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Measurements of liquid sound velocity with droplet manipulation using surface acoustic wave

弾性表面波による液滴搬送を伴う液体の音速の測定

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1. Introduction

Surface acoustic wave (SAW) propagates on the surface of an elastic material with concentrating its energy. As the SAW can be used to manipulate a droplet on a device, the SAW can be applied to a digital microfluidic systems (DMFS)[1].

The position and sound velocity of a microdroplet have been estimated from the acoustic flow or sound wave propagation path in the droplet[2] In order to apply this method to actual DMFS, it is necessary to combine droplet transportation and mixing with measuring sound velocity. The purpose of this study is to measure the liquid sound velocity after transport and mixing of droplets by SAW for the DMFS application.

2. Measurement system

Interdigital transducers (IDTs) were fabricated on 128YX-LiNbO3. Electrode materials were gold and chromium. Center frequency was 50 MHz. The measurement system is shown in **Fig. 1**. A continuous wave of 50 MHz from a signal generator and a pulse signal with a frequency of 10 kHz and a duty ratio of 1% from a function synthesizer were mixed and amplified by an amplifier to generate a burst wave signal that was excited for 1 μs. The signal was input to the SAW device via the directional coupler. The responses of the incident, reflected and transmitted signals were observed by an oscilloscope. A sound velocity of a droplet was calculated from the delay time between the reflected and transmitted signals. For the droplet manipulation, the duty ratio was set to 50% Water and a 10% wt~50% wt glycerin solution were used as the liquid in the droplets.

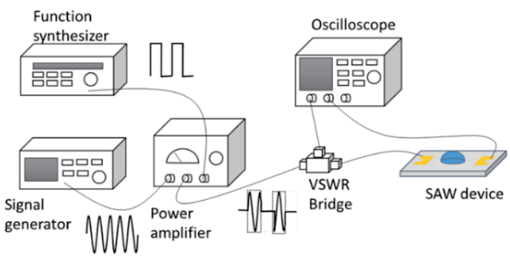

Fig. 1 Experimental system

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3. Measurements of liquid sound velocity

As shown in **Fig. 2**, the SAWs excited from IDT1 radiates a longitudinal wave in a liquid. The longitudinal wave propagates along the path πr (r :radius of the droplet) and are then reflected along to the IDT1 side. The propagation time T_r of the reflected wave is expressed as eq. (1).

$$T_r = \frac{L+\pi r}{v_L}\frac{2A}{v_{SAW}} \tag{1}$$

where v_{SAW} (= 3990.6 m/s) is the velocity of the SAW and v_L is the liquid sound velocity. The propagation time T'_r of the reflected wave in the case of excitation from IDT2 is similarly expressed by eq. (1).

The transmitted wave also propagates along path $A + L + B$ and are received by the IDT2. The propagation time of the transmitted wave T_t is given by eq. (2).

$$T_t = \frac{A+B}{v_{SAW}} + \frac{L}{v_L} \tag{2}$$

From these equations, the following function for the liquid sound velocity is derived.

$$f(v_L) = \frac{1}{2}\pi(r+h)(1+a) + \frac{v_L}{v_{SAW}}\left(X - 2T\frac{v_L}{\pi}\right) - T_t v_L \tag{3}$$

where h is the height of the droplets and $A+B+2r$ is the distance between the IDTs.

$$a = \frac{3b^2}{10+\sqrt{4-3b^2}} \quad , \quad b = \frac{r-h}{r+h} \tag{4}$$

The longitudinal wave velocity is obtained by applying the Newton-Raphson method to eq. (3).

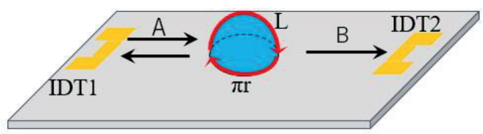

Fig. 2 SAW propagation path

4. Effects of contact angle of droplets

In eq. (3), the shape of a droplet is assumed to be hemispherical, so the shape of the droplet in the experiment affects the accuracy. However, the shape of the droplet easily changes depending on the surface condition of the substrate. Therefore, the effect of the hydrophobic surface on the accuracy of the contact angle was investigated. Three cases of the contact angles were compared. Table 1 shows the results of the sound velocity measurements for different contact angles. For the low contact angle, which means the hydrophilic surface, the accuracy is poor. For hydrophobic surface, the accuracy is allowable. Therefore, it is necessary to keep the contact angle of the droplets above 90°.

Table 1. Comparison of errors in calculated sound velocity at different contact angle.

Contact angle (°)	Droplet volume (μl)	Liquid sound velocity (m/s)	Error rate (%)
68	6	1708	13.0
	8	1672	10.6
	10	1746	15.5
89	6	1580	4.5
	8	1593	5.3
	10	1640	8.5
104	6	1562	3.3
	8	1602	6.0
	10	1615	6.8

5. Droplet transfer on a water-repellent surface

When a droplet is manipulated by SAW, the shape of the droplet changes and the contact angle decreases as shown in **Fig. 3**. This is the influence of the radiation pressure to the droplet. When the contact angle becomes low, the measurement accuracy reduces. Therefore, a coating of SLIPS[3] (slippery liquid infused porous surfaces) was applied to the substrate surface. The SLIPS is constructed with a silicone-based water repellent coating that is covered with a lubricant for maintaining stable lubrication under pressure and impact. Therefore, the droplet shape can be maintained during transport.

Water droplet with a diameter of 5 mm was manipulated on the SLIPS treated surface or no-treated surface. **Fig. 4** shows the estimated sound velocity for before manipulation, and after manipulation with or without the SLIPS treatment. For the surface without the SLIPS treatment, as the droplet shape was changed due to the manipulation, the measured values are different from the results before the manipulation. On the other hand, the SLIPS treated surface maintains the droplet shape, so the estimated values almost agree with those before the manipulation.

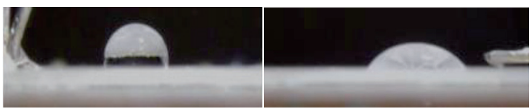

Fig. 3 Droplet shape (left: before manipulation, right: after manipulation)

Droplets of water and glycerin solution were manipulated and mixed on the substrate by SAW. Then the sound velocity was estimated. **Fig. 5** shows the estimated sound velocity. The results do not agree with the literature values, which are shown by the solid line. It is difficult to keep the droplet shape after mixing of two droplets. In order to improve the accuracy, it is necessary to use a mixing method that minimizes the shape change of the droplets.

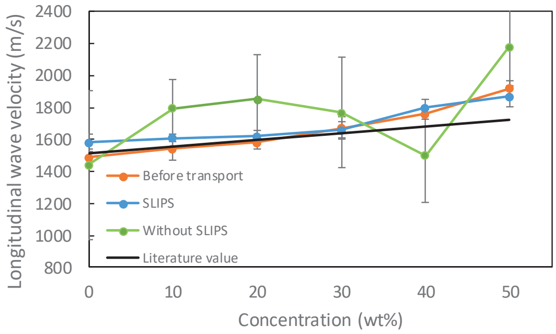

Fig. 4 Difference in post-transfer measurement results due to surface processing

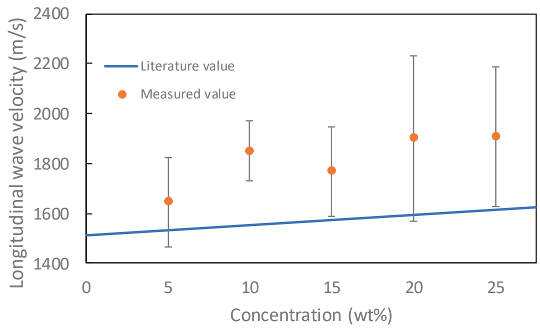

Fig. 5 Sound velocity after mixing droplets

7. Conclusion

In this study, measurements of longitudinal sound velocities with droplet manipulation using SAW were performed to improve the accuracy of the device by surface processing. In the future, a method for mixing droplets while maintaining the shape of the device should be investigated.

References

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2. S. Tsunogaya, et al., ibid. 57, 07LD03 (2018).
3. J. T. Luo, et al., Phys. Rev. Appl. 7, 014017(2017).