Three-layer type digital microfluidic system using surface acoustic wave device

弾性表面波デバイスを用いた 3 層構造のデジタル式マイクロ流体システム

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1. Introduction

A microfluidic system is a device that can control and measure the movement of droplets by compacting and integrating chemical reactions and sensors[1]. Consolidating the processes separately performed conventionally into one device can reduce the sample amount and shorten the analysis time. From this, it can be expected to be applied in the medical and biotechnology field. Techniques for manipulating the droplets are important for consolidating a plurality of processes, and various methods are being studied.

In this paper, surface acoustic wave (SAW) was used for the droplet manipulation, and an interdigital electrode (IDE) sensor was used for measurement. Manipulation using the SAW can perform stirring at the same time. The structure of the SAW actuator is simple. When a droplet is manipulated, there is a problem that liquid adheres to the substrate surface. Therefore, a three-layer structure of "cover glass/liquid layer/piezoelectric substrate" was proposed[2]. By manipulating a droplet on the cover glass, inexpensive and disposable devices are realized. In this paper, droplets were manipulated, mixed, and measured using a three-layer type digital microfluidic system (DMFS, see **Fig. 1**).
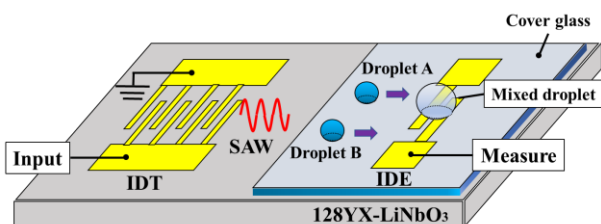

Fig. 1 Three-layer type digital microfluidic system using surface acoustic wave device.

2. Principle

SAW is a wave propagating by concentrating energy near the surface of an elastic body and can be generated by applying a high frequency signal to an interdigital transducer (IDT) on a piezoelectric substrate. As shown in **Fig, 2**, the SAW emits a longitudinal wave when it is transmitted to the

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liquid. Longitudinal waves cause reflection at the interface with the glass and re-excitation of the Leaky-SAW and transmit bulk acoustic wave, such as the Lamb wave, to the inside of the glass. This vibration propagates from the top of the glass to droplets. As longitudinal waves propagate throughout the liquid layer, forces act on all droplets on the glass. In this way, droplets were manipulated using the streaming phenomenon caused by the SAW radiating energy into droplets.
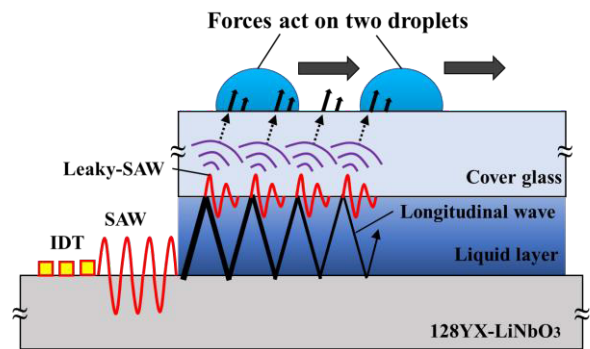

Fig. 2 Droplet manipulation mechanism in three-layer structure.

When an alternating current is applied to the IDE, an electric field is generated between the adjacent electrodes. The impedance of the droplet can be measured by measuring the current and voltage between the electrodes. Furthermore, by using the equivalent circuit model (**Fig. 3**), the theoretical value of the impedance of the droplet on the electrode can be calculated. Here, C_{dl} is the electric double-layer capacity, R_{sol} is the solution resistance, and C_{de} is the solution capacity.
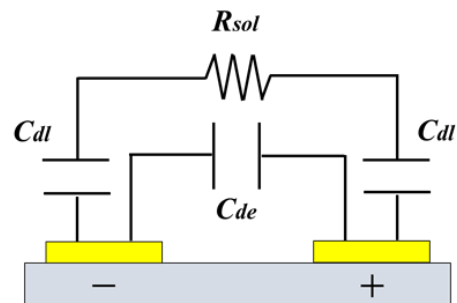

Fig. 3 Equivalent circuit model of droplet on electrodes.

3. Measurement method

An IDE sensor was fabricated on the cover glass and the impedance spectrum of distilled water and NaCl aqueous solutions with three concentrations of 0.1, 0.5, and 1.0 wt% were measured. Then, the three-layer structure was constructed, and two droplets of the distilled water and the 1.0 wt% NaCl aqueous solution on the glass were manipulated and mixed by the SAW. Mixed droplets were manipulated to the IDE and the time response of the impedance was measured using the LCR meter. For comparison, the same measurement was carried out when droplets were directly dropped on the IDE and mixed. In addition, cover glass was coated to form a branch path[3] in the propagation path of SAW in order to smooth transportation of droplets.

4. Results and discussions

Fig. 4 shows the impedance spectrum of the experimental and theoretical[2] values for 0.5 wt% NaCl aqueous solution. The both results are in good agreement. Therefore, the proposed DMFS can be used for liquid evaluation because it shows different impedance for each concentration.
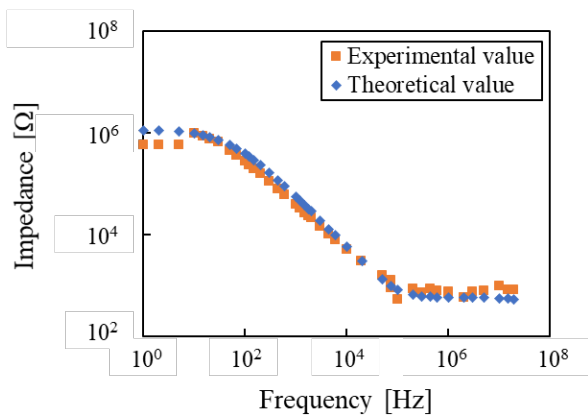
Fig. 4 Impedance spectrum of 0.5 wt% NaCl aqueous solution.

Fig. 5 shows the impedance during the manipulating, and mixing of two droplets. The frequency of the LCR meter was fixed at 1 MHz. When the elapsed time was about 20 s, the mixed droplet was manipulated to the IDE. The impedance of the mixed droplet agrees with the result in Fig. 4. In the case of direct dropping, the impedance fluctuation was large and reproducibility was low, but when stirred by SAW, impedance fluctuation was small and reproducibility was high. From this fact, the effectiveness of SAW stirring was confirmed.
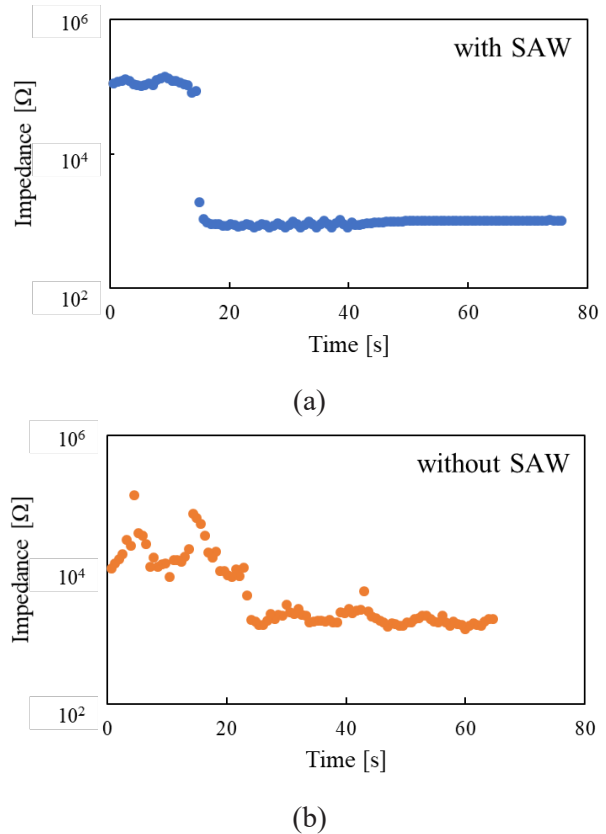
(a)

(b)

Fig. 5 Time response of droplets mixing.
(a) With and (b) without SAW.

5. Conclusion

Droplets were manipulated and mixed using the SAW. In this paper, the impedance during mixing by the SAW was measure by the IDE sensor. The high accurately measurements of the droplet is possible with the IDE sensor. The theoretical values calculated using the equivalent circuit was in good agreement with the experimental values. In addition, by coating the glass and forming a branch path, it was possible to smoothly manipulate the droplets. Using a three-layer structure, we created a low cost, disposable device. In a three-layer type digital microfluidic system, it was demonstrated that SAW stirring is effective and impedance measurement is possible. The future task is to integrate optical sensor etc. to perform multilateral liquid evaluation and optimization of three-layer structure using numerical analysis.

References

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