1J3-1

Solidly-Mounted High Frequency Thickness Shear Mode Bulk Acoustic Wave Resonator Using X-$LiTaO_3$ Thin Plate and SiO2/Ta Multilayer Acoustic Films
X-$LiTaO_3$薄板と音響多層膜を用いた高周波厚みすべりバルク波共振子

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1. Introduction

Surface and bulk acoustic wave (SAW and BAW) filters are key RF devices in mobile phone systems. Recently, the acoustic wave filters are expected to cover a higher frequency range up to 5 GHz. Comparing SAW and BAW devices, it is commonly understood that the BAW devices are suitable for high frequency applications. As a piezoelectric material for the BAW devices, AlN and ScAlN are widely used. Most of AlN and ScAlN films are polycrystalline, but there are a few reports on BAW devices using monocrystalline AlN.

$LiTaO_3$ (LT) and $LiNbO_3$ (LN) are piezoelectric single crystals and widely used for SAW devices, while there are limited reports on high frequency BAW resonators using LT and LN. The major reason is that LT and LT are difficult to obtain as monocrystalline thin films. Kadota *et al.* reported a thickness extension (TE) mode 3 GHz BAW resonator with an impedance (*Z*) ratio of 40 dB using a 0.41 μm thick epitaxial LN thin film deposited by CVD (1, 2). However, the LN thin film obtained was only c-axis oriented. Also, the performance of the resonator was insufficient for practical applications.

In recent years, LT and LN thin plates with different orientations are available by polishing or ion slicing (e.g. "Smart Cut") technique. Such LT and LN thin plates are exhibiting promising performances for Hetero Acoustic Layer (HAL) types of SAW device (3,4,5). However, there are limited reports on BAW devices using the LT or LN thin plate. Potential advantages of LT and LN as BAW device materials include monocrystallinity and the variety of cut angles, and it is worth investigating BAW devices using LT or LN.

Tai *et al.* reported a TE mode 2.2 GHz BAW resonator with an *Z* ratio of 64 dB using a 1 μm thick 45°Y LN thin plate (6). Matsumoto *et al.* reported a TE mode 800 MHz BAW resonator with an *Z* ratio of 45 dB using a 4 μm thick 36°Y LN thin plate (7). Both resonators used a self-suspended LN, namely a structure of film bulk acoustic resonators (FBAR). For a higher frequency range over 3.5 GHz, however, the thickness of the thin plate is submicron, and the mechanical stability of the thin plate may be a critical problem in the production as well as practical uses.

Compared with the FBAR, a solidly-mounted resonator (SMR) is advantageous in terms of mechanical stability, heat dissipation and the easiness of wafer-level packaging. In the previous study, we fabricated a prototype of a strip type shear mode SMR a 2 μm thick LT and demonstrated an Z ratio of 62 dB and a bandwidth (BW) of 6.7% at 1 GHz (8). The strip type SMR requires grooves on both sides of the active area, which were made by saw dicing. However, such grooving may be difficult for higher frequency resonators because of fabrication tolerance.

Against such background, we investigated a thickness shear (TS) mode SMR using a LT thin plate in this study. Based on our analysis, the TS mode SMR does not need grooves for acoustic energy confinement and thus simpler in structure than the TE mode strip type SMR. In this paper, we mainly report the fabrication and experimental characterization of a prototyped device working at 1 GHz.

2. Fabrication of TS mode SMR

The TS mode SMR was fabricated as follows. First, a 250 μm thick single-side-polished X-LT substrate was prepared, and an Al bottom electrode with a thickness of about 100 nm was deposited on the polished plane. Subsequently, 450-500 nm thick low acoustic impedance SiO_2 layers and 450-600 nm thick high acoustic impedance Ta layers were alternately deposited, forming an acoustic Bragg reflector with 8 (4+4) layers in total. A 400 μm thick (100) Si substrate was bonded to the Bragg reflector with adhesive. Then, the LT substrate was polished and thinned to 1.5 μm thickness.

A 100 nm thick upper electrode was fabricated on the polished LT surface. The desired structure of the TS mode SMR consists of one electrode on each side of the LT plate. In this study, however, we fabricated the structure shown in Fig. 1, which had two electrodes on the upper surface and one common electrode on the backside of the LT plate.

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The equivalent circuit is represented by two resonators connected in series. An independent single resonator can be fabricated by etching LT till the Al bottom electrode, but the simpler fabrication process was adopted in this study. Figure 1 also shows the cross section of the Bragg reflector.

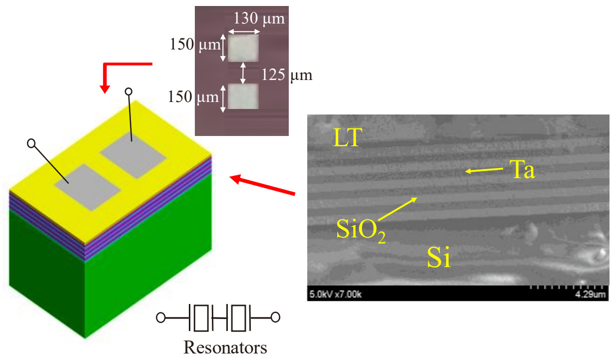

Fig. 1 Structure of fabricated TS mode SMR and the cross section of Bragg reflector.

3. Frequency Characteristic

Figure 2 shows the measured frequency characteristic. The resonance frequency f_r is 1.14 GHz and the antiresonance frequency f_a is 1.23 GHz. A BW $((f_a-f_r)/f_r)$ of 6.7 % and an Z ratio of 61 dB were obtained. The BW and Z ratio are almost identical to those of the strip type SMR (8). There is no ripple in the passband, while there are spurious responses at the lower side of the passband, which was predicted by FEM.

The demonstration of the TS mode SMR using LT in GHz range has been first reported as far as we know. A measured Z ratio of 60 dB in the first prototype suggests a high potential of this device. However, the obtained performance is significantly lower than expected one from FEM simulation. This may be partly because the structure fabricated in this study was not optimized. In addition, a relatively large impedance at the resonance suggests that there is a room for improvement in terms of the quality of the Al electrode as reported in (9).

4. Conclusion

A TS mode SMR using 1.5 µm thick X-LT was first fabricated and characterized. A Bragg reflector is made of 8 (4+4) layers of SiO_2 and Ta. The fabricated device worked at a resonance frequency of 1.14 GHz and an antiresonance frequency of 1.23 GHz, showing a BW of 6.7%. The measured Z ratio is 61 dB, although the structure and fabrication process were not optimized yet, suggesting a high potential of this device

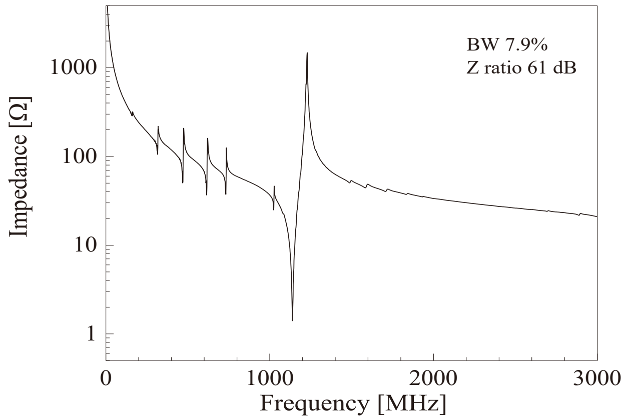

Fig. 2 Frequency characteristic of fabricated TS mode SMR.

Acknowledgment

This work was partly supported by Ministry of Internal Affairs and Communications, SCOPE #195002001. We would like to thank Mr. Shigeharu Matsumoto and his colleagues at SHINCRON Co., Ltd. for thin film deposition.

References

1. M. Kadota, Y. Suzuki, and Y. Ito, IUS2010, p.91.
2. M. Kadota, Y. Suzuki, and Y. Ito, Jpn. J. Appl. Phys., 50 (2011),07HD10.
3. T. Takai etal., IEEE trans. UFFC, vol. 84, p.1382, 2017.
4. M. Kadota, Y. Ishii, and S. Tanaka, IUS2018, 6J-2.
5. S. Inoue and M. Sola, IUS2018, 6J-5.
6. T. Tai, M. Sakai, Y. Osugu, and K. Suzuki, Proc. use2007, vol. 28, p.151.
7. K. Matsumoto, M. Kadota, and S. Tanaka, Jpn. J. Appl. Phys., 59(2020) 036506.
8. M. Kadota, Y. Ishii, and S. Tanaka, IUS2020, B3L-05-2.
9. M. M. Kadota, Y. Ishii, and S. Tanaka, IUS2019, TuG6-1.