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X-cut $LiNbO_3$ Based Multi-Strip Acoustic Resonator (XSAR) Surrounded by Groove and Airgap

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1. Introduction

The demand for wideband filters was steadily increasing due to the growing need for high volumes of data. The shear horizontal (SH) type surface acoustic wave (SAW) devices were reported to show wideband using hetero acoustic layer (HAL) structure [1),2)], but the frequency was limited to be lower than 3.4 GHz due to the power handling. For the 5G and new frequency bands over 5 GHz, bulk acoustic wave (BAW) devices are considered more promising.

The film bulk acoustic resonator (FBAR) using Y-cut $LiNbO_3$ (LN) were reported to show good performances [3)–5)], but the bandwidth (BW) was not wide enough to satisfy the ultra-wide bands such as n77. To realize larger BW, new crystalline orientations, X-cut LN, were reported [6),7)], and ultra-wide BW were successfully realized. However, these devices show severe in-band spurious response caused by slow shear mode. The twisted bilayer X-cut LN was reported to show spurious free characteristic[8)], but the structure becomes more complex.

Previously, we proposed a new serially connected strip-type acoustic resonator using X-40° Y LN (XSAR), and the devices were demonstrated in macro scale[9)] and micro scale[10)]. The ultra-wide BW over 30% was realized as expected, but the spurious responses were not well suppressed and the impedance ratio (Z-ratio) was low. In this work, we investigate the performance enhancement of XSAR based on the fabrications and simulations. A new XSAR structure surrounded by airgap and groove are proposed and its excellent performance is proved by simulation.

2. Analysis of XSAR

The XSAR untilizes the SH_1 mode and its performance shows an ψ dependence (ψ is the 3rd Euler angle). The piezoelectric constants e_{34}, e_{35} and e_{36} as a function of (90°, 90°, ψ°) are shown in **Fig. 1** by red, blue and black dotted curves, respectively. It is shown the e_{34} and e_{35}, which affect the coupling of shear waves, vary significantly with the change of ψ and reach maximal values in (90°, 90°, 33°) and (90°, 90°, 123°), respectively. This indicates the main mode (SH_1 mode) and the slow shear mode will be strongly excited simultaneously in conventional FBAR structures. This is why the slow shear mode spurious response exists in previous reports.

To solve the above problem, XSAR with multi strips was proposed, as shown in **Fig. 2** [10)]. The ψ to obtain maximal e_{34} and e_{35} has 90° difference, as shown in **Fig. 1**. Consequently, by using narrow strip that has a large length and a narrow width, the main mode is enhanced and the slow shear mode is suppressed. Combining the penetrated structure and narrow strip, wideband and spurious free characteristic can be realized simultaneously.

However, the performance was not as good as expected. The measured XSAR based on structures in **Fig. 2** are shown in **Fig. 3** [10)]. Two patterns with strip width of 12 μm and 3 μm are shown by black and red curves, respectively. Although the BW is as large as 33%, the spurious responses are too large and the Z-ratio is too low.

Apart from the fabrication defects, there are mainly two reasons for the low performances.

Firstly, the groove between the left and right strip patterns will cause severe performance degradation. The simulated frequency characteristics using 2D model with groove and airgap are shown in **Fig. 4** by black and red curves, respectively. The 2D models are shown in left top and right bottom corners, respectively. Clearly, the groove between the left and

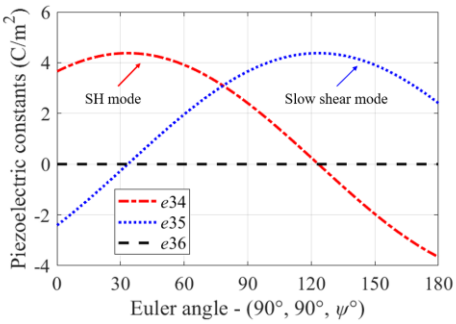

Fig. 1. Piezoelectric constants e_{34}, e_{35} and e_{36} as a function of (90°, 90°, ψ°)

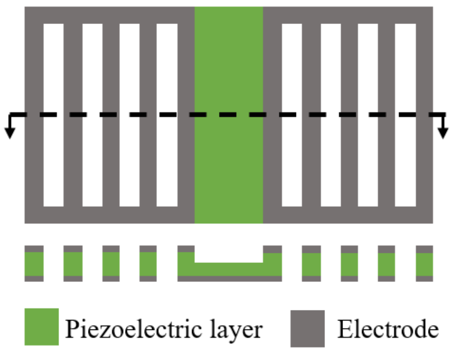

Fig. 2. Structure of previously proposed XSAR using X-40°Y LN [10)]

right strip patterns (as shown in **Fig. 2**) give large negative effects.

Secondly, large energy leakage occurs in busbar regions. The simulated frequency characteristic considering the busbar regions is shown in **Fig. 5 (1)**. The busbar region will generate severe in-band ripples even though the busbar width in simulation is only 3 μm.

3. Newly proposed XSAR structure

Based on the above analysis, a new structure is proposed, as shown in **Fig. 6**. The groove is replaced by airgap, which provides perfect energy confinement properties. The new grooved regions are located in top and bottom side, which eliminate the negative effects of busbars. The strip units are connected by the connection strips instead of busbars, as marked by red dotted rectangular.

The simulated frequency characteristics with new structure is shown in **Fig. 5 (2)**. Perfect performance with high *Z*-ratio and spurious free characteristic is successfully realized.

4. Conclusion

The properties of XSAR were discussed and the two main problems existed in the previous reports were analyzed. It was found the groove, and the busbar were two factors for the low performance. Then, a new structure surrounded by groove and airgap was proposed to solve the problems, excellent performance was demonstrated by simulation.

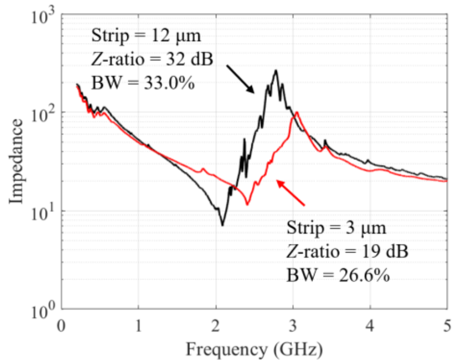

Fig. 3. Measured frequency characteristic of proposed XSAR [10)]

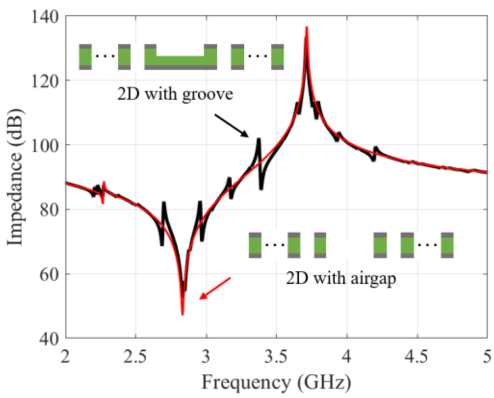

Fig. 4. Simulated frequency characteristic using 2D model with groove and airgap

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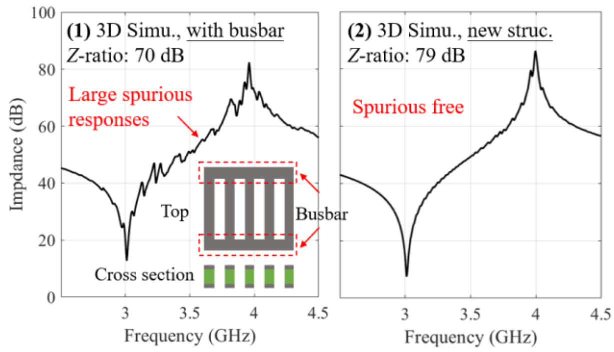

Fig. 5. Simulated frequency characteristic considering the effect of busbar

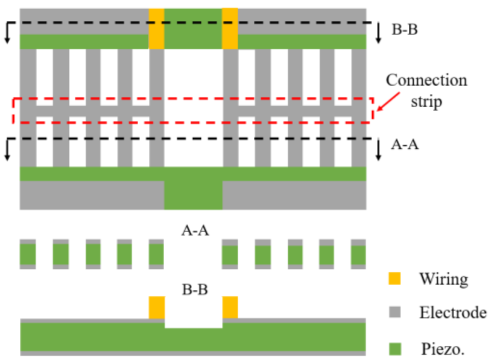

Fig. 6. Proposed new XSAR structure