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Proceedings of Symposium on Ultrasonic Electronics, Vol. 35 (2014) pp. 89-90
3-5 December, 2014

Love-type Surface Acoustic Wave on Y-X LiTaO$_3$ with Amorphous Ta$_2$O$_5$ Thin Film

アモルファス Ta$_2$O$_5$ 薄膜装荷 Y-X LiTaO$_3$ 上のラブ波型弾性表面波

Shoji Kakio[†], Haruka Fukasawa, and Keiko Hosaka (Univ. of Yamanashi)
垣尾 省司[†]，深沢 遼，保坂 桂子（山梨大院・医工）

1. Introduction

Amorphous Ta$_2$O$_5$ (a-Ta$_2$O$_5$) thin films have high permittivity, a high refractive index, and high density compared with other dielectric thin-film materials. Owing to their properties, a-Ta$_2$O$_5$ thin films have been applied as insulator films in metal-insulator-semiconductor devices and as a thin-film material in multilayer structures.

On the other hand, in the field of surface acoustic wave (SAW) devices, it has been reported that trapping effects, such as the transformation from a leaky SAW (LSAW) to a Love-type SAW (Love SAW) and an increase in the coupling factor, can be achieved by loading a LiNbO$_3$ (LN), quartz, or langasite substrate with an a-Ta$_2$O$_5$ thin film with a thickness of a few percent of the wavelength.[1-4] However, optimization of the deposition conditions to reduce the propagation loss and decrease the temperature coefficient is required.

In this study, the propagation properties of a Love SAW on Y-X LiTaO$_3$ (LT)[5-7] with an a-Ta$_2$O$_5$ thin film deposited by an RF magnetron sputtering system with a long-throw sputter (LTS) cathode were investigated. In general, an LTS cathode can produce a thin film with a smooth surface because the substrate is not directly exposed to plasma.

2. Sample Fabrication

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 a propagation path of length *L* of 5, 10, 25, or 50 λ was fabricated on Y-X LT using a 0.013-λ-thick Al film. Next, an a-Ta$_2$O$_5$ thin film was deposited on the IDT pair and the metallized propagation path using an RF magnetron sputtering system (ULVAC MPS-2000) with an LTS cathode. The sputtering parameters except for the substrate temperature T_S were similar to those in our previous report,[8] in which *X*-axis-oriented Ta$_2$O$_5$ piezoelectric thin films were deposited using the same RF magnetron sputtering system. T_S was set to 150 ˚C to obtain an amorphous thin film. The deposition rate was 0.31–0.41 μm/h. Samples with normalized film thicknesses (*h*/λ) of 0.047–0.151 were fabricated.

Moreover, samples with resonator electrodes consisting of an IDT (λ=8.0 μm, *W*=50 λ, *N* =70.5) and reflectors with a shorted grating having 50 refractors were also fabricated.

3. Propagation Properties

Figure 1 shows the measured frequency responses for *L*=50 λ. For the sample without the thin film (virgin), the response of the LSAW was observed at a center frequency of 495 MHz and the insertion loss *IL* was measured to be over 55 dB owing to the huge attenuation. It was observed that *IL* was decreased and the center frequency was shifted to a lower frequency by loading with an a-Ta$_2$O$_5$ thin film. When the film thickness was 0.120 λ, *IL* was 40 dB less than that for the sample without a film owing to a transformation to a Love SAW as described later.

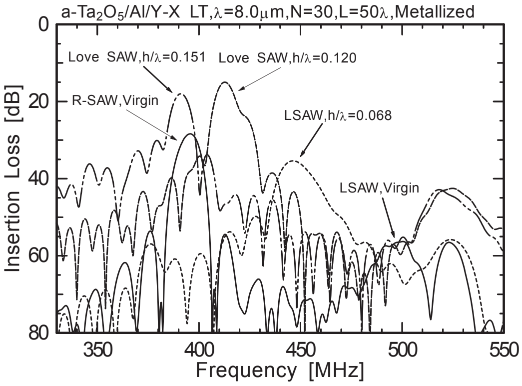

Fig. 1 Frequency responses.

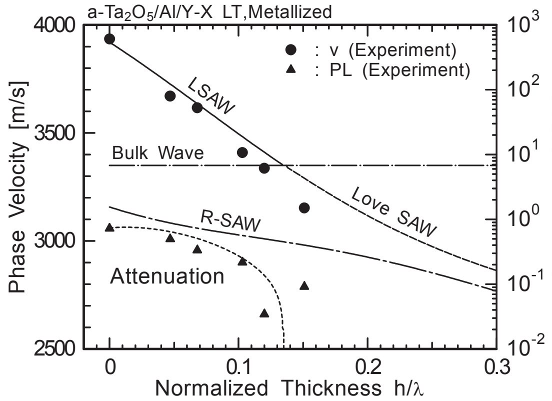

Fig. 2 Phase velocity and propagation loss.

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kakio@yamanashi.ac.jp

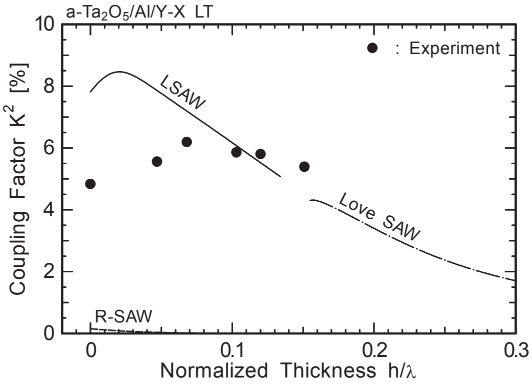

Fig. 3 Coupling factor K^2.

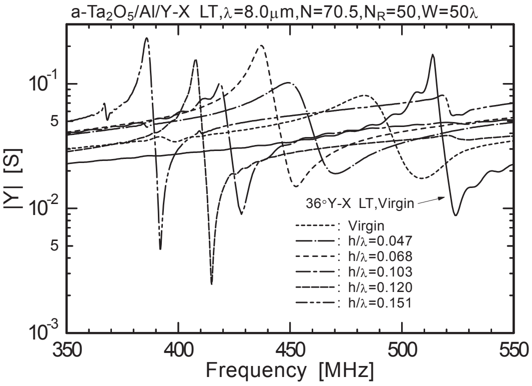

Fig. 4 Resonance properties.

Figure 2 shows the phase velocity *v* measured from the center frequency. The theoretical values of the phase velocity for the LSAW, the Love SAW, and the Rayleigh wave (R-SAW) calculated using the elastic constants determined for an a-Ta_2O_5 thin film deposited using a planar-type RF magnetron sputtering system[9] are also shown in Fig. 2. When the film thickness was greater than 0.120 λ, the LSAW became a Love SAW because the measured phase velocity was lower than that of the slow-shear bulk wave.

The propagation loss *PL* measured from the slope in the *IL* vs propagation length *L* graph is also shown in Fig. 2 together with the calculated attenuation of the LSAW. The reduction of *PL* owing to the transformation to the Love SAW was observed. The minimum *PL* of 0.03 dB/λ was obtained for the sample with h/λ=0.120.

The value of K^2 determined from the measured IDT admittance is shown in **Fig. 3** together with the calculated K^2. At film thicknesses of less than 0.068 λ, the measured K^2 was smaller than the calculated value owing its large *PL*. K^2 of 5.8% was obtained for the sample with h/λ=0.120, for which the minimum *PL* was obtained.

4. Resonance Properties

Figure 4 shows the measured amplitude of the admittance for the resonator on a-Ta_2O_5/Al/Y–X LT. Table I shows the measured resonance properties, including the admittance ratio, the minimum phase of admittance *Y*, the bandwidth ratio $(f_a-f_r)/f_a$ (f_a: antiresonance frequency, f_r: resonance frequency), the resonance quality factor Q_r, and the antiresonance quality factor Q_a for each sample. For comparison, the resonance properties of a similar resonator sample for an LSAW on Al/36° Y-X LT are also shown in Fig. 4 and Table I. The resonance properties improved as the a-Ta_2O_5 film thickness increased. For the sample with h/λ=0.120, the resonance properties of the Love SAW were almost equal to or better than those for the LSAW on Al/36° Y-X LT, except for the bandwidth ratio.

5. Conclusions

The propagation properties of a Love SAW on Y-X LT with an a-Ta_2O_5 thin film deposited by an RF magnetron sputtering system with an LTS cathode were investigated. K^2 of 5.8% and *PL* of 0.03 dB/λ were obtained for a normalized thickness h/λ of 0.120. Moreover, the resonance properties of the Love SAW were almost equal to or better than those for an LSAW on Al/36° Y-X LT, except for the bandwidth ratio.

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Table I Measured resonance properties.

Structure	h/λ	Admittance ratio [dB]	Minimum phase of *Y* [°]	$(f_a-f_r)/f_a$ [%]	Q_r	Q_a
a-Ta_2O_5/Al/Y-X LT	0	13.3	-3.3	4.9	21.6	25.3
	0.068	22.6	-38.7	3.4	63.1	45.5
	0.120	36.1	-68.7	1.7	136	369
Al/36°Y-X LT	0	25.8	-62.3	1.9	137	83.9