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Analysis and verification of surface acoustic wave propagation characteristics in cover glass/liquid layer/$LiNbO_3$ structure

カバーガラス/液体層/$LiNbO_3$ 構造における弾性表面波伝搬特性の解析と検証

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1. Introduction

In the medical and biotechnology fields, there is a need for digital microfluidic systems that can integrate pretreatments and sensors onto substrates, and manipulate and measure a droplet. Surface acoustic waves (SAW) are attracting attention, because not only manipulation, but also stirring are possible using the SAW. Rayleigh-SAW radiates longitudinal wave when it propagates liquid/solid interface. Droplet manipulation is possible, when the power is sufficiently large. As the liquid adheres to the substrate surface, which requires cleaning. Therefore, a three-layer structure of "cover glass/thin liquid layer/128YX-$LiNbO_3$" was proposed[1)] (see **Fig. 1**). A disposable device can be realized by replacing an inexpensive glass. A three-layer structure has the problem that the power required for manipulation increases due to wave energy loss in the liquid layer. Therefore, optimization of the three-layer structure is required for efficient manipulate. In this paper, numerical analysis and longitudinal wave radiation experiments were carried out, and the propagation characteristics of waves transmitting in a three-layer structure were investigated.

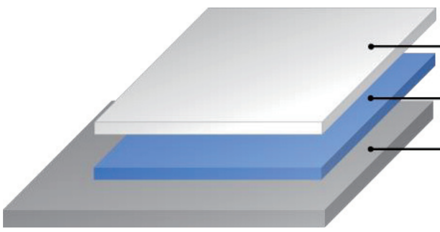

Fig. 1 Schematic of a three-layer structure.

2. Numerical analysis of wave propagation characteristics

Fig. 2 shows the numerical analysis model. The SAW propagates in x-direction and attenuates in the $-z$-direction. The y-direction is assumed as uniform. The initial velocity was set to 1000 to 5000 m/s. Then, the frequency equation was calculated, the solution was selected, and the eigenvector was calculated. If the determinant of the boundary condition matrix satisfied the convergence condition, the velocity was determined. If the determinant did not satisfy, a new initial velocity is assumed using the secant method. As boundary conditions, "liquid layer/$LiNbO_3$" and "glass/liquid layer" interfaces were continuous stress, particle displacement, electric flux density, and potential. At the "air/glass" interface, the stress was zero, and the electric flux density and potential were continuous. The velocity and particle displacement distribution of the wave propagating through a three-layer structure were calculated by changing the thickness of the liquid layer.

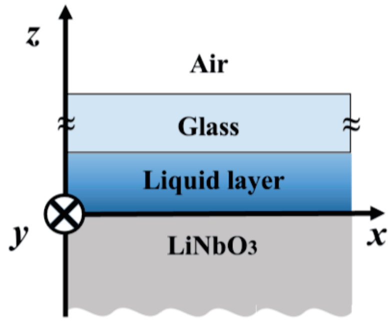

Fig. 2 Numerical analysis model.

3. Observation of longitudinal wave radiation

Fig. 3 shows the experimental system. The three-layer structure with a liquid layer thickness of about 20 μm was created. The glass surface was hydrophobized. A signal generator generates a sine wave signal with a center frequency of 56.4 MHz for the SAW device, and a function synthesizer generates a pulse wave with a frequency of 1 kHz, an input voltage of 10 $V_{p\text{-}p}$, and a duty ratio of 50 %. The signal was mixed and amplified by an RF-power amplifier and applied to the IDT to excite the SAW. Longitudinal wave radiation was photographed with a video camera, the trajectory of the scatterers was analyzed (**see Fig. 4**), and the Rayleigh angle was measured with ImageJ. The velocity of the lamb wave propagating through the glass can be obtained from the Rayleigh angle.

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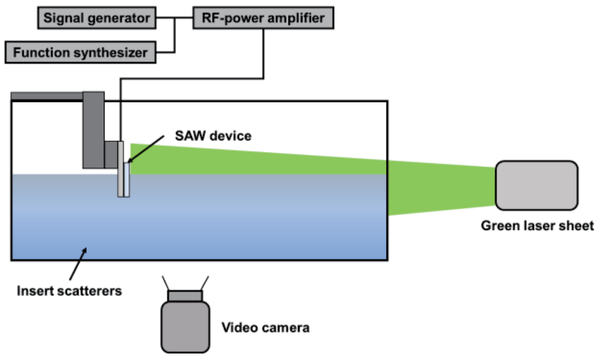

Fig. 3 Experimental system.

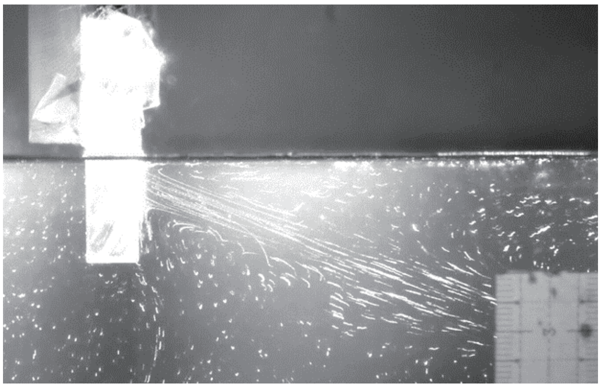

Fig. 4 Trajectories of scatterers moving in water.

Table 1 Experimental results of Rayleigh angle and Lamb wave velocity.

Input power [W]	Rayleigh angle [°]	Lamb wave velocity [m/s]
0.4	22.7	3892
0.7	21.6	4069
1.0	22.3	3946
Average	22.2	3969

The obtained Rayleigh angle and Lame wave velocity are summarized in Table 1. Whereas the input power was varied, the Lamb wave velocity is almost constant. The average value of the velocity was calculated about 4000 m/s.

4. Numerical analysis results

Figs. 5 and 6 show the numerical analysis results. The wave near 1500 m/s is the same as the sound velocity in water, so there is a high probability that the guided mode is a combination of Stoneley modes at the upper and lower interfaces of the liquid layer. The Stoneley mode propagates along the solid-liquid interface without decaying, and its velocity is slightly slower than the speed of sound in water. From the particle displacement, in the piezoelectric substrate Rayleigh-SAW behavior is obtained. In the liquid layer, there is almost no

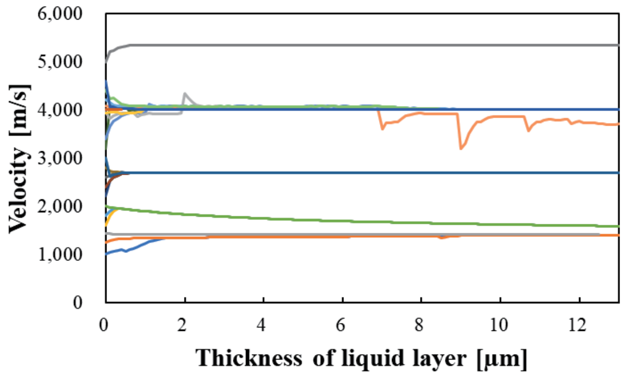

Fig. 5 Numerical results of SAW velocity in three-layer structure.

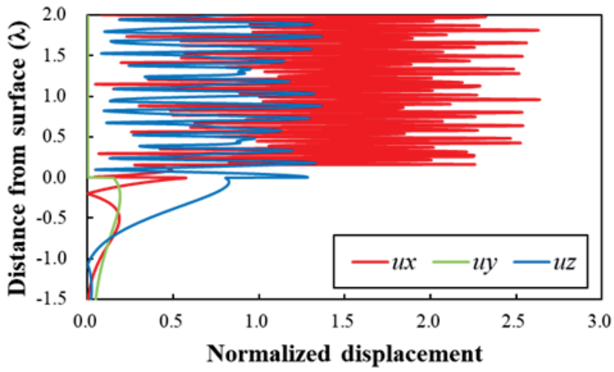

Fig. 6 Particle displacement at the velocity of 4000 m/s and a liquid layer thickness of 13 µm.

displacement of u_y, and u_x and u_z are mainly transmitted. It was found that u_x and u_z were transmitted even in glass, and higher-order vibration modes of the Lame wave were generated.

From Fig. 5, the wave with 4000 m/s are generated. Compared with Table 1, the Lamb wave velocity in three-layer structure is 4000 m/s.

5. Conclusion

From the numerical analysis and the experimental results of the longitudinal wave radiation, the propagation characteristics of the wave propagating through the three-layer structure were discussed. From the experimental results, it was found that Lamb wave with a velocity of about 4000 m/s were transmitted through the glass. Numerical analysis also confirmed that this velocity wave may occur. Future works are to optimize the structure by numerical analysis and to measurement the time response of transmitted waves.

References

1. N. Yasuda, M. Sugimoto, J. Kondoh, Jpn. J. Appl. Phys. 48, 07GG14 (2009).