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High overtone mode BAW resonators with polarization inverted multilayer ScAlN/SiAlN films

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1. Introduction

BAW resonators for frequency filters are increasingly required to operate at high frequency for future mobile communications. Very thin piezoelectric films of several hundred nm are need for the high frequency operation. However, the very thin films degrade the power handling capability and the resonace performance of BAW resonators. Polarization inverted BAW resonators (**Fig. 1 (a)**) may solve the problems of high-frequency BAW resonators. The resonance mode of polarization inverted BAW resonators is determined by the number of piezoelectric film layers. When n-layer polarization inverted BAW resonators and single-layer BAW resonators (**Fig. 1 (b)**) are operated at the same frequency, n-layer polarization inverted BAW resonators can have a n-times larger film thickness than single-layer BAW resonators.

We reported the fabrication of polarization inverted N-polar SiAlN/ Al-polar AlN multilayer film BAW resonators[1]. In addition, these resonators operated in high-overtone mode resonance. ScAlN films have higher piezoelectricity and larger electromechanical coupling factor than those of AlN films[2]. Therefore, the performance of the high-overtone mode BAW resonators might be improved by using ScAlN films as Al-polar layer in polarity inverted structure.

In this study, multilayer polarization inverted films were fabricated by stacking SiAlN films and ScAlN films. In addition, the frequency characteristics of polarization inverted multilayer ScAlN/SiAlN film BAW resonators were investigated.

2. Two-layer polarization inverted ScAlN/SiAlN film BAW resonator

To fabricated two-layer polarization inverted film, SiAlN (1st layer, N-polar) and ScAlN (2nd layer, Al-polar) films were grown on Ti/silica glass substrates by RF magnetron sputtering. **Fig. 2** shows the film deposition apparatus. SiAl (7.5 wt%) alloy target and Sc ingots on Al target were used in SiAlN and ScAlN films growth, respectively. Solid red line in **Fig. 3** shows θ-2θ XRD patterns of

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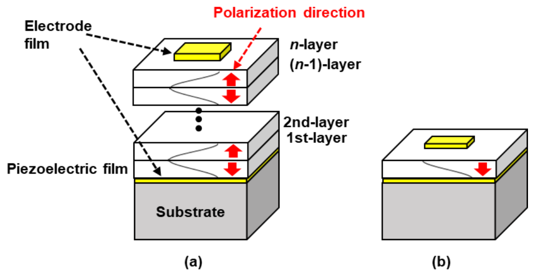

Fig. 1 (a) *n*-layer polarization inverted BAW resonator and (b) Single-layer BAW resonator.

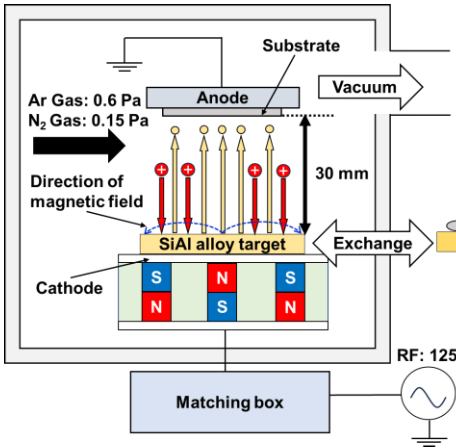

Fig. 2 Deposition apparatus for SiAlN or ScAlN film growth.

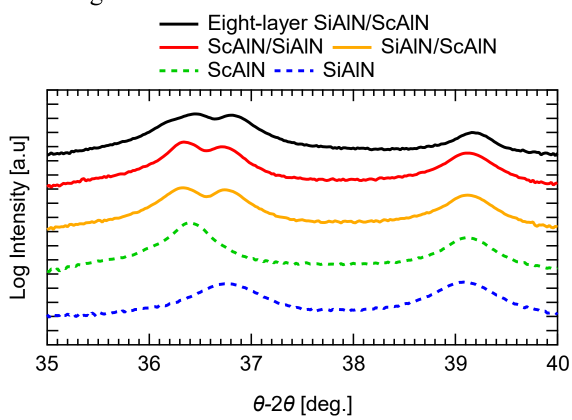

Fig. 3 θ-2θ XRD patterns of eight-layer SiAlN/ScAlN film, two-layer ScAlN/SiAlN film, two-layer SiAlN/ScAlN film, single-layer ScAlN film, and single-layer SiAlN film structures.

ScAlN/SiAlN/Ti/silica glass. We found two peaks at 36.4° and 36.8° for (0002) ScAlN and (0002) SiAlN, respectively. The conversion loss (CL) of the BAW resonator with Au/ScAlN/SiAlN/Ti/silica glass substrate was measured using a network analyzer. As shown in **Fig. 4 (a)**, the CL of the second overtone mode is smaller than that of other modes. Therefore, it was found that this resonator operated in the second overtone mode resonance. In addition, the tendency of the CL is similar to the theoretical curve calculate from Mason's equivalent circuit model. Therefore, a two-layer polarization inverted structure could be fabricated by stacking SiAlN and ScAlN films. The k_t^2 of the 1st layer SiAlN and 2nd layer ScAlN films were 2.65% and 6.96%, respectively. The minimum CL of this BAW resonator was 3.7 dB at 2.26 GHz. This minimum CL was smaller than those of the single-layer ScAlN film BAW resonator (=4.3 dB) SiAlN/AlN film BAW resonator (=3.9 dB)[1].

Next, two-layer polarization inverted N-polar SiAlN/Al-polar ScAlN films were grown on Ti/silica glass substrates. Solid orange line in Fig. 3 shows θ-2θ XRD patterns of SiAlN/ScAlN/Ti/silica glass. As in the case of the ScAlN/SiAlN films, a (0002) ScAlN peak at around 36.4° and a (0002) SiAlN peak at around 36.8° were observed. As shown in **Fig. 4 (b)**, this SiAlN/ScAlN film BAW resonator operated in second overtone mode resonance. The k_t^2 of the 1st layer ScAlN and 2nd layer SiAlN films were 7.29% and 2.89%, respectively. The minimum CL of 3.2 dB at 2.16 GHz in this BAW resonator was smaller than those in the two-layer ScAlN/SiAlN and SiAlN/AlN film[1] BAW resonators.

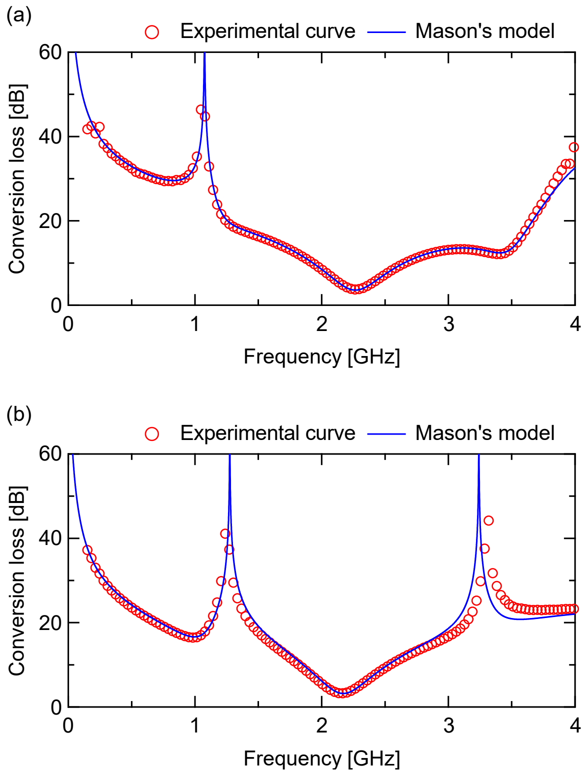

Fig. 4 Conversion loss of the two-layer polarization inverted (a) ScAlN/SiAlN and (b) SiAlN/ScAlN film BAW resonators.

3. Eight-layer polarization inverted SiAlN/ScAlN film BAW resonator

Al-polar ScAlN (1st, 3rd, 5th, 7th layer) and N-polar SiAlN (2nd, 4th, 6th, 8th layer) films were grown on Ti/silica glass substrates. Solid black line in Fig. 3 shows θ-2θ XRD patterns of eight-layer SiAlN, ScAlN/Ti/silica glass. A (0002) ScAlN peak and a (0002) SiAlN peak were observed in the eight-layer polarization inverted structure as well as the two-layer polarization inverted films. As shown in **Fig. 5**, the CL of the eighth overtone mode is smaller than that of other modes. Therefore, this eight-layer SiAlN/ScAlN BAW resonator could operate in eighth overtone mode resonance. In addition, the tendency of the CL was similar to the theoretical curve from Mason's equivalent circuit model considering an eight-layer polarization inverted structure. The minimum CL of this BAW resonator (1.7 dB at 2.37 GHz) was better than those of the two-layer polarization inverted BAW resonators.

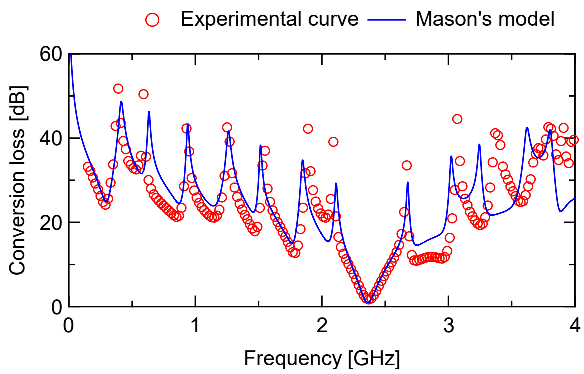

Fig. 5 Conversion loss of eight-layer polarization inverted SiAlN/ScAlN film BAW resonator.

4. Conclusion

We fabricate two-layer and eight-layer polarization inverted film BAW resonators by alternately growing ScAlN and SiAlN films. The two-layer and eight-layer polarization inverted film BAW resonators could operate in second overtone mode and eighth overtone mode, respectively. The minimum CL of the eight-layer SiAlN/ScAlN film BAW resonator was improved than those of the single-layer and two-layer polarization inverted film BAW resonators.

References

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2) M. Akiyama, Advanced Materials, **21**, p 594, (2009).