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k_{eff}^2-E hysteresis curve of ferroelectric ScAlN thin film

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1. Introduction

Electromechanical coupling coefficient k_t^2 of AlN can be improved by doping of Sc[1,2]. Furthermore, in 2019, ferroelectricity of ScAlN was discovered by Fichtner et al. and *P-E* hysteresis curves were reported[3]. If the direction of polarization can be inverted by an external electric field, a polarization inverted multilayer structure can be realized. The resonance mode change owing to the polarization inversion allows a frequency-switchable operation in the BAW filters[4]. In this application, the k_t^2 in each layer are required to be adjusted. The adjustment of k_t^2 can be carried out by utilizing k_t^2 hysteresis curve. Thus, measuring the k_t^2 hysteresis curve is important.

Wang et al. reported a k_t^2-E hysteresis curve in ScAlN FBAR with 30% Sc concentration5. They reported that k_t^2 of 1.3% for Al-polar ScAlN film after polarization inversion is less than k_t^2 of 10.3% for the N-polar ScAlN film before polarization inversion. This indicates an incomplete polarization inversion. In this study, we fabricated a ScAlN thin film with 40% Sc concentration on a Bragg reflector, which has a smaller coercive field. The k_{eff}^2-E hysteresis curves were then acquired.

2. Experiment

ScAlN thin film was deposited on (111) Pt/ Bragg reflector by RF magnetron sputtering. The thicknesses of ScAlN and Pt measured by SEM-EDX (JIB-4700F, JEOL) are 455 nm and 75 nm, respectively. The Sc concentration of the ScAlN thin film was measured to be 40 %. Hysteresis curves of impedance of ferroelectric ScAlN thin film SMR were measured using a network analyzer (E5071C, Agilent Technologies) with bias-tee (PE1616, Pasternack). Impedance measurements with DC bias voltage were performed in five processes: (i) 0 V to -80 V, (ii) -80 V to 0 V, (iii) 0 V to +60 V, (iv) +60 V to 0 V, (v) 0 V to -80 V. To decrease the coercive field of the ScAlN thin film, the SMR was heated to 200 °C while conducting measurement6. Figure 1 shows the real part of admittance in process (i).

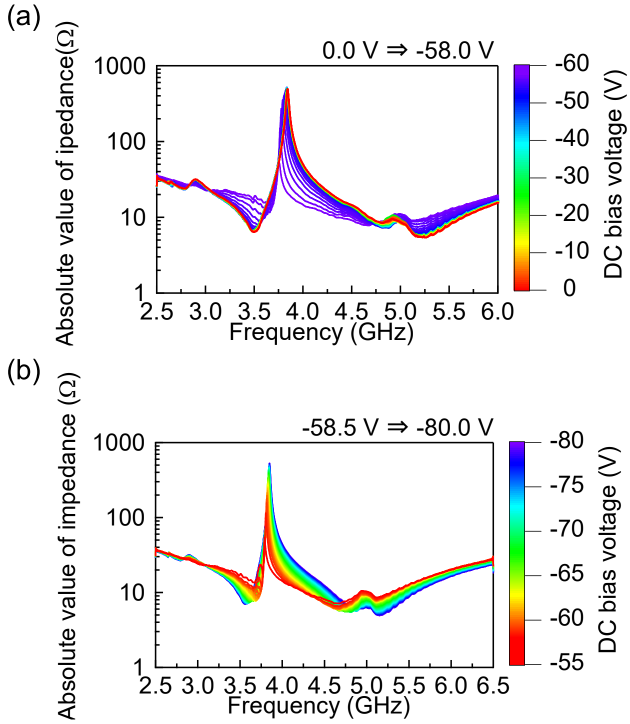

Fig. 1 Absolute impedance of ScAlN SMR film with bias voltage (a)from 0 V to -58.0 V and (b) -58.5 V to -80.0 V.

Figure 2 shows the resonant and anti-resonant frequencies for each process. The resonant and anti-resonant frequencies were obtained from the peak frequencies of the real part of admittance and real part of impedance. As shown in Fig. 2, the anti-resonant frequencies before the coercive field in processes (i) and (v) are shifted to the lower frequency side with negative DC bias voltage. This indicates ScAlN at 0 V in processes (i) and (v) are Al-polarity[7]. On the other hand, the anti-resonant frequency before the coercive field in process (iii) is shifted to the lower frequency side with positive DC bias voltage. Therefore, the ScAlN at 0 V in process (iii) is N-polarity[7].

Figure 3 shows the effective electromechanical coupling coefficient keff2 of the SMR obtained from the resonance-anti-resonance method as shown in **Eq. (1)**.

$$k_{\mathrm{eff}}^2 = \frac{\pi^2}{4} \times \frac{f_s(f_p - f_s)}{f_p^2} \qquad (1)$$

where f_s and f_p are series and parallel frequency.
Fig. 3 shows the k_{eff}^2-E hysteresis curve of the SMR. k_{eff}^2 of as-grown ScAlN is estimated to be 19.6 %.

Note that this high effective electromechanical coupling coefficient is an overestimation due to the parasitic inductance of the electrode. The coercive fields were found to be -1.3 MV/cm in process (i), 0.9 MV/cm in process (iii), and -1.2 MV/cm in process (v). For processes (i) and (v), polarization reversals in the same direction from N polar to Al polar. However, the coercive field of process (v) was lower than that of process (i). Therefore, the coercive field varies with the number of polarization reversals. This indicates the importance of measurement of the k_t^2-E hysteresis curve for the fabrication of frequency-switchable filters.

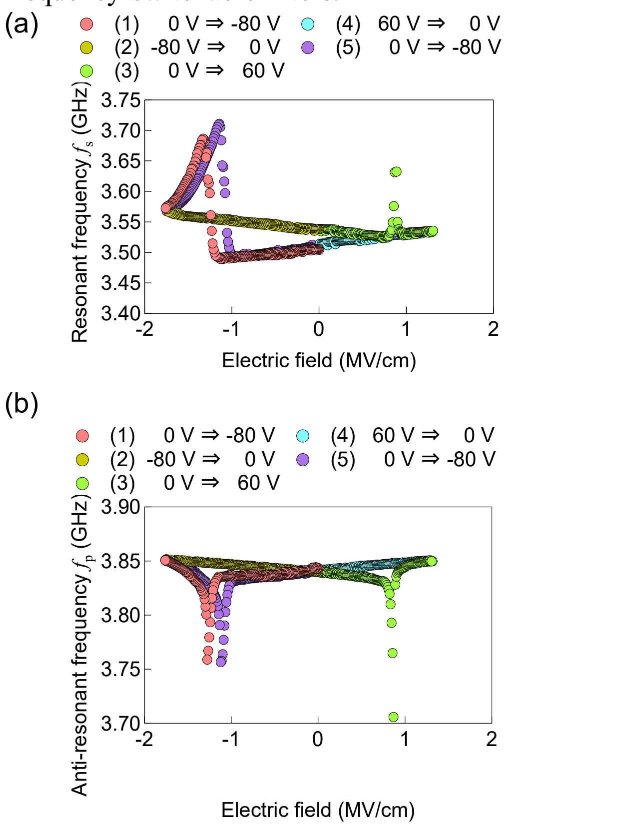

Fig. 2 Hysterisys curve of (a) resonant frequency and (b) anti-resonant frequency in the ScAlN SMR

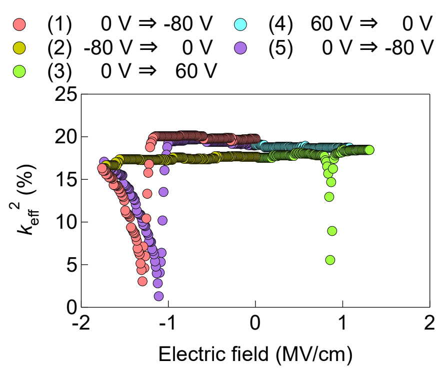

Fig.3 k_{eff}^2-E hysteresys curve of ScAlN SMR.

3. Conclusion

Ferroelectric ScAlN thin film was deposited on a Bragg reflector. The effective electromechanical coupling coefficient k_{eff}^2 of the fabricated SMR was 19.6 %. This high k_{eff}^2 is an overestimation due to the parasitic inductance of the electrode. The k_{eff}^2-E hysteresis curve was measured with DC bias voltage. The k_{eff}^2 of the as grown Al-polar film and polarity inverted N-polar SMR at no bias voltage (0 V) were 19.6 % and 17.7 %, respectively. Similar k_{eff}^2 of the film in both Al-polarity and N-polarity indicates complete polarity inversion of ScAlN film. As a future research subject, the measurement of k_t^2-E hysteresis curve without the influence of the parasitic inductance of the electrode must be conducted.

Acknowledgment

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