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Study of the LT/Quartz Bonded SAW Substrate for high performance filter solutions

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Abstract*— For expanding into various newly allocated frequency bands, high K^2, high Q filter solutions are strongly demanded for RF filter modules. Recently, SAW-type devices with bonded wafer structures have been widely studied for achieving high Q, high K^2 and excellent TCF. For example, 42YX-$LiTaO_3$ bonded onto Quartz has been studied as a candidate combination to provide high performance filter solutions with high Q, excellent TCF, and a spurious-free clean response. This paper proposes 25YX-$LiTaO_3$ bonded on 70Y90X-Quartz to give high K^2, high Q, and good TCF while suppressing spurious transverse modes, without any other special treatment to support piston mode operation. A parametric sweep study for this feature was conducted by piezoelectric simulation. Experimental filters and resonators were fabricated on 25YX-$LiTaO_3$ bonded on 70Y90X-Quartz, and the resulting performance and TCF were evaluated. This paper proposes 25YX-$LiTaO_3$ bonded on 70Y90X-Quartz as a candidate structure for high performance filter solutions. Ladder and DMS-type filter prototypes are demonstrated with excellent TCF performance and clean pass bands free of transverse modes.

***Keywords*—SAW, Bonded substrate, $LiTaO_3$, Quartz**

I. Introduction

Presently, surface acoustic wave (SAW) devices are widely used in modern communication systems thanks to their high performance and low cost, and many novel device structures have been proposed to meet the growing demand for temperature stability, low loss and wide bandwidth. Among various innovations, TF (Thin Film)-SAW devices using sub-wavelength piezo layer bonded on support substrate are proposed. For example, I.H.P SAW structure shows high Q, high K^2 and high-power durability [1]. Among bonded substrate candidates, thin $LiTaO_3$ layer bonded on a Quartz substrate was studied by several groups [1-16]. First, LT/Quartz structure shows unique characteristics which are not observed on other bonding structures with a high velocity support substrate such as Sapphire or Silicon. LT/Quartz shows a less bonded surface reflection response in higher frequency area [6,11]. Second, TCF (Temperature Coefficient of Frequency) the resonant and anti-resonant frequencies are both simultaneously close to zero [12]. One more interesting feature is that the transverse mode is naturally suppressed under these specific conditions without having to apply a trick to excite the piston mode operation [13]. In this study, firstly, crystal orientation of each piezo layer and Quartz orientation optimized with 2D FEM simulation. Next, suitable IDT structure is discussed with 3D FEM simulation. And finally, fabricated resonator and filter performance are evaluated.

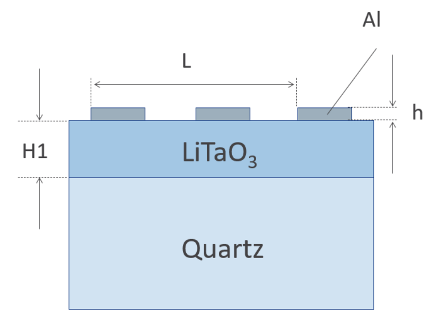

Fig. 1. Cross Sectional View of LT/Quartz Structure

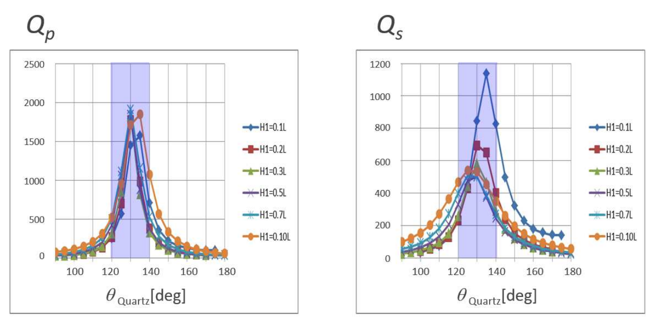

Fig. 2. Simulated Q_p and Q_s of 42YX-LT/rotated Y cut 0X propagation Quartz structure.

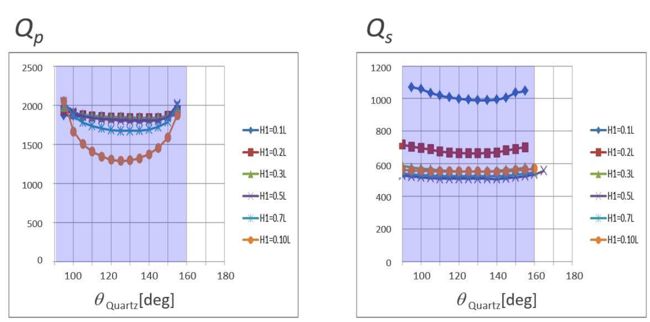

Fig. 3. Simulated Q_p and Q_s of 42YX-LT/rotated Y cut 90X propagation Quartz structure.

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II. ORIENTATION OPTIMIZATION BY 2D SIMULATION

Figure 1 shows the cross-sectional view of a LT/Quartz structure. The LT/Quartz structure is composed by a thin LT layer and Quartz substrate. Both components are piezoelectric, therefore combination of crystal orientation affects the acoustic property. 2D FEM simulation is done to determine the optimal orientation combination. First, the optimization of the Quartz orientation is discussed. Figure 2 shows simulated quality factor Q_s and Q_p at the resonant and anti-resonant frequency with rotated Y cut 0X propagation Quartz. Here, top LT layer orientation is fixed as 42YX and the IDT thickness is 0.075*L*. Both Q_s and Q_p of 0X propagation Quartz shows peak value near θ=120 deg. with the 0X-Quartz, design space is limited by Q_s and Q_p. Figure 3 shows, similar plot with 90X-Quartz. Q_s and Q_p. are stable over θ. 90X-Quartz has a wider design space. Figure 4 shows, 90X- Quartz K^2 and TCF. Design space includes TCF close to zero area from θ=150 deg to 170 deg. LT thickness was determined to be 0.15L to obtain good Q, K^2 and TCF. In the above discussion, the Quartz substrate orientation is determined to be 70Y90X-Quartz. Once the Quartz orientation was optimized, the LT orientation was optimized to maximize K^2. Figure 5 shows simulated K^2 as the rotation cut angle is swept. 25YX-LT has a maximum K^2. 25YX-LT on 70Y90X-Quartz is selected as an optimized combination.

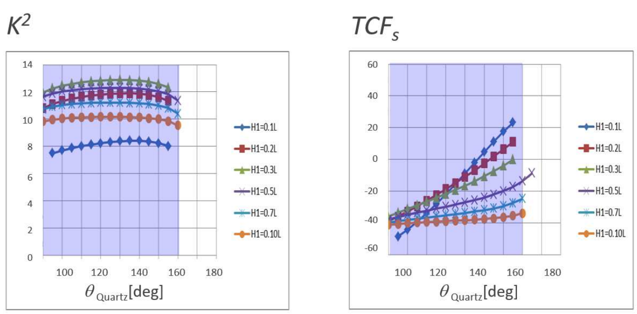

Fig.4 Simulated K2 and TCF of 42YX-LT/rotated Y cut 90X propagation Quartz structure.

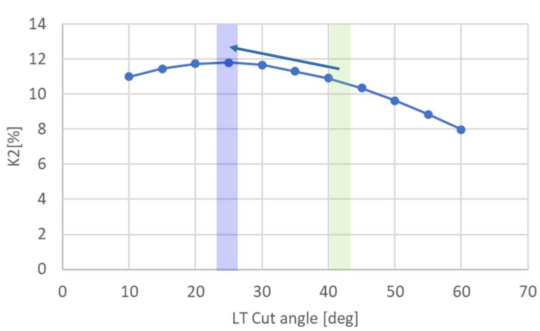

Fig.5 Simulated K2 of rotated Y cut X propagation-LT/70Y90X Quartz structure.

III. IDT SHAPE AND TRANSVERSE MODE SUPRESSION

In this section, the IDT geometry for the LT/Quartz structure is discussed. It has a large impact on the resonator performance. For using standard 42LT SAW case, IDT composed by narrow gaps and dummy IDT as shown in Figure 6(a) is commonly used for concave to flat surface slowness. TCSAW with SiO_2/128LN case, without dummy IDT with wide gap structure, shown in Figure 6(b), is preferred to trap the energy in the active region with convex surface slowness.

Figure 7 shows the Y11 response of a 3D FEM simulated resonator using: (1) a dummy IDT structure and (2) a wide gap IDT structure on LT/Quartz respectively. Strong wave leakage is observed near anti-resonant frequency with the wide gap IDT. The differences in performance between (1) and (2) come from the surface plane slowness behavior. LT/Quartz surface slowness curve is near flat. Dummy IDT structure is preferred for LT/Quartz substrate. Transverse mode suppression is also the concern to achieve good filter

Fig. 6. Geometry of (a) IDT with dummy (b) IDT with wide gap

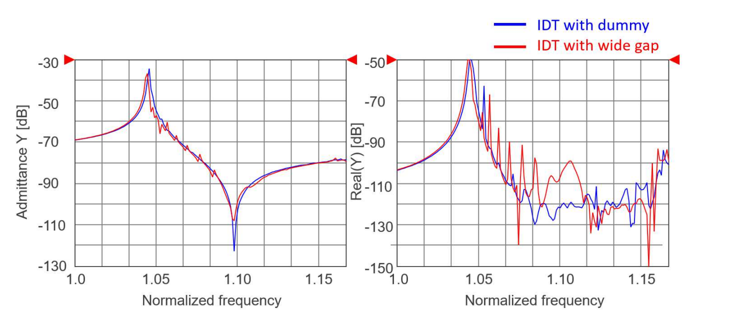

Fig. 7. 3D FEM simulated resonator peformance of 25LT/70Y90XQuartz with dummy IDT structure and wide gap structure.

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performance. By choosing the appropriate thickness of the IDT and piezo layer, the chosen Quartz orientation gives a flat slowness for surface plane, and under this condition, transverse mode is naturally suppressed without any special trick to operate the piston mode [13]. 25YX-LT/Quartz vs. 42YX-LT/Quartz transverse mode suppression condition is discussed. Figure 8 shows the simulated wave number for aperture direction β_y and frequency dispersion of 42LT/Quartz and 25LT/Quartz with various IDT thickness. IDT thickness h/L=0.075 curve is almost flat on 42LT. On the other hand, the dispersion curve is more convex on 25LT case. To obtain flat slowness on 25YX, IDT thickness should be thinner than 42LT case. Figure 9 shows 3D FEM simulation result (Y11) of the 42LT/70Y90X Quartz resonator. Transverse modes are suppressed when h/L=0.075 on 42LT. Figure 10 shows the same plot for the 25LT case. Transverse modes are suppressed at h/L=0.050 and this result is congruous with the simulated dispersion characteristics shown in Figure 8.

IV. Experimental verification

In the previous section, the cut angle orientation and IDT structure optimization is discussed. In this section the optimized structure is experimentally verified. LT/Quartz bonding substrate is provided from Tohoku Universty. 1 um thickness 25YX-LT thickness is bonded on 70Y90X-Quartz substrate. Fabricated IDT thickness h are 300nm, 350nm, 400nm with Aluminium respectively. Figure 11 shows measured resonator characteristics of the dummy IDT and wide gap IDT structures. As predicted by the 3D FEM simulation, strong leakage degradation on real(Y11) is observed near the anti-resonant frequency. Figure 12 shows the measured resonator characteristics with various IDT thicknesses. The transverse mode behavior shows good agreement with predicted in Figure 10. The transverse mode suppressed on h/L=0.055 in measurement. Figure 13 shows measured temperature dependencies of resonator characteristics. Almost zero temperature drift is observed at both resonant and anti-resonant frequencies. Figure 14 shows fabricated filter performance over the temperature. Clean pass band response without transverse mode spurious response is obtained for both Ladder type filter and DMS type filter. Temperature drift is small for both the lower and the upper pass band edge.

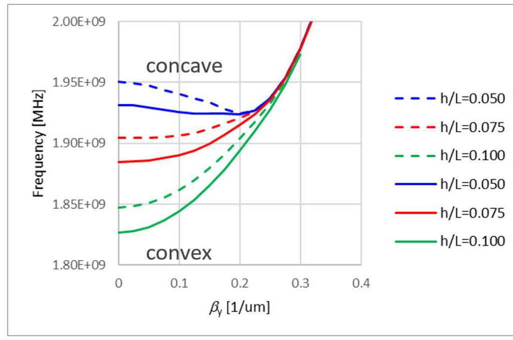

Fig. 8. Simulated dispersion characteristics of β_y and frequncy with 42LT/25LT on 70Y90X Quartz

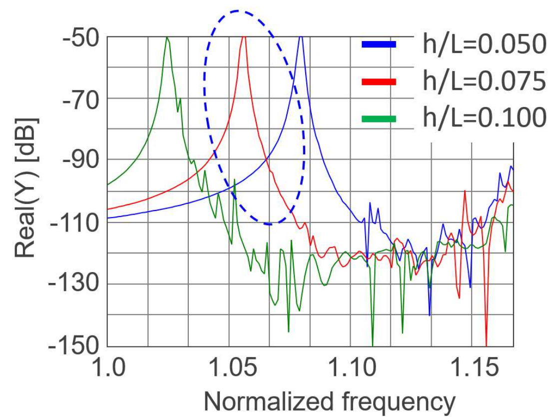

Fig. 9. Simulated 42LT/70Y90X Quartz resonator performance by 3DE FM.

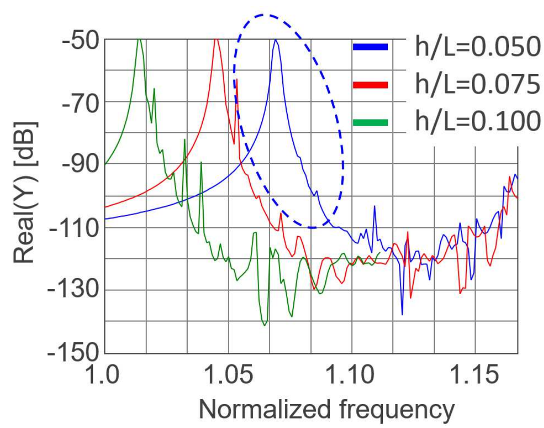

Fig. 10. Simulated 25LT/70Y90X Quartz resonator performance by 3D FEM.

V. Conclusions

In this study, LT/Quartz substrate is studied for high performance filter application. Piezo layer and substrate Quartz orientation optimization by the 2D FEM simulation is performed. Suitable IDT structure for optimized LT/Quartz substrate is discussed. To verify the simulated result, both the resonator and the filter were fabricated and evaluated. Clean pass band responses without transverse mode spurious response were obtained for both a Ladder type filter and a DMS type filter. Temperature drift was small both on the lower and the upper pass band edges.

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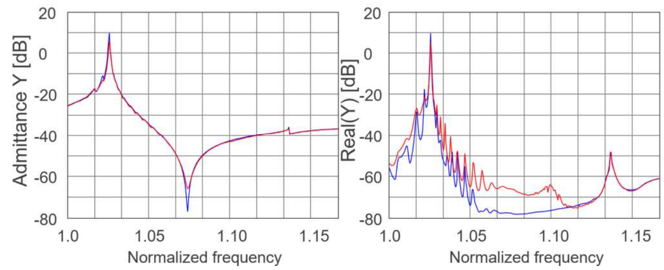

Fig. 11. Measured resonator peformance of 25LT/70Y90XQuartz with dummy IDT structure and wide gap structure.

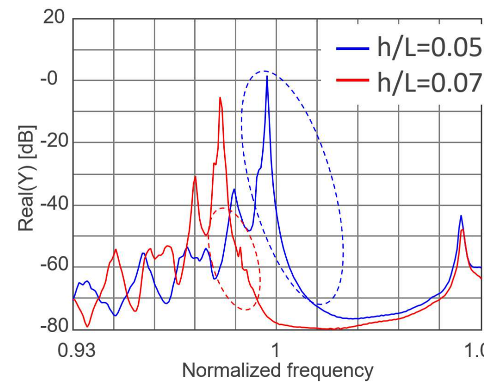

Fig. 12. Measured resonator peformance of 25LT/70Y90XQuartz with dummy IDT structure and wide gap structure for 3 different h/L ratios.

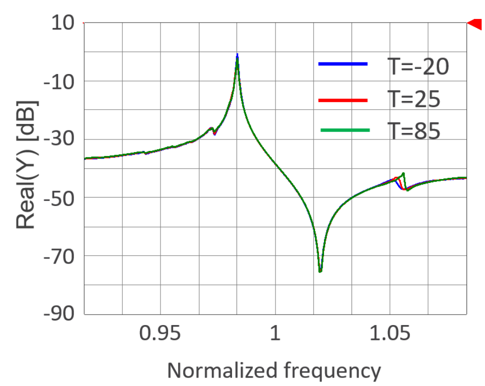

Fig. 13. Measured TCF performance of resonator

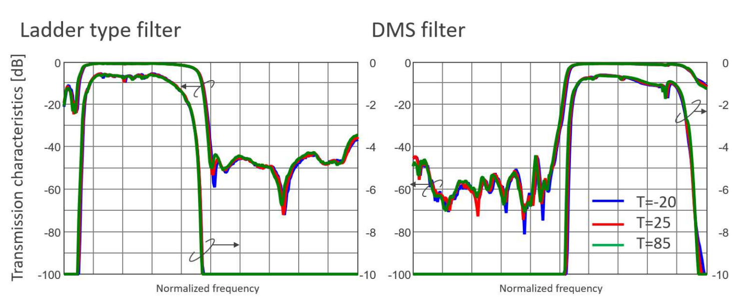

Fig. 14. Measured TCF performance of filter

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