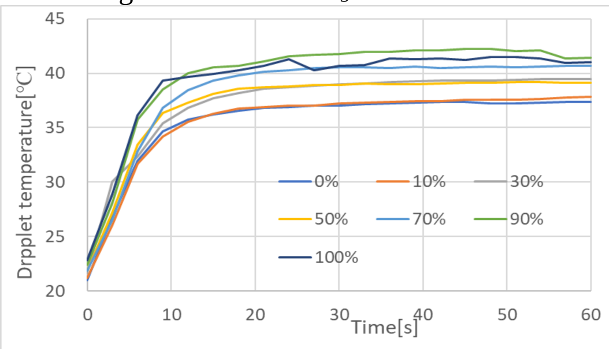

Fig. 4 Relationship between droplet temperature and mixing time on IDT

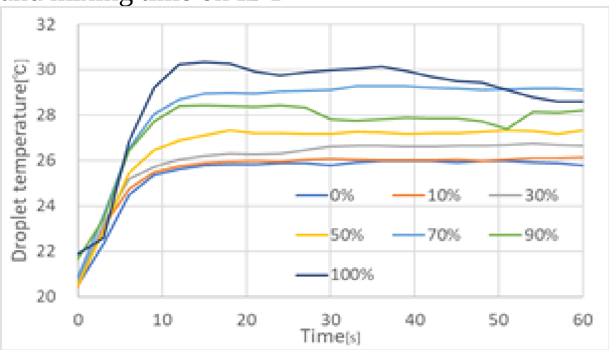

Fig. 5 Relationship between droplet temperature and mixing time in the case of a three-layer structure.

Figure 4 shows the results when the droplets are mixed on the IDT. The results of Figs. 3 and 4 show that the maximum temperature and the temperature rise rate of the droplets increase with increasing glycerin concentration. The time required for the temperature rise to reach saturation was also the same, about 10 seconds. On the other hand, the maximum temperature at each glycerin concentration was higher when the mixing location was on the IDT.

Figure 5 shows the results of droplet mixing on a three-layer structure. Only when the droplets were mixed on a three-layer structure, the droplets were mixed with glycerin only, not with water droplets and glycerin. The results in Fig. 5 show the same tendency as the results for the non-three-layer structure. Figure 5 shows that mixing and heating of droplets can be achieved even in a three-layer structure. However, the maximum temperature at each glycerin concentration was lower than that at the mixing location on the substrate or IDT.

The droplets were mixed at three different locations: on the piezoelectric substrate, on the IDT, and on the three-layer structure. In all cases, the maximum temperature of the droplets increased with the concentration of glycerin. This is due to the fact that the longitudinal waves emitted in the droplet as shown in Fig. 1 attenuate with the viscosity of the liquid. The maximum temperature at each glycerin concentration increases in the order of the mixing location, i.e., three-layer structure, piezoelectric substrate, and IDT. The reason why the maximum temperature was lower in the three-layer structure than in the other two cases may be that the amplitude of the SAW decayed as it propagated from the substrate to the water to the glass. The reason for the higher maximum temperature of the droplet when mixed on the IDT is due to the good heat conductivity of the gold used in the IDT and the reflected SAW waves from the IDT, which radiates more longitudinal waves into the droplet.

4. Conclusion

In this study, the temperature rise of the droplet was investigated by varying the viscosity of the droplet and the mixing location. The temperature of the droplet tends to increase as the viscosity of the droplet increases because the attenuation of the longitudinal waves emitted in the droplet increases. The droplets were mixed on a piezoelectric substrate, an IDT, and a three-layer structure. The experimental results showed that the droplets were heated more on the IDT, the piezoelectric substrate, and the three-layer structure when the SAW excitation conditions were the same.

On the other hand, the reason why the temperature rise of the droplet saturates to about 10 seconds regardless of the viscosity of the droplet and the location of the mixture is not fully investigated yet, and will be discussed in the future. In this study, only the temperature of the top surface of the droplet was measured using a non-contact thermometer, but we will study the convection inside the droplet in more detail using thermocouples and simulations.

References
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