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LT/Quartz HAL SAW Resonator with Large LT Thickness over Severalfold Wavelength

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***Abstract*—A Hetero Acoustic Layer (HAL) surface acoustic wave (SAW) device is a new class of SAW device using a thin LT or LN layer rigidly mounted on a substrate. In the past reports, the LT layer was as thin as 0.13-0.22λ (<0.7 µm for 1 GHz devices) to obtain a high impedance ratio (e.g. >80 dB), but this range of thickness is not easy to control in mass-production. In this study, we investigated the design space at larger LT thickness by FEM simulation. In the design space near the conventional one, in-band ripples and/or out-of-band spurious responses are generated. If a 1.4 times thicker Al or Cu electrode is combined with a LT layer thicker than a specific value (1λ for Al and 4λ for Cu), however, the ripples and spurious responses almost disappear and the deterioration of impedance ratio is limited. On the other hand, by using further thicker electrodes, a higher mode of SAW is excited preferentially at 2-2.6 times higher frequency than the fundamental mode.**

Keywords*—*SAW resonator, LiTaO₃, quartz, HAL SAW, impedance ratio, thick electrode, thick LT, higher mode

I. Introduction

A hetero Acoustic Layer (HAL) surface acoustic wave (SAW) device is a new class of SAW device which uses a thin piezoelectric single crystal layer solidly mounted on a support substrate [1-14]. One successful combination of materials is 20-43°YX $LiTaO_3$ (LT) as a thin layer and 35-50°Y90°X quartz as a substrate [14-16]. Leaky SAW is strongly confined in the LT layer and a large impedance ratio (Z ratio) is obtained. A small temperature coefficient of frequency (TCF) is also obtained by the cancellation of a negative TCF of LT and a positive TCF of quartz [15, 16]. Moreover, spurious-free characteristics up to a very high frequency was reported [16].

In the past study, promising designs were in the region where the thickness of LT is smaller than 1λ, where λ is wavelength. Typically, a large Z ratio around 80 dB is obtained without significant spurious responses at LT thickness of 0.14-0.22λ and Cu electrode thickness of 0.06-0.07λ [16, 17]. If the LT layer is made thicker with keeping the electrode at the same thickness, in-band ripples and out-of-band spurious responses appear and Z ratio deteriorates to 70 dB or even lower. LT thickness of 0.14-0.22λ corresponds to less than 0.7 µm for 1 GHz devices, and the control of this range of thickness in mass-production is a large challenge.

In this study, we investigated the design space at larger LT thickness by FEM simulation. Finally, we found that spurious-free characteristic could be obtained at one order of magnitude larger LT thickness with a limited penalty of Z ratio, if a thick electrodes is employed.

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II. Sumamry of LT/ quartz HAL SAW device

Typical measured frequency characteristics of LT/quartz HAL SAW resonators are shown in Fig. 1. Fig. 1 (a) exhibits an Z ratio of 82 dB at 480 MHz, which was achieved by the combination of 20°YX LT (0.144λ) and 40°Y90°X quartz using Cu electrodes (0.06λ). The values in the parentheses are thickness, where λ = 7.64 µm. Fig. 1 (b) exhibits an Z ratio of 80 dB at 900 MHz, which was achieved by the combination of 25°YX LT (0.15λ) and 42°45'Y90°X quartz using Cu electrodes (0.07λ), where λ = 4.12 µm. The Z ratio is 15-17 dB higher than that of standard Al/ 42°YX LT SAW resonators [9].

Near-zero TCF is obtained by optimizing LT thickness and Euler angle θ of LT and quartz. We measured a very small TCF of 2 ppm/°C at series resonance using 0.126λ thickness of 42°YX LT bonded with 42°45'Y90°X quartz [15, 16]. Spurious-free characteristics in a wide frequency range is another merit of the LT/quartz HAL SAW resonator. This merit was experimentally confirmed at least up to 14 GHz using crystal combinations within 20-42°45'YX LT/ 35-50°Y90°X quartz [16].

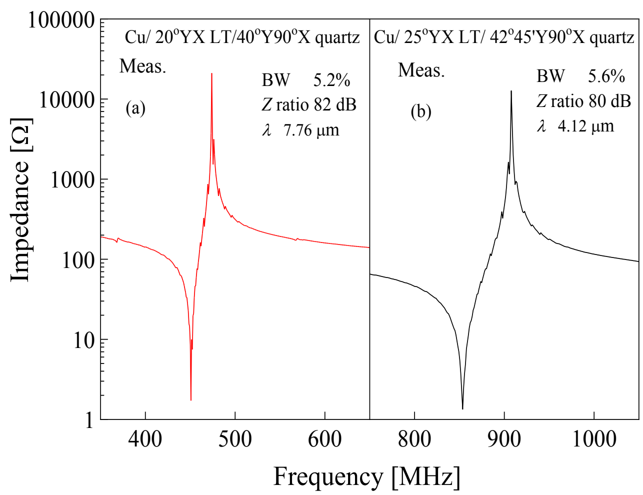

Fig. 1 Measured frequency characteristics of HAL SAW resonators composed of (a) Cu/ 20°YX LT/ 40°Y90°X quartz and (b) Cu/ 25°YX LT/ 42°45'Y90°X quartz.

III. Frequency characteristics in larger LT thicknesses

As mentioned in the previous section, the best thickness of LT in the past study was 0.1-0.2λ [10, 17]. If a thicker LT is used, Z ratio changes as shown in Fig. 2, which is a simulation result for 20°YX LT/ 40°Y90°X quartz resonators with Cu electrode (0.07λ). Loss tangent is assumed as the Z ratio of the standard SAW device is 65 dB [9]. The Z ratio gradually decreases with the LT thickness, but it is still as high as 70 dB at 1λ. It should be noted that measured Z ratio roughly agree with the simulated one at a small LT thickness. Below 1λ thickness of LT, no significant ripple or spurious response is observed.

A LT thickness of 1λ is within a controllable range, if the frequency is up to 2 GHz. However, a Z ratio of 70 dB is not satisfactory compared with our best results mentioned above. Thus, we investigated a larger LT thickness range with changing Cu electrode thickness also. Fig. 3 shows examples of simulation results, where a combination of 20°YX LT and 40°Y90°X quartz is assumed. Fig. 3 (a) shows the frequency characteristic of the conventional design with 0.15λ thick LT and 0.07λ thick Cu. A clean response with a Z ratio of 78 dB is confirmed. Fig. 3 (b) is for a LT layer as thick as 8λ. In-band ripples and out-of-band spurious responses appear intensively, and the Z ratio significantly decreases. In Fig. 3 (c), Cu electrode thickness is increased to 0.1λ. The ripples almost disappear in band and the Z ratio returns to 73 dB, suggesting that a thicker electrode may be effective for a thick LT layer.

Figs. 4 and 5 show calculated Z ratios of Cu- and Al-metalized HAL SAW resonators, respectively, in a wide range of LT thickness. Different electrode thicknesses from 0.07λ to 0.3λ are assumed. In the figures, the solid lines represent the sections without significant in-band ripples or out-of-band spurious responses, i.e. useful sections. There are useful sections with a relatively high Z ratio around 73 dB at LT thickness larger than 4λ and 1λ, if a Cu electrode of 0.1λ and an Al electrode of 0.19λ are employed, respectively. The dotted lines represent the sections without significant in-band ripples but with small out-of-band spurious responses. In the sections shown by the dashed lines, in-band ripples or large out-of-band spurious responses appear.

In conclusion, we have a chance to use a very thick LT layer, if a penalty of about 5 dB in Z ratio is accepted. This option is useful for more controllable production of LT/quartz hybrid wafers.

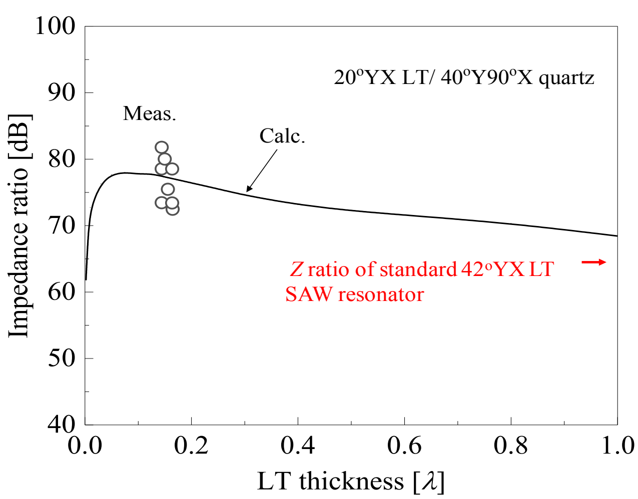

Fig. 2 LT thickness dependency of Z ratio of Cu/ 20°YX LT/ 40°Y90°X quartz HAL SAW (Solid line by calculation, Circles by measurement).

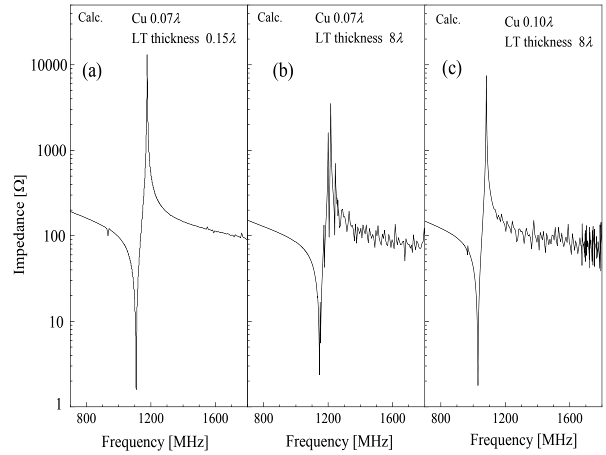

Fig. 3 Simulated frequency characteristics of Cu/ 20°YX LT/ 40°Y90°X quartz HAL SAW resonators with different LT and Cu thicknesses.

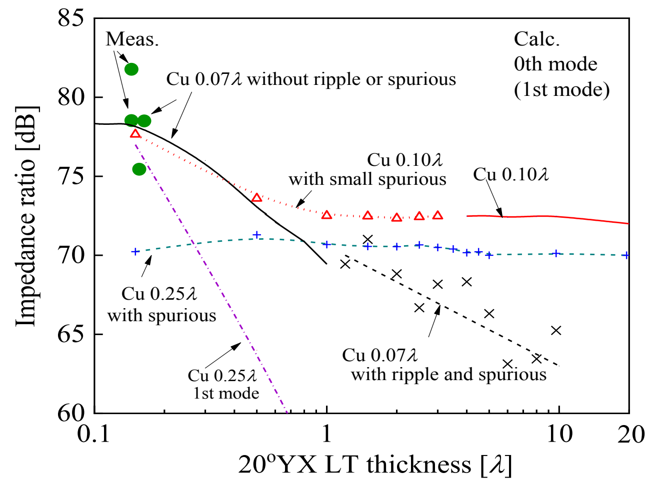

Fig. 4 Calculated Z ratios vs. LT thickness for HAL SAW resonators with different Cu electrode thicknesses.

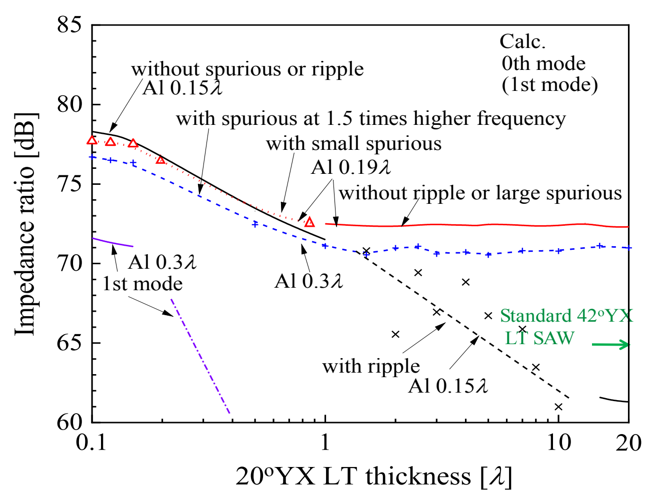

Fig. 5 Calculated Z ratios vs. LT thickness for HAL SAW resonators with different Al electrode thicknesses.

IV. Higher mode excitation

During the simulation mentioned in the previous section, we found a higher mode SAW was preferentially excited by a thick electrode on thin LT supported by quartz. Figs. 6 and 7 show the simulated frequency characteristics of the fundamental (0th) and higher (1st) modes excited by 0.3λ thick Al and Cu electrodes, respectively, on 20°YX LT (0.15λ)/ 42°45'Y90°X quartz, where λ = 3.0 µm. As found in Fig. 6, the 1st mode with a bandwidth (BW) of 3.4% at 2.6 times higher frequency than the 0th mode is excited by the Cu electrode, but the *Z* ratio is only 54 dB. A higher *Z* ratio may be obtained by optimization. As shown in Fig. 7, a higher Z ratio of 71 dB is obtained by the Al electrode. The frequency of 1st mode is twice as high as the 0th mode, and the BW is 3.6%. Even considering the frequency drop by a thick (heavy) electrode, preferential 1st mode excitation by the thick electrode is still advantageous in terms of frequency.

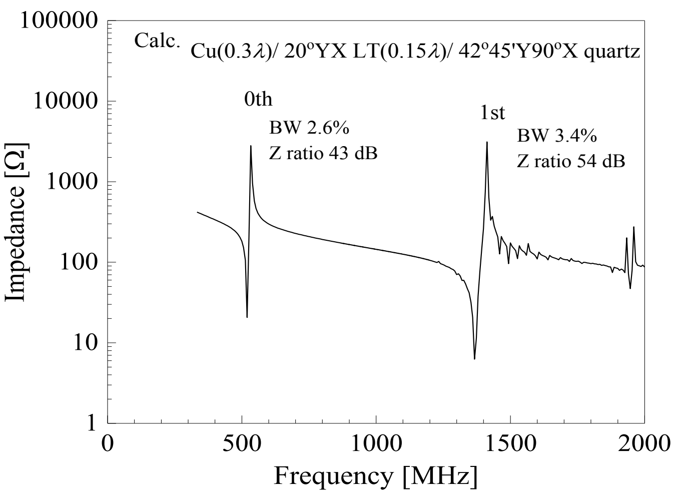

Fig. 6 Simulated frequency characteristic of 0th and 1st modes excited by 0.3λ thick Cu electrode on 20°YX LT (0.15λ)/ 42°45'Y90°X quartz.

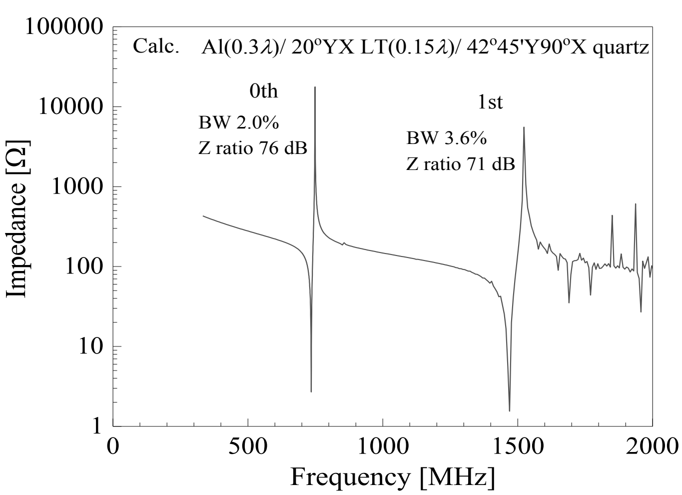

Fig. 7 Simulated frequency characteristic of 0th and 1st modes excited by 0.3λ thick Al electrode on 20°YX LT (0.15λ)/ 42°45'Y90°X quartz.

V. Conclusion

In the previous study, the best performance of the LT/quartz HAL SAW resonator was obtained at LT thickness as small as 0.1-0.2λ. This range of LT thickness may not be easy to control in mass-production, if the frequency is a few GHz or higher. In this simulation study, we found the new design space where the LT thickness is one order of magnitude larger. If a specific larger thickness of an electrode is selected, a ripple-free frequency characteristic is obtained on thick LT with a penalty of about 5 dB in *Z* ratio. In addition, we found that a higher (1st) mode was preferentially excited by a thick (heavy) electrode on thin LT. *Z* ratio higher than 70 dB and BW around 3.5% are expected. The higher mode excitation is still attractive in terms of frequency, even if frequency drop by the thick electrode is taken into account.

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