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Wideband Acoustic Wave Resonators Composed of Hetero Acoustic Layer Structure

ヘテロ音響層構造を有する広帯域弾性波共振子

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1. Introduction

A plate wave resonator illustrated in Fig. 1 (a) has attractive features such as large electromechanical coupling factor (k^2) and high phase velocity. For example, 0-th shear horizontal (SH_0) mode plate wave has k^2 larger than 50% in a $LiNbO_3$ (LN) plate thinner than 0.1λ around an Euler angle of (0º, 120º, 0º).[1)] In our previous study,[2, 3)] an SH_0 mode plate wave resonator exhibited a large bandwidth (BW) of 22%. Ladder filters for a TV white space cognitive radio[4)] were also prototyped using the plate wave resonators, and extremely wide passband at 6 dB attenuation of 41 to 51%, which was enough to fully cover digital TV band in Japan, USA and EU, was obtained.[3)] On the other hand, the ultra-thin LN plate thinner than 0.1λ was more fragile than expected, which must be addressed for practical application.

To solve the problem, a lot of attentions are recently paid to a new type of acoustic wave device, "Hetero Acoustic Layer (HAL) SAW device," which has a single crystal piezoelectric thin plate solidly supported with a substrate, as shown in Fig. 1 (b).[5-10)] Our previous papers reported SH type LN HAL SAW resonators with a high velocity of 6,000 m/s or a wideband of 20%, but the measured impedance ratio was smaller than expected.[6,8)] In this study, we achieved a very high impedance ratio of 83 dB using a 3.5 μm thick LN plate. This paper reports the finite element method (FEM) simulation, fabrication and characterization of the HAL SAW resonator.

2. Simulation

The HAL SAW resonator developed in this study is composed of an interdigital transducer (IDT), grating reflectors at both sides of the IDT, a LN thin plate, an acoustic reflector and a glass support substrate, as shown in Fig. 2. The acoustic reflector consists of six-layered alternately-laminated low and high acoustic impedance films, which are made of SiO_2 and AlN, respectively. For FEM simulation, a c-axis orientated piezoelectric AlN film is assumed. The thicknesses of SiO_2 and AlN films were determined at 0.05λ and 0.11λ, respectively, at which no spurious responses were found between resonance (f_r) and anti-resonance (f_a) frequencies.

In Fig. 3, solid lines represent the BWs of the HAL SAW resonators using different metal IDTs (Pt, Cu and Al) as a function of Euler angle θ of LN of 0.33λ thickness. As a reference, the BW of the cavity type

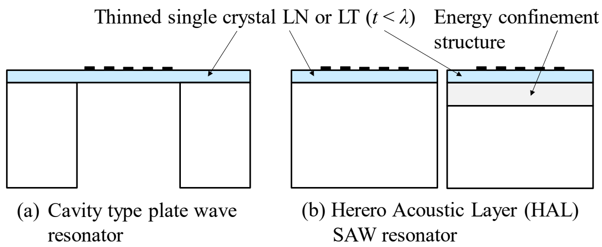

Fig. 1 Two types of acoustic wave device using single crystal piezoelectric thin plate.

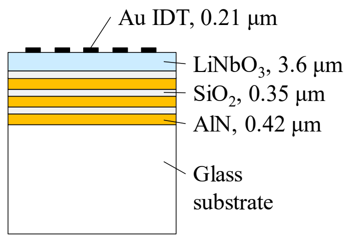

Fig. 2 Structure of SH type HAL SAW resonator.

SH_0 plate wave resonator using an Al-IDT of 0.04λ thickness in a LN plate is also shown by a broken line. The BW is defined as $(f_a - f_r)/f_r$. Euler angle around (0º, 90º, 0º) gives the largest bandwidth for the SH type HAL SAW resonator, while the plate wave resonator has a large bandwidth around an Euler angle of (0º, 120º, 0º). The BW is dependent on IDT materials. High density metals such as Pt and Cu is suitable to obtain large BW for the HAL SAW resonator. This is also different from the plate wave resonator, where a large BW is obtained using low density Al.[1)]

Fig. 4 shows the BWs of the HAL SAW resonator using different metal IDTs on (0º, 90º, 0º) LN as a function of LN thickness. As a reference, the BW of the plate wave resonator using an Al IDT on (0º, 120º, 0º) LN is shown by a broken line.[1)] A large BW is obtained at the thickness of 0.3~1.0λ for the HAL SAW resonator, showing small dispersion regardless of IDT materials. The best thickness of LN for the HAL SAW resonator is 3 to 10 times larger than that of the plate wave resonator, which is convenient from fabrication and robustness points of view.

3. Fabrication and Evaluation

For the acoustic reflector, 4 layers of 0.35 μm thick SiO_2 and 3 layers of 0.42 μm thick AlN (i.e. 7 layers in total) were alternately deposited on a (0º, 90º, 0º) LN substrate of 350 μm thickness. The 7-th layer of SiO_2 was polished to obtain a flat surface for bonding with a glass substrate. After bonding using epoxy adhesive, the LT plate was polished to 3.5 μm thickness. 60 pairs of IDT with a pitch of 5.25 μm and an aperture of 40λ as well as grating reflectors with 50 fingers at each side of the IDT were patterned by lift-off with 0.21 μm thick evaporated Au.

Fig. 5 shows the measured frequency characteristic of the HAL SAW resonator. The BW is 21.3%, which is almost the same as that of the ultrawide band plate wave resonator reported in Ref. 2). It is worth noting that the plate wave resonator shows a significantly larger BW than the HAL SAW resonator in Fig. 3 simulated by FEM, which is different from the measured result. The impedance ratio, which is defined as the ratio of impedance at f_r and f_a, has reached 83 dB, which is a very large value and even larger than that of the plate wave resonator. The results demonstrated that the HAL SAW resonator was promising for high performance acoustic wave filters etc.[10)]

4. Conclusion

A SH type HAL SAW resonator using a thin LN plate was designed and fabricated. The suitable Euler angle and thickness of LN and the suitable IDT material were found by FEM. The optimized design is different from that of the cavity type plate wave resonator. According to the FEM-based design, the HAL SAW resonators were fabricated. The structure is composed of Au-IDT, a 3.5 μm thick LN plate, a 6-layered acoustic reflector made of SiO_2 and AlN, and a glass substrate. An excellent frequency characteristic with a very large BW of 21% and a very large impedance ratio of 83 dB was obtained. The used LN plate thickness is 7 times thicker than that for a SH_0 plate wave resonator. This is advantageous in terms of velocity dispersion, mechanical stability, thickness controllability and fabrication yield.

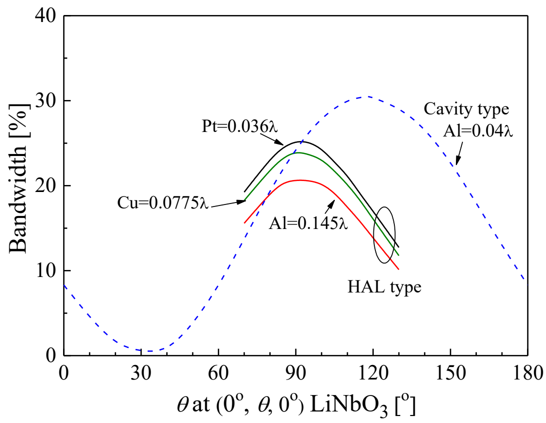

Fig. 3 BW of HAL SAW resonator (solid lines) and cavity plate wave resonator (broken line) as a function of Euler angle of LN.

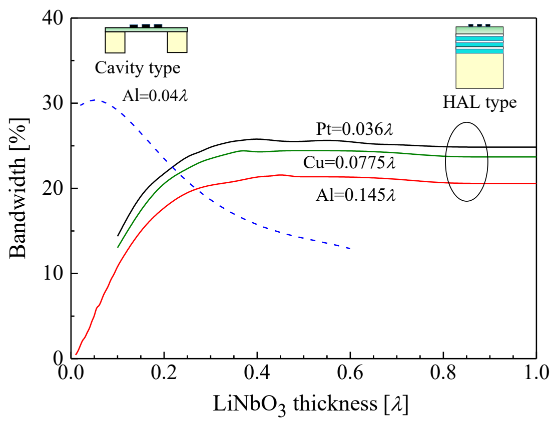

Fig. 4 BW of HAL SAW resonator (solid lines) and plate wave resonator (broken line) as a function of LN thickness.

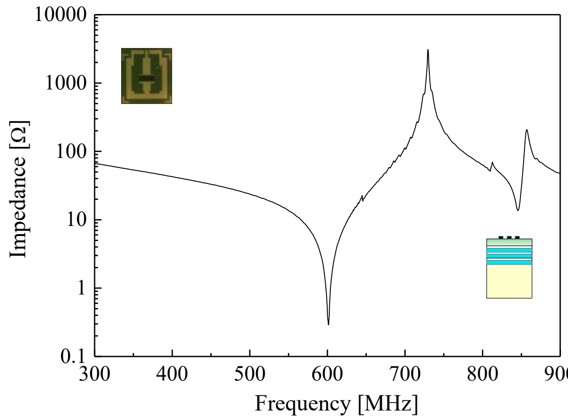

Fig. 5 Measured frequency characteristic of HAL SAW resonator.

Acknowledgments

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