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Application for shear horizontal surface acoustic wave sensing system using compact vector network analyzer

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1. Introduction

Shear horizontal surface acoustic wave (SH-SAW) devices are suitable for liquid-phase sensors. This is because SH-SAW propagates at the solid-liquid interface without radiating its energy into the liquid. The development of a measurement system is essential for the practical application of SH-SAW sensors. Previous studies used large equipment such as vector voltmeters and standard signal generators[1)]. In addition, studies including the development of a compact measurement system using an oscillation circuit and online signal processing were also conducted,[2,3)]. In recent years, compact and inexpensive network analyzers have become easily available. In this study, we report on the results of verification of the use of the nano vector network analyzer (Nano-VNA, HCXQS), one of the VNA, for measurements.

2. Experimental method

The measurement is shown in **Fig. 1**. The SH-SAW sensor fabricated on 36° YX-$LiTaO_3$ single crystal consisted of a dual delay line. SH-SAW was excited and received by a floating electrode unidirectional electrode (FEUDT). The center frequency of the sensor was 155 MHz. The propagation surface of one delay line was electrically shorted by titanium/gold film. The other surface was the exposed crystal surface. Hereafter, the shorted and crystal-exposed sides are called the short and open channels, respectively. Each channel was connected to the Nano-VNA controlled by a PC via USB.

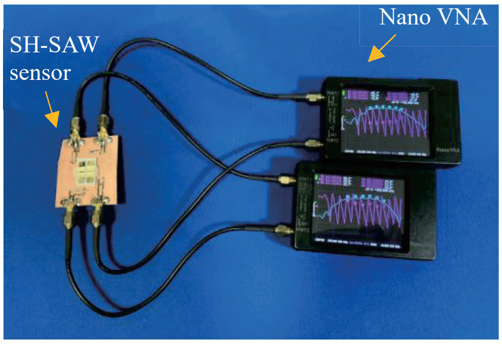

Fig. 1 Experimental system used in this study.

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A silicon pool was placed on the propagation surface to keep liquid in it. The electrical properties of liquid, that are dielectric constant and conductivity, are obtained from the differential signal between open and short channels. Mechanical properties of viscosity and density are obtained from the short channel. Both electrical and mechanical properties were simultaneously measured by the SH-SAW sensor. Glycerol solutions of 10, 20, 30, 40, and 50 wt% were used as sample liquids for mechanical properties. Sodium chloride (NaCl) aqueous solutions were used for conductivity measurement. The measurements were performed at 25°C. The passband characteristics, S_{21}, were measured using the Nano VNA for reference and sample liquids loaded on the sensor, and the amplitude ratio and phase shift at the center frequency were obtained.

3 Numerical analysis method

A well-known method for numerical analysis of SAW was proposed by Campbell and Jones[4)]. The real and imaginary parts of the complex phase velocity obtained by the numerical analysis were used to obtain the amplitude ratio and phase shift. The phase shift is obtained by Eq. (1) and Eq. (2). The amplitude ratio is obtained by substituting the result of Eq. (3) into Eq. (4).

$$\frac{\Delta V}{V} = -\frac{1}{k}\left(\frac{\omega V_r'}{{V_r'}^2 + {V_j'}^2} - \frac{\omega V_r}{{V_r}^2 + {V_j}^2}\right) \qquad (1)$$

$$\Delta\emptyset = \emptyset\left(\frac{\Delta V}{V}\right) \qquad (2)$$

Where, V_r and V_j are real and imaginary parts of the velocity in the reference liquid, respectively, V_r' and V_j' are the real and imaginary parts of the velocity in the sample liquid, respectively, k is the wavenumber, and $\emptyset$ is the phase in reference solution. The phase shift is obtained by substituting the result of Eq. (1) into Eq. (2).

The amplitude ratio is obtained by substituting the result of Eq. (3) into Eq. (4).

$$\frac{\Delta\alpha}{k} = \frac{1}{k}\left(\frac{\omega V_j'}{V_r'^2 + V_j'^2} - \frac{\omega V_j}{V_r^2 + V_j^2}\right) \quad (3)$$

$$\frac{A_S}{A_R} = e^{-(\Delta\alpha l)} \quad (4)$$

Where l is the interaction length between SH-SAW and liquid.

4 Results and discussion

4. 1 Mechanical properties of liquid

Fig. 3 shows the amplitude ratio and phase shift as a function of glycerin solution concentration. Theoretical values using numerical analysis are also plotted. The error rate of the amplitude ratio increased with increasing concentration, reaching a maximum of 4.2 % at 50 wt%. The phase shift error was less than 0.5 deg. These values are comparable to those of conventional methods. Thus, Nano VNA can evaluate mechanical properties.

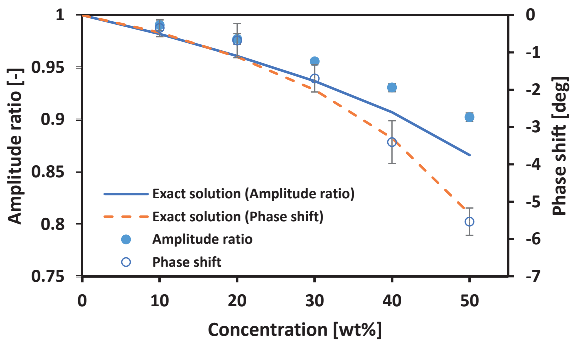

Fig. 3. Amplitude ratio and phase shift as a function of glycerol concentration.

4.2 Electrical properties

Fig. 4 shows the amplitude ratio and phase shift versus NaCl conductivity. Theoretical values using numerical analysis are also plotted. Obtained results from the short channel showed little change in both experimental and numerical analysis. This shows little change in the viscosity and density of NaCl. The differential between the open channel value and the short channel value was determined, and the phase shift and amplitude ratio were obtained. The open channel shows a decrease in amplitude ratio and a large phase shift with increasing conductivity. The same trend was observed in the numerical analysis results. However, the results were not as consistent as the mechanical properties. This may be due to the difference caused by the interaction length of the propagation path in the experiment and the interaction length of the propagation path in the numerical analysis. Thus, Nano VNA was also found to be available for electrical properties.

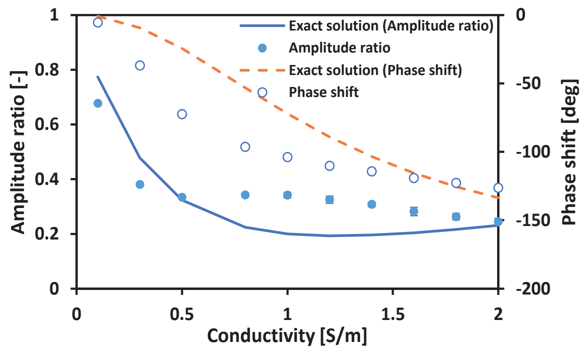

Fig. 4. Amplitude ratio and phase shift as a function of NaCl conductivity.

5 Conclusion

The results obtained in this study show that the Nano VNA can be used as a measurement system for SH-SAW sensors. Two Nano VNA was used in this study. Short channels and open channels could be obtained at the same time, which made it possible to obtain two values of mechanical and electrical properties at the same time. The results were compared with those of the numerical analysis, and comparable trends were observed. The use of Nano VNA made it possible to downsize the experimental system. We will apply this method to the characterization of engine oil in the future.

References

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