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Analysis of Longitudinal Leaky SAW on Quartz Thin Plate Bonded to Similar-material Substrate
水晶同種接合構造上の縦型漏洩弾性表面波の解析

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1. Introduction

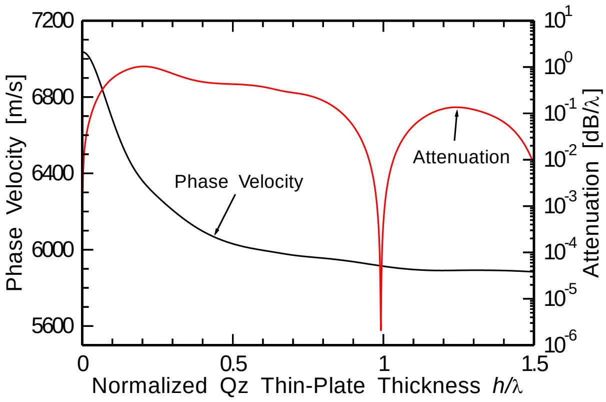
High-performance surface acoustic wave (SAW) devices with characteristics such as high frequency, large bandwidth (BW), and high *Q* factor are required for next-generation communication systems. In our laboratory, we clarified theoretically that better resonance properties can be obtained for a leaky SAW (LSAW) on a similar-material bonded structure of Quartz (Qz) with different cut angles.[1]

In this study, the propagation and resonance properties of a longitudinal LSAW (LLSAW) with high phase velocity on a bonded structure comprising a Qz thin plate and a Qz support substrate are investigated theoretically.

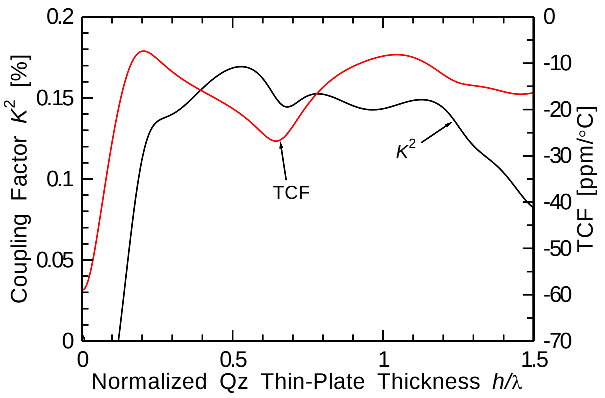
2. Calculation of Propagation Properties

The propagation properties (phase velocity, attenuation, coupling factor (K^2), and temperature coefficient of frequency (TCF)) for the thin-plate thickness h/λ normalized by wavelength λ on a bonded structure using an X-cut Qz (X-Qz) as the thin plate were calculated. First, X41°Y-Qz was chosen as a support substrate because it has the highest phase velocity in the X-Qz (Euler angle: (90°,90°,ψ)) for LLSAW. When a thin plate was chosen to be X176.5°Y-Qz, a small attenuation was obtained at a certain thin-plate thickness. **Figure 1** shows the propagation properties of LLSAW on the X176.5°Y-Qz/X41°Y-Qz. The attenuation shows a minimum value (1.8×10^{-5} dB/λ) at h/λ=0.99. The K^2 at h/λ=0.99 is 0.14%, which is about 50 times higher than the K^2 (0.0026%) of the single X41°Y-Qz. Furthermore, the TCF of at h/λ=0.99 is –8.6 ppm/°C, which is about sevenfold lower than the TCF (–58.9 ppm/°C) of the single X41°Y-Qz.

Second, AT39°X-Qz with a high phase velocity for LLSAW was also chosen as a support substrate, and X160°Y-Qz as a thin plate was found to exhibit a small attenuation when combined with the support substrate. **Figure 2** shows the propagation properties of LLSAW on X160°Y-Qz/AT39°X-Qz. The attenuation is minimum value (6.7×10^{-4} dB/λ) at h/λ=0.18. The K^2 at h/λ=0.18 is 0.15%, which is about 330 times higher than the K^2 (0.00046%) of the single AT39°X-Qz. Furthermore, the TCF at h/λ=0.18 is 7.8 ppm/°C, which is about sixfold lower than the TCF (–42.4 ppm/°C) of the single AT39°X-Qz. It was also found that zero TCF appeared at h/λ=0.16, 0.6 and 0.72.



(a) Phase velocity and attenuation



(b) K^2 and TCF

Fig. 1 Calculated propagation properties of LLSAW on X176.5°Y-Qz/X41°Y-Qz.

Moreover, the attenuation was reduced by optimizing the Euler angle of the thin plate. For the (89°,88.7°,160°)-Qz/AT39°X-Qz bonded structure, a smaller attenuation (7.9×10^{-6} dB/λ) than that of X160°Y-Qz/AT39°X-Qz at h/λ=0.18 was obtained, as shown in Fig. 2(a).

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}: thickness).

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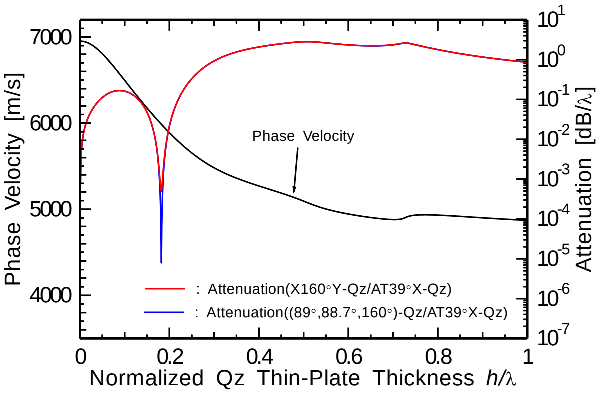
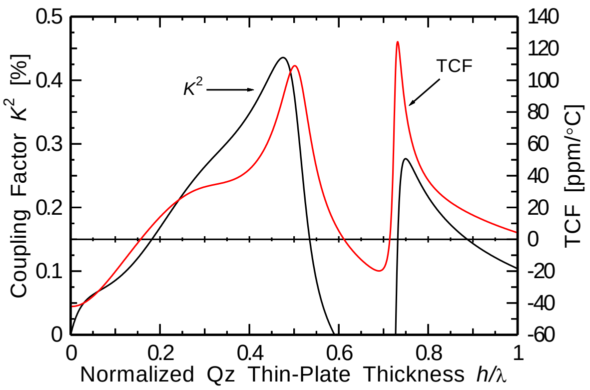


(a) Phase velocity and attenuation



(b) K^2 and TCF

Fig. 2 Calculated propagation properties of LLSAW on X160°Y-Qz/AT39°X-Qz.

A perfect matching layer was provided at the bottom of the support substrate with a 10λ thickness. The mechanical loss was not taken into consideration. The resonance properties of X176.5°Y-Qz/X41°Y-Qz (h/λ=0.98, h_{Al}/λ=0.005), (89°,88.7°,160°)-Qz/AT39°X-Qz (h/λ=0.18, h_{Al}/λ=0.00125), and a single X176.5°Y-Qz are shown **Fig. 3**. The h_{Al} values were optimized for each case so that a larger admittance ratio is obtained. In Fig. 3, the horizontal axis is converted from the frequency f to the phase velocity v using the relationship $v=f\lambda$.

As shown in Fig. 3 and **Table I**, a high admittance ratio and high resonance and antiresonance Q factors (Q_r, Q_a) can be obtained at a phase velocity of approximately 6,000 m/s by utilizing bonded structures, whereas the single Qz has a slight resonance for LLSAW.

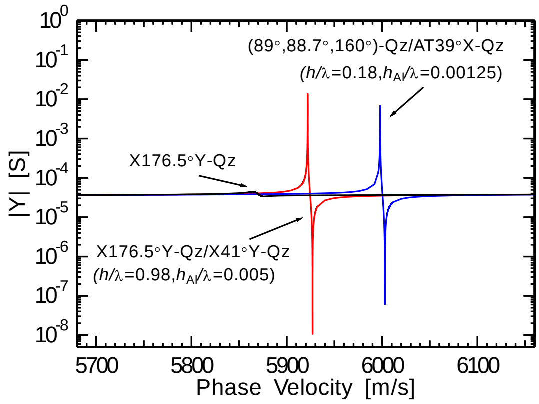


Fig. 3 Simulated resonance properties of LLSAW on single Qz substrate, X176.5°Y-Qz/X41°Y-Qz, and (89°,88.7°,160°)-Qz/AT39°X-Qz.

The X59°Y-Qz(h/λ=0.40)/X41°Y-Qz was also found to have a large resonance property. The X176.5°Y-Qz/X41°Y-Qz exhibits the largest resonance property with the admittance ratio of 122 dB among these bonded structures. The (89°,88.7°,160°)-Qz/AT39°X-Qz shows 26 dB larger admittance ratio (101 dB), 2.3 times higher Q_r (107,100), and eight times higher Q_a (375,200) than those for the X160°Y-Qz/AT39°X-Qz.

The fractional BWs of these structures ranged from 0.070 to 0.086%. The construction of a filter with a large BW and steep cutoff characteristics can be expected by combining the bonded structure with a ceramic LC filter having broad cutoff characteristics.

4. Conclusions

In this study, the propagation and resonance properties of LLSAW on a bonded structure comprising a Qz thin plate and a Qz support substrate were investigated theoretically. It was found that LLSAWs with low attenuation and large admittance ratio, which cannot be achieved with a single Qz, appear when an X-Qz thin plate is bonded to an X-Qz support substrate with a different propagation direction. As the next step, we will investigate such bonded structures experimentally.

References

1. T. Fujimaki, *et al.*, JJAP **60** (2021) SDDC04.

Table I Simulated resonance properties.

	Admittance ratio [dB]	Fractional BW [%]	Q_r	Q_a
X59°Y-Qz(h/λ=0.40)/X41°Y-Qz	78	0.082	216,700	288,980
X176.5°Y-Qz(h/λ=0.98)/X41°Y-Qz	122	0.086	185,060	740,880
X160°Y-Qz(h/λ=0.18)/AT39°X-Qz	75	0.070	46,900	46,900
(89°,88.7°,160°)-Qz(h/λ=0.18)/AT39°X-Qz	101	0.083	107,100	375,200