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Analysis of longitudinal leaky SAW in leaky region on $LiNbO_3$/SiC structure

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1. Introduction

High-performance surface acoustic wave (SAW) devices with characteristics, such as high frequency and *Q*-factor are required. Longitudinal leaky SAWs (LLSAWs) have high phase velocity, which is advantageous for use in high-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 the large attenuation. Recently, it has been reported that the attenuation of LLSAW can be reduced by bonding LN thin plates to SiC, which has high phase velocity and thermal conductivity, as a support substrate (LN/SiC).[1,2)] In these studies, effective resonance properties were obtained at the plate thickness of LN, where the LLSAW phase velocity was slower than that of the bulk shear wave of 4H-SiC (7126 m/s), placing it in the non-leaky region and thus eliminating the LLSAW attenuation. However, the high-phase velocity characteristics of SiC are not fully utilized for the LN plate thicknesses.

Our group reported the plate thickness dependence of LLSAW attenuation and resonance properties with a high *Q* factor analyzed using the finite element method (FEM) for a range of LN thin-plate thickness h/λ normalized by wavelength λ, in the leaky region, where the LLSAW phase velocity on an X-cut LN/SiC structure is faster than 7126 m/s.[3)]

In this study, the propagation and resonance properties of LLSAW in the leaky region on a rotated Y-cut 90°X-LN/SiC (Rot.Y90°X-LN/SiC) were theoretically investigated because LLSAW does not combine with the fast shear wave component of Rot.Y90°X-LN, and small attenuation can be expected in the leaky region.

2. Calculation of propagation properties

We first calculated the LLSAW attenuation on the Rot.Y90°X-LN/4H-SiC to determine the second Euler angle (θ) of the LN. The Euler angles (0°, 0°, 0°) of the 4H-SiC support substrate were used.

Figure 1 shows the LLSAW attenuation on the Rot.Y90°X-LN/4H-SiC for a free surface as a function of θ, obtained from analytical calculations. The parameter was set to h/λ=0.043–0.048, where the LLSAW attenuation tends to reach a minimum value in LN/SiC. The attenuation exhibited a minimum value at θ=140°–180°. This trend was also observed for the metalized surfaces. Moreover, for most values of θ, the main LLSAW response split into two responses but nearly merged into a single response at θ=160°. Based on these results, 70°Y90°X-LN (0°, 160°, 90°) was chosen as the piezoelectric thin plate.

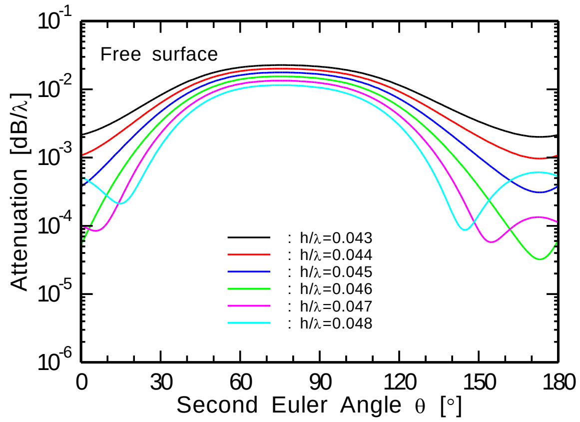

Fig. 1 Calculated attenuation of LLSAW on Rot.Y90°X-LN /4H-SiC.

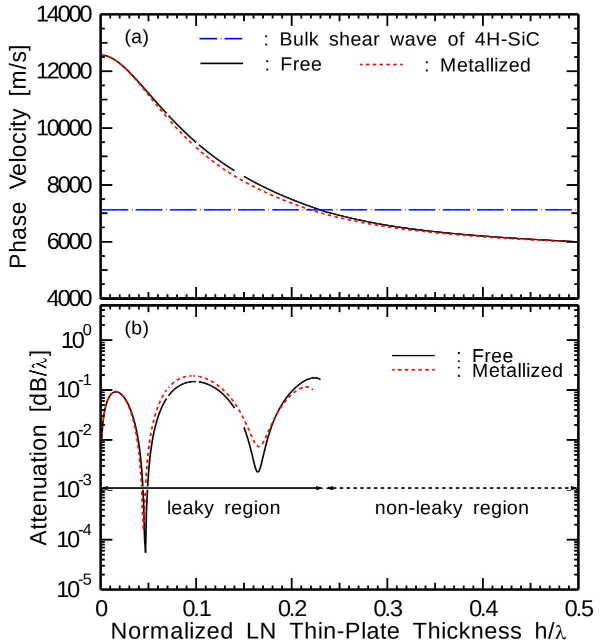

Fig. 2 Calculated propagation properties for (a) phase velocity and (b) attenuation of LLSAW on 70°Y90°X-LN /4H-SiC.

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Figures 2(a) and **2(b)** show the propagation properties for (a) phase velocity and (b) attenuation of LLSAW on 70°Y90°X-LN/4H-SiC as a function of h/λ. The attenuation for both free and metallized surfaces is as small as 5.4×10^{-4} dB/λ at h/λ=0.046, with phase velocities of approximately 11,300 m/s. The attenuation disappears above certain values of h/λ, specifically 0.24 and 0.23 for the free and metalized surfaces, respectively, where the phase velocity of the LLSAW is lower than 7126 m/s.

3. Simulation of resonance properties

We analyzed the resonance properties of the LLSAW on 70°Y90°X-LN/4H-SiC using the FEM in the case of forming an infinitely periodic interdigital transducer (IDT) with a period λ of 10 µm and an Al thin film. Material Q of LN was set at 600.

Figures 3(a) and **3(b)** show resonance Q (Q_r) and antiresonance Q (Q_a) factors of the LLSAW as a function of the Al thin film thickness h_{Al}/λ normalized by λ. The parameter was set to h/λ=0.04–0.09, , where around h/λ = 0.046 with a small LLSAW attenuation to obtain a relatively high Q factor in the leaky region. The h_{Al}/λ value required to achieve the maximum Q_r and Q_a increased with h/λ. This indicates that as h_{Al}/λ increases, the LN thin plate thickness needed to obtain the local minimum of the LLSAW attenuation shifts to a thicker plate thickness at an h/λ around 0.046. These results indicate that effective resonance properties can be obtained even in the leaky region by selecting the appropriate h/λ and h_{Al}/λ, which allow relatively large Q_r and Q_a to be obtained simultaneously.

Figure 4 shows the resonance properties of the LLSAW on 70°Y90°X-LN/4H-SiC under optimum conditions. The results for X36°Y-LN/4H-SiC in Ref. 3 are shown in Fig. 4 for comparison. In the leaky region, clean resonance properties were obtained near the main LLSAW response because the LLSAW higher-order modes were not excited owing to the cutoff plate thickness. On 70°Y90°X-LN/4H-SiC, Q factor values exceeding 1,000 and an LLSAW response with an admittance ratio (*AR*) of 64 dB were obtained over a relatively wide range of h_{Al}/λ=0.031–0.036 and h/λ=0.07–0.09, even at high phase velocity of 9,500 m/s. Conditions with a fractional bandwidth (*FBW*) of 1.6%, which is more than twice as large as that of X36°Y-LN/4H-SiC[3] at approximately 11,000 m/s, can be selected.

4. Conclusions

In this study, the propagation and resonance properties of LLSAW on 70°Y90°X-LN/4H-SiC were investigated theoretically. We clarified the LN plate thickness at which LLSAW attenuation

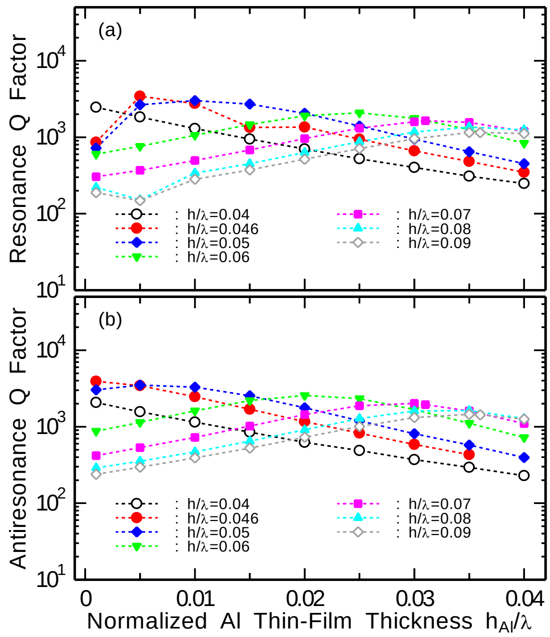

Fig. 3 Al thin film thickness dependences of (a) resonance and (b) antiresonance Q factors of LLSAW.

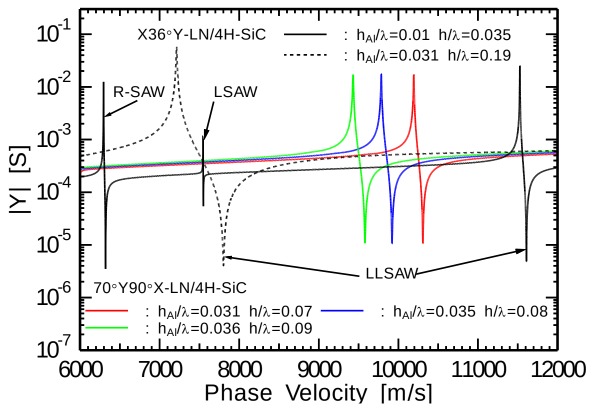

Fig. 4 Simulated resonance properties on 70°Y90°X-LN /4H-SiC.

reached its minimum value. Moreover, the resonance properties were simulated using FEM at an LN thin-plate thickness near this minimum value. It was found that the Q factor of the LLSAW was sensitive to both the LN thin-plate and Al thin-film thicknesses. These results clarify a relatively wide range of conditions for LLSAW resonance properties in the leakage region, with a Q factor of more than 1,000, phase velocities of approximately 10,000 m/s, and *FBW* of 1.6%.

References

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