3P3-9

Observation of reflected and transmitted waves caused by acoustic streaming in droplet on SAW devices

SAW デバイス上の液滴内部に誘起される音響流により生じる反射波と透過波の観察

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1. Introduction

Research on droplet transportation and atomization using surface acoustic wave (SAW) and droplet interaction is becoming more and more active. Along with advances in liquid droplet transport technology by SAW, detection of droplet position was also required. Renaudin and colleagues reported that when SAW was excited with a short burst wave, reflected waves could be observed from droplets on the SAW propagation surface, and applied to droplet position measurement1. However, they do not consider propagation path in the droplet. In order to realize a practical droplet position measurement, it is necessary to clarify the longitudinal wave propagation path. In this paper, we focus on the acoustic streaming in the droplet and report on experimental results about longitudinal wave propagation path.

2. Figures and Tables

Fig. 1 shows the measurement system used in this study. A short burst wave was generated using a continuous wave (50.95 MHz) and a pulse wave with the frequency of 10 kHz and the duty ratio of 1%, and was fed to an interdigital transducer (IDT) formed on a piezoelectric crystal, that is 128° rotated Y-cut X- propagation $LiNbO_3$. Reflected signals from the IDT were observed using an oscilloscope with a directional coupler. The SAW device actually used and its dimensions are shown in **Fig. 2**. The droplet drip position was determined by placing the SAW device on a grid paper. The acoustic streaming in the droplet was mixed with rock paint and observed by a conventional video.

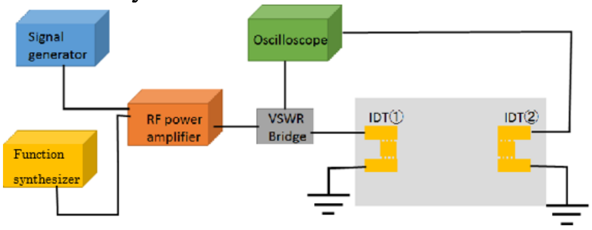

Fig.1 Measurement system

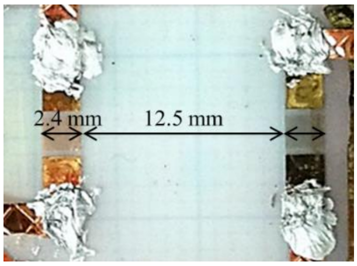

Fig.2 Size of SAW device used for experiment

3. References

A typical time response when measuring reflected waves from droplets is shown in **Fig.3**. When the reflected wave response time is T and the position and shape of the droplet are determined as shown in **Fig.4**, the longitudinal wave propagation time T_{in} inside the droplet can be obtained by the following equation.

$$T_{in} = T - \frac{2A}{V_{SAW}} \qquad (1)$$

Where, V_{SAW} is the phase velocity of the SAW. **Fig. 5** shows the experimental results of T_{in}, when volume of the droplet was varied. As the volume of droplets increases, the propagation time in the droplets also increases. In previous research[2], we assumed that longitudinal waves propagate through L_1 in Fig. 4. This is an assumption that takes into consideration that the SAW radiates a longitudinal wave inclined at the Rayleigh angle in the droplet. T_{in} is obtained from the following equation.

$$T_{in} = \frac{L_1 + d}{V_L} \qquad (2)$$

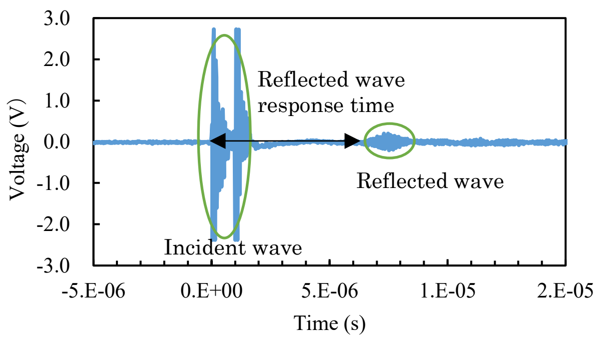

Fig.3 Time response of reflected wave

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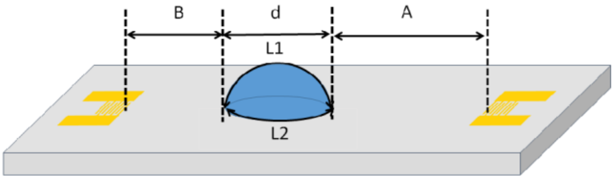

Fig.4 Propagation path dimension

Where V_L is the longitudinal wave velocity of the liquid. The calculated values using eq. (2) are plotted on Fig. 5. The same tendency with the experiment results is obtained. However, the results do not agree. Therefore, the propagation path of the longitudinal wave in droplet were discussed by observing acoustic streaming caused in the droplet. The photograph of the acoustic streaming observed is shown in **Fig. 6**. Two vortices are generated in the droplet by the SAW, and the direction of the vortex is drawn in the figure. If the reflected wave is returning along the internal flow, the side of the vortex is predicted as a propagation path. Based on the above discussion, we have assumed a path that propagates through L_1 in Fig.4 and returns along L_2. T_{in} for this case is obtained from the following equation.

$$T_{in} = \frac{L_1 + L_2}{V_L} \tag{3}$$

The calculated results using eq. (3) are also plotted on Fig. 5. It is found that eq. (3) agrees well with experimental results. Therefore, we concluded that the vortex contributes to the measurement.

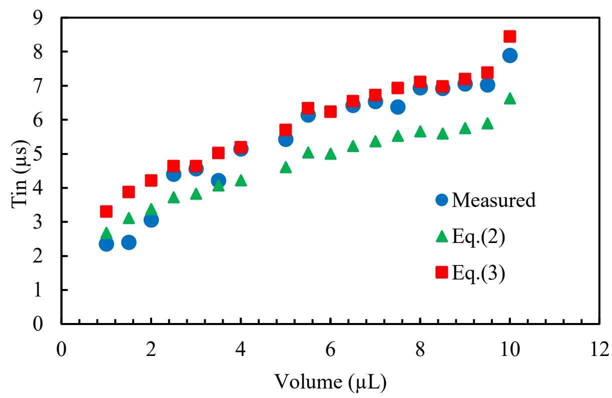

Fig.5 Measured results and calculated ones using eqs. (2) and (3)

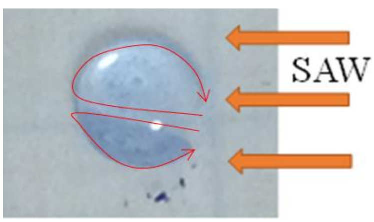

Fig.6 Observation of acoustic streaming in droplet.

Transmitted wave was also measured. The responses of the transmitted wave for pure water (0 wt%) and glycerin aqueous solution of 50 wt% at a droplet volume of 10 μl are shown in **Fig. 7**. Increasing the glycerin concentration increases the viscosity and increases the velocity of the longitudinal wave. The response enclosed in a square is not affected by concentration. The response enclosed by the ellipse is affected by the concentration and the response time has changed. In other words, this response is a response that has propagated through the liquid. Assuming that the response time of this wave is T_t, the experimental result agrees well with the value of the following equation.

$$T_t = \frac{A + B}{V_{SAW}} + \frac{L_1}{V_L} \tag{4}$$

It has been confirmed that the transmitted wave changes complicatedly depending on the amount and shape of the droplet. Therefore, it can be applied to droplet position measurement along with reflected waves by further research in our future work.

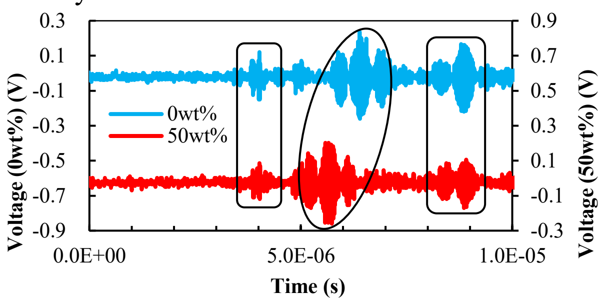

Fig.7 Transmission response of different concentrations

4. Conclusion

In this paper, we investigated the measurement of droplet position using longitudinal wave radiation into the droplet by SAW. To clarify the experimental results, the acoustic streaming was focused. By considering the acoustic streaming in the droplet, the calculated results are consistent with the experiment ones with higher accuracy. Moreover, the transmitted wave was observed and indicated the possibility of application to the position measurement of the droplet. We plan to conduct research on more advanced position measurement considering both reflected wave and transmitted wave in the future.

References

1. J. P. Renaudin, et al., Sensors and Actuators B, 138, pp. 374-382 (2009).
2. J. Kondoh et al., Proc. IEEE Sensors 2016, pp. 634-637 (2016).