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Propagation Properties of Leaky Surface Acoustic Wave on Water-loaded Piezoelectric Substrate

水負荷圧電基板上の漏洩弾性表面波の伝搬特性

Ryota Suenaga[1‡], Masashi Suzuki[1], Shoji Kakio[1] , Yuji Ohashi[2] , Mototaka Arakawa[2] , and Jun-ichi Kushibiki[2] ([1]Univ. of Yamanashi; [2]Tohoku Univ.)

末永 凌大 [1‡]，鈴木 雅視 [1]，垣尾 省司 [1] ，大橋 雄二 [2] ，荒川 元孝 [2] ，櫛引 淳一 [2]

([1] 山梨大学, [2] 東北大学)

1. Introduction

An accurate evaluation of the acoustical loss of substrate materials and loaded thin films is required to design a surface acoustic wave (SAW) device. Line-focus-beam (LFB) acoustic microscopy[1] is suitable for measuring the elastic properties of materials for highly accurate, nondestructive, and noncontact. This measurement method provides the velocities and attenuation of leaky SAWs (LSAWs) excited on a water-loaded material surface. However, the LSAWs propagate at the boundary between water and the material while leaking the acoustic energy of waves into water therefore, the measured attenuation for LFB acoustic microscopy includes leakage loss into water. Thus, it is difficult to evaluate the acoustical loss of materials using this method. However, there is a possibility that acoustical loss can be evaluated by LFB acoustic microscopy by subtracting the calculated leakage loss into water from the measured value.

In this study, the propagation properties of LSAWs on a water-loaded 128° Y-X $LiNbO_3$ (LN) with an amorphous Ta_2O_5 thin film~~s~~ deposited by RF sputtering were measured from SAWs excited by interdigital transducers (IDTs) before and after water loading on surface of the sample. In addition, the acoustical loss of an a-Ta_2O_5 thin film was evaluated by subtracting the calculated attenuation from the measured propagation loss *PL* after water loading.

2. Calculated Propagation Properties

Figure 1 shows the calculated phase velocities of a Rayleigh wave (R-SAW), a Love-type SAW (Love SAW), and a pseudo-SAW (PSAW) on the 128° Y-X LN with the a-Ta_2O_5 thin film. Moreover, the measured phase velocities (described later) are also shown in Fig. 1. First, the material constant of LN reported by Kushibiki *et al.*[2] and that of a-Ta_2O_5 reported by Kakio *et al.*[3] were used. Then, the measured value was lower than the calculated value of the R-SAW, while it was higher for the Love SAW. Therefore, the constants c_{11} and c_{44} of the a-Ta_2O_5 thin film were determined again to minimize the difference in the square of errors between the measured and calculated values. The density ρ and relative permittivity $\varepsilon/\varepsilon_0$ were assumed to be 6.88×10^3 kg/m^3 and 38, respectively. The constants c_{11} and c_{44}, which were determined to be 1.18×10^{11} and 0.46×10^{11} N/m^2, respectively, were used for the calculation.

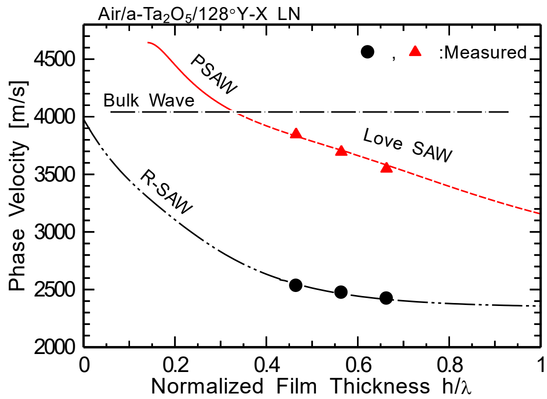

Fig. 1 Phase velocity on the free surface.

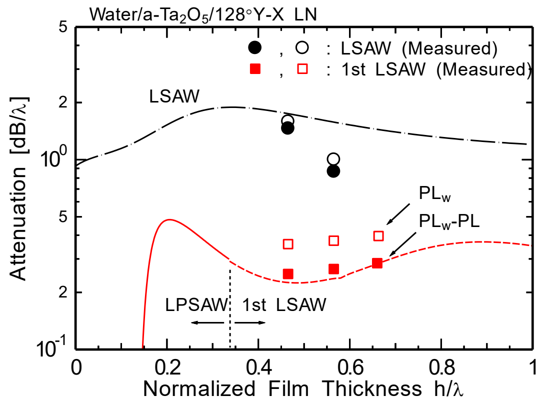

Fig. 2 Attenuation on water-loaded surface.

Figure 2 shows the calculated attenuations of the LSAW and a leaky pseudo-SAW (LPSAW) as a function of the normalized thickness h/λ using the constants determined for the water-loaded substrate. The LSAW radiates the acoustic energy of wave into water. On the other hand, the LPSAW radiates the acoustic energy of wave into both water and the substrate. When the film thickness was greater than 0.34 λ, the LPSAW degenerated the LSAW because the LPSAW no longer radiated the acoustic energy into the substrate owing to its phase velocity being lower than that of a slower shear bulk wave.

g17te014@yamanashi.ac.jp

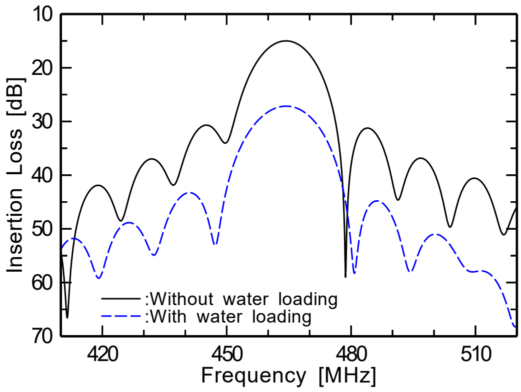

Fig. 3 Frequency responses of PSAW before and after water loading.

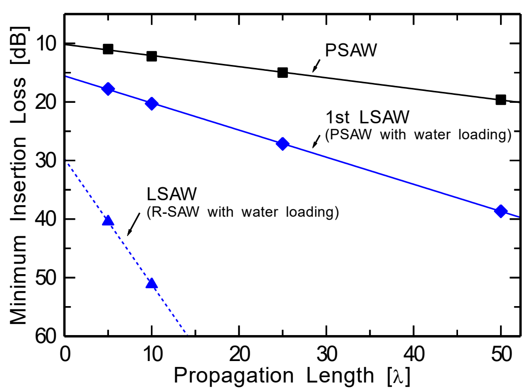

Fig. 4 Minimum insertion loss vs. propagation length.

Therefore, the 1st LSAW mode was named here. It was found that the attenuations of the LPSAW and 1st LSAW mode are one order of magnitude less than that of the LSAW.

3. Measured Propagation Properties

First, a simple delay line with a single-electrode IDT pair with a period λ of 8.0 μm, an overlap length *W* of 50 λ, *N*=30 finger pairs, and propagation path lengths *L* of 5, 10, 25, and 50 λ was fabricated on 128° Y-X LN substrate using an Al film. Next, an a-Ta_2O_5 thin film was deposited on the IDT pair and propagation path using an RF magnetron sputtering system (ULVAC MPS-2000) with a long-throw-sputter cathode. Samples with normalized film thicknesses (h/λ) of 0.47–0.66 were fabricated.

Figure 3 shows examples of the frequency responses of the PSAW for *L*=25 λ before and after water loading on the sample surface measured using a network analyzer. In these results, the responses due to electromagnetic waves and a triple transit echo were removed by a time gate option. It was observed that the insertion loss *IL* increased with leakage loss into water. Phase velocity was determined by multiplying the center frequency of the measured frequency response between IDTs by λ. **Figure 4** shows the minimum insertion loss *MIL* as a function of the propagation path length *L* for the PSAW and 1st LSAW mode together with the *MIL* of the LSAW. For the LSAW, the *MIL* shows only two points with 5 λ and 10λ because no response of the LSAW at more than 25λ was observed owing to a large leakage loss. The propagation losses without water loading *PL* and with water loading PL_w were measured from the slope in Fig. 4. PL_w is shown in Fig. 2 together with the calculated attenuation. Furthermore, the measured leakage loss into water was determined by subtracting *PL* from PL_w and is also shown in Fig. 2. The value of PL_w-*PL* was in disagreement with the calculated attenuation for the LSAW, whereas good agreement was obtained between the calculated and measured values for the 1st LSAW mode.

Table I Results of evaluating acoustical loss of a-Ta_2O_5.

h/λ	PL_w [dB/λ]	PL_w-*Att.* [dB/λ]	PL_R [dB/λ]
0.47	0.36	0.13	0.13
0.56	0.37	0.14	0.14
0.66	0.40	0.11	0.16

4. Evaluation of Acoustical Loss

Acoustical loss was evaluated by subtracting the calculated attenuation from the measured PL_w of the 1st LSAW mode. **Table I** shows evaluation results. Good agreement was obtained between the evaluated acoustical loss (PL_w-*Attenuation*) and the measured PL_R of the R-SAW corresponding to the acoustical loss of the material. A similar experiment was conducted with a SiO_2 thin film instead of an a-Ta_2O_5 thin film. The result of evaluation was the same as that previously obtained, and it was found that the acoustical loss can be evaluated by using a wave mode with a small leakage loss such as LPSAW or 1st LSAW mode selected in the present experiment.

5. Conclusions

The propagation properties on free and water-loaded surfaces were investigated and the acoustical losses were evaluated. The results of evaluation using a wave mode with a small leakage loss such as an LPSAW were in good agreement with PL_R corresponding to acoustical loss. In the future, the evaluation of acoustical loss using an LFB-UMC system will carried out including a wave mode with a large leakage loss.

References

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