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Growth of polarity inverted SiAlN/AlN multilayered films and applications to high-order mode BAW resonators

極性反転 SiAlN/AlN 多層膜を用いた高次モード BAW 共振子

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1. Introduction

Alminum nitride (AlN) films possess high bulk acoustic wave velocity. They are used as piezoelectric layers in film bulk acoustic wave resonators (FBARs) for mobile communication devices. High frequency FBAR filters will be required because our future communication devices will communicate at high frequency. Wurtzite AlN has two types of polarity such as Al-polarity and N-polarity. AlN films grown by RF magnetron sputtering have Al-polarity. A standard BAW resonator (electrode/AlN thin film/electrode) excites fundamental mode resonance. However, *n*-layer polarity inverted BAW resonators with N-polar/Al-polar AlN film can exicite *n*-th mode resonance. Therefore, they can operate higher frequency than the standard BAW. When polarity inverted BAW resonators operate at the same frequency as a standard BAW, polarity inverted BAW film thickness becomes thick. Therefore, polarity inverted BAW resonator possesses high power capability.

Ion beam irradiation[1] or insertion of a buffer layer[2] are known as methods for controlling the polarity of AlN films. The fabrication of more than three layered polarity inverted BAW resonator using these methods have not been reported. Anngraini *et al.* reported that 1-15% Si doping for the AlN thin films induce polarity reversal from Al-polar to N-polar.

In this study, we fabricated SiAlN films by an RF magnetron sputtering deposition with Si of 0-17%. Crystal orientation was measured by X-ray diffraction (XRD). AlN film's polarity was evaluated by press test. The electromechanical coupling factor k_t^2 of the SiAlN films was determined from the frequency characteristics of conversion loss in SiAlN film high-overtone bulk acoustic resonators (HBARs). We fabricated two-eight layered AlN/SiAlN film HBAR. Crystal orientation and k_t^2 of each layer were evaluated.

2. SiAlN deposition

Si grains (0-0.5 g) were put on the 2-inch Al target. SiAlN films were grown on Ti/SiO_2 substrates by an RF magnetron sputtering deposition. RF power was 125 W. Sputtering gas pressure was 0.6 Pa, and gas ratio was Ar/N_2=2. Si concentrations of SiAlN films measured by EPMA were 0-17%. SiAlN film thickness was determined to be 1.69-6.47 μm.

3. Characteristic of SiAlN thin films

As shown in **Fig. 1,** for Si concentration of less than 7.2 %, (0002)AlN peak was observed at around 36º. The peaks of (0002)AlN disappeared in Si concentration more than 11 %. FWHM increased with increasing Si concentration, as shown in **Fig. 2** .

Polarity direction was determined by press test (**Fig. 3**). Positive voltage was generated when compressive stress applied to AlN thin film. However, negative voltage was generated in SiAlN thin films. From these result, Si doping caused polarity inversion from Al-polarity to N-polarity.

k_t^2 of SiAlN films was evaluated from frequency characteristics of conversion loss in SiAlN film HBARs measured by a network analyzer. As shown in **Fig. 2**, k_t^2 was decreased with increasing Si concentration in SiAlN thin films. This is may be caused by degrade of crystalline orientation of SiAlN films.

4. Polarity inverted SiAlN/AlN thin film

Two-eight layered polarity inverted SiAlN/AlN films were fabricated on Ti/SiO_2 substrate. Al-polarity AlN films were grown in odd layer, and N-polarity $Si_{0.05}Al_{0.995}N$ films were grown in even layer. Crystalline orientation in each layer was evaluated by XRD. As the layer of the thin film added, intensity of the (0002)AlN peaks was decreased.

Frequency characteristics of conversion loss in two-eight layered SiAlN/AlN thin film HBAR were measured by a network analyzer. **Figures 4**, **5,** and

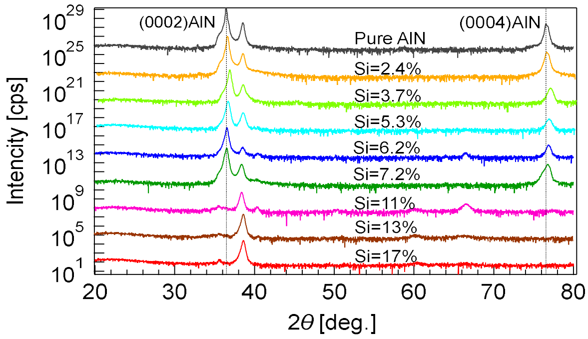

Fig.1 θ-2θ XRD patterns of $Si_xAl_{1-x}N$ films.

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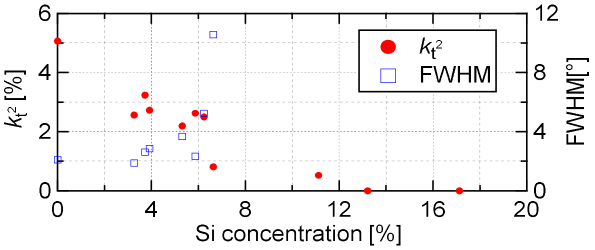

Fig. 2 k_t^2 in SiAlN films as a function of Si concentration.

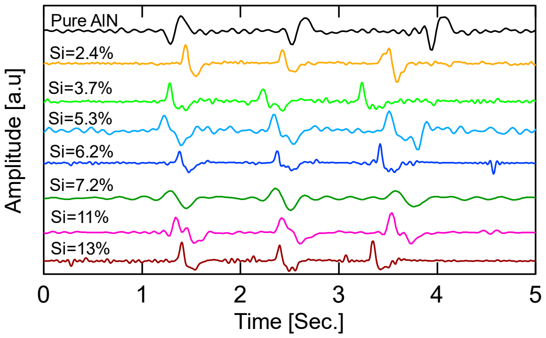

Fig. 3 Press test in SiAlN thin film as a function of Si concentration.

6 show the frequency characteristic of conversion loss in one-four layer, five-seven layer, and eight-layer SiAlN/AlN film HBARs, respectively. As shown in **Fig. 4**, the one layer resonates in the fundamental mode, the two-layer resonates in the 2nd-order mode, the three-layer resonates in the 3rd-order mode, and the four-layer resonates in the 4th-order mode. As shown in **Fig. 5**, the five-layer resonates in the 5th-order mode, the six-layer resonates in the 6th-order mode, and the seven-layer resonates in the 7th-order mode. As shown in **Fig. 6**, the eight-layer thin film acoustic resonator resonates in the 8th-order mode. Moreover, experimental curve agreed with calculated curve by Mason's equivalent circuit considering polarity inversion. From these results, we confirmed that two-eight layered polarity inverted structures could be fabricated. The conversion loss at the resonant frequency was improved from 6.63 dB for the single-layer resonator to 3.08 dB for the eight-layered polarity-inverted resonator. The k_t^2 of first layer, second, third, fourth, fifth, sixth, seventh, eighth-layer were determined to be 2.82%, 1.69%, 1.69%, 1%, 1.56%, 1.44%, 1%, and 0.81% respectively.

5. Conclusion

We grew SiAlN films with Si concentration of 0-17 %. The k_t^2 was decreased with increasing Si concentration in SiAlN films. We fabricated two-eight layered polarity inverted SiAlN/AlN film HBAR. 2-8th mode resonance were observed in the HBARs.

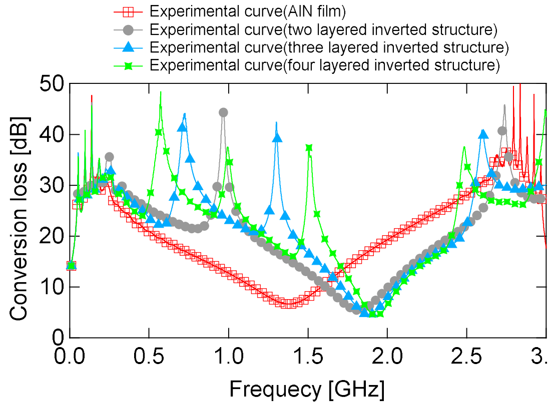

Fig. 4 Experimental longitudinal wave conversion loss of one-layered, two-layered, three-layered, and four-layered polarity inverted SiAlN/AlN film HBARs.

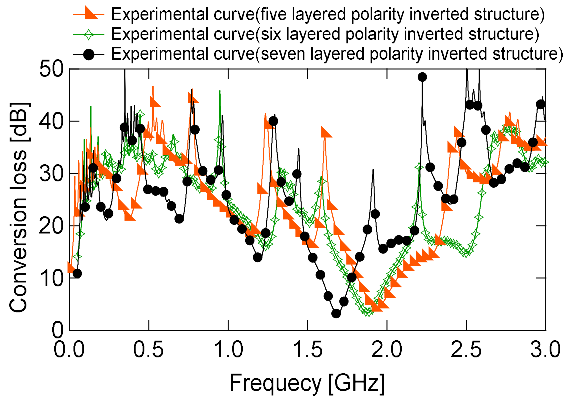

Fig. 5 Experimental longitudinal wave conversion loss of five-layered, six-layered, and seven-layered polarity inverted SiAlN/AlN film HBARs.

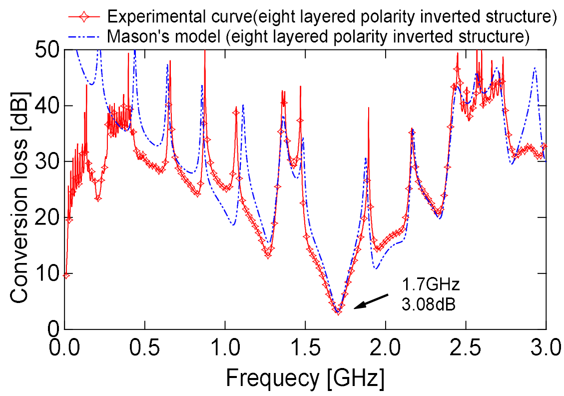

Fig. 6 Experimental and calculated longitudinal wave conversion loss of eight- layered polarity inverted film HBAR.

References

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2. J. D. Larson III, S. Mishin, and S. Bader, Proc. IEEE Ultrason. Symp., vol. 1054, (2010).