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High Coupling and Highly Stable Leaky SAWs on $LiTaO_3$ Thin Plate Bonded to Quartz Substrate

$LiTaO_3$薄板と水晶基板の接合によるリーキー系弾性表面波の高結合・高安定化

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1. Introduction

Surface acoustic wave (SAW) propagation modes such as leaky SAWs (LSAWs) and longitudinal-type LSAWs (LLSAWs) have been studied to obtain a higher frequency, a larger electromechanical coupling factor (K^2), a larger Q factor, and a smaller temperature coefficient of frequency (TCF). Our research group has reported the propagation properties of LSAWs and LLSAWs on a $LiTaO_3$ (LT) or $LiNbO_3$ (LN) thin plate bonded to a high-velocity substrate.[1] In that study, K^2 larger than that of a single LT substrate was obtained theoretically when 36°Y-cut X-propagating LT (36°YX-LT)/AT-cut 90°X-propagating quartz (AT90°X-quartz) for an LSAW and X-cut 31°Y-propagating LT (X31°Y-LT)/ AT45°X-quartz for an LLSAW were employed.

In this study, some bonded samples were practically prepared, and the propagation properties, the resonance characteristics, and the TCFs for LSAWs and LLSAWs on the bonded structures were investigated experimentally.

2. Experiment and Discussion

2.1. Sample preparation

Although 90°X propagating was desirable for the LSAW, AT-cut quartz was set to X propagating since K^2 was almost the same as that for 90°X. First, the surface of a 3- or 4-inch wafer of LT and AT-cut quartz with thicknesses of 0.2–0.8 mm was activated in $Ar+O_2$ plasma after RCA cleaning. Next, the surfaces of LT and AT-cut quartz were bonded under atmospheric pressure. Moreover, the bonded wafers were annealed for several hours at 100–300 °C. After dicing to a size of 20×15 mm, the surface on the LT wafer side was thinned to a plate thickness h in the range of 3.0–9.0 μm. Then, a single-electrode interdigital transducer (IDT) was prepared with period λ values of 8–64 μm and finger pairs N of 10–30 on the polished surface of LT using a 1500-Å-thick Al thin film. For comparison, IDTs were also fabricated on the surface of a single LT substrate.

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2.2. Coupling factor K^2

The K^2 values of the LSAW and LLSAW were determined from the admittance properties of IDTs (N=10 or 15). The measured K^2 values of the LSAW and LLSAW are shown in **Figs. 1 and 2**, respectively, with the calculated K^2 results.[1] For the LSAW, K^2 larger than that for the single LT substrate was obtained for three samples with different normalized LT thin-plate thicknesses. For the sample with h/λ=0.25, K^2 increased from 5.9% for the single LT substrate to 11.8% for the bonded structure. For the LLSAW, K^2 increased to 6.2% at h/λ=0.28 and was 2.4 times as much as 2.5% for the single LT substrate. However, the K^2 of the bonded substrate for the LLSAW was slightly smaller than the calculated result. This is considered to be due to the deterioration of K^2 caused by the bonding condition.

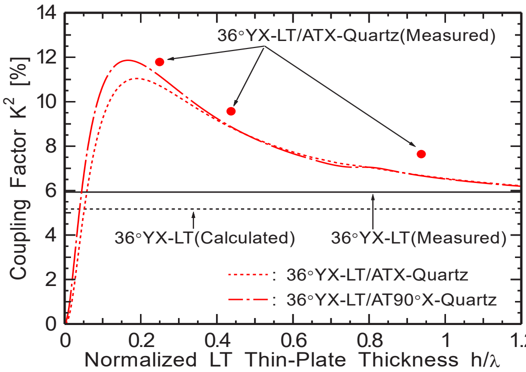

Fig. 1　K^2 for LSAW vs LT thin-plate thickness.

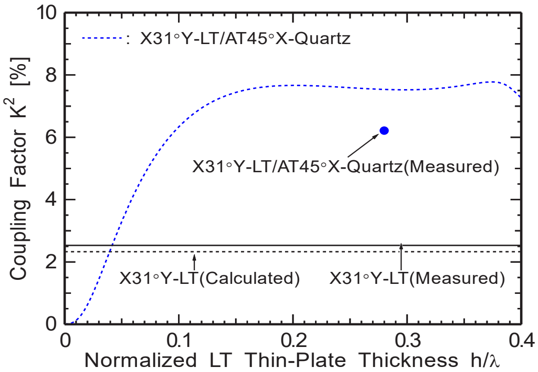

Fig. 2　K^2 for LLSAW vs LT thin-plate thickness.

2.3. Resonance characteristics

Figures 3 and 4 show the measured admittance properties of the bonded structure and single LT substrate for the LSAW and LLSAW, respectively. Models of the same structure for the LSAW and LLSAW were simulated using the FEM system (Femtet, developed by Murata Software). The simulated results are also shown in Figs. 3 and 4. For the LSAW, the admittance ratio and fractional bandwidth for an IDT (N=30) were increased from 22 dB and 4.5% for the single LT substrate to 39 dB and 5.3% for the bonded structure with h/λ=0.44, respectively. For the LLSAW, the admittance ratio and fractional bandwidth for an IDT (N=30) were increased from 7.8 dB and 4.1% for the single LT substrate to 16 dB and 5.0% for the bonded structure with h/λ=0.28, respectively. Although they were roughly in agreement with FEM analysis results, they were slightly smaller than the simulated results at approximately the resonance frequency f_r and anti-resonance frequency f_a. This is considered to be due to the unevenness of the surface condition and resistance of the Al thin film.

2.4. Temperature coefficient of frequency

The frequency shift properties for LSAW and LLSAW in temperature were measured in a thermostatic oven with temperatures ranging from 0–80 °C. The experimental TCF values were determined from the slope of the measured frequency shift. **Figure 5** shows the measured TCF values of the LSAW with the calculated results. The TCF at h/λ=0.38 was improved from -35.3 ppm/°C for the single LT substrate to -17.2 ppm/°C for the bonded structure. The measured results were roughly in agreement with the calculated results. The TCF of the LLSAW was -17.2 ppm/°C, which was also improved as compared with the calculated result of the single LT.

Furthermore, the TCF of the LSAW on 36°YX-LT/AT90°X-quartz was calculated. The calculated result is also shown in Fig. 5. There was a normalized LT thin-plate thickness that the TCF became 0 ppm/°C. In addition, the previously calculated K^2 of the LSAW on 36°YX-LT/AT90°X-quartz[1] is also shown in Fig. 1. From both calculated results, the K^2 of approximately 12% and the TCF of 0 ppm/°C were theoretically obtained simultaneously for the LSAW on 36°YX-LT/AT90°X-quartz of h/λ=0.17.

5. Conclusions

In this study, we investigated LSAWs and LLSAWs on an LT thin plate bonded to an AT-cut quartz substrate experimentally. Samples with 36°YX-LT/ATX-quartz for the LSAW and X31°Y-LT/AT45°X-quartz for the LLSAW were fabricated and measured.

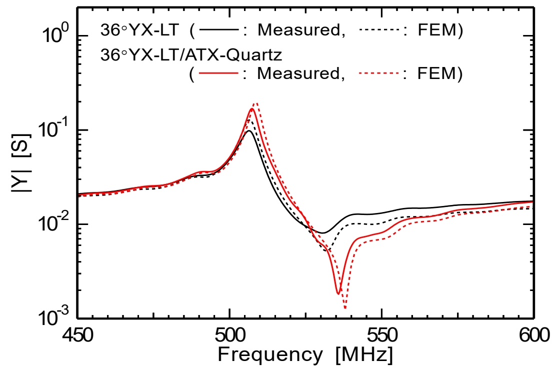

Fig. 3 Resonance properties for LSAW.

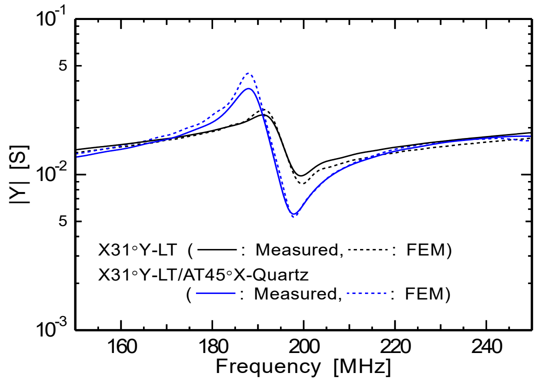

Fig. 4 Resonance properties for LLSAW.

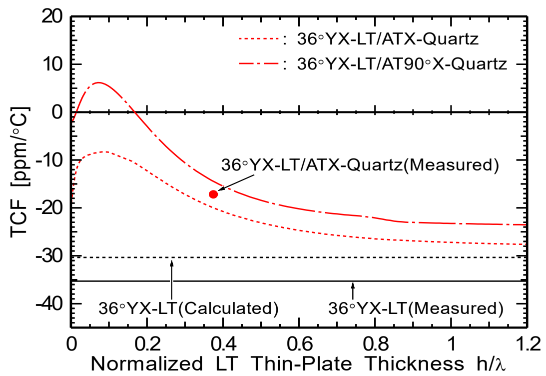

Fig. 5 TCF for LSAW vs LT thin-plate thickness.

The K^2 of the LSAW increased from 5.9% for a single LT substrate to 11.8% for the bonded structure with h/λ=0.25. The K^2 of the LLSAW increased from 2.5% for the single LT substrate to 6.2% for the bonded structure with h/λ=0.28. Also, the resonance characteristics of both the LSAW and LLSAW were improved as compared with the single LT substrate. The improvements of TCF for the LSAW and LLSAW were also observed. Furthermore, when the TCF of the LSAW on 36°YX-LT/AT90°X-quartz was calculated, K^2 of approximately 12% and TCF of 0 ppm/°C were theoretically obtained simultaneously at a certain thin-plate thickness.

References

1. M. Gomi, T. Kataoka, J. Hayashi, and S. Kakio, Jpn. J. Appl. Phys. **56** (2017) 07JD13.