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Enhancement of Leaky SAW Harmonics Excitation Using Bonded Dissimilar Material Structures
異種材料接合構造を用いたリーキーSAW 高調波の強勢励振

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1. Introduction

To develop next-generation mobile communication systems, high-performance surface acoustic wave (SAW) devices with a high frequency, a wide bandwidth, a large *Q* factor, and a small temperature coefficient of frequency (TCF) are required. As an approach to achieving high-frequency operation, the utilization of high-order SAW harmonics has been proposed. The SAW excited by an interdigital transducer (IDT) contains an odd-order harmonics component in addition to the fundamental wave. Their excitation intensity depends on the ratio of the electrode width *a* to the pitch *p* (metallization ratio: *a*/*p*) of an IDT.[1] Dependence of the excitation of SAW harmonics on the metallization ratio and electrode shape has been reported so far.[2]

On the other hand, our research group reported that, in a bonded structure comprising a $LiNbO_3$ (LN) or $LiTaO_3$ (LT) thin plate with a thickness of less than one wavelength and a quartz substrate, a large electromechanical coupling factor (K^2) and a small TCF for leaky SAWs (LSAWs) and longitudinal LSAWs (LLSAWs) can be obtained simultaneously.[3,4]

In this study, the LSAW third harmonic on bonded dissimilar-material structures, such as LT/quartz and LN/quartz, was investigated theoretically and experimentally.

2. Theoretical Analysis

First, for the bonded structure of a 36°Y-cut X-propagating LT (36°YX-LT) or 27°Y-cut X-propagating LN (27°YX-LN) thin plate and AT-cut 90°X-propagating quartz (AT90°X-quartz), LSAW propagation properties were calculated as functions of thin-plate thickness *h*.[5,6] The calculated values of K^2 of LSAW on LT/quartz with h/λ=0.17 (λ: wavelength) and LN/quartz with h/λ=0.3 were 11.9 and 25.0%, respectively, and a low attenuation of less than 10^{-4} dB/λ for the metallized surface was obtained simultaneously for both cases. By setting the thin-plate thickness of LT or LN so that the largest K^2 appears for the third harmonic, the enhancement of the third-harmonic excitation can be expected.

Next, by the finite element method (FEM), we simulated the resonance properties of the LSAW third harmonic for LT/quartz and LN/quartz. Assuming an infinitely periodic single-electrode IDT with λ=2.5 μm and a/p=0.8 as the simulation model, the thin-plate thicknesses *h* of LT and LN were set to 0.06λ and 0.1λ, respectively, such that the largest K^2 was obtained at these thicknesses for the third harmonic. The mechanical loss Q_m of either LT or LN was disregarded.

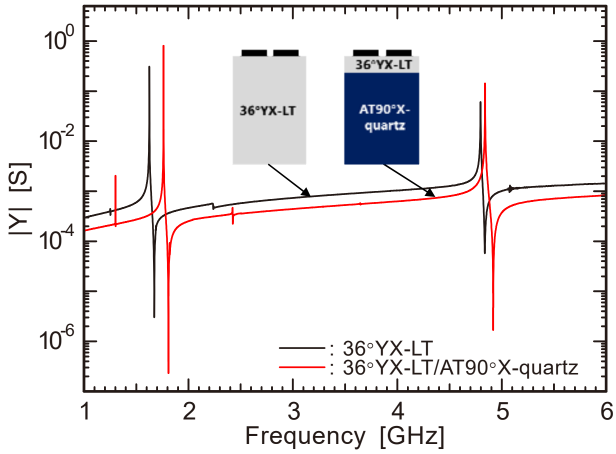

Fig. 1. Simulated resonance properties of fundamental LSAW and third harmonic.

As an example, **Fig. 1** shows the simulated resonance properties on 36°YX-LT/AT90°X-quartz and single LT. The responses of the LSAW third harmonic were observed at around 4.8–4.9 GHz. The fractional bandwidth for the third harmonic on LT/quartz with h/λ=0.06 and LN/quartz with h/λ=0.1 were 1.6% and 3.5%, respectively, which were larger than that of the single LT or LN.

3. Experiments

Next, we conducted experiments using 36°YX-LT/AT0°X-quartz with *h*=1 μm. Resonator patterns with a period λ of 20 μm (h/λ=0.05), number of finger pairs *N* of 100.5 or 200.5, reflector number N_R of 0 or 100, an aperture width *W* of 25λ and a/p=0.4–0.8 were fabricated on the LT surface using a 380-nm-thick Al thin film. For comparison, a single 36°YX-LT sample was also fabricated (a/p=0.4–0.85). **Figure 2** shows the measured resonance properties for *N*=100.5, N_R=100, and a/p=0.8. For the third harmonics at around 610–650 MHz, the fractional bandwidth, admittance ratio, and resonance *Q* factor on

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LT/quartz increased to 1.4%, 63 dB, and 1,770 from 0.8%, 31 dB, and 480 for the single LT, respectively. In addition, the admittance ratio and resonance Q factor of the third harmonic on LT/quartz were larger than those (51 dB and 1,440) of the fundamental LSAW for the single LT at around 210 MHz. As a result of the experimental evaluation, the admittance ratio and the fractional bandwidth of the third harmonics on the LT/quartz were found to increase with increasing a/p.

The TCF was determined by measuring the rate of variability of the resonance and antiresonance frequencies (f_r, f_a) of the fundamental LSAW and the third and fifth harmonics when the hot plate on which the sample placed was changed from room temperature to 75°C. **Figure 3** shows the measured TCF together with the calculated TCF as functions of h/λ for the free and metallized surfaces. For the single LT (a/p=0.85), the TCF of the fundamental LSAW and that of the third harmonic were measured to be almost the same value. The h/λ dependence of the measured TCF for f_a on LT/quartz (a/p=0.8) was in good agreement with the calculated value for the free surface. On the other hand, the measured values of TCF for f_r on LT/quartz were worse than those of the calculated value for the metallized surface, but the values were better than those of single LT.

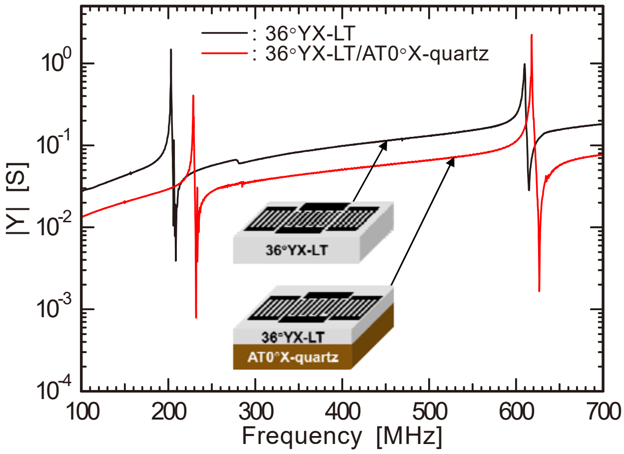

Fig. 2. Measured resonance properties of fundamental LSAW and third harmonic.

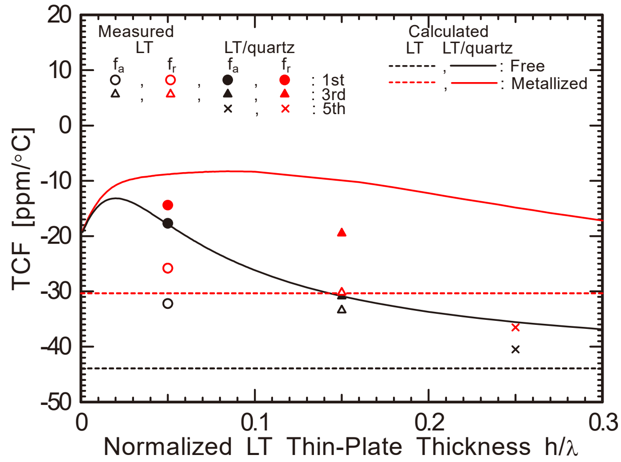

Fig. 3. Measured and calculated TCF of fundamental LSAW, third, and fifth harmonics.

4. Conclusions

In this study, to obtain a high-performance structure at higher frequency, the propagation and resonance properties of LSAW harmonics on an LT/quartz or LN/quartz structure were investigated theoretically and experimentally.

The largest K^2 values were calculated to be 11.9% for 36°YX-LT/AT90°X-quartz with h/λ=0.17 and 25.0% for 27°YX-LN/AT90°X-quartz with h/λ=0.3, and low attenuation of less than 10^{-4} dB/λ for the metallized surface was obtained simultaneously for both cases. These properties were better than those of the single LT or LN. By setting the thin-plate thickness of LT or LN such that the largest K^2 appears for the third harmonic, the enhancement of the third-harmonic excitation can be expected. Using the FEM, the bonded structure with the AT90°X-quartz support substrate was found to be effective for enhancing the third-harmonic excitation.

On the basis of these results, the LSAW resonators for the third harmonic were fabricated on 36°YX-LT/AT0°X-quartz, and the resonance properties and TCF of LSAW harmonics were measured for the fundamental LSAW and the third harmonic. For the bonded structure, the measured fractional bandwidth, admittance ratio, and Q factor increased to 1.4%, 63 dB, and 1,770 from 0.8%, 31 dB, and 480 for the single LT, respectively. The h/λ dependence of the measured TCF for f_r on the bonded structure (a/p=0.8) was in good agreement with the calculated values. In the future, we will investigate the proposed scheme to a LLSAW.

Acknowledgments

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References

1. H. Engan, IEEE Trans. Electron Devices, **ED-16** (1969) 1014.
2. H. Nakahata, *et al.*, Proc. IEEE Ultrason. Symp., p.349 (2000).
3. M. Gomi, *et al.*, Jpn. J. Appl. Phys., **56** (2017) 07JD13.
4. S. Asakawa, *et al.*, Jpn. J. Appl. Phys., **59** (2020) SKKC12.
5. J. Hayashi, *et al.*, Jpn. J. Appl. Phys., **57** (2018) 07LD21.
6. S. Asakawa, *et al.*, The 80th JSAP Autumn Meeting, 18a-C206-9 (2019).