3Pa3-2

4 GHz Solidly Mounted Thickness Extension Mode Bulk Acoustic Wave Resonator using 36°Y $LiNbO_3$

Micho Kadota[1†], Fuyuko Yamashita[1] and Shuji Tanaka[1]
([1]Dept. Robotics, Grad. School Eng., Tohoku Univ.)

1. Introduction

Surface and bulk acoustic wave (SAW and BAW) filters are widely used in mobile phone systems. Recently, they are expected to cover a higher frequency range. The highest frequency limit of SAW devices is about 3.2 GHz due to power handling. On the other hand, BAW devices are better suited for high-frequency applications than SAW devices. For the BAW devices, AlN and ScAlN films are used, and an electromechanical coupling factor (k^2), Q factor (Q) or k^2Q product is primarily limited by the materials. Therefore, BAW devices using single-crystal $LiNbO_3$ (LN) or $LiTaO_3$ (LT) thin plates are attracting attention for high frequency applications.

There are two kinds of thickness modes, extension (TE) and shear (TS) modes, and both modes of self-suspended BAW resonators (BAWRs) were prototyped using LN and LT[1-7]. The center frequencies (f_c) higher than 4 GHz were reported for TE and TS mode LN BAWRs. The thickness of LN used in such high frequency BAWRs is smaller than 0.3 µm, making the devices fragile. This is a major challenge for practical use.

Compared with the BAWR, a solidly mounted resonator (SMR) is advantageous in terms of mechanical strength and structural robustness. 3.28–3.4 GHz TE mode SMRs using 0.9–1 µm thick 20–43°Y LN and a 1.8 GHz TS mode SMR using 1 µm thick 20°Y LN have been reported[8, 9]. We developed 1–3.4 GHz strip-type TS mode and 1.19 GHz TS modes BAW SMRs with impedance (Z) ratio of 48–62 dB and bandwidth (BW) of 6.7–6.8%[10, 11]. The temperature coefficient of frequency (TCF) is -17 and -34 ppm/°C at series and parallel resonance frequencies using 0.56–2 µm thick X LT.

In this study, a 4 GHz TE mode BAW SMR using 36°Y LN was studied. TE mode has approximately twice as high velocity as that of TS mode, and a thicker piezoelectric layer can be used.

2. Fabrication of 4 GHz TE mode BAW SMR

A 36°Y LN plate is suitable for TE mode resonators, because it strongly couples with TE mode but does not couple with TS modes at all[3, 13]. The BAW SMRs were fabricated according to the fabrication process shown in Fig. 1.

A 4-inch 36°Y LN wafer is prepared (1), and a bottom electrode consisting of 10 nm thick Ti and 370 nm thick Al is formed (2). Subsequently, a Bragg reflector is made using 3 pairs of 380 nm thick Ta and 380 nm thick SiO_2 and an additional 380 nm thick Ta layer (3). On it, 3 µm thick SiO_2 is deposited and polished as a bonding layer. All deposition is done by RF sputtering method.

A 350 µm thick 4-inch quartz substrate with a total thickness variation (TTV) of less than 0.3 µm is directly bonded to the polished SiO_2 film plane of the LN wafer (4). The LN layer is then thinned to a thickness of about 1 µm by polishing (5). On the polished LN, the top electrode is formed with 10 nm thick Ti and 100 nm thick Al by lift-off (6).

The variation of the LN plate thickness is 0.5 to 1.2 µm after polishing. In this prototype, 0.81 µm thick region of the LN was used. A pair of the top electrodes were fabricated for each series-connected pair of the BAW SMRs. This configuration omits the fabrication of the bottom electrode connection by etching LN, which is necessary for a single resonator configuration[10, 11, 12].

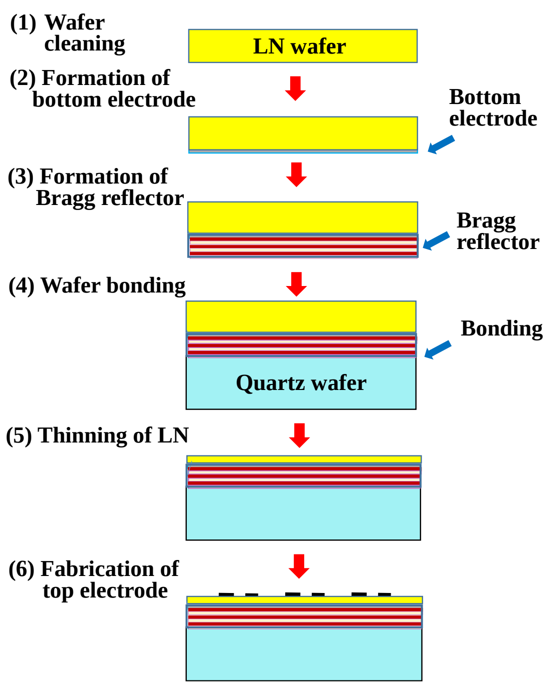

Fig. 1 Fabrication process of BAW SMR.

*mkadota@tohoku.ac.jp

3. Measured frequency characteristics

Figure 2 shows the structure of the fabricated BAW SMR and the measured frequency characteristic. The width (*W*) and length (*L*) of the top electrodes are 115 μm and 125 μm, respectively. The gap (*G*) between the electrodes is 90 μm. Other devices with *W* of 80–280 μm, *L* of 60–280 μm and *G* of 90–270 μm were also fabricated. Among them, the device shown in Fig. 2 exhibited the best characteristic. The resonance and antiresonance frequencies (f_r and f_a) are 3.83 and 4.16 GHz, respectively. The BW, *Z* ratio and k^2 are 8.4%, 54 dB and 17.7%, respectively, where k^2 is calculated by IEEE standard definition.

Figure 3 (a) shows the equivalent circuit which assumes the series connection of two identical resonators and fits Fig. 2. The series resistance (R_s) is 0.5 Ω, which may be caused by the resistance of the electrodes. The resistivity of deposited Al is 44 nΩ·m, which is larger than the bulk's value by 70%. Neglecting R_s, the frequency characteristic of the single resonator is calculated as shown in Fig. 3 (b) by blue dashed line. The clamp capacitance (C_0) includes the parasitic capacitance which is mainly introduced by the Bragg reflector. If the metal (Ta) is replaced with a dielectric such as HfO_2 as suggested in Ref. 14, a better characteristic is expected. In addition, W is better than Ta from an acoustic point of view[12].

4. Conclusion

High frequency TE mode BAW SMRs were fabricated using 0.81 μm thick 36°Y LN. Bragg reflector is composed of 1 layers of 10/ 370 nm thick Ti/ Al, 4 layers of 380 nm thick Ta, and 3 layers of 380 nm thick SiO_2, which are alternately stacked. Series pairs of two resonators were fabricated to simplify the fabrication process. The 4 GHz BAW SMRs exhibited an *Z* ratio of 54 dB and k^2 of 17.7%.

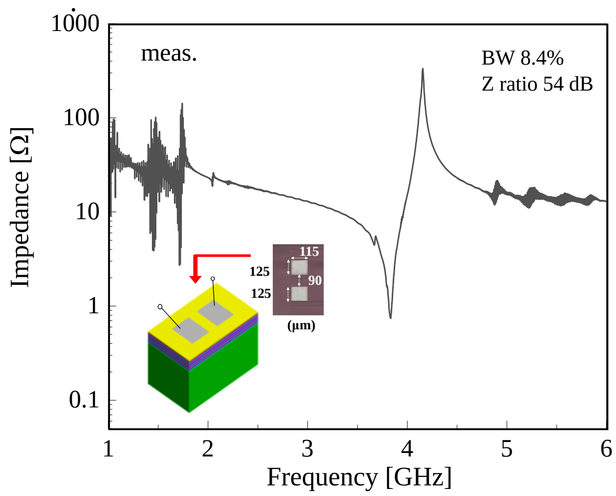

Fig. 2 Structure of fabricated BAW SMR exhibiting the best characteristic and the measured frequency characteristic.

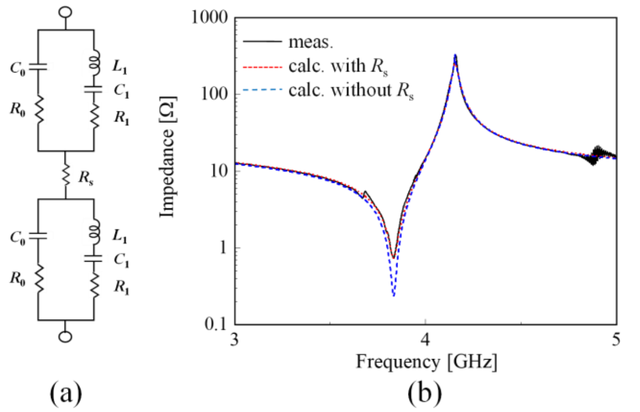

Fig. 3 (a) Equivalent circuit with two resonators connected in series and (b) calculated frequency characteristics with R_s (dot line) and without R_s (dashed line).

Acknowledgments

This work was partly supported by the Ministry of Internal Affairs and Communications, SCOPE #JP225002001. We would like to thank Mr. Shigeharu Matsumoto, Mr. Yuya Nonaka and Mr. Yosuke Inase at SHINCRON Co., Ltd., and Nanotech. Hub at Kyoto Univ. for their support.

References

1) M. Kadota *et al.*, Jpn. J. Appl. Phys., **50**, 07HD10 (2011).
2) T. Tai *et al.*, Proc. Symp. Ultrason. Electronics, p. 151, 2007.
3) K. Matsumoto *et al.*, Jpn. J. Appl. Phys., **59**, 036506 (2020).
4) M. Gorisse *et al.*, Proc. IEEE Int. Freq. Contr. Symp., MoAt1-2, 2019.
5) M. Bousquet *et al.*, Proc. IEEE Int. Ultrason. Symp., p. 84, 2019.
6) M. Bousquet *et al.*, Proc. IEEE Int. Ultrason. Symp., E2L-05-04, 2021.
7) M. Bousquet *et al.*, Proc. IEEE Int. Ultrason. Symp., DIP-06-4, 2020.
8) K. Matsμmoto, *et al.*, Proc. IEEE Int. Ultrason. Symp., B3L-05-05, 2020.
9) L. Lv *et al.*, IEEE Trans. Ultrason. Ferroelect. Freq. Contr., **69,** p. 1535 (2022).
10) M. Kadota *et al.*, Proc. IEEE Ultrason. Symp., B3L-05-02, 2020.
11) M. Kadota *et al.*, Jpn. J. Appl. Phys., **60**, SDDC11 (2021).
12) M. Kadota *et al.*, Jpn. J. Appl. Phys., **61**, SG1041 (2022).
13) A. W. Warner *et al.*, J. Acoust. Soc. Am., **42**, p. 1223 (1967).
14) Z. Wu, *et al.*, Jpn. J. Appl. Phys., **61**, SG1001 (2022).