Development of SH-SAW Sensing System for Liquids

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***Abstract*— Developments of sensors using surface acoustic wave (SAW) devices have been attractive. A shear horizontal SAW (SH-SAW) sensor can detect liquid properties and chemical reactions in liquid. For practical applications of the SAW sensor, it is necessary to discuss its properties. In this paper, the SH-SAW sensors with a floating electrode unidirectional transducer (FEUDT) or an interdigital transducer (IDT) are compared. Frequency-phase characteristics and frequency-insertion loss profiles are measured. Also, phase shift and amplitude ratio between sample and reference liquids are evaluated. The results indicate that the SH-SAW sensor with the FEUDT has suited for liquid measurements. Then the SH-SAW sensor with FEUDT is mounted in the SH-SAW sensing system. The system configuration is the same of a vector voltmeter measurement system. However, exclusive circuits are developed, so its size is reduced. Using the system, several liquids are measured.**

I. Introduction

Acoustic-wave devices have been applied as chemical and physical sensors for gas and liquid phases. The acoustic wave sensors are classified on the bases of their vibration and wave modes [1, 2]. All acoustic wave devices can be applied as gas sensors, whereas acoustic wave devices with a shear horizontal mode (SH mode) or 0th antisymmetric Lamb wave, namely, a flexural plate wave (FPW), are applied as liquid-phase sensors. For liquid-phase sensor applications using acoustic wave sensors, the detection mechanisms are based on mechanical and electrical perturbations. Mass loaded onto the acoustic wave sensors, and density and viscosity products of the adjacent liquid are detected by the mechanical perturbation (or mechanical interaction), whereas the conductivity and the dielectric constant of the adjacent liquid are detected by the electrical perturbation (or an acoustoelectrical interaction).

Feature of an SH-surface acoustic wave (SH-SAW) based liquid-phase sensor is simultaneous detection of liquid mechanical and electrical properties with high sensitivity [3, 4]. Many sensors, such as optical, electrical, electrochemical based sensors, have been investigated. However, only the SH-SAW sensor can detect mechanical and electrical properties. Therefore, it is important to commercialize SH-SAW sensing system. For developing the SH-SAW sensing system, there are two major tasks. One is phase property. Reibel et al. reported that phase shift depended on the phase position [5]. If the relationship between phase and frequency is not linear, obtained results depend on the phase position. The other is development of smart, portable, and not-expensive sensing system. Normally, oscillation circuit is used for an acoustic wave sensor circuit. Kondoh et al. also developed SH-SAW sensing system with oscillation circuit [6]. However, for practical application, we have considered that phase measurement is adapted to determine liquid property [7]. In this paper, we describe our approaches about these problems: first, to improve phase property, a floating electrode unidirectional transducer (FEUDT) is used for generating and receiving SAW. Second, SAW sensing system for detecting phase and amplitude is developed. The SH-SAW sensor with FEUDT is compared with the sensor with a normal interdigital transducer (IDT) and confirmed its validity through experiments. The several liquids are measured using the developed SAW sensing system.

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II. Detection Principle of SAW Sensing System and Previous SH-SAW Sesor

An acoustic wave that propagates in or on a piezoelectric material is a coupling wave of strains and an electrical potential. When an SH- SAW propagation surface is contact with a liquid, evanescent fields of an SH displacement and a piezoelectric potential extend outside from the surface. The evanescent fields are influenced by external properties. The changes of evanescent field profiles lead to measurable change of velocity and amplitude of the SH-SAW. The changes of the wave are measured as frequency shift, phase shift and amplitude change. Figures 1 and 2 show the principle of frequency and phase detection, respectively. For Fig. 1, the frequency at phase = 0º is measured. For Fig. 2, frequency is fixed and phase shift is measured. If phase has a distortion as shown in Fig. 3, frequency and phase shifts depend on the phase position. The distortion appears reflection from edge of the device and a triple transit echo (TTE). These signals are spurious components, so it is necessary to reduce the spurious signals. Figure 4 shows our previous SH-SAW sensor [8]. Two channels of Ch. 1 and Ch. 2 are electrically shorted by Au/Cr evaporated films. The other channel of Ch. 3 has a free

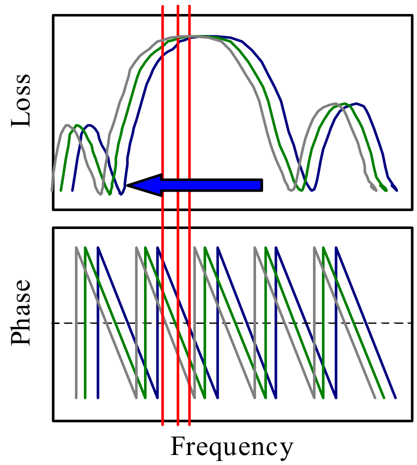


Figure 1. Schematic illustration of the detection principle of the frequency.

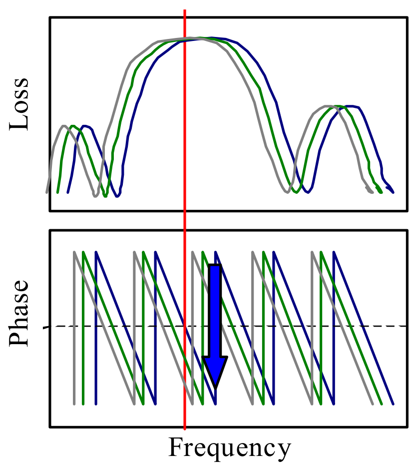


Figure 2. Schematic illustration of the detection principle of the phase.

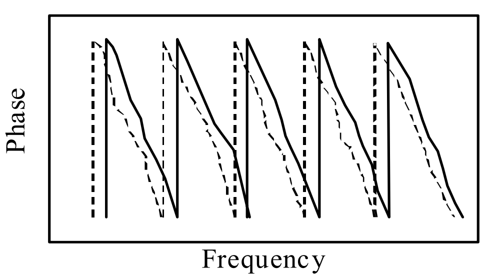
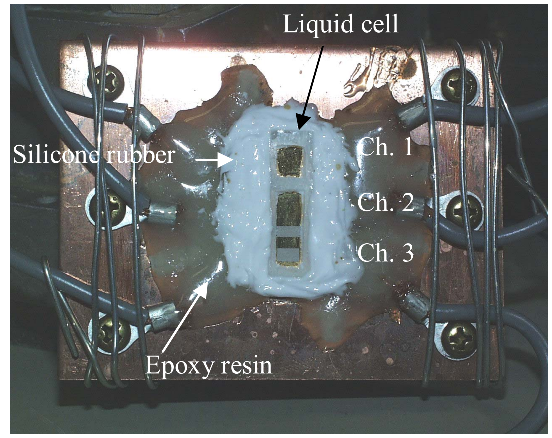
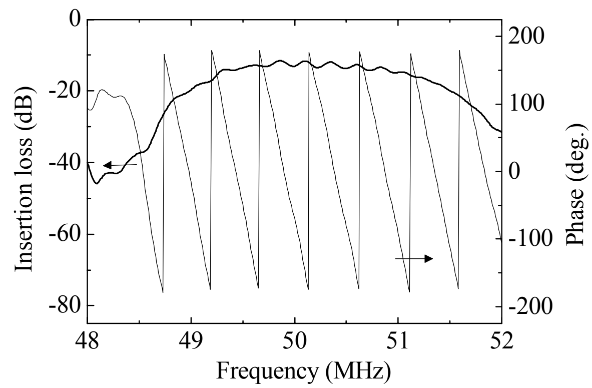


Figure 3. Schematic illustration of the phase distortion.

surface area for working as an electrically active area. To reduce reflection from the edge, epoxy was coated. Figure 4(b) shows insertion loss and phase as a function of frequency. Whereas the TTE is not reduced, good phase characteristics are realized. However, as fabrication of the SH-SAW sensor as shown in Fig. 4(a) is not easy, the sensor is not adapted for practical applications.



(a)



(b)

Figure 4. (a) Photograph and cross-section of the previous SH-SAW sensor. (b) Frequency characteristics.

III. Floating Electrode Unidirectional Transducer

Unidirectional transducers are proposed for improvement of the characteristics of the SAW device. A floating electrode unidirectional transducer (FEUDT) [9] is one of them. In this paper, we used the FEUDT for the SH-SAW sensor. Figure 5 shows the frequency characteristics without matching. Directional property is observed.

IV. Comparison of SH-SAW Sensors with FEUDT or Normal IDT

The comparison of the SH-SAW sensors with FEUDT or IDT was carried out using a network analyzer (Agilent E4991A). A liquid cell was loaded on the SAW propagating surface. Distilled water and glycerol/water mixture were used as sample solutions. Hereafter, the SH-SAW sensor with FEUDT is called FEUDT-SAW and the SH-SAW sensor with IDT is called IDT-SAW.

Fundamental properties of the FEUDT-SAW and IDT-SAW are shown in Fig. 6. Note that the IDT-SAW was fabricated in house and is not covered by silicone rubber and epoxy like Fig. 4. Also, its property is not the best. The insertion loss is improved and the TTE is reduced by using the FEUDT. Also, good phase property is realized. Then, glycerol/water mixture was injected into the liquid cell and

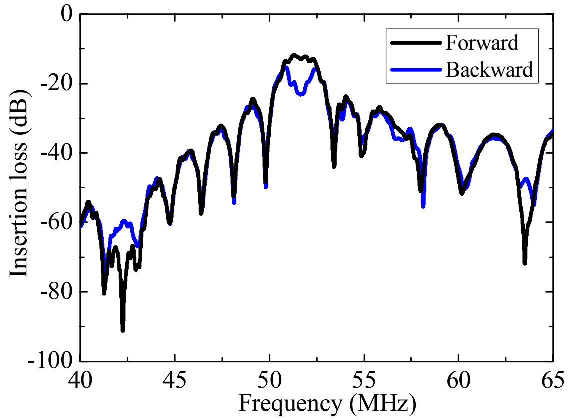
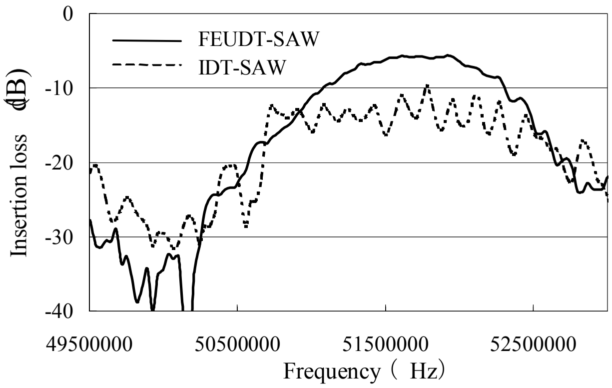
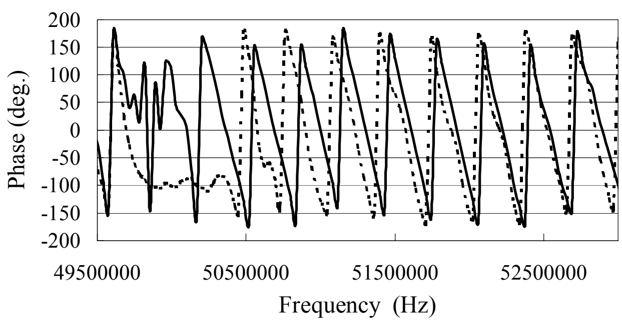


Figure 5. Frequency responses of FEUDT in the forward and backward directions.



(a)



(b)

Figure 6. Fundamental properties of the FEUDT-SAW and IDT-SAW. (a) Insertion loss and (b) phase.

measured. The results are shown in Figs. 7 and 8. Insertion loss increases with concentration and phase shifts to left side. These are reasonable results. However, the shape of insertion loss for the IDT-SAW changes with increasing concentration. Also, phase distortion increases. These mean that the detection of high viscous solution using IDT-SAW is difficult. In the practice measurements, phase shift and amplitude ratio between sample and reference liquid, which is normally distilled water, are detected. Using the results in Figs. 8 and 9, phase shift and amplitude ratio were derived and shown in Figs. 9 and 10. For FEUDT-SAW, phase shift and amplitude ratio from 51 to 52 MHz are almost constant at a concentration below 90 % by weight. Also, in near the center

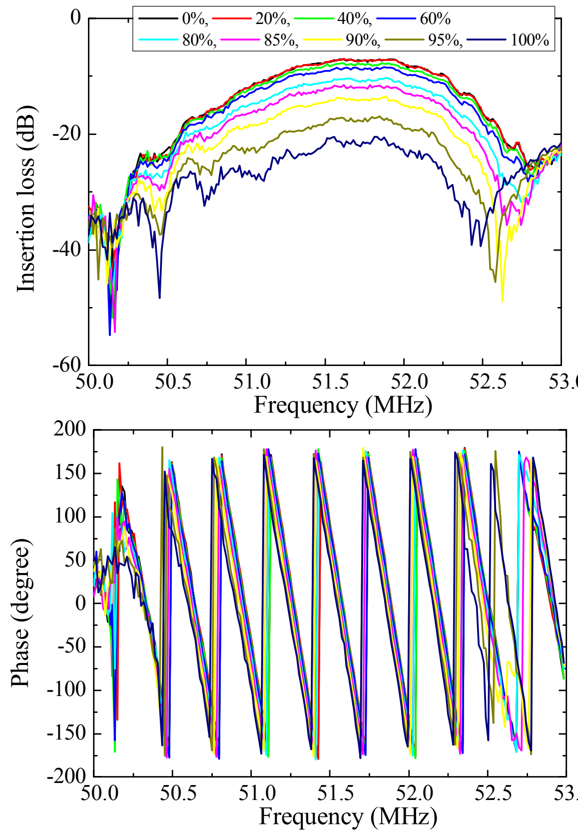


Figure 7. (a) Insertion loss and (b) phase of FEUDT-SAW. Glycerol/water mixture is used as sample solution.

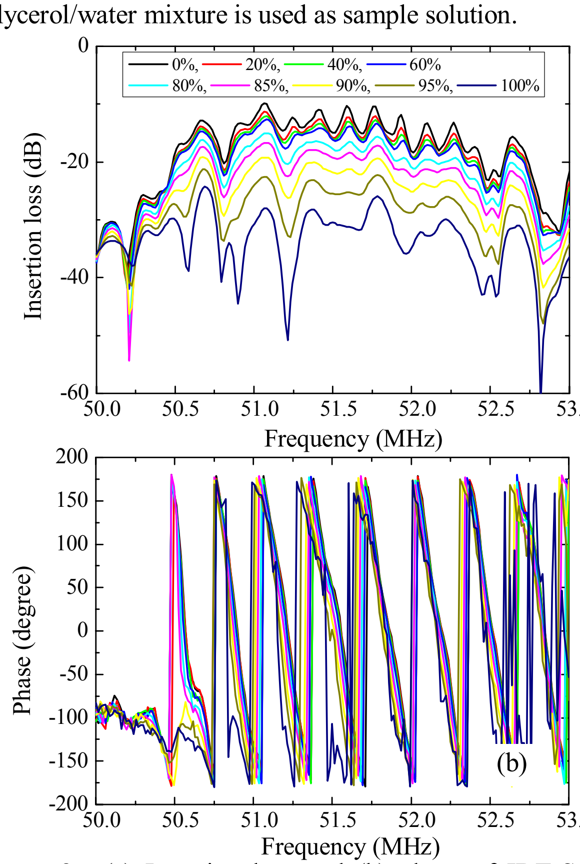


Figure 8. (a) Insertion loss and (b) phase of IDT-SAW. Glycerol/water mixture is used as sample solution.

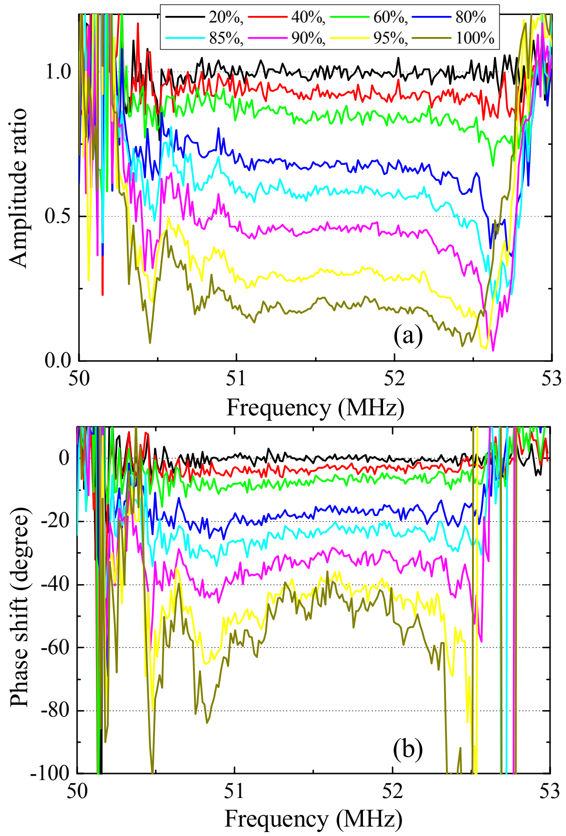


Figure 9. (a) Amplitude ratio and (b) phase shift of FEUDT-SAW. Glycerol/water mixture is used as sample solution.

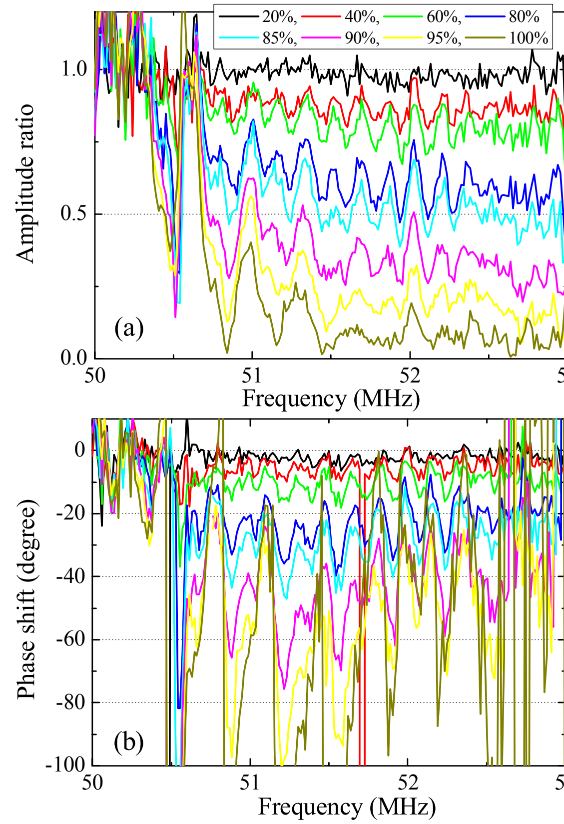


Figure 10. (a) Amplitude ratio and (b) phase shift of IDT-SAW. Glycerol/water mixture is used as sample solution.

frequency of 51.5 MHz, the FEUDT-SAW can detect high viscosity solutions. On the other hand, for IDT-SAW, phase position greatly influences the phase shift and amplitude ratio. Tuning of the frequency is very important for the IDT-SAW. Moreover, the measurement of high viscosity solution is impossible. Therefore, based on those results, we concluded that FEUDT-SAW must be used for sensor applications. As the SH-SAW sensor detects liquid electrical properties, we have been comparing FEUDT-SAW and IDT-SAW for those solutions.

V. DEVELOPMENT SH-SAW SENSING SYSTEM

A new SH-SAW sensing system is fabricated. The idea of the sensing system is to reduce the size of vector voltmeter measurement system. Figure 11 shows the vector voltmeter measurement system. Signal generator was replaced by a SAW signal generator and phase shift and amplitude detection circuit was fabricated in place of the vector voltmeter. Figure 12 shows the fabricated sensing system. Output signals are leaded to PC via analog/digital (AD) converter. FEUDT-SAW was used in the developed system. The sensor constituted of two delay lines. Propagating surface of the one delay line is metallized and electrically shorted. The other has free surface area and electrically opened. Figure 13 shows the time responses of ethanol/water mixture and glycerol/water mixture. These samples were loaded onto the shorted and open surfaces. Concentrations of the solutions are shown in the figure. The output signals of phase shift and amplitude are depended on the concentrations. Therefore, the

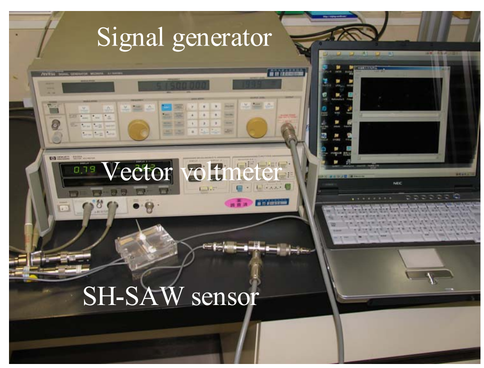


Figure 11. Vector voltmeter measurement system.

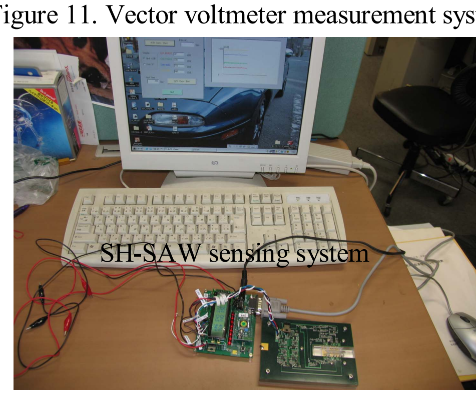
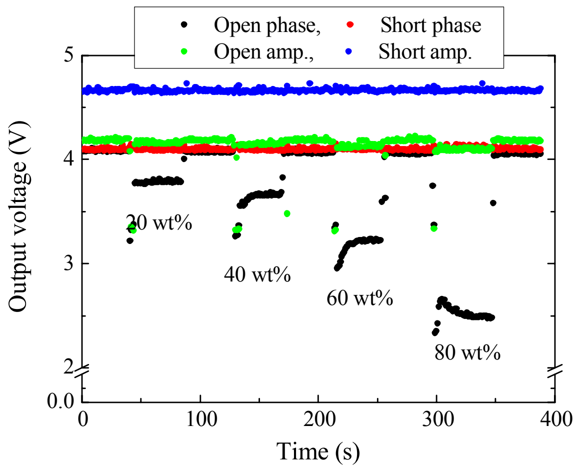
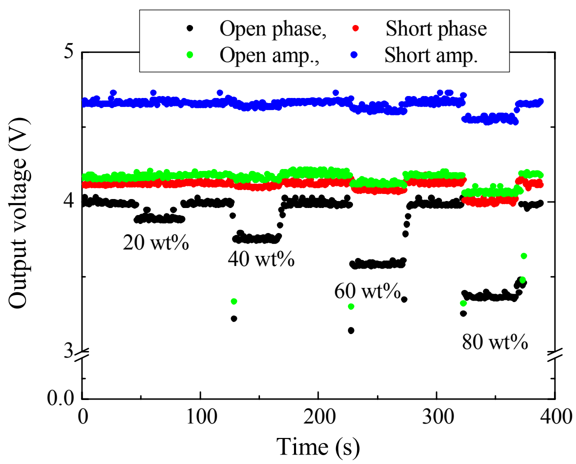


Figure 12. Developed sensing system



(a)



(b)

Figure 13. Time responses of (a) ethanol/water mixture and (b) glycerol/water mixture using the developed SH-SAW sensing system.

developed system can be applied for the liquid property detection.

VI. CONCLUSIONS

Commercialization of the SH-SAW sensing system is important, because it has an excellent ability for liquid characterization. For this purpose, phase property is discussed. For improving phase characteristics, FEUDT is adapted. The FEUDT-SAW is compared with the IDT-SAW. The results indicate that the FEUDT-SAW has high predominance for liquid sensing. Using FEUST-SAW, a SH-SAW sensing system is developed. The detection mechanism of the system is the same as the vector voltmeter measurement system. The several samples are measured by using the developed system. From the results, we conclude that the developed SH-SAW sensing system can be used for liquid property detection.

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