3P3-1

Analysis of SAW propagation properties on piezoelectric substrates with periodic voids

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1. Introduction

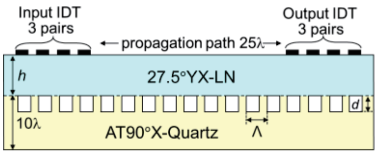
Surface acoustic wave (SAW) devices are required to achieve higher performance, such as a higher frequency and wider bandwidth. Plate waves, which are in a propagation mode advantageous for a wide bandwidth, propagate while completely reflecting off the top and bottom surfaces of thin piezoelectric crystal plates. However, plate waves, where plates thinner than 1λ (λ:wavelength) must be held, are extremely fragile. To obtain resonance properties close to plate waves on a structurally stable substrate, we propose structures consisting of an $LiNbO_3$ (LN) thin plate and a support substrate with periodic voids and a rectangular cross section and the resonance properties of leaky SAW (LSAW) and longitudinal LSAW (LLSAW) were analyzed using the finite element method (FEM), and it was deduced that resonance properties close to the plate waves were obtained.[1)]

In this study, the propagation properties of LSAW on LN and Quartz (Qz) bonded structures with a grating consisting of periodic voids at the interface were analyzed using FEM. Next, the frequency response of a Z-cut X-propagation LN (ZX-LN) substrate with internal voids is analyzed as an example of controlling propagation properties using periodic voids.

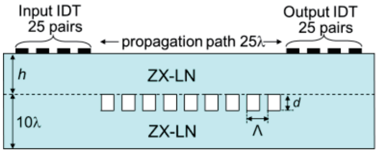
2. Analysis of propagation properties on LN/Qz

As shown in **Fig. 1(a)**, the frequency response between the input and output Al interdigital transducers (IDTs) with a wavelength λ of 4.0 μm was analyzed for a bonded structure consisting of a 27.5°YX-LN thin plate and an AT90°X-Qz support substrate with periodic voids at the bonded boundary interface. The thickness of the support substrate and Al-IDT were set to 10λ and 0.04λ, respectively. The LN thin plate thickness *h* and the void depth *d* were both fixed to 0.1λ, the number of finger pairs of IDT was 3, and the propagation path length was 25λ. The period of the voids Λ under the propagation path was used as a parameter.

First, the frequency response without voids was analyzed, and the LSAW response with a main lobe from 0.73 to 1.51 GHz was observed as shown in **Fig. 2**. Next, the frequency response of the model shown in Fig 1(a) with the voids of the boundary between LN and Qz under the IDT and under the propagation path with a period of λ/2 was analyzed and are shown in Fig. 2 as "Voids under IDT and propagation path." The properties of the case with voids only on the boundary surface under the IDT are shown in Fig. 2. For the response as "Voids under IDT" with a main lobe from 0.65 to 1.45 GHz, the loss increased at frequencies higher than 1.16 GHz and decreased again by approximately 10 dB at 1.30 GHz when the voids were placed under the IDT and propagation path. These frequencies are the lower-



(a) for LN/Qz



(b) for ZX-LN

Fig. 1 Analytical model.

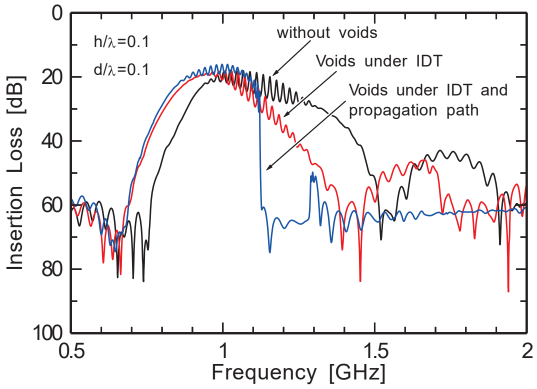


Fig. 2 Frequency responses between input and output IDTs for LN/Qz.

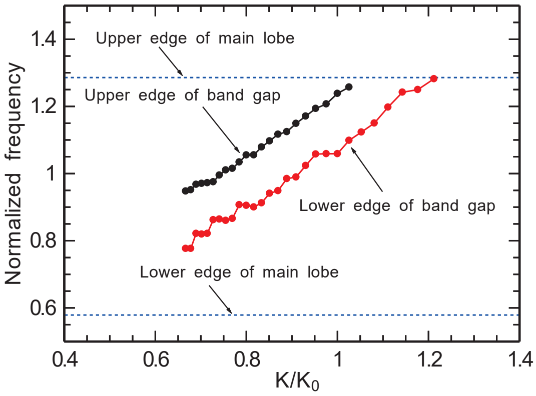


Fig. 3 Normalized band gap frequency vs. normalized wavenumber of periodic voids.

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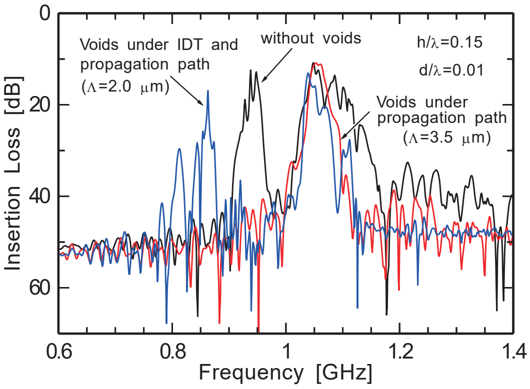

Fig. 4 Frequency responses between input and output IDTs for ZX-LN.

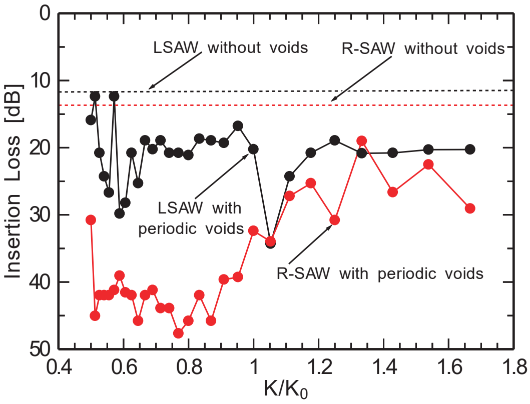

Fig. 5 Insertion Loss vs. normalized wavenumber of periodic voids.

and upper-bandgap frequencies, respectively, and their variations with the wavenumber of the void below the propagation path are shown in **Fig. 3**.

The horizontal axis is K/K_0, where the wavenumber K of the void period Λ is normalized by the wavenumber K_0 of the IDT pitch (p=λ/2=2.0 μm), and the vertical axis is the frequency normalized by the center frequency f_0 (1.05 GHz) of "Voids under IDT". The dotted lines indicate the lower and upper frequencies of the main lobe of "Voids under IDT". The lower and upper bandgap frequencies increased with an increase in the wavenumber K.

3. Analysis of propagation properties on ZX-LN

To evaluate the control of the SAW propagation properties using the band gap of the periodic void at the boundary between the thin plate and support substrate, the frequency responses of the Rayleigh-type SAW (R-SAW) and LSAW propagating on a structure with a ZX-LN set for both the thin plate and support substrate were analyzed. Here, ZX-LN, which has an equivalent K^2 for R-SAWs and LSAW, was used for the analysis.[2)]

Figure 1(b) shows the analytical model with periodic voids at the boundary between the thin-plate LN and LN support substrate. The frequency response between the input and output IDTs was analyzed with λ of 4.0 μm. The LN thin plate thickness h and the void depth d were fixed to 0.1λ and 0.01λ, respectively, the number of finger pairs of IDT was 25, and the propagation path length was 25λ.

Figure 4 shows the frequency response, R-SAW with a main lobe from 0.90 GHz to 0.98 GHz and LSAW with a main lobe from 1.00 GHz to 1.18 GHz without voids. Next, the frequency response is shown as "Voids under IDT and propagation path (Λ=2.0 μm)" in Fig. 4 for the Voids under IDT and the propagation path with a period of λ/2 on the boundary surface between the LN thin plate and the LN support substrate. In the model shown in Fig. 1(b), the frequency response is shown in Fig. 4 as "Voids under propagation path (Λ=3.5 μm)" for the voids only under the propagation path with a period of Λ=3.5 μm at the boundary between the LN thin plate and LN support substrate. For voids under the propagation path, the minimum insertion loss of the LSAW and the frequency at which the response appears remain almost unchanged, whereas only the response of the R-SAW shows an increase in the loss.

Figure 5 shows the dependence of the period of voids Λ under the propagation path. The horizontal axis represents K/K_0, whereas the vertical axis represents the minimum insertion loss. The minimum insertion loss of the main lobe (13.7 dB and 11.5 dB) for the R-SAW and LSAW without voids is indicated by the dotted lines. It was deduced that there are conditions under which the minimum insertion loss of the R-SAW increases with a decrease in the wavenumber K and that the minimum insertion loss of the LSAW is maintained at the same level as in the case where no voids are provided.

4. Conclusions

The frequency responses between the input and output IDTs of LN/Qz and ZX-LN with periodic voids at the bonded-boundary interface were analyzed. The bandgap frequency can be controlled by periodic voids at the boundary surface between the thin plate and support substrate.

It was also deduced that the periodic voids under the propagation path increased only the R-SAW loss among the R-SAWs and LSAW. In future work, we will experimentally evaluate substrates with periodic voids.

Acknowledgment

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References

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