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Serially-connected strip-type acoustic wave resonator using X-40°Y $LiNbO_3$ – Feasibility study using macro model

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1. Introduction

Surface acoustic wave (SAW) and bulk acoustic wave (BAW) devices are key components in telecommunications. The former is more suitable for the applications lower than 3.4 GHz due to the limitation of power handling, and already realized high performance using layer structure such I.H.P. (incredible high performance) SAW and HAL (hetero acoustic layer) SAW[1)].

Compared with SAW, a BAW device is considered to be more suitable for the high frequency range, which uses AlN as a piezoelectric film[2)] and known as film bulk acoustic wave resonator (FBAR). However, the bandwidth (BW) of the FBAR utilizing AlN is narrow. Although scandium-dopped AlN (ScAlN) can improve the BW, it requires the trade-off of quality (Q) factor, and the BW is still not wide enough for wide bands such as n77. An FBAR utilizing monocrystalline $LiNbO_3$ (LN) and $LiTaO_3$ (LT) is becoming attractive because crystal thinning technique is available in recent years. Many studies about thickness expansion (TE) mode[3)] and thickness shear (TS) mode[4)] were reported, but the BW still cannot satisfy n77 requirement.

Another kinds of resonator is so called YBAR[5)], which can be regarded as a serially connected strip-type BAW device using Y-cut LN[6)]. The reported YBAR realized frequency width of 750 MHz centered around 3.7 GHz, which is one of the best BW ever reported.

In this paper, we propose a new serially connected strip-type TS mode acoustic wave resonator using X-40°Y LN, XSAR. The cut angle is optimized according to the piezoelectric constants analysis and simulation. The resonator is prototyped in a low frequency range, by which the ultra-wide BW is confirmed. Grooved and suspended structure are studied to eliminate the spurious responses.

2. Design and Simulation

Fig. 1 shows the schematic of the proposed XSAR, where the suspended structure with fully etched holes is shown. The structure can also be the grooved type that does not etch through the hole (e.g. 50%) in LN, as reported by S. Yandrapalli *et al*[5)].

The cut angle is of vital importance in this work. The conventional TS mode resonator usually uses 170°YX LN for the highest coupling factor (k^2), because at this angle the piezoelectric constant e_{34} reaches the maximum.[7)] Different from the conventional cut angle, we propose a new cut angle of X-40°Y. At this angle the e_{34} is even higher, resulting in a higher BW and overall performance.

Fig. 2 shows the displacement, stress, and electric field (E field) of the strip-type TS mode resonator. It is shown the stress is applied in YZ plane, and the E field is along Z direction with a cosine shape amplitude. Consequently, e_{34} is a key piezoelectric constant to determine the k^2.

Fig. 3 shows the calculated piezoelectric constant of LN in terms of Euler angle. It is shown that e_{34} reaches the maximal value of 3.84 C/m^2 when the Euler angle is (0°, 81.5°, 0°) using rotated Y-cut LN. In comparison, e_{34} reaches 4.38 C/m^2 at (90°, 90°, 33.5°) using X-cut rotated Y LN, which is 14% larger than (0°, 81.5°, 0°). Furthermore, the other piezoelectric constants are all near zero when

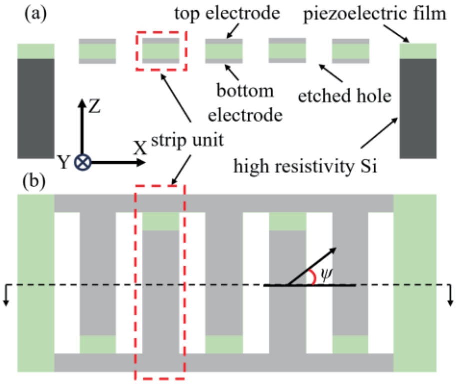

Fig. 1. Schematic of the proposed XSAR. (a) Cross section. (b) Top view

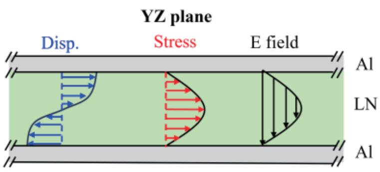

Fig. 2. Displacement, stress, and E field of strip-type TS mode resonator.

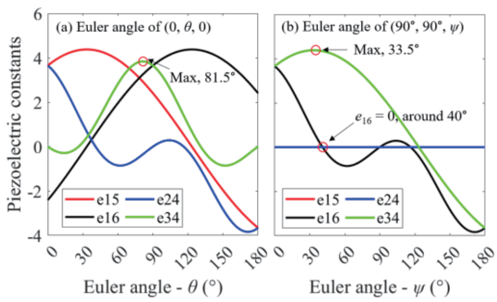

Fig. 3. Calculated piezoelectric constant e_{34} in LN in terms of Euler angle. (a) Euler angle of (0°, θ, 0°). (b) Euler angle of (90°, 90°, ψ).

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ψ is around 40°. It is also shown that the proposed X-cut resonator is highly dependent on the propagation direction, which is quite different from the conventional BAW devices.

Fig. 4 shows simulated impedance ratio (Z-ratio) and BW in terms of Euler angle ψ. Z-ratio is defined as the impedance difference between resonance frequency (f_r) and anti-resonance frequency (f_a). The 2D suspended structure shown in Fig. 1, where Al thickness of 0.08 µm and LN thickness of 0.5 µm, $1/Q_m$ of 0.004 for LN, and a strip width of 5 µm were assumed. It is shown that all ψ from 5° to 55° show Z-ratio larger than 86 dB and BW larger than 32%.

3. Prototype and Discussion

The resonator was firstly prototyped in low frequency range. The width and length of one strip unit are 5 mm and 20 mm, respectively. The thickness of LN plate is 350 µm. The measured frequency characteristic with two strips is shown in **Fig. 5**. Despite of spurious responses, the simulation result matches well with the measured result. BW more than 30% was successfully realized and can be further improved after optimization. The prototype was fabricated by Cu film deposition to form the electrodes and diced by a saw dicer to form the grooved structure, which was approximately 270 µm in depth and 200 µm in width. Consequently, the grooved area is not well controlled and results in large spurious responses.

The simulated frequency characteristics using the optimized design are shown in **Fig. 6**. The Z-ratio of the grooved and suspended structures are as high as 86 dB and 90 dB, respectively. Both structures show BW higher than 30%. A large spurious response is observed in the grooved structure, which is slow shear mode[8] and can be attenuated by adjusting strip width and etched depth. A spurious free characteristic is obtained using the suspended structure as shown in Fig. 6 (b). More study is required to obtain spurious-free characteristic using the grooved structure because the robustness of the grooved structure is better than suspended type.

4. Conclusion

A new serially-connected strip-type TS mode acoustic wave resonator using X-40°Y LN, XSAR, was reported. The piezoelectric constant e_{34} determines k^2 of the proposed resonator and reaches the highest when ψ=33.5°. The resonator was prototyped in a low frequency range and an ultra-wide BW was confirmed. A high Z-ratio, wide BW, and spurious-free characteristic can be realized after optimized design.

Acknowledgment

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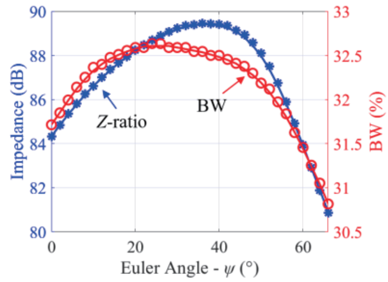

Fig. 4. Simulated Z-ratio and BW in terms of Euler angle ψ at (90°, 90°, ψ).

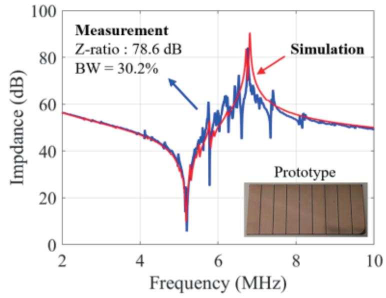

Fig. 5. Measured frequency characteristic of prototyped low frequency resonator.

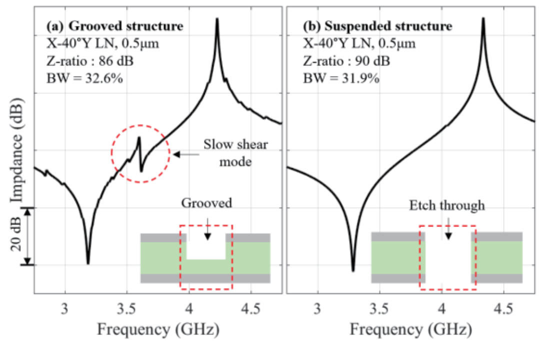

Fig. 6. Simulated frequency characteristic of two types of structures. (a) Grooved structure. (b) Suspended structure.

References

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