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Analysis of Longitudinal Leaky Surface Acoustic Waves on Piezoelectric Thin Plates Bonded to Diamond Substrate

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1. Introduction

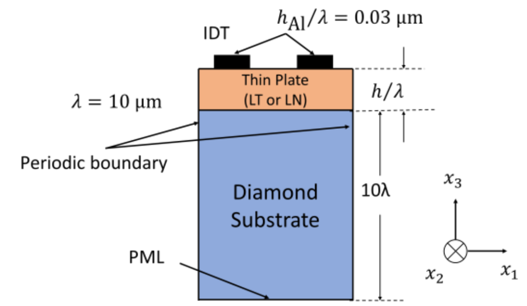
Longitudinal leaky surface acoustic waves (LLSAWs) have a phase velocity that is 1.5 to 2 times higher than that of conventionally used leaky surface acoustic waves (LSAWs), making them advantageous for use in higher frequency SAW devices. However, there is a problem of large attenuation and low Q factor due to the radiation of two types of bulk wave into the substrate. As a method of reducing attenuation, the utilization of bonded structures, that is, a piezoelectric thin plate bonded to a support substrate having a higher phase velocity than the piezoelectric thin plate, has been reported[1].

In this study, the resonance properties of the LLSAW propagating on the bonded structures consisting of a diamond substrate with very high phase velocity and a $LiTaO_3$ (LT) or $LiNbO_3$ (LN) piezoelectric thin plate are analyzed by the finite element method (FEM).

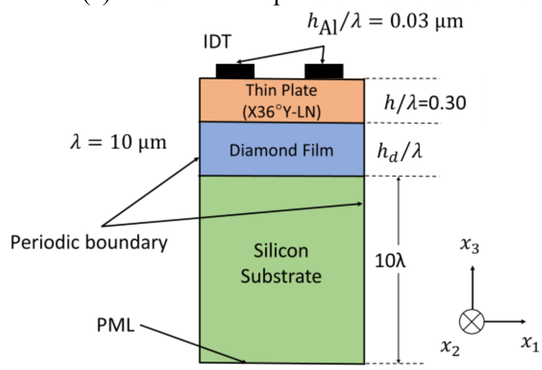
2. Simulation of Resonance Properties of LLSAW

Figure 1(a) shows the FEM analysis model of the bonded structure with a diamond single-crystal support substrate. As piezoelectric thin plates, X31°Y-LT and X36°Y-LN, which have a large coupling factor for LLSAWs, are used. An infinitely periodic interdigital transducer (IDT) with a period λ of 10 μm and an Al thin film with normalized thickness h_{Al}/λ=0.03 was assumed. A perfectly matching layer was provided at the bottom of the support substrate with 10λ. The material constants for diamond were the values reported for single crystals[2]. The mechanical loss Q_m of the thin plate was set to 1,000 and Q_m of the support substrate was set to 100, assuming the use of a polycrystalline film with large acoustic loss instead of an expensive diamond crystal.

Figures 2(a) and 2(b) show the resonance properties of LT and LN thin plates with a normalized plate thickness h/λ of 0.30, respectively. The horizontal axis in these figures is converted to phase velocity by multiplying frequency by λ. For the LLSAW on the LT thin plate, the phase velocity of the antiresonance, v_a, is 6,540 m/s, the fractional bandwidth (*FBW*) is 3.2%, the admittance ratio (*AR*) is 69 dB, the resonance Q factor Q_r is 800, and the antiresonance Q factor Q_a is 870. On the other hand,



(a) LT or LN thin plate/diamond substrate



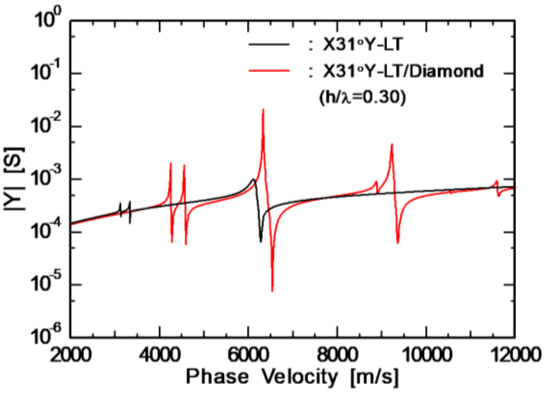
(b) LN thin plate/diamond film/silicon substrate

Fig. 1 FEM analysis models.

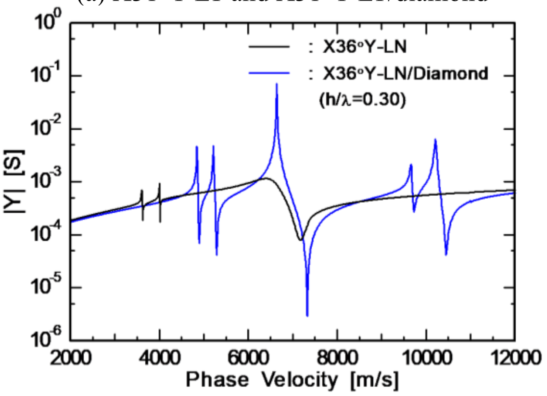
for the LLSAW on the LN thin plate, v_a is 7,326 m/s, *FBW* is 9.4%, *AR* is 88 dB, Q_r is 772, and Q_a is 951, showing a 19 dB larger *AR* and an approximately 3 times larger *FBW* than those of the LT. However, in addition to the main response of the LLSAW, spurious responses due to Rayleigh-type SAWs and LSAWs, as well as their higher-order modes, appeared in all resonance properties.

Figures 3(a) and 3(b) show particle displacement distributions at the resonance frequencies of the LLSAWs on the single LN and the LN/diamond bonded structures, respectively, when a sinusoidal AC voltage of ±1.0 V was applied to the IDT. Compared with the single LN, particle displacements were greatly concentrated near the surface when the LN thin plate was bonded with the diamond support substrate. This is the reason why bonding the piezoelectric thin plate to a diamond support substrate improves the resonance properties compared with the single piezoelectric substrate.

Figure 4 shows the phase velocity v_a and effective coupling factor K^2_{eff} as functions of the normalized plate thickness h/λ. As the plate thickness increased, v_a changed from the phase velocity of the diamond substrate to that of LN or LT.

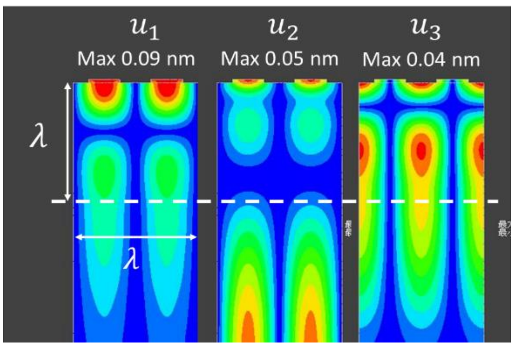


(a) X31°Y-LT and X31°Y-LT/diamond

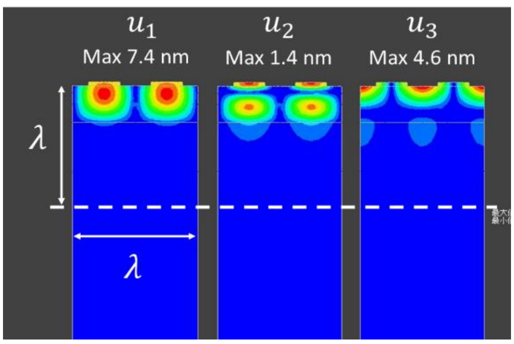


(b) X36°Y-LN and X36°Y-LN/diamond

Fig. 2 Simulated resonance properties.



(a) X36°Y-LN



(b) X36°Y-LN/diamond (h/λ= 0.3)

Fig. 3 Particle displacement distribution at the resonant frequency of LLSAW.

K^2_{eff} tended to saturate at a certain thickness for both LT and LN thin plates.

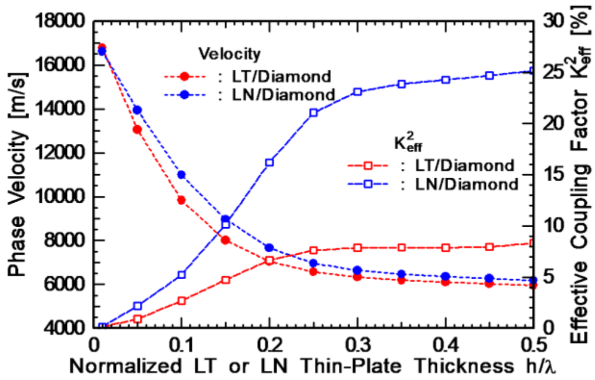


Fig. 4 Phase velocity and effective coupling factor K^2_{eff}.

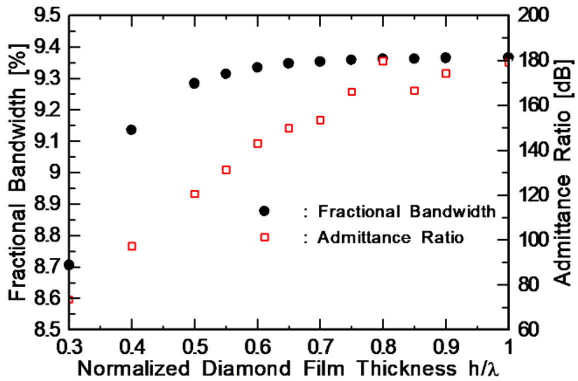


Fig. 5 Fractional bandwidth and admittance ratio.

3. LN Thin Plate/Diamond Film/Silicon Substrate

With a diamond polycrystalline film deposited on a Si support substrate, the resonance properties of the LLSAW on the LN thin plate/diamond film/Si structure, as shown in **Fig. 1(b)**, were also analyzed by FEM. When the normalized diamond film thickness h_d/λ was about 0.7 or more, the same resonance properties as in the case of the diamond support substrate (Fig. 2(b)) were observed. **Figure 5** shows the simulated *FBW* and *AR* as functions of h_d/λ. *FBW* tends to saturate at h_d/λ= 0.7, while *AR* tends to increase monotonically with increasing h_d/λ.

4. Conclusions

In this study, the resonance properties of the LLSAW on a bonded structure consisting of a diamond support substrate and LN or LT thin plate were evaluated by FEM analysis. It was found that the resonance properties were improved by bonding the piezoelectric thin plate to a diamond support substrate, because particle displacements are greatly concentrated near the surface. However, several spurious responses were also observed. It was also found that the LN/diamond film/Si structure exhibited properties comparable to those of the diamond substrate structure.

References

1. M. Gomi, *et al.*, JJAP **56** (2017) 07JD13.
2. H. J. McSkimin and W. L. Bond, Phys. Rev. **105** (1957) 116.