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Analysis of Leaky Surface Acoustic Waves on Quartz Thin Plates Bonded to Similar-Material Substrate

水晶を用いた同種材料接合構造におけるリーキーSAW の解析

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1. Introduction

For next-generation mobile communication systems, surface acoustic wave (SAW) devices with a large electromechanical coupling factor (K^2), high Q factor, and high stability are required. Control of the SAW propagation properties, that is, high coupling factor and low attenuation, can be expected by using a similar-material bonded structure and the elastic anisotropy of $LiTaO_3$ (LT) and $LiNbO_3$ (LN). On the basis of this expectation, for a shear horizontal leaky SAW (LSAW), we clarified theoretically that propagation and resonance properties superior to those on a single substrate can be obtained by utilizing bonded structures comprising an LT or LN thin plate and their similar-material substrate.[1] Moreover, we also experimentally evaluated the LSAW propagation and resonance properties on a 5°Y-cut X-propagating LN (5°YX-LN) thin plate bonded to a 64°YX-LN substrate, and a lower propagation loss and a wider fractional bandwidth than those of the single LN were obtained.[2]

On the other hand, an LST-cut quartz (LST-Q) has a stable temperature property and low attenuation for an LSAW, however, K^2 is small.[3] We expected that by using similar-material bonded structures for quartz, we can obtain a larger K^2 than that of a single quartz substrate.

In this study, LSAW propagation and resonance properties on similar-material bonded structures for quartz were investigated theoretically.

2. Theoretical Calculation

Figures 1(a) and 1(b) show theoretical analysis models. AT-cut 0°X-propagating quartz (AT0°X-Q, Euler-angle: (0°,125°,0°)) was chosen as the support substrate because it exhibits the highest phase velocity in rotated (Rot.) YX-Q. As the thin plates, Z-cut quartz (Z-Q, (0°,0°,ψ)) and LST-Q (0°,196°,0°) were chosen. The LSAW propagation properties on these bonded structures were calculated.

Figures 2(a) and 2(b) show K^2 and the attenuation as functions of the propagation angle ψ of the Z-Q thin plate for the free surface on Z-Q/AT0°X-Q. The parameter is the normalized thin-plate thickness h/λ (λ: wavelength) in the range from 0.05 to 0.6.

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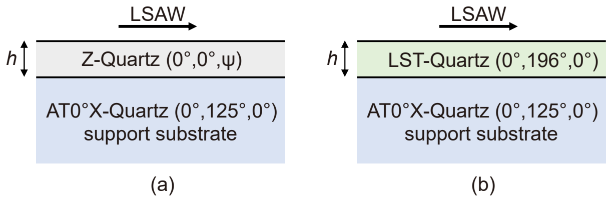

Fig. 1 Theoretical analysis models of (a) Z-Q/AT0°X-Q and (b) LST-Q/AT0°X-Q structures.

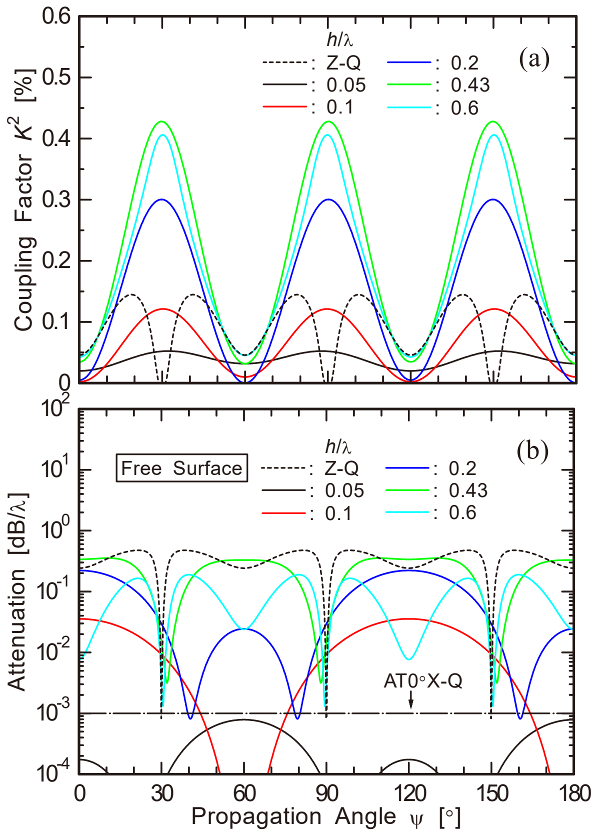

Fig. 2 (a) Coupling Factor K^2 and (b) attenuation of LSAW on single Z-Q and Z-Q/AT0°X-Q structures as functions of propagation angle of Z-Q thin plate.

The single Z-Q exhibits the highest K^2 (0.14%) at certain propagation angles. However, a large attenuation (>0.1 dB/λ) occurs at those propagation angles. The minimum attenuation occurs at ψ= 30°, 90°, and 150° on the single Z-Q; but K^2 is zero. The AT0°X-Q used as a support substrate has low attenuation (~0.001 dB/λ); but K^2 is very small (0.007%). On the other hand, K^2 on the bonded structure of Z-Q/AT0°X-Q increased with increasing

h/λ and showed a maximum value of 0.43% at h/λ=0.43, which was about three times that of the single Z-Q. The maximum K^2 appeared at around ψ=30°, 90°, and 150°, at which the minimum attenuation occurred for the single Z-Q, and the attenuation for Z30°X-Q(h/λ=0.43)/AT0°X-Q was approximately 0.02 dB/λ. For Z32°X-Q(h/λ=0.43) /AT0°X-Q, a lower attenuation (0.003 dB/λ) was obtained.

Figure 3 shows the LSAW attenuation on the Z32°X-Q/AT0°X-Q and LST-Q/AT0°X-Q structures as a function of h/λ for a free surface. For LST/AT0°X-Q, zero attenuation occurred at h/λ=0.71, whereas the single LST-Q has an attenuation of approximately 0.0001 dB/λ; but K^2 was relatively small (0.12%).

3. Finite Element Method (FEM) Analysis

Regarding Z32°X-Q(h/λ=0.43)/AT0°X-Q with large K^2 and LST-Q(h/λ=0.72)/AT0°X-Q with low attenuation as described above, the admittance properties of an LSAW were analyzed by an FEM. For LST-Q/AT0°X-Q, the optimum h/λ was slightly modified from that given in section 2 because of the use of an aluminum electrode. An infinite periodic interdigital transducer (IDT) with a period λ of 8.0 μm and an aluminum thin film of 0.1 μm (0.013λ) thickness were assumed. The side of the model was assigned a periodic boundary, and a perfect matching layer was provided at the bottom of the support substrate. The mechanical loss Q_m and dielectric loss were not taken into consideration.

Figure 4 shows the resonance properties of these bonded structures and single LST-Q. Z32°X-Q/AT0°X-Q showed an admittance ratio of 57 dB and a fractional bandwidth of 0.23%, which were larger than those of single LST-Q (26 dB and 0.076%). Resonance Q_r and anti-resonance Q_a were Q_r=5,420 and Q_a=5,880, which were higher than those of the single substrate. On the other hand, for LST-Q/ AT0°X-Q, a larger admittance ratio of 65 dB and higher Q_r and Q_a (34,900 and 27,160, respectively) than those of single LST-Q were obtained, but the fractional bandwidth (0.071%) was almost the same as that of single LST-Q. The above analyzed resonance properties are summarized in Table I.

4. Conclusion

In this study, we theoretically investigated the propagation and resonance properties of an LSAW on similar-material-bonded structures for quartz. It was found that, by utilizing the similar-material-bonded structure, we can obtain K^2 about three times larger than the maximum value of a single substrate and better resonance properties than those on a single substrate. As the next step, we will experimentally investigate LSAW properties on such bonded structures.

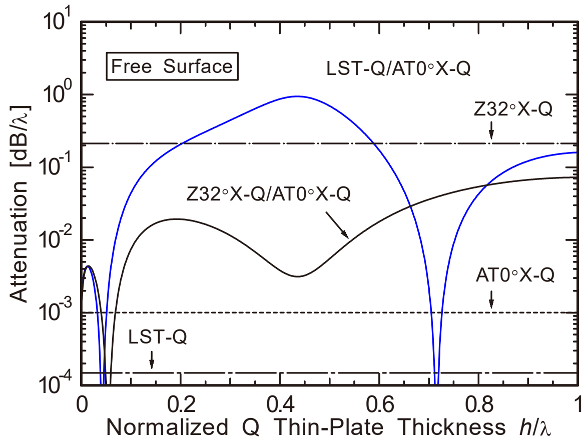

Fig. 3 Attenuation of LSAW on LST-Q/AT0°X-Q and Z32°X-Q/AT0°X-Q structures for free surface as functions of h/λ.

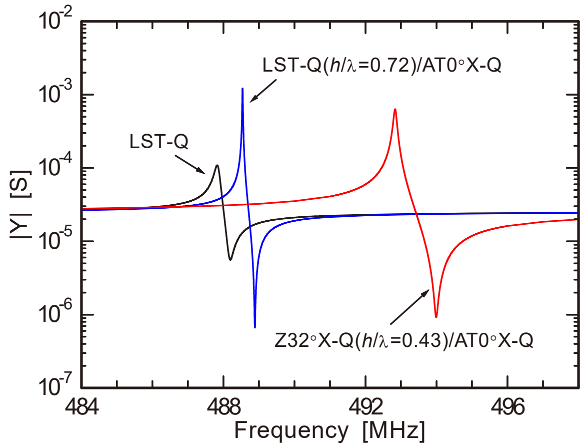

Fig. 4 Simulated resonance properties of LSAW on LST-Q, LST-Q/AT0°X-Q, and Z32°X-Q/AT0°X-Q structures with λ=8.0 μm.

References

1. T. Fujimaki, *et al.*: Jpn. J. Appl. Phys. **59** (2020) SKKC01.
2. T. Fujimaki, *et al.*: The 81st JSAP Autumn Meeting (2020) 10p-Z22-11.
3. Y. Shimizu, *et al.*: Electron Letters **21** (1985) 225.

Table I Resonance properties of LSAW.

Substrate structure	Admittance ratio [dB]	Fractional bandwidth [%]	Q_r	Q_a
LST-Q	26	0.076	3,050	3,090
LST-Q(h/λ=0.72)/AT0°X-Q	65	0.071	34,900	27,160
Z32°X-Q(h/λ=0.43)/AT0°X-Q	57	0.23	5,420	5,880