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Analysis of A_0- and A_1-mode Lamb waves resonance properties on piezoelectric substrates with periodic voids

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1. Introduction

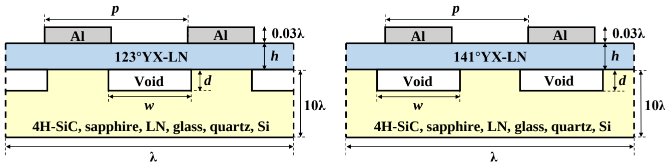
Surface acoustic wave (SAW) devices are required to possess high-performance characteristics, such as high frequency, high Q, and wide bandwidth. Among the propagation modes of plate waves that propagate by totally reflecting off the top and bottom surfaces of a thin piezoelectric crystal plate, the A_0-mode Lamb wave has a slow phase velocity, which is advantageous for the miniaturization of devices[1)]. The A_1-mode Lamb wave, which is a higher-order mode, propagates with a very high phase velocity and a relatively high electromechanical coupling factor, making it advantageous for higher frequencies and wider bandwidths[1)]. However, there is a problem that the structure for such plate waves, where there is a need to hold a plate thinner than λ (λ: wavelength), is very fragile. Our research group proposed a bonded structure with periodic voids formed on the surface of the support substrate and showed through theoretical analysis using the finite element method (FEM) that resonance properties similar to those of SH_0 plate waves and S_0-mode Lamb waves can be obtained[2)].

In this study, we analyzed the resonance properties of A_0- and A_1-mode Lamb waves propagating in a thin $LiNbO_3$ (LN) plate on a bonded structure with periodic voids.

2. Analysis of A_1-mode Lamb wave

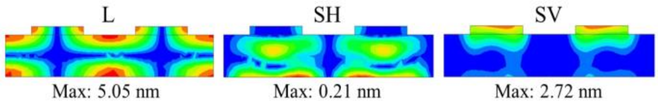
The search for the cut angle with the largest fractional bandwidth (*FBW*) in the A_1-mode Lamb wave of the LN was 10.4% for the 123°YX-LN when the normalized LN thickness h/λ was 0.15. The resonance property of the infinite periodic structure of an Al interdigital transducer (IDT) on a 123°YX-LN thin plate was simulated using FEM. The analytical model is illustrated in **Fig. 1(a)**. A void with a rectangular cross-section of width w and depth d = 0.1 λ was placed at the boundary between the LN thin plate with thickness h/λ and the support substrate. The void had the same pitch p as that of the IDT. The thickness of the support substrate was 10 λ, and the thickness of the Al-IDT was set to 0.03 λ (λ = 2p = 2.63 µm). The material Q (Q_m) of the LN was set to 600. Various support substrate materials were considered, including 4H-SiC, sapphire, LN, glass, quartz, and silicon.

Figures 2(a-1) and **2(a-2)** show the simulated particle displacements of the A_1-mode Lamb wave

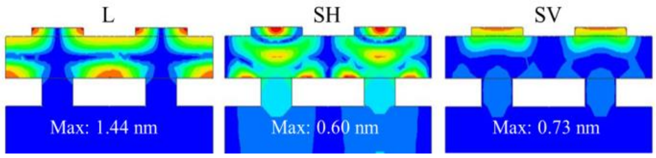


(a) for A_1-mode (b) for A_0-mode

Fig. 1 Analytical models.

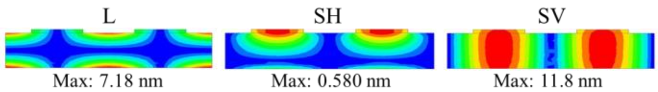


(a-1) Single 123°YX-LN thin plate (h/λ = 0.15).

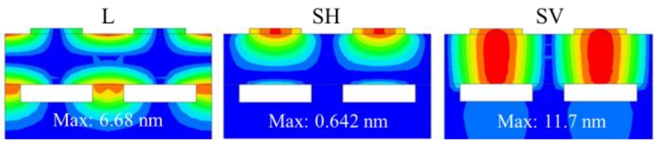


(a-2) 123°YX-LN/4H-SiC (h/λ = 0.15, w/p = 0.7).

(a) for A_1-mode.



(b-1) Single 141°YX-LN thin plate (h/λ = 0.28).



(b-2) 141°YX-LN/glass (h/λ = 0.28, w/p = 0.7).

(b) for A_0-mode.

Fig. 2 Simulated particle displacements.

for the single LN thin plate and the structure bonded to 4H-SiC, respectively. As shown in Fig. 2(a-1), the node of the longitudinal (L) component, which is the main displacement of the A_1-mode Lamb wave, is located directly below the electrodes. Therefore, voids are placed between the electrodes to minimize the obstruction of the L component.

Figure 3(a) shows the resonance properties of 123°YX-LN/4H-SiC with h/λ = 0.15 and a parameter of w/p. The horizontal axis represents the phase velocity converted from frequency multiplied by λ. The resonance properties approached those of A_1-mode Lamb waves with increasing w/p. Spurious-free characteristics are obtained for 4H-SiC and sapphire, as shown in Fig. 3(a), whereas numerous spurious responses appear from the resonance frequency to the antiresonance

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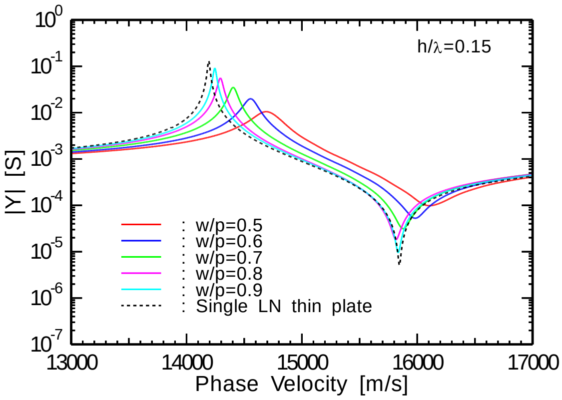
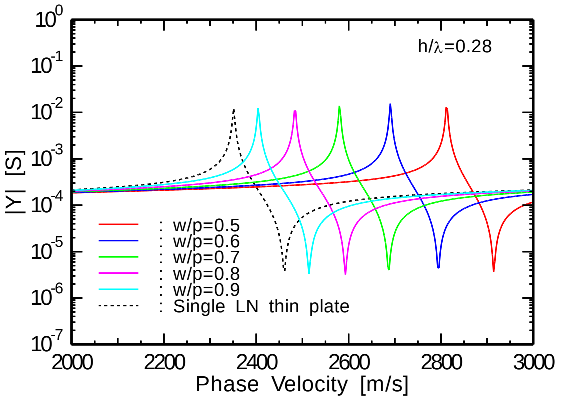


(a) A_1-mode on 123°YX-LN/4H-SiC.



(b) A_0-mode on 141°YX-LN/glass

Fig. 3 Simulated resonance properties.

frequency with other support substrates. These spurious responses were caused by the leakage of shear horizontal (SH) and shear vertical (SV) components into the support substrate via the bonding area.

Figure 4 shows the phase velocity and *FBW* as functions of h/λ with w/p fixed at 0.7. The phase velocity and *FBW* increased with a decrease in h/λ. The *FBW* of 123°YX-LN/4H-SiC with periodic voids at h/λ = 0.15 was 9.3%, which was close to the value of 10.4% for a single 123°YX-LN thin plate.

3. Analysis of A_0-mode Lamb wave

The search for the cut angle with the largest *FBW* in the A_0-mode Lamb waves of the LN was 4.5% for the 141°YX-LN with h/λ = 0.28. Similarly, for the A_1-mode Lamb wave, the A_0-mode resonance property was simulated using FEM for the analytical model, as illustrated in **Fig. 1(b)**.

Figure 2(b) shows the simulated A_0-mode particle displacements. The voids were placed below the electrodes to minimize the obstruction of the SV component, which was the main displacement of the A_0-mode Lamb wave.

Figure 3(b) shows the resonance properties of 141°YX-LN/glass with h/λ = 0.28. The spurious -free resonance properties approached those of A_0-mode Lamb waves with increasing w/p.

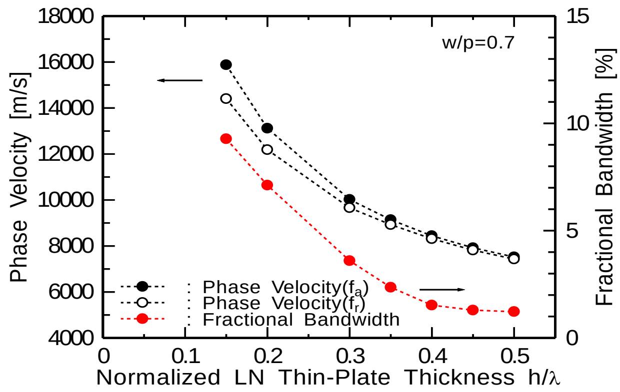


Fig. 4 Simulated phase velocity and *FBW* of A_1-mode on 123°YX-LN/4H-SiC with periodic voids.

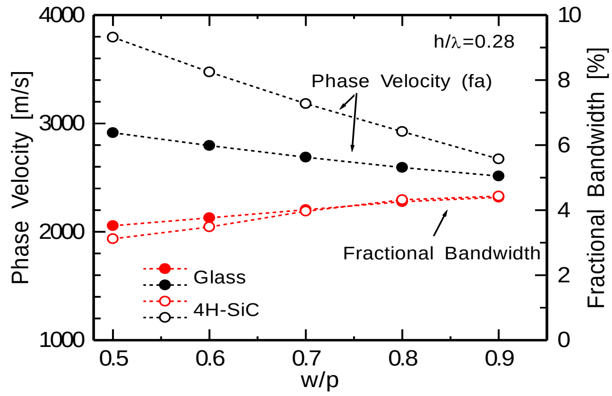


Fig. 5 Simulated phase velocity and *FBW* of A_0-mode on 141°YX-LN/glass, 4H-SiC with periodic voids.

Figure 5 shows the phase velocity and *FBW* of the glass and 4H-SiC support substrates as functions of w/p with h/λ fixed at 0.28. The *FBW* was unchanged owing to the differences in the support substrates and was 4.0% for the glass substrate with w/p = 0.7. The phase velocity in glass was lower than that in 4H-SiC.

4. Conclusion

In this study, we analyzed the resonance properties of the A_0- and A_1-mode Lamb waves propagating in a thin LN plate on a bonded structure with periodic voids. Resonance properties similar to those of A_0- and A_1-mode Lamb waves were obtained by bonding a thin LN plate to a support substrate with periodic voids. It was found that the phase velocity and spurious responses could be controlled by varying the supporting substrate.

Acknowledgment

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References

1) M. Kadota, *et al.*, Jpn. J. Appl. Phys. **48**, 07GG08 (2009).
2) T. Suzuki, *et al.*, Jpn. J. Appl. Phys. **62**, SJ1008 (2023).