Program Digest, 2019 IEEE International Ultrasonics Symposium (IUS)
Glasgow, Scotland, October 6-9, 2019

Suppression of Lowest-Order Plate Mode in Wafer-Bonded SAW Devices Using $LiTaO_3$ Thin Plate

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***Abstract*—This paper describes a suppression technique for the lowest-order plate mode in wafer bonded surface acoustic wave (SAW) devices using $LiTaO_3$ (LT) thin plate. When LT plate thickness is close to the SAW wavelength, say micron order, the lowest-order plate mode appears near the main resonance. It is shown that the plate mode can be suppressed by choosing LT cut angle, electrode thickness and LT plate thickness properly. It is also shown that when the acoustic length is finite, the leaky nature causes additional loss even when the LT plate is extremely thin. Detailed discussions are also given how the additional loss changes with the plate thickness.**

Keywords—*SAW, $LiTaO_3$ thin plate, spurious suppression, leaky loss*

I. Introduction

The leaky SAW on a 42°YX-$LiTaO_3$ (42LT) substrate have been used for long years. It is the fast shear (FS) wave coupled with the electric potential ϕ, and the reflection at the top surface causes coupling with the slow shear (SS) wave resulting in radiation their energy to bulk, namely leaky nature[1]. It is known that when the surface boundary conditions such as electrode thickness h and the substrate rotation angle θ are chosen properly, LSAW decouples with the SS wave, and the leaky loss disappears.[2]

Recently, use of the $LiTaO_3$ (LT) thin plate bonded to a high velocity substrate is paid much attention for realization of high performance surface acoustic wave (SAW) devices.[3-7] In the structure, the radiated SS component is trapped in the LT layer, and thus wave energy leakage to the substrate can be suppressed. However, the energy trapping also generates multiple guided plate modes, which cause spurious resonances. FS and longitudinal (L) bulk waves also cause plate mode resonances.

A common practice is reduction the plate thickness H for making the lowest-order plate mode cut-off near the pass-band. Thus required H is much smaller than the IDT period p_I, say sub microns, and this often causes difficulties in SAW device fabrication.

It is reported that spurious resonances by the FS and L plate modes can be suppressed by selecting quartz as supporting substrate owing to unique property of the quartz substrate. [5,6] Nevertheless, plate modes by the SS wave often appear near the filter pass-band, and thus H was set sub-micron order.

This paper describes a suppression technique of the lowest-order plate mode by the SS wave even when H is close to p_I. It is based on adjusting θ, h and H so that the decoupling with the SS mode occurs at the fist SS plate mode resonance. leaky SAW (LSAW) on LT decouples from the SS wave when the rotation angle and electrode thickness are properly chosen.[2]

In addition, It is also shown that when the acoustic length (IDT + reflector lengths) is finite, the leaky nature causes additional loss even when the LT plate is extremely thin. It is due to leakage of the SS wave from the reflector edges. Detailed discussions are also given how this loss changes with H.

II. Suppression Technique of Lowest-Order Plate Mode

Figure 1 shows input admittance of an infinitely long Al IDT 42LT substrate. The calculation was performed by the 2.5D finite element method (FEM), and additional loss components, i.e. material viscous loss, dielectric loss and electrode ohmic loss, are not included. Here h is 10%p_I. The resonance and anti-resonance frequencies, f_r and f_a, respectively, are seen at fp_I=3,860 m/s and 4,020 m/s, respectively, and the cut-off of FS wave exists at 4,211 m/s. Furthermore, a notch is seen in the conductance curve at a frequency f_d. In this case, f_d ~ 3,780 m/s, and can decrease with h and increase with θ.[2]

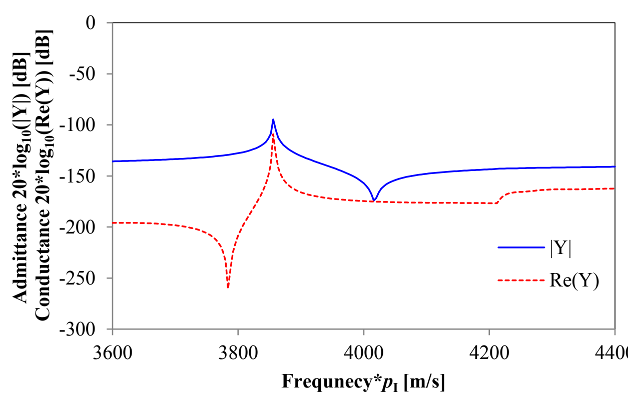


Fig.1. Simulated input admittance of 42LT with 10%p_I Al electrodes.

Fig. 2 shows the input admittance of an infinitely long Al IDT on the LT plate bonded with the Si substrate. Here h is 0.1p_I and LT thickness H is set three cases: 1.15p_I, 1.35p_I, and 1.55p_I. To increase visibility, each results shifted by 20. Although f_r and f_a scarcely change with H, amplitude and position changes with H for spurious resonances of the plate modes. Note that spurious resonances near 4,400 m/s are due to the plate mode by the FS wave.

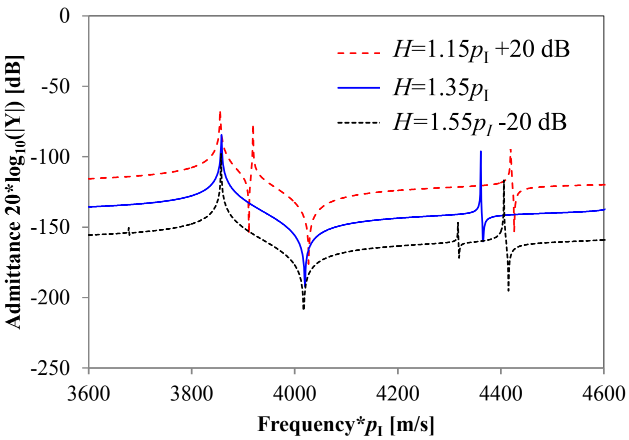


Fig.2. Simulation result of input admittance 42LT/Si substrate with 10%p_I Al electrodes in different H.

Fig. 3 shows variation of the resonance frequency f_{PM} of the lowest plate mode with H. Setting H extremely small allows us to move f_{PM} much than f_a. This is the main reason why I.H.P. chooses very small H.

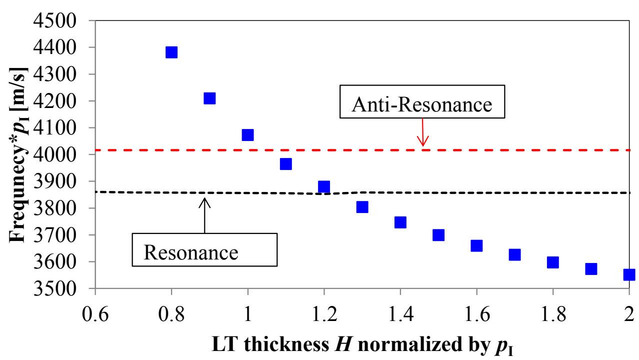


Fig.3. Lowest order plate mode frequency dependency of H in 42LT/Si substrate with 10%p_I Al electrodes.

It is seen that f_{PM} can locate much lower than f_r. However, higher-order plate modes appear close to the main resonance when H is large. We can see this situation in Fig. 2 when H=1.55p_I.

When H=1.35p_I, on the other hand, the plate mode resonance by the SS wave disappears. This is due to coincidence of f_{PM} with f_d where the SS wave decouples. In this case, H is about 2 μm even when f_r is 2.4 GHz. It is much easier for fabrication than H in sub microns used for I.H.P. Note that optimal H for this design is dependent on θ and h because f_d depends on them.

This technique is also applicable for the case when quartz is employed as the high velocity substrate[6,7]. Fig. 4 shows the input admittance of an infinitely long Al IDT (h=0.1p_I) on the LT plate bonded with the quartz substrate. In this case, optimal H is 1.17p_I. This slight variation is due to difference in the reflection phase for the SS wave at the LT bottom surface. Spurious responses by the higher-order modes and those by the FS wave are well suppressed. Therefore we can realize spurious free characteristics with large H by combining the spurious suppression technique proposed in this paper and employing quartz as the support substrate.

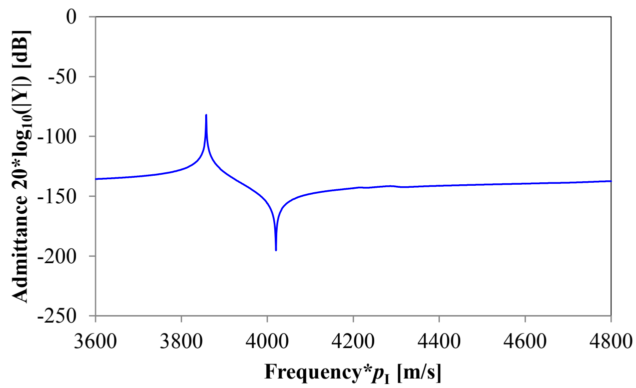


Fig.4. Simulation result of input admittance 42LT/quartz with optimum H of 1.17p_I and10%p_I Al electrodes.

III. Acoustic Loss Improvement by Using Thin Plate

LSAW can be non-leaky by bonding LT with a high velocity substrate. However, portion of the leaked SS wave reflected from the LT bottom surface will not arrive to the grating region, and run away from the reflector edges when the acoustic length (IDT + reflector lengths) L is finite. This will cause reduction of the resonance Q which is expected to be serious when H is large and/or L is small.

Influence of finite L is analyzed by the 2.5D FEM combined with the hierarchical cascading technique (HCT).[8] The simulated model is shown in figure 5. Here p_I is 4 μm, the numbers of fingers are 257 and 32 for the IDT and reflectors, respectively. No additional loss is included.

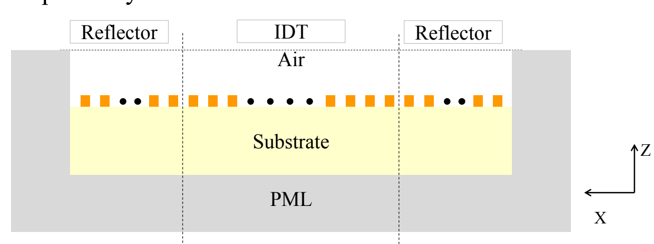


Fig.5. Simulation model of 2.5D FEM with infinite IDT width and finite grating number.

Four structures shown in Table 1 are simulated. #1 is the normal LSAW structure on 42LT as a reference. #2 and #3 are micron order thin plate cases introduced in previous section, #4 is the I.H.P. SAW structure in [4] as a benchmark.

Table I. Design parameters of substrate for synchronous resonator.

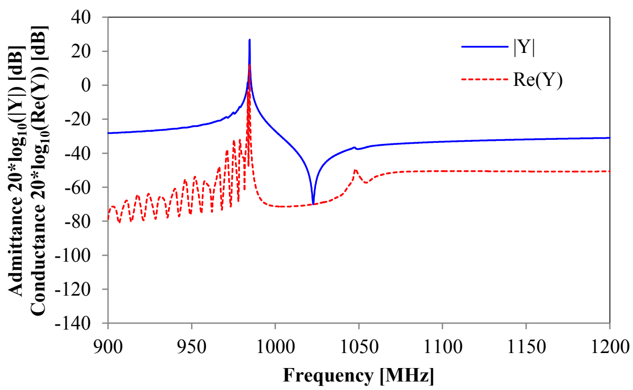
	#1	#2	#3	#4
Al thickness h	0.08p_I	0.1p_I	0.1p_I	0.08p_I
42LT thickness H	Infinite	1.35p_I	1.17p_I	0.3p_I
Functional layer	N/A	N/A	N/A	SiO_2 0.3p_I
Support substrate	N/A	Si	Quartz	Si

Calculated admittance characteristics are shown in Fig. 6. Results for #2 and #3 show improvement of acoustic loss from #1, i.e. normal 42LT. Conductance level at anti-resonance frequency is improved about 10 dB. Nevertheless, the improvement is limited comparing with the result for #4.

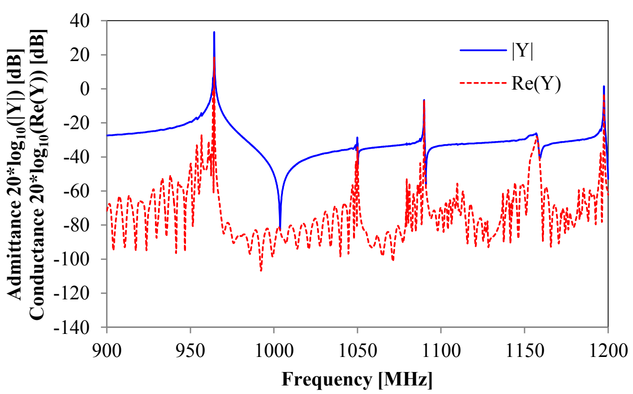
Fig. 7 show the estimated Bode Q[9] of these four resonators in log scale. In the figure, the frequency is normalized by f_r. Bode Q takes a maximum near f_r and decreases with f, and improvement at f_a is much more significant than that at f_r.

#4, i.e. I.H.P., gives extremely large Bode Q. Since its value is much higher than the experimental ones[3-7], it means that the loss mechanism discussed here is negligible for I.H.P. On the other hand, the value at f_a is close to the experimental one for #1, i.e. conventional LSAW. This means this mechanism, namely bulk wave leakage, is not negligible in the case.

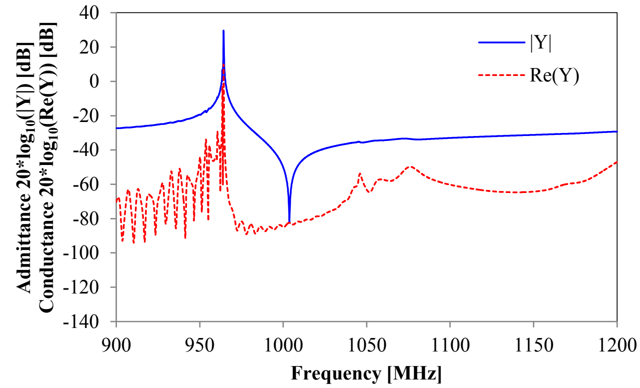
Bode Q for #2 and #3 is much larger than that for #1, the values are still higher than experimental ones for I.H.P.[3-7] This indicates that the bulk wave leakage from reflector side edges is not significant in practice even when H is set close to one p_I order.



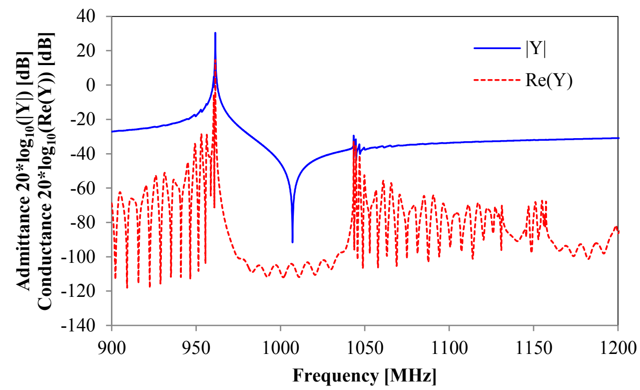
(a) #1 normal 42LT substrate frequency characteristics.



(b) #2 42LT/Si substrate frequency characteristics.



(c) #3 42LT/Quartz substrate frequency characteristics.



(d) #4 I.H.P. SAW structure frequency characteristics.

Fig.6. Simulation results of synchronous resonator with different substrate.

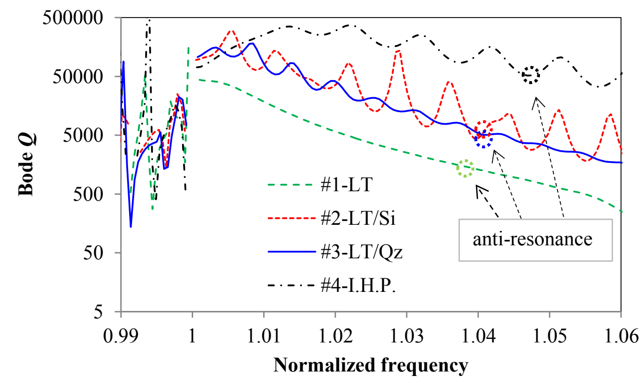


Fig.7. Bode Q characteristics of synchronous resonator with different substrate.

Estimated effective K^2 is 8.8%, 9.3%, 9.3% and 10.7% for #1 to #4, respectively. K^2 for #2 and #3 is scarcely dependent on H when H is larger than $1p_I$. This indicates that slight increase in K^2 for #2 and #3 is mainly owed to slightly larger h. In fact, field distribution for #2 and #3 is almost identical with #1 at the main resonance. On the other hand, increase in K^2 is significant for #4. This is due to SAW energy concentration in the thin LT layer.

IV. Conclusions

This paper described suppression of the lowest order plate mode by SS wave in wafer bonded SAW devices using LT thin plate. It is based on adjustment of substrate parameters; LT cut angle θ, electrode thickness *h* and LT plate thickness *H* to coincide the resonance frequency for the lowest-order SS plate mode with the frequency where LSAW decouples with the SS component.

It was also shown that other spurious resonances due to higher-order plate modes and those of due to the FS wave can be suppressed by employing quartz as support substrate. Combination of these two techniques allows us to realize spurious free characteristics even when *H* is set close to p_I. Temperature compensation is also expected owing to difference in thermal expansion coefficients in bonding wafer structure.[10]

Furthermore, the leaky loss was discussed in wafer bonded SAW devices with finite acoustic length. It was shown that the loss reduction is possible even when *H* is relatively large, and the improvement is significant near the anti-resonance frequency.

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