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Analysis of Longitudinal Leaky SAWs on Bonded Structures Consisting of Similar and Dissimilar Materials

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1. Introduction

Recently, longitudinal leaky surface acoustic waves (LLSAWs) with a high phase velocity, which are advantageous for high-frequency SAW devices, have attracted attention; however, they have inherently a large attenuation. In our laboratory, LLSAWs with a high *Q*, a large bandwidth (BW), and a high temperature stability have been developed by utilizing dissimilar-material bonded structures consisting of a $LiTaO_3$ (LT) or $LiNbO_3$ (LN) thin plate and a quartz (Qz) support substrate; however, a small plate thickness of less than 0.1λ (λ: wavelength) is required[1]. We have also theoretically clarified LLSAWs with a small attenuation and a high *Q* by utilizing a similar-material bonded structure consisting of a Qz thin plate and a Qz support substrate with different Euler angles. Unfortunately, the fractional BW is narrow, less than 0.1%[2].

In this study, the propagation and resonance properties of LLSAWs on an LT thin plate bonded to Qz similar-material bonded structures are investigated theoretically.

2. Calculation of Propagation Properties

We calculated the LLSAW propagation properties on a structure consisting of an LT thin plate bonded on X176.5°Y-Qz/X41°Y-Qz[2], which exhibits high *Q* LLSAW resonance properties. **Figures 1(a)** and **1(b)** show the attenuation and coupling factor (K^2) of LLSAWs, respectively, on X-cut LT(X-LT)/X176.5°Y-Qz/X41°Y-Qz for the metallized surface. The horizontal axis of these figures is the propagation angle ψ of X-LT from the Y-axis, and the parameter in the figure is the LT thickness h_{LT}/λ normalized by λ. The attenuation shows a minimum value (2.8×10^{-4} dB/λ) at h_{LT}/λ=0.6 and ψ=15°. K^2 is 1.15%, which is about eight times higher than that of X176.5°Y-Qz/X41°Y-Qz. Furthermore, the attenuation also decreases at h_{LT}/λ=0.5 and 0.7. For the free surface, the attenuation shows a minimum value (3.7×10^{-4} dB/λ) at h_{LT}/λ=0.5 and ψ=125°, while its K^2 is 0.16%. These values of h_{LT}/λ, which show the minimum attenuation, are larger than that of the LT/Qz structure. of the LT/Qz structure.

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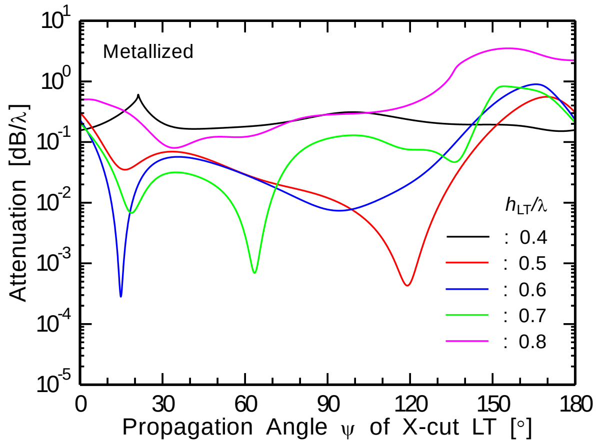
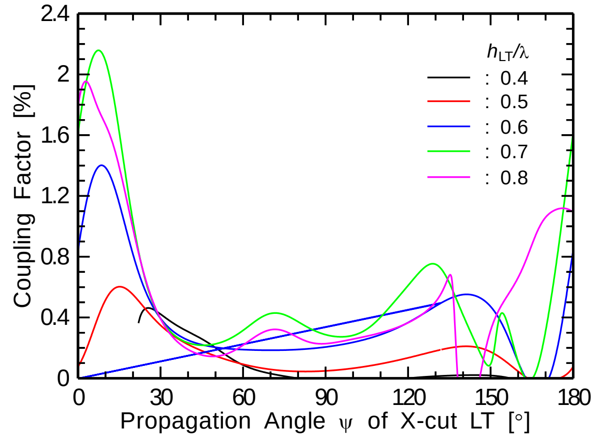


(a) Attenuation



(b) K^2

Fig. 1 Calculated attenuation of LLSAWs on X-LT/X176.5°Y-Qz/X41°Y-Qz.

3. Simulation of Resonance Properties

By a finite element method, we analyzed the resonance properties of an LLSAW in the case of forming an infinitely periodic interdigital transducer (IDT) with a period λ of 8.0 μm and an Al thin film (h_{Al}: 100 nm). A perfect matching layer was provided at the bottom of the support substrate with 10λ thickness. The mechanical loss was not taken into consideration. The resonance properties of X15°Y-LT(h_{LT}/λ=0.6)/X176.5°Y-Qz/X41°Y-Qz and X125°Y-LT(h_{LT}/λ=0.5)/X176.5°Y-Qz/X41°Y-Qz are shown in **Fig. 2**. In Fig. 2, the horizontal axis is converted from the frequency *f* to the phase velocity *v* using the relationship $v=f\lambda$.

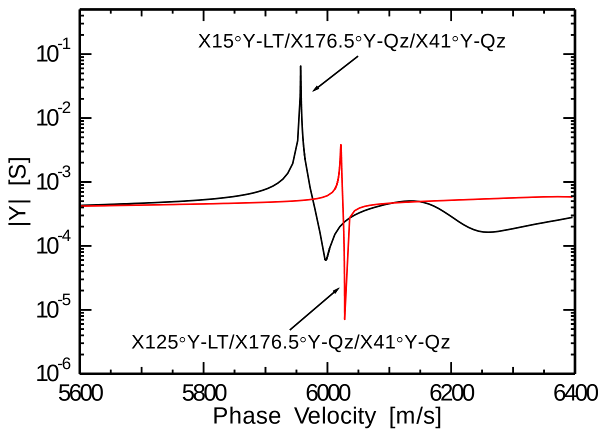


Fig. 2 Simulated resonance properties of LLSAWs on X15°Y-LT(h_{LT}/λ=0.6)/X176.5°Y-Qz/X41°Y-Qz and X125°Y-LT(h_{LT}/λ=0.5)/X176.5°Y-Qz/X41°Y-Qz.

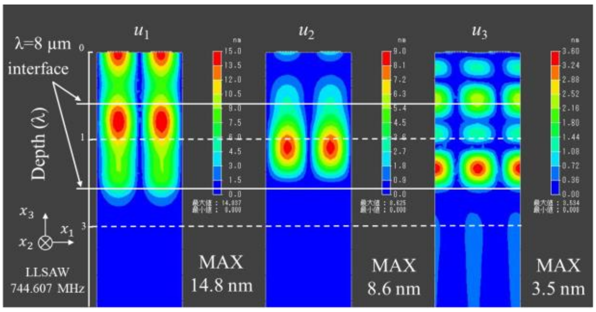
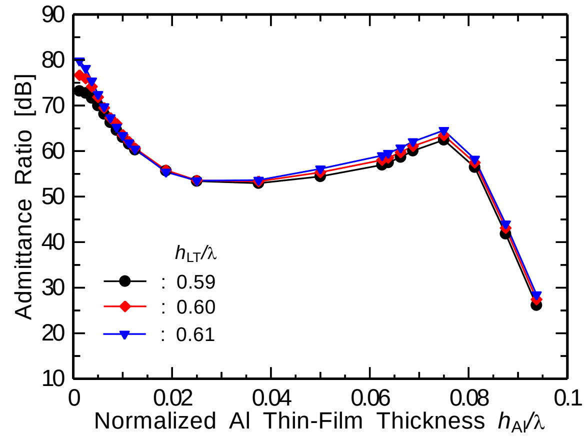


Fig. 3 Simulated particle displacements of LLSAW on X15°Y-LT(h_{LT}/λ=0.6)/X176.5°Y-Qz/X41°Y-Qz.

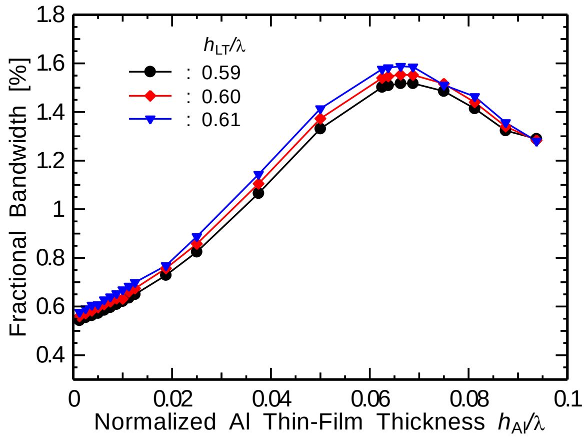
In Fig. 2, the X15°Y-LT/X176.5°Y-Qz /X41°Y-Qz bonded structure exhibits an admittance ratio of about 60 dB, a resonance Q factor (Q_r) of about 10,000, and a fractional BW of 0.67%. This fractional BW is about eight times higher than that of X176.5°Y-Qz/X41°Y-Qz (0.086%). Furthermore, the X125°Y-LT/X176.5°Y-Qz/X41°Y-Qz bonded structure exhibits an admittance ratio of about 50 dB, an antiresonance Q factor (Q_a) of about 4,000, and a fractional BW of 0.1%.

Figure 3 shows the particle displacement at the resonance frequency for the X15°Y-LT /X176.5°Y-Qz/X41°Y-Qz bonded structure. The longitudinal component (u_1), which is the main displacement of an LLSAW, shows a larger amplitude than the transverse components (u_2, u_3), indicating that the displacement is trapped in the middle layer at X176.5°Y-Qz where the phase velocity is low. Therefore, the leakage component into the substrate is considered to be small.

To obtain large admittance ratio and fractional BW by optimizing the Al film and LT thin plate thicknesses on the bonded structure, we investigated the dependence of the Al thin film thickness on the X15°Y-LT/X176.5°Y-Qz /X41°Y-Qz bonded structure.



(a) Admittance ratio



(b) Fractional BW

Fig. 4 Al thin-film thickness dependence of resonance properties on X15°Y-LT/X176.5°Y-Qz/X41°Y-Qz.

Figure 4 shows the (a) admittance ratio and (b) fractional BW for the normalized Al thin film thickness (h_{Al}/λ). The parameter in these figures is the normalized thin plate thickness h_{LT}/λ. The largest admittance ratio (80 dB) and fractional BW (1.61%) are obtained at h_{LT}/λ=0.61.

4. Conclusions

In this study, the propagation and resonance properties of LLSAWs on an LT thin plate bonded to a Qz similar-material bonded structure were investigated theoretically. As a result, it was clarified that a structure with a small attenuation and a high Q can be obtained with a relatively large LT normalized thin plate thickness. As the next step, we will investigate the structures in which displacement is trapped in the LT thin plate.

References

1. J. Hayashi, *et al.*, Jpn. J. Appl. Phys. **58** (2019) SGGC12.
2. Y. Fujii, *et al.*, Jpn. J. Appl. Phys. **61** (2022) SG1052.