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# Analysis of SAW Resonance Properties on Piezoelectric Substrates with Periodic Voids

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## 1. Introduction

Surface acoustic wave (SAW) devices are required to have high performance characteristics, such as high frequency, high $Q$, and wide bandwidth. Plate waves, which are in a propagation mode advantageous for wide bandwidth, propagate while totally reflecting off the top and bottom surfaces of a piezoelectric crystal thin plate. Shear horizontal (SH) $SH_0$-mode plate waves propagating in a thin $LiNbO_3$ (LN) plate have a very large electromechanical coupling factor $K^2$ of 55%[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.

In this study, we analyzed the resonance properties of leaky SAWs (LSAWs) and longitudinal LSAWs (LLSAWs) on structures with periodic voids (air gaps) placed in the vicinity of the surface of the LN substrate or into the bonded structure of a thin LN plate and a glass support substrate by the finite element method (FEM).

## 2. Periodic voids in the LN substrates

The resonance properties of LSAWs for an infinite periodic structure of an Al interdigital transducer (IDT) on 27.5°YX-LN[1] as the thin plate and support substrate, which has the largest $K^2$ for the $SH_0$-mode plate wave of LN, were simulated by FEM. The analytical model is shown in **Fig. 1(a)**. A void with a rectangular cross section of width $w$ and depth $d$=0.1λ was placed at the boundary between the LN thin plate with thickness $h$/λ and the LN support substrate. The void was placed below the electrode and had the same pitch $p$ and period as the electrode. The thickness of the support substrate is 10λ, and the thickness of the Al-IDT is set to 0.04λ (λ=2$p$=4.0 μm). The mechanical loss of LN is not considered.

First, voids were placed at $h$/λ=0.05, at which the largest $K^2$ occurs for the $SH_0$-mode plate wave in 27.5°YX-LN. The resonance properties are shown in **Fig. 2(a)** with the ratio $w/p$ as a parameter. The horizontal axis is the phase velocity converted from the frequency multiplied by λ. The fractional bandwidth ($FBW$) and admittance ratio ($AR$) of the $SH_0$ mode plate wave at $h$/λ=0.05 are 22.0% and 125 dB, respectively. For the structure with voids with $w/p$=0.5–0.9, $FBW$ and $AR$ ranged from 14.5% to 21.7% and from 94 to116 dB, respectively.

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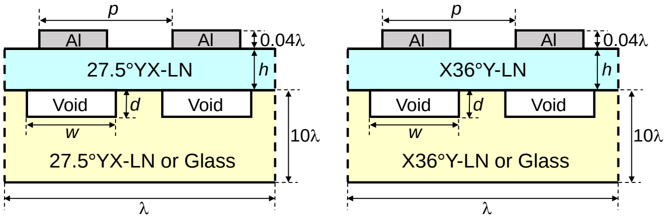
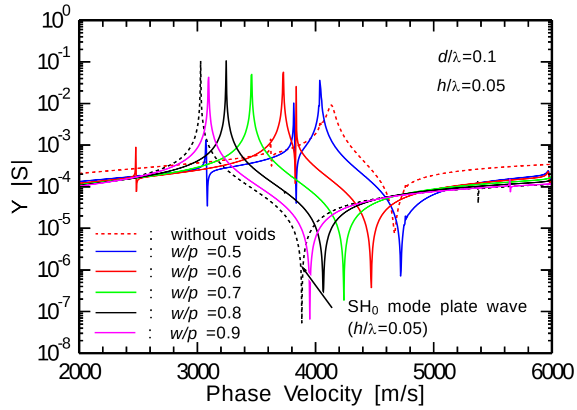
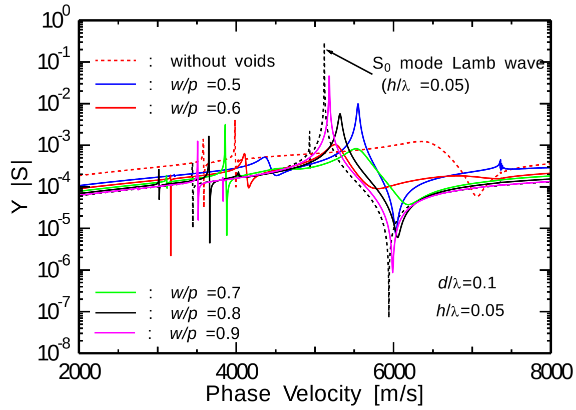



(a) for LSAW (b) for LLSAW

Fig. 1 Analytical models.




(a) LSAW on 27.5°YX-LN/27.5°YX-LN

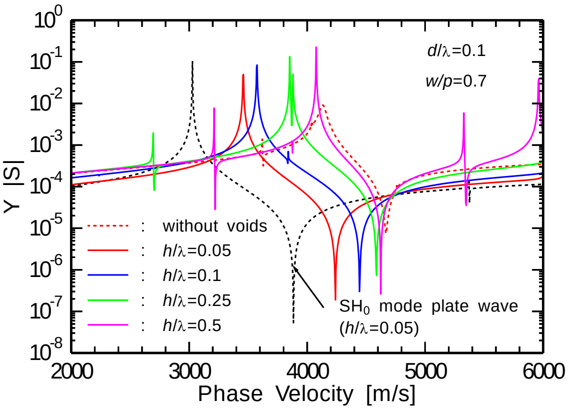



(b) LLSAW on X36°Y-LN/X36°Y-LN

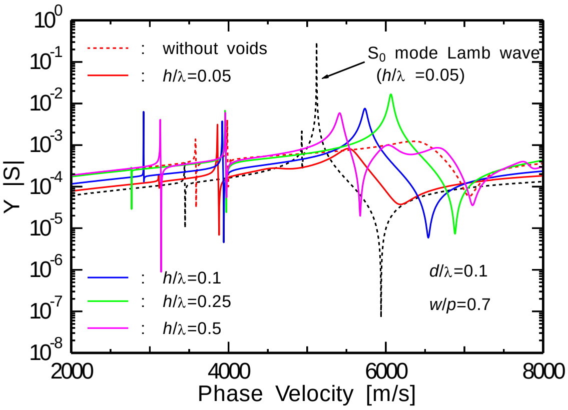
Fig. 2 Resonance properties with periodic voids.

Compared with the LSAW with $FBW$ of 11.5% and $AR$ of 62 dB for the single LN without voids, the resonance properties were improved and approached those of the $SH_0$-mode plate with increasing $w/p$. For $w/p$=0.7, 0.8, and 0.9, spurious free responses were obtained, whereas spurious responses were observed near the main response for $w/p$=0.5 and 0.6.

Similarly, for the model with the thin plate and support substrate set to X36°Y-LN, as shown in **Fig. 1(b)**, the LLSAW resonance properties were analyzed for $w/p$=0.5–0.9 and $h$/λ=0.05.

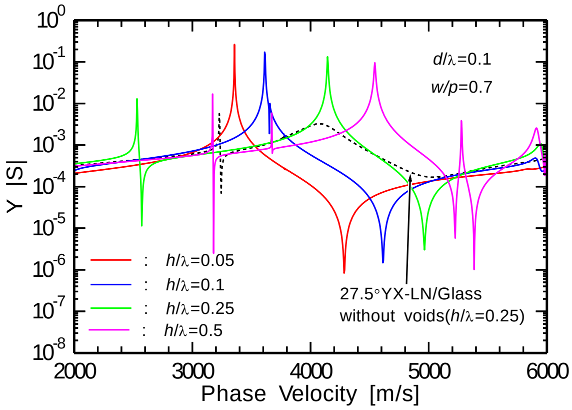



(a) LSAW on 27.5°YX-LN/27.5°YX-LN

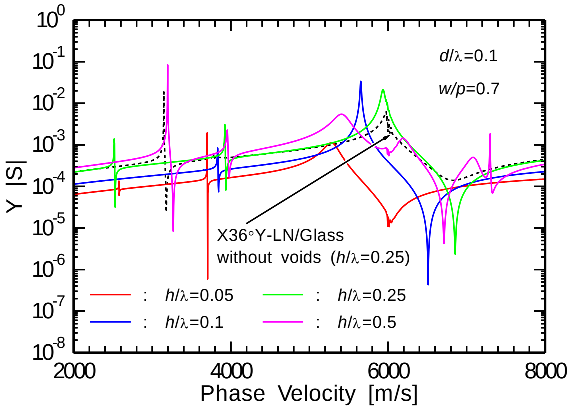



(b) LLSAW on X36°Y-LN/X36°Y-LN

Fig. 3 Resonance properties with periodic voids.




(a) LSAW on 27.5°YX-LN/glass




(b) LLSAW on X36°Y-LN/glass

Fig. 4 Resonance properties with periodic voids.

As shown in **Fig. 2(b)**, the resonance responses close to that of the $S_0$-mode Lamb wave were observed when voids were placed into the LN substrate, whereas no effective resonance was obtained for the single LN without voids. *FBW* of the $S_0$-mode Lamb wave on X36°Y-LN at $h/\lambda$ =0.05 was 13.8% and *AR* was 132 dB. For the structure with voids with $w/p$=0.5–0.9, *FBW* and *AR* ranged from 8.0% to 13.4% and from 21 to 94 dB, respectively.

Next, the $h/\lambda$ dependence was analyzed when $w/p$ was fixed at 0.7. The resonance properties of LSAWs are shown in **Fig. 3(a)**. As $h/\lambda$ increased, *FBW* saturated at 11.8%, which is slightly larger than that of the LSAW on the single LN, while *AR* was higher than that of the LSAW on the single LN. For $w/p$=0.7, the structure with $h/\lambda$=0.1 was found to exhibit the largest *FBW* of 19.5% and *AR* of 109 dB.

The $h/\lambda$ dependences of the LLSAW resonance properties for $w/p$=0.7 are shown in **Fig. 3(b)**. *FBW* and *AR* for $h/\lambda$=0.1 were 12.3% and 62 dB, respectively, which were higher than those on the single LN without voids (*FBW*=9.9% and *AR*=26 dB).

## 3. Periodic voids in the glass bonding structure

The bonded structures of a thin LN plate and a glass support substrate, as shown in Figs. 1(a) and 1(b), were also investigated. The resonance properties of LSAWs and LLSAWs for $w/p$=0.7 are shown in **Figs. 4(a)** and **4(b)**, respectively. As shown in these figures, the resonance responses with a high *Q* factor were observed by introducing voids, while no effective resonance can be obtained for the LN/glass bonded structure without voids.

For $h/\lambda$=0.05 in Fig. 4(a), *FBW* and *AR* were 21.7% and 110 dB, respectively, and *FBW* was larger than the maximum *FBW* (19.5%) on the structure in which voids were introduced into the LN. For $h/\lambda$=0.5 in Fig. 4(a), a large spurious response near the antiresonance frequency was observed. As shown in Fig. 4(b), *FBW* of 13.2% and *AR* of 98 dB were obtained for $h/\lambda$=0.1.

## 4. Conclusions

As described above, simulations revealed that, by introducing periodic voids into the vicinity of the surface of the LN substrate or at the boundary between the LN thin plate and the glass support substrate, resonance properties close to those of plate waves with higher *FBW* and *Q* factors than LSAWs and LLSAWs on a single LN substrate without voids can be obtained.

## References


1. M. Kadota, *et al.*, JJAP, **52** (2013) 07HD04.