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# Analysis of propagation and resonance properties of longitudinal leaky SAW on $LiNbO_3$/SiC structure


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## 1. Introduction

High-performance surface acoustic wave (SAW) devices with characteristics such as high frequency, large bandwidth, and high *Q*-factor are required. Longitudinal leaky SAWs (LLSAWs) have high phase velocity, making them advantageous for use in higher frequency SAW devices. However, no effective resonance response of LLSAW appears on a single substrate, such as $LiTaO_3$(LT) or $LiNbO_3$(LN), owing to large attenuation. Our group reported that the attenuation of LLSAWs can be reduced by bonding LT or LN thin plates to a support substrate with a higher phase velocity than that of thin plates such as quartz, sapphire, and diamond.[1-3)]

However, because SiC has a high phase velocity and thermal conductivity, it can be utilized as a support substrate for LLSAWs,[4)] and high-frequency and high-power handling performance SAW devices can be expected.

In this study, the propagation and resonance properties of LLSAWs on a bonded structure comprising an LN thin plate and a SiC support substrate (LN/SiC) are theoretically investigated.

## 2. Calculation of propagation properties

We calculated the propagation properties (phase velocity, attenuation, and electromechanical coupling factor ($K^2$)) of the LLSAW as a function of LN thin-plate thickness $h/\lambda$ normalized by wavelength $\lambda$ of the LN/SiC structure. For the piezoelectric thin plate, X36°Y-LN, which has a large $K^2$ for LLSAWs, was used, and the Euler angles (0°, 0°, 0°) of the 4H-SiC support substrate were used.

**Figures 1(a)–1(c)** show the propagation properties of LLSAW on the X36°Y-LN/4H-SiC as a function of $h/\lambda$ obtained from analytical calculation. In Figs. 1(a) and 1(c), the plots show the phase velocity and effective electromechanical coupling factor ($K_{eff}^2$) obtained from the resonance properties analyzed by the finite element method (FEM), which is described later.

As shown in Fig. 1(a), the phase velocity decreased as $h/\lambda$ increased for both the free and metallized surfaces that were slower than those analyzed by the FEM. As shown in Fig. 1(b), the attenuation showed the minimum value ($7.4 \times 10^{-6}$ dB/$\lambda$) at $h/\lambda$=0.161, with a phase velocity of 7,800 m/s.

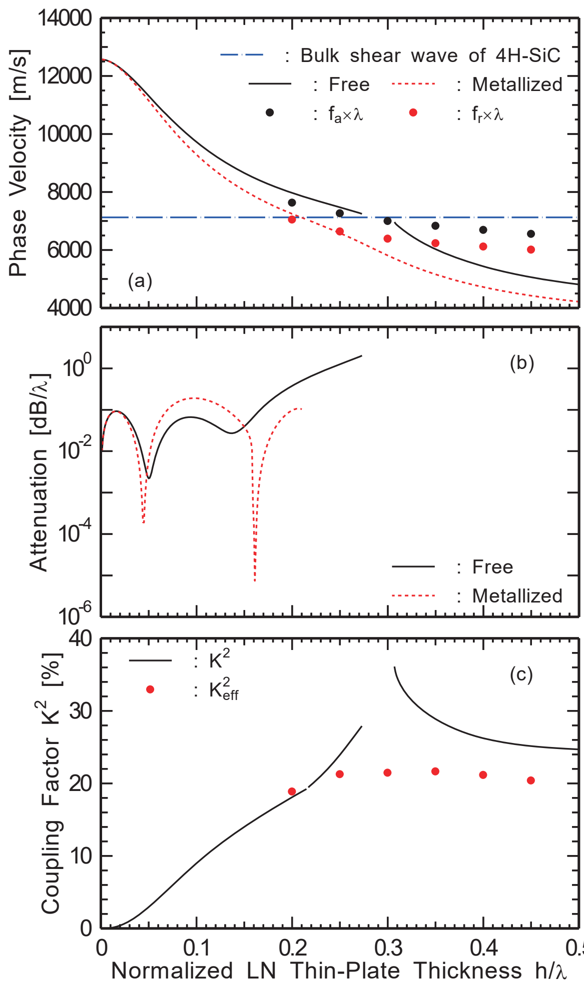


Fig. 1 Calculated propagation properties, (a) phase velocity, (b) attenuation, and (c)$K^2$, of LLSAW on X36°Y-LN/4H-SiC.

The attenuation disappeared at a certain $h/\lambda$, where the phase velocity of the LLSAW was lower than the bulk shear wave velocity of 4H-SiC (7,126 m/s). As shown in Fig. 1(c), $K^2$ exhibited an apparent maximum value (36%) at $h/\lambda$=0.30; this might be because of the phase velocity of the free surface approaching that of the 4H-SiC bulk shear wave. The maximum reliable $K^2$ was 22%, obtained as $K_{eff}^2$ using the FEM.

## 3. Simulation of resonance properties

We analyzed the resonance properties of the LLSAW using the FEM in the case of forming an infinitely periodic interdigital transducer (IDT) with


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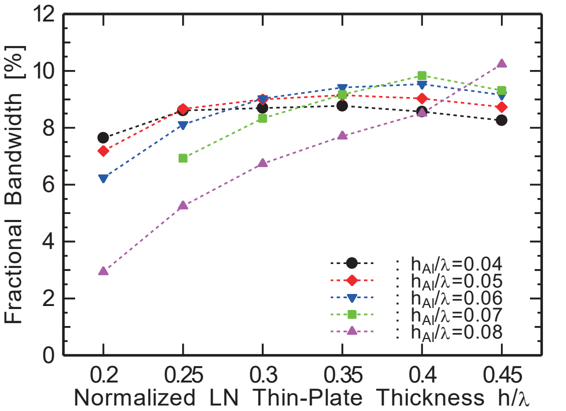


Fig. 2 Simulated fractional bandwidth of LLSAW on X36°Y-LN/4H-SiC.

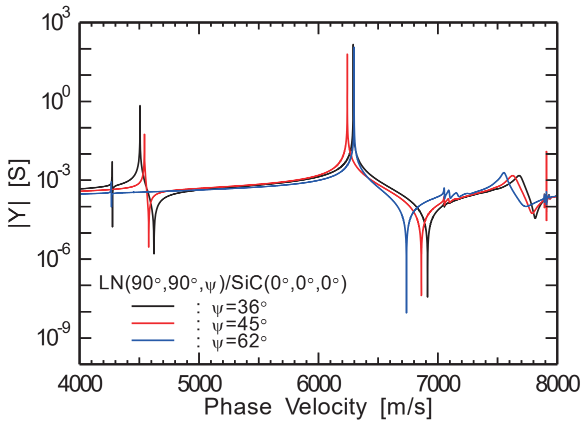


Fig. 4 Simulated resonance properties with the third Euler angle (ψ) of the LN thin plate.

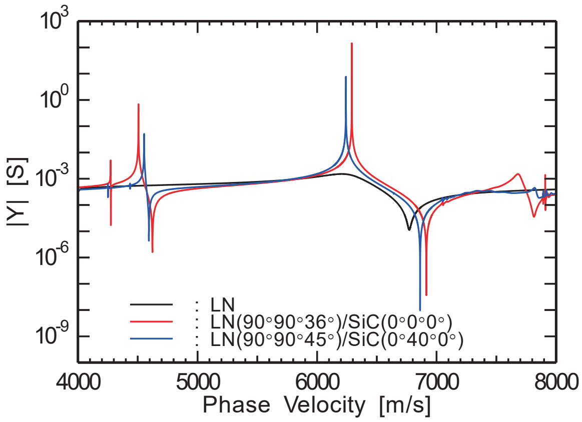


Fig. 3 Simulated resonance properties on X36°Y-LN/4H-SiC.

a period λ of 10.0 μm and an Al thin film. A perfect matching layer was provided at the bottom of the support substrate with a 10λ thickness. Material *Q* was not considered.

**Figure 2** shows the fractional bandwidth (*FBW*) of the LLSAW as a function of $h/\lambda$. Al electrode film thickness $h_{Al}/\lambda$, normalized by wavelength λ, was used as the parameter. As $h/\lambda$ increased, the *FBW* increased and reached the maximum value at the range of $h/\lambda$=0.3–0.4 for most $h_{Al}/\lambda$. The red line in **Fig. 3** shows the resonance property of the LLSAW with an *FBW* of 9.02% and admittance ratio (*AR*) of 192 dB for $h_{Al}/\lambda$=0.06 and $h/\lambda$=0.30. The horizontal axis in Fig. 3 is converted to phase velocity by multiplying frequency by λ. The response of the LLSAW at 6,200–6,900 m/s was significantly stronger than that of a single LN (black line). For the LLSAW at $h/\lambda$=0.39, the *FBW* was 9.53%. However, in addition to the main response of the LLSAW, a spurious response owing to its higher-order mode, appeared near the antiresonance.

**Figure 4** shows the resonance properties for $h_{Al}/\lambda$=0.06 and $h/\lambda$=0.30 with the third Euler angle (ψ) of the LN thin plate as a parameter. As ψ increased, the spurious responses owing to Rayleigh-type SAW and leaky SAW around 4,500 m/s were reduced and reached a minimum at ψ=62°; however, the *FBW* of the LLSAW decreased to 6.51%, and a spurious response appeared at 7,100 m/s. For ψ=45°, the *FBW* was 9.05%, and the spurious response at 7,100 m/s remained small. Moreover, as the second Euler angle (θ) of the SiC support substrate increased from 30° to 55° under the same conditions, the spurious response owing to the LLSAW higher-order mode at 7,700 m/s was reduced.

From the above results, when ψ of the LN thin plate and θ of the SiC support substrate were set to 45° and 40°, respectively, both spurious responses were weakened while maintaining the strong response of the LLSAW, as shown in Fig. 3.

## 4. Conclusions

In this study, the propagation and resonance properties of the LLSAW on a bonded structure comprising an X36°Y-LN thin plate and a 4H-SiC support substrate were theoretically investigated. Notably, the strong LLSAW response was obtained at $h/\lambda$ where the phase velocity of the LLSAW was slower than that of the bulk shear wave of 4H-SiC, and the *FBW* of 9–10% was obtained under conditions for $h_{Al}/\lambda$=0.06–0.07 and $h/\lambda$=0.30–0.40. Moreover, the spurious responses were weakened by optimizing ψ of the LN thin plate and θ of the SiC support substrate. In future studies, we will experimentally investigate such bonded structures.

## References

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