Suppression of Transverse Mode on $LiNbO_3$/ Quartz Hetero Acoustic Layer Surface Acoustic Wave Resonator by Zigzag Shape Apodization

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***Summary*—Transverse mode suppression is a great challenge for high performance surface acoustic wave (SAW) resonators. Conventional methods only work well on narrow band resonators and will cause severe quality (Q) factor deterioration if they are directly applied to wideband resonators. In this work, we designed and fabricated new dummy electrode shapes and new apodization shapes to suppress transverse modes in a wideband $LiNbO_3$/ Quartz resonator. The results show that the shape of the dummy electrode is not the dominant factor to affect the transverse mode. The zigzag shape apodization can realize high Q factor with suppressed transverse mode.**

Keywords—surface acoustic wave; hetero acoustic layer; dummy electrode; zigzag shape apodization; transverse mode; $LiNbO_3$, Quartz

I. Introduction

Surface acoustic wave (SAW) devices are one of the core components in 5G communications. To meet the demands at increasingly busy frequency bands, the steepness of the passband, the temperature stability and the spurious free characteristic are three main requirements for high performance SAW devices. Hetero acoustic layer, which combines a thin piezoelectric layer and a Quartz (Qz) substrate, is promising to realize the above requirements because Qz has a lower loss compared with amorphous SiO_2 and has a positive temperature coefficient of frequency (TCF) on specific Euler angle, which is able to compensate the negative TCF of LN [1].

However, the transverse mode becomes severe when the Quality (Q) factor is high. One of the well-known methods is the apodization. But the traditional apodization will cause lateral acoustic leakage, which deteriorates the Q factor near anti-resonance frequency (Q_a). Inoue *et al.* proposed 42°YX $LiTaO_3$ (LT)/ 69°Y90°X Qz structure to suppress the transverse mode by designing a vertical slowness curve. However, the thickness of the electrode is strictly confined as the slowness curve is sensitive to the electrode. Besides, several different kinds of structures are proposed to suppress the transverse mode, including manipulating the dummy electrode [2], bent structure [3] and crossed interdigital transducer (IDT) [4]. These methods show good performances on narrow band SAW resonators using LT as piezoelectric layer, but high Q factor and suppressed transverse mode on wideband resonator are not demonstrated [5].

In this work, we show two groups of different designs to suppress the transverse modes based on LN/ Qz structure by fabrication. The designs include several kinds of shapes with different dummy electrode and apodization. Normal design, crossed IDT, triangle dummy electrode and traditional apodizations are also fabricated in the same sample as references. The results show that the newly developed zigzag shape apodization can realize high Q factor and suppressed transverse mode simultaneously.

II. Design

The apodization is the most commonly used method to suppress the transverse mode. However, the apodization will deteriorate Q_a due to the radiation of shear horizontal (SH) waves to the apodization border [6]. As a result, new approaches are required to maintain Q factor.

As we know, the transverse mode includes the resonance perpendicular to the propagation direction, as shown in Fig. 1. Therefore, the transverse mode is possible to be eliminated by designing the waveguide at top and bottom sides of the pattern. Here we proposed two groups of designs to suppress the transverse mode, including the design of the dummy electrode and the air gap. They are marked by green and red dotted lines in Fig. 1, respectively.

A. The design of the dummy electrodes

Fig. 2. (4) – (6) shows the schematic diagrams with different dummy electrode shapes studied in this work, including the zigzag shape, circular shape, and inverse circular shape dummy electrode. The proposed new designs can provide a flexible incident angle without impact on the fundamental modes. If the incident angle is well designed, the transverse mode can be leaked out whereas the fundamental mode does not.

B. The design of the apodization shapes

The traditional and new apodization shapes are shown in Fig. 2. (1), (7), and (8), respectively. Two kinds of apodizations, which called symmetric type and anti-symmetric type, are considered. Compared with the traditional apodization, the new designs only apply the apodization at the top and bottom sides, which reduces the radiation losses of the fundamental SH mode. Furthermore, the apodization shape can be controlled by two parameters, θ and L defined in Fig. 3, which shows a higher freedom of design. Additionally, only experimental study is carried out in this work because the 3D simulation of our proposed designs is too time-consuming. This is also one difficulty we are facing.

III. Fabrication

Hetero acoustic layer (HAL) structure combining 11°YX LN and 70°Y90°X Qz is used in this work for demonstration. The fabrication process is shown in Fig. 4. The optical images of fabricated patterns are shown in Fig. 5.

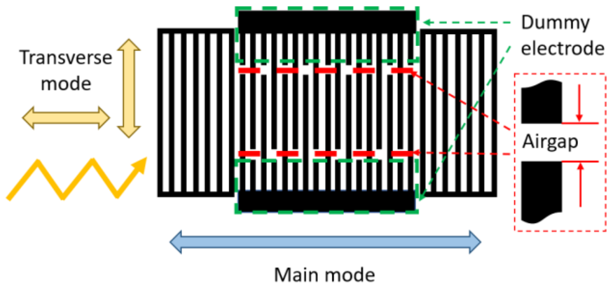

Fig. 1. Key factors affect transverse mode.

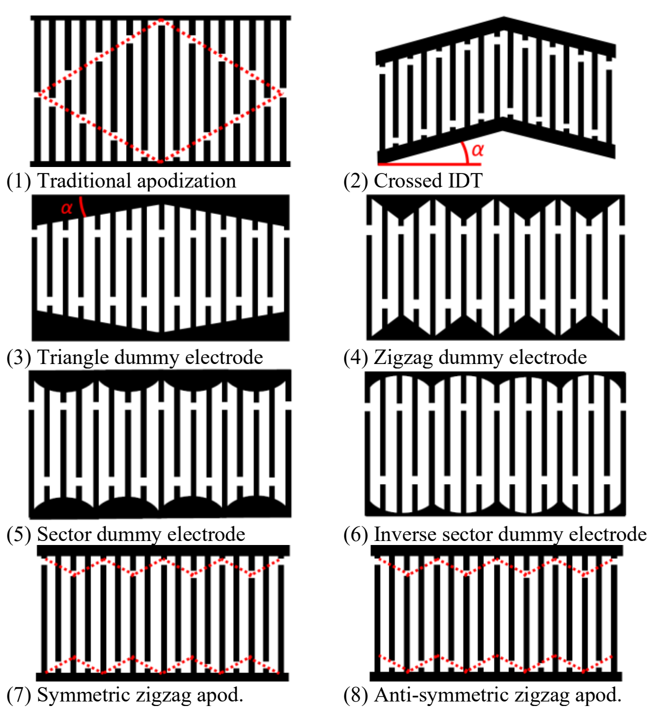

Fig. 2. Schematic diagram of different dummy electrodes and apodizations, (4)–(8) are newly proposed designs.

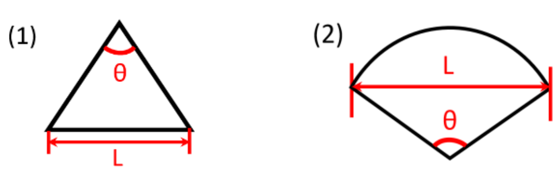

Fig. 3. Parameters studied in this work.

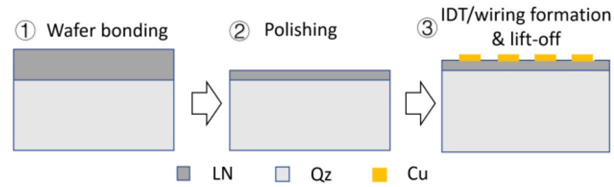

Fig. 4. Fabrication process.

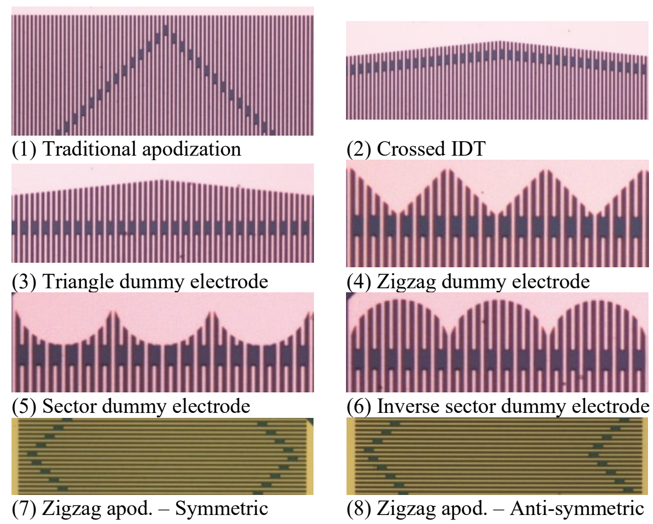

Fig. 5. Optical images of fabricated patterns.

IV. Results and Discussion

A. Measured results using different dummy electrode

The measured impedance and resistance with different dummy electrodes are shown in Fig. 6 (a) and (b), respectively. The normal type, traditional apodization, crossed IDT, triangle dummy electrode, zigzag dummy electrode, sector dummy electrode and inverse sector dummy electrode were fabricated. Different numbers denote different shapes, and their corresponding type and parameters are summarized in Table I.

In Fig. 6 (a) and (b), there is no significantly different transverse mode between the normal type and various kinds of dummy electrode designs. Only the traditional apodization shows great transverse mode suppression ability. After careful check of measured results, the crossed IDT also shows suppressed transverse mode although the suppression ability is not as good as traditional apodization when α is small. This conclusion shows consistency with the reported work using LN/ SiO_2/ Si [7]. In that work, it is shown that the tilted angle of 16° is required to suppress the strong transverse mode in wideband resonators, and maximal Bode-Q is reduced from 1107 to 603.

According to the fact that only crossed IDT and traditional apodization can suppress the transverse mode, it is speculated the airgap is the dominate factor to affect the transverse mode. Following this hypothesis, we designed the new shape of the airgap, which has been discussed in section II.

B. Measured results using zigzag shape apodization

The IDT pairs, aperture length and λ used to check the performance of zigzag apodization are 72, 35λ and 4.8 µm, respectively. We checked L from 3λ to 18λ and θ from 30° to

165° to find the best parameters. It is found that the symmetric type and anti-symmetric type do not show a large difference in terms of transverse mode intensity, and the symmetric type shows a slightly higher impedance ratio (Z-ratio). However, it is noted that the difference of Z-ratio is not checked by simulation. On the other hand, larger L and θ are preferred to obtain both high Q and suppress transverse mode.

The measured impedance and resistance using optimized parameters are shown in Fig. 7 (a) and (b), respectively. Three kinds of shapes, normal type, traditional apodization and zigzag shape apodization are shown. The in-band spurious responses marked by red dotted lines are Rayleigh mode, which can be easily eliminated by adjusting cut angle of LN or electrode thickness. Therefore, it is not important in this work.

The normal type and zigzag apodization show similar Q_a and Z-ratio, whereas Q_a and Z-ratio of the traditional apodization decreased about 500 and 8 dB, respectively. On the other hand, the transverse modes of the traditional and zigzag apodization as shown in the measured resistance figure are at the same level. Both of them show better suppression ability compared with normal type. Therefore, the high Q factor and suppressed transverse mode are realized simultaneously by the zigzag shape apodization.

TABLE I. FABRICATION PARAMETERS FOR DUMMY ELECTRODE

No.	Type	Parameter	
1	Apod.	*AR* [a]	100%
2	Crossed IDT	α [b]	9°
3	Triangle	α	6°
4	Zigzag	L, θ	6 λ, 60°
5	Sector	L, θ	4 λ, 90°
6	Inverse sector	L, θ	6 λ, 180°

a. Apodization ratio

b. α is explained in Fig. 2.

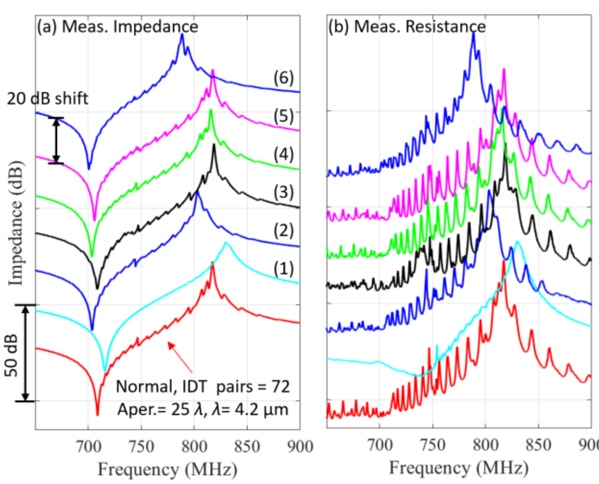

Fig. 6. Measured frequency characteristics with different dummy electrodes. (a) Measured impedance. (b) Measured resistance.

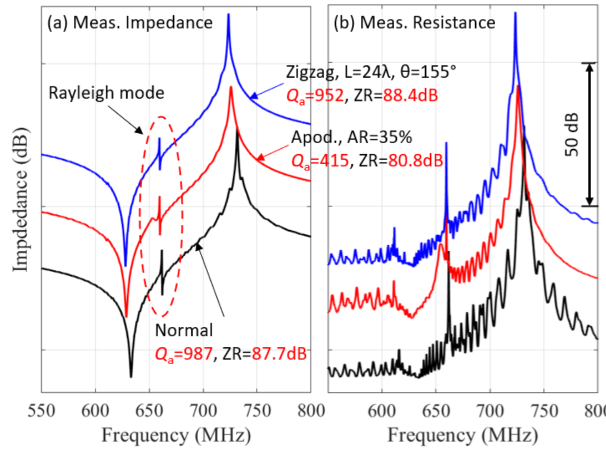

Fig. 7. Measured frequency characteristics of normal type, traditional apodization and zigzag apodization. (a) Measured impedance. (b) Measured resistance.

V. Conclusions

The shape of the dummy electrodes and the apodization are studied by experiment using LN/ Qz. The measured results show that the shape of the dummy electrode is not the dominant factor to affect the transverse mode. Additionally, after parameter optimization, it was demonstrated that the zigzag shape apodization was able to realize high Q and suppress transverse mode simultaneously in a wideband resonator.

Acknowledgment

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References

[1] M. Kadota, Y. Ishii, and S. Tanaka, "Surface Acoustic Wave Resonators with Hetero Acoustic Layer (HAL) Structure Using Lithium Tantalate and Quartz," IEEE Trans. Ultrason. Ferroelectr. Freq. Control, vol. 68, no. 5, pp. 1955–1964, 2021.

[2] T. Omori, T. Suyama, K. Shimada, C.-J. Ahn, M. Yamaguchi, and K. Hashimoto, "Theoretical considerations on suppression mechanism of spurious transverse mode resonances in wideband SAW resonators on $LiNbO_3$," in Proc. IEEE Int. Ultrason. Symp., Oct. 2011, pp. 830–834.

[3] Y. Liu, J. Liu, Y. Wang, and C. S. Lam, "A Novel Structure to Suppress Transverse Modes in Radio Frequency TC-SAW Resonators and Filters," IEEE Microw. Wirel. Compon. Lett., vol. 29, no. 4, pp. 249–251, Apr. 2019.

[4] Y. Yin, W. Jiang, W. Huang, and A. Gao, "Using Crossed IDTs to Suppress Transverse Modes in SAW Resonators Based on POI Substrate," in Proc. IEEE Int. Ultrason. Symp., Oct. 2022, doi: 10.1109/IUS54386.2022.9957707.

[5] M. Kadota, Y. Kuratani, T. Kimura, M. Esashi, and S. Tanaka, "Ultra-wideband and high frequency resonators using shear horizontal type plate wave in LiNbO3 thin plate," Jpn. J. Appl. Phys., vol. 53, no. 07KD03, 2014.

[6] S. Matsuda, M. Miura, M. Ueda, Y. Satoh, and K. Hashimoto, "Experimental Studies of Quality Factor Deterioration in Shear-Horizontal-Type Surface Acoustic Wave Resonators Caused by Apodization of Interdigital Transducer," Jpn. J. Appl. Phys., vol. 50, no. 07HD14, Dec. 2011.

[7] S. Wu, F. Bao, F. Xu, J. Zou, M. Li, and G. Tang, "Tilted Interdigital-transducer in NS-SAW Resonator for Transverse Mode Suppression," in Proc. Joint Conf. IEEE Int. Freq. Control Symp. Euro. Freq. Time Forum, Apr. 2022. doi: 10.1109/EFTF/IFCS54560.2022.9850616.