2E2-1

High-Frequency SH_1 Mode Plate Wave Resonator on $LiTaO_3$ Using Aluminum as Backside Electrode

Ferriady Setiawan[1‡], Michio Kadota[1], and Shuji Tanaka[1] ([1]Grad. School Eng., Tohoku Univ.)

1. Introduction

Recently, high-frequency surface acoustic wave (SAW), bulk acoustic wave (BAW) and plate wave devices have been studied extensively for realizing filters for 5G and beyond 5G communication[1)]. Higher modes of both Lamb wave and shear horizontal wave have high phase velocity. First anti-symmetric mode Lamb wave (A_1) and its higher modes on $LiNbO_3$ (LN) and $LiTaO_3$ (LT) were utilized for high-frequency devices[2-5)]. On the other hand, Kadota *et al.* reported the first shear horizontal mode (SH_1) 3.23 GHz resonator with a high velocity of 21,000 m/s on an LN thin plate[6)]. A high phase velocity was obtained by making an electrically shorted plane on the bottom LN plate opposite to the interdigital transducer (IDT). After that, an SH_1 resonator of 2.82 GHz on an LT plate with the backside electrically shorted by Cu was reported. It showed a phase velocity of 14,020 m/s[7)].

This paper reports a high-frequency SH_1 mode resonator using a Cu IDT and an LT thin plate with an electrically shorted Al bottom plane. The temperature coefficient of frequency (TCF) of the SH_1 mode resonators with various frequencies is also discussed.

2. Phase Velocity and Coupling Factor Simulation by FEM

The phase velocity and coupling factor (k^2) of the SH_1 mode resonator on an LT thin plate with a thickness of 0.1λ (wavelength λ = 1 µm) were reported in Ref. 7. Only SH_1 mode uses an electrically short plane on the bottom side of LT. SH_1 mode on (0°, 63°, 0°) LT has a high phase velocity of 20 km/s and a high k^2 of 14% while k^2 of other modes is low to avoid spurious response. **Fig. 1** shows the simulated phase velocities of various modes on (0°, 63°, 0°) LT as a function of normalized LT thickness. The dashed line showed simulation results without considering an IDT. The velocity of SH_1 and A_1 modes largely depend on the LT thickness. The phase velocity drastically decreases as the LT thickness thickens from 0.1λ to 0.2λ.

3. Fabrication and Measurement

Figs. 2 and 3 show the schematic cross-section of the SH_1 mode resonator on a 0.65 µm thick (0°, 63°, 0°) LT plate and the frequency characteristic, respectively. The IDT wavelengths are designed within 2.57-3.57 µm. Then, 214 nm thin Cu IDT films were formed on the LT plate by lift-off technique with a metallization ratio (MR) of 0.6. As the backside electrode, a 34 nm thick Al film is used. The backside Si etching was done in 2 steps. Firstly, deep reactive ion etching (RIE) was performed to a depth of about 300 µm. Next, the remaining 50 µm thick Si was removed by isotropic plasma etching with SF_6 gas to disconnect the backside electrode from the side wall of the Si substrate to decrease stray capacitance.

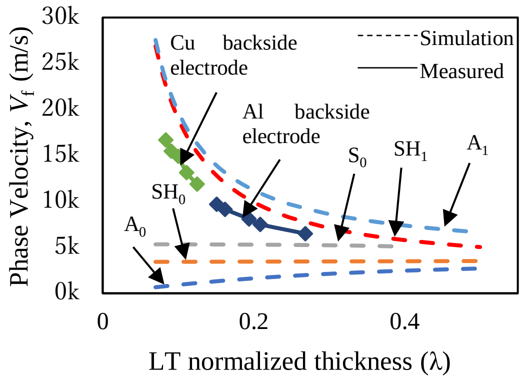

Fig. 1 Phase velocity (V_f) of various modes of plate waves on (0°, 63°, 0°) LT with electrically shorted bottom plane as a function of LT normalized thickness.

A resonance frequency (f_r) of 2.18 GHz, an anti-resonance frequency (f_a) of 2.27 GHz, a bandwidth (BW) of 3.8%, and a Z ratio of 31.5 dB were measured by using Keysight's E5071C Network Analyzer. The anti-resonant velocity is 7,700 m/s, which is lower than that reported in Ref. 7 because the resonator was fabricated on a thicker LT plate (0.19λ). The solid curves in **Fig. 1** show the measured phase velocity of the SH_1 mode resonators using Cu and Al as the backside electrode. The phase velocity decreases with the presence of the IDT electrode as well as the backside electrode. The Z ratio is low because of the presence of the backside metal electrode, which increases the mechanical loss. It is estimated by the FEM simulation that the mechanical quality factor (Q_m) of Al used in this fabrication is lower than 10, which is lower than the Q_m of Cu used in the previous study[7)]. This suggests that there are other losses such as leakage and scattering.

Figs. 4 and 5 show the shifts of f_r and f_a for various LT normalized thicknesses as a function of temperature (25°C, 45°C, 65°C and 85°C). **Fig. 6** shows the TCF as a function of the normalized LT

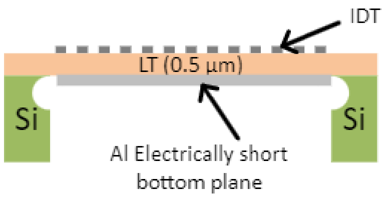

Fig. 2 Structure of fabricated SH_1 mode resonator.

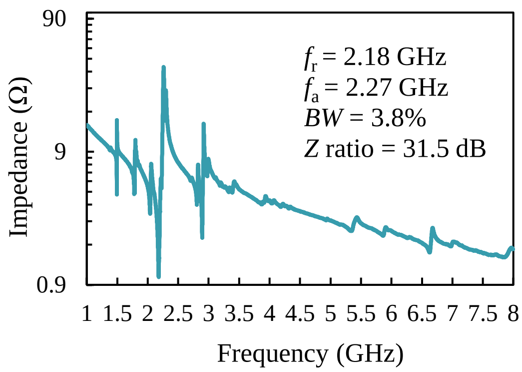

Fig. 3 Measured frequency characteristic of fabricated SH_1 mode plate wave resonator.

thickness. The TCF largely depends on the LT thickness and varies from -67 ppm/°C to -38 ppm/°C as LT thickens from 0.15λ to 0.27λ. The TCF of A_1 mode on 0.17λ thick (0°, 63°, 0°) LT is -38 ppm/°C[4]. The TCF of SH_1 mode is higher than A_1 mode when the LT thickness is identical.

4. Conclusion

This paper discussed the SH_1 mode resonator fabricated on an LT thin plate with Cu IDT and Al backside electrode. The measured f_r of 2.18 GHz, f_a of 2.27 GHz, BW of 3.8%, and Z ratio of 31.5 dB were reported. The phase velocity at f_a was 7,700 m/s, which was low because the resonator was fabricated on a 0.19λ LT thickness. The poor Z ratio was caused by the mechanical losses from the low Q_m of the Al backside electrode, leakage, and scattering losses. The TCF of SH_1 mode plate wave resonators on various LT thicknesses from 0.15λ to 0.27λ were reported. The TCF of f_r and f_a largely depends on the LT thickness and varies from -67 ppm/ °C to -38 ppm/ °C as the LT thickens changes from 0.15λ to 0.27λ.

Acknowledgment

This work was supported by Dr. Hideki Takagi at National Institute of Advanced Industrial Science and Technology (AIST) for the bonding of the wafers.

References

1. 5G/NR - FR/Operating Bandwidth, http://sharetechnote.com/html/5G/5G_FR_Bandwidth.html (accessed in July 2022).

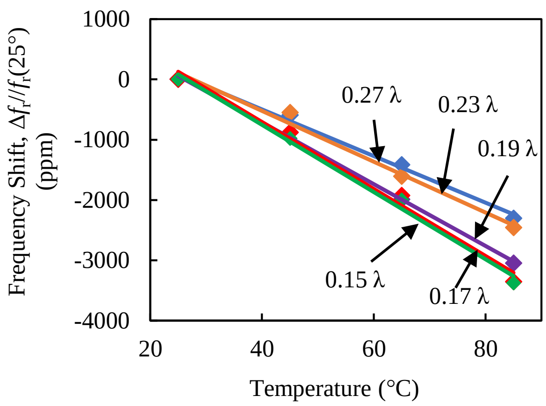

Fig. 4 Normalized resonance frequency shift of SH_1 mode resonator as a function of temperature.

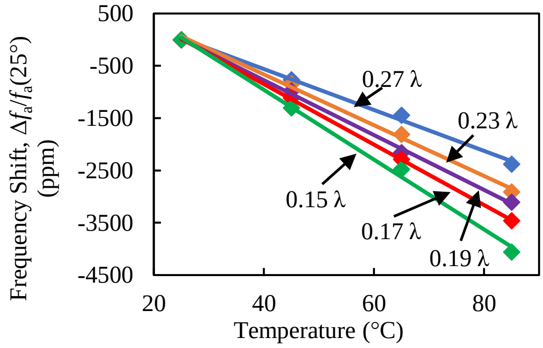

Fig. 5 Normalized anti-resonance frequency shift of SH_1 mode resonator as a function of temperature.

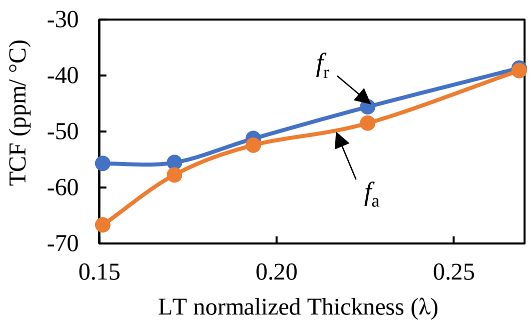

Fig. 6 Measured TCF of SH_1 mode resonator as a function of LT normalized thickness.

2. M.Kadota, T. Ogami, K. Yamamoto, H. Tochishita and Y. Negoro: IEEE Trans. Ultrason. Ferroelectr. Freq. Contr., 57 (2010) 2564.
3. M. Kadota and T. Ogami: Jpn. J. Appl. Phys. 50 (2011) 07HD11.
4. N. Assila, M. Kadota and S. Tanaka: IEEE Trans. Ultrason. Ferroelectr. Freq. Contr., 66 (2019) 1529.
5. Y. Yang, R. Lu, L. Gao and S. Gong: IEEE Trans. Microw. Theory Tech., 68 (2020) 5211.
6. M. Kadota, S. Tanaka and T. Kimura: Proc. IEEE Int. Ultrason. Symp. 2015, P4B1-5-1
7. F. Setiawan, M. Kadota and S. Tanaka: Proc. IEEE Int. Ultrason. Symp. 2021, B3L-05-02.

Setiawan.ferriady.r1@dc.tohoku.ac.jp