2Pa3-4

$LiNbO_3$/Quartz Hetero Acoustic Layer Surface Acoustic Wave Resonator for Wide Band Filter

Yong Guo[1‡], Micho Kadota[1], and Shuji Tanaka[1] ([1]Grad. School Eng., Tohoku Univ.)

1. Introduction

Surface acoustic wave (SAW) filters are widely used in modern telecommunication systems. Currently, frequency is busy due to the spread of smart phones below 3.4 GHz. The filters with good steepness of the passband and a low temperature coefficient of frequency (TCF) are required.[1] The bandwidth (BW) of the filter depends on mobilephone bands. In general, $LiNbO_3$ (LN) is suitable for wide bands comapred with $LiTaO_3$ (LT), becase it has a higher electromechanical couplig factor (k^2). On the other hand, LN has a larger TCF.

The motivavtion of this study is to demonstrate a wideband SAW resonator with a low TCF. To obtain a better frequency chracteristic, Hetero Aoustic Layer (HAL) structure combining a piezoelectric thin plate and a support substrate was considered.

Kadota *et al.* developed HAL SAW resonators using LT and quartz (Qz)[1]. The impedance (Z) ratio is as large as 84 dB, and the TCF is only 2 ppm/°C and -10 ppm/°C for the series (f_s) and parallel resonance (f_p) frequencies, respectively. However, the resonator is for narrow band filters with bandwidth up to 4.5%.

Chua *et al.* reported a HAL SAW resonator using 0.8λ thick 11°YX LN and YX Qz[2] (λ is wavelength). A low velocity of 2,416 m/s, a BW of 11% and an Z ratio of 80 dB were obtained, but the TCF are as large as -129 ppm/°C and -135 ppm/°C for resonance (f_r) and anti-resonance (f_a) frequencies, respectively. To improve TCF, Chua *et al.* also prototyped a HAL SAW resonator using LN and glass with a low coefficient of thermal expansion (CTE)[3]. The TCF improved to -67 ppm/°C and -69 ppm/°C for f_r and f_a, resepctively, while Z ratio decreased by 10 dB.

In this study, we again combined a LN thin plate and a Qz substrate to demonstrate wideband HAL SAW resonators with a lower TCF and a higher Z ratio than those of the past LN/Qz and LN/glass HAL SAW resonators. By optimizing the design parameters, excellent performance was confirmed by simulation and measurement.

2. Design

Fig. 1 shows the simulated Z ratio and BW in terms of the second Euler Angle of LN (θ_{LN}) as well as the simulation model. The best θ_{LN} is around 100–110°, where the Z ratio and BW show peaks and as high as Kadota and Tanaka reported[4]. Note that the negative plane of LN is used to fabricate an interdigital transducer (IDT) because the negative device surface exhibits higher Z ratio and BW than the positive one[1].

The second and third Euler angles of Qz (θ_{Qz} and ψ_{Qz}) were chosen from a viewpoint of TCF compensation. The TCF of Qz reaches the positive maximum when θ_{Qz} is around 160° and ψ_{Qz} is 90°[1,5]. Thus, the best Euler angles of LN and Qz are (0°, 100–110°, 0°) and (0°, 160°, 90°), respectively.

The Z ratio and BW were also simulated as functions of 11°YX LN thickness on 70°Y90°X Qz and Cu IDT thickness, as shown in **Fig. 2**. Considering both BW and Z ratio, the suitable normalized 11°YX LN thickness is around 0.1–0.2λ, which is significantly thin compared with 0.8λ thick 11°YX LN on YX Qz reported by Chua *et al.*[2] The suitable IDT thickness is around 0.05–0.1λ.

The specific parameters of LN thickness and IDT thickness were finally selected considering spurious responses. **Table I** summarizes the parameters. Lift-off process was used to fabricate the Cu IDT. λ is ranging from 3–10 μm with a step of 1 μm.

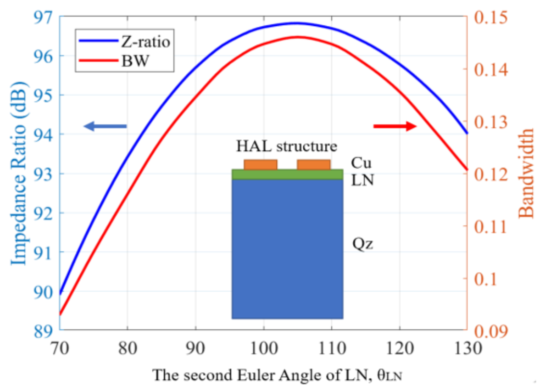

Fig. 1. Z ratio and BW as a function of θ_{LN}.

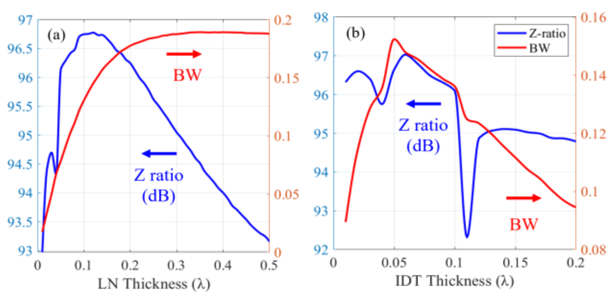

Fig. 2. Z ratio and BW as a function of (a) 11°YX LN and (b) Cu IDT thickness.

Table I.

Wavelength (μm)	3–10
LN thickness (μm)	Around 1.07
Euler angle of LN	(0°, 101°, 0°)
Euler angle of Qz	(0°, 160°, 90°)
Cu thickness (μm)	0.6

3. Evaluation

The 1-port S-parameters were measured using Keysight's E5071C ENA Vector Network Analyzer equipped with Cascade Microtech's ACP40-GS-450 RF probes. The impedance and Smith chart of selected devices are shown in **Fig. 3**. The *Z* ratio is as high as 83 dB with a BW of 14.5%. In addition, transverse mode ripples are small. This ripple-free characteristic of LN on 70°Y90°X Qz is analogous with LT on 69°Y90°X Qz in the past study.[2, 3, 5]

Fig. 4 shows the measured *Z* ratio and BW as a function of normalized LN thickness. Considering *Z* ratio and BW, the suitable LN thickness is around 0.1–0.15λ, which agree with the simulation result in Fig. 2. However, the *Z* ratio and BW decrease quickly when LN thickness increases. This is because the Cu thickness is not suitable when the wavelength becomes small.

Fig. 5 shows the measured frequency shift at 25°C, 45°C, 65°C and 85°C. The minimum TCF reaches -85 and -57 ppm/°C for f_r and f_a, respectively, which are smaller than those for the previous LN/Qz device[2)]. In addition, the TCF increases when the normalized thickness of LN gets thicker.

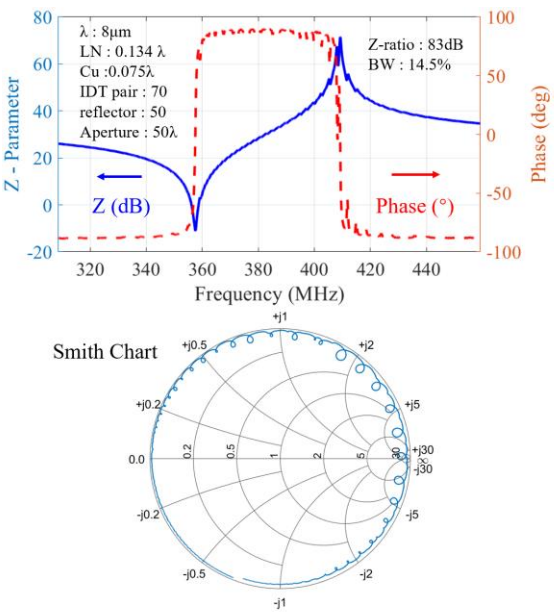

Fig. 3. Measured frequency characteristic and Smith chart.

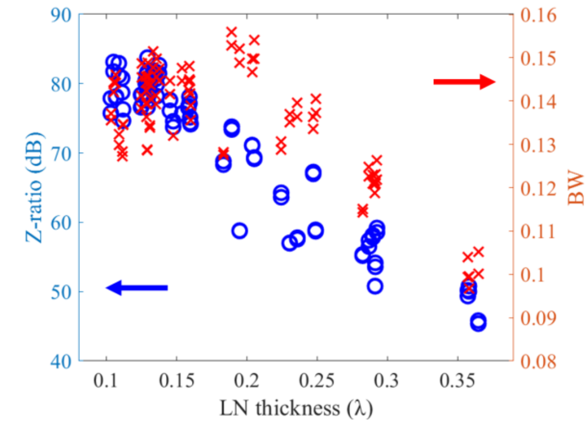

Fig. 4. Measured *Z* ratio and BW as a function of LN thickness.

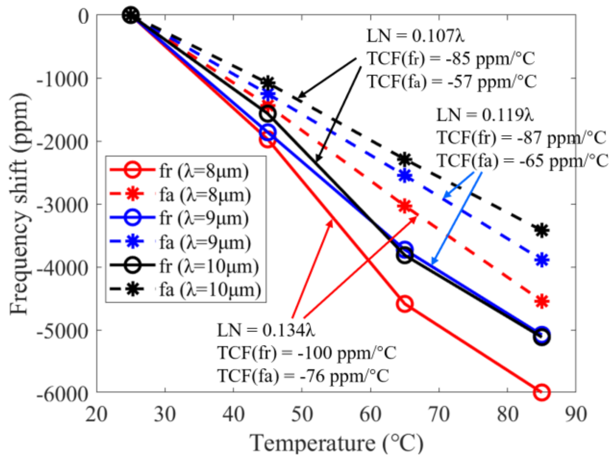

Fig. 5. Measured frequency shift as a function of temperature.

4. Conclusion

Wideband HAL SAW resonators using LN and Qz were studied by simulation and fabrication to reduce the TCF. The measured *Z* ratio and BW of the fabricated device are as large as 83 dB and 14.5%, respectively. Furthermore, few transverse ripples appear. The TCF are -85 ppm/°C and -57 ppm/°C for f_r and f_a, respectively, which are significantly smaller than the reported values for LN/Qz HAL SAW resonators.

References

1. M. Kadota, Y. Ishii, S. Tanaka: IEEE Trans. Ultrason. Ferroelectr. Freq. Contr. **68** (2020) 1955.
2. T. L. Chua, M. Kadota, S. Tanaka: Proc. IEEE Int. Freq. Contr. Symp. 2021.
3. T. L. Chua, M. Kadota, S. Tanaka: Proc. IEEE Int. Ulrtason. Symp. 2021.
4. M. Kadota, S. Tanaka: Proc. IEEE Int. Freq. Contr. Symp. 2017, 206.
5. S. Inoue, M. Solal, Proc. IEEE Int. Ulrtason. Symp. 2020.