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# Improvement of piezoelectric properties in ScAlN film by suppression of highly-energetic-negative-ion bombardment from sputtering target

スパッタターゲットから飛来する高速負イオンの
照射抑制による ScAlN 薄膜の圧電性向上

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## 1. Introduction

ScAlN films are suitable for high-frequency acoustic wave devices because of their high bulk acoustic wave velocity and high piezoelectricity. The film growth method for highly-crystalline orientation is very important for their devices.

ScAlN films are usually grown by a sputtering method. Impurities of Sc metal target is, however, seriously problem. In previous study, we demonstrated Sc ingot sputtering deposition in which Sc ingots were set on an Al metal target[1)]. We found highly-energetic negative ions, such as $O^-$ and $CN^-$, generated from Sc metal during sputtering deposition. Then, the effects of the negative ion bombardment to the substrate investigated. The crystalline orientation and electromechanical coupling of the ScAlN films were degraded with increasing negative ion bombardment. Therefore, the supression of the negative ion bombardemet is required for ScAlN film deposition with high Sc concentration. In this study, we investigated the supression method.

## 2. Energy Distributions of Negative Ions

During a sputtering deposition of ScAlN, if the target contains oxygen and carbon as impurities, $O^-$ and $CN^-$ negative ions generate around the target. These negative ions are accelerated toward the substrate by the negatively biased target. Then, they bombard the substrate surface, resulting in the degradation of the crystalline orientation and electromechanical coupling[1)]. On the other hand, in our study of ZnO sputtering, the negative ion bombardment decreased with the decrease of target temperature[2)]. Based on the ion bombardment suppression, Sc ingots were embedded in a cooled Al target in this study. Sc ingot temperatures during sputtering were measured by an infrared radiation thermometer. The surface temperatures of the ingots decreased from 890ºC to 630ºC by embedding them in the Al target.

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The energy distributions of the negative ions were measured by an energy analyzer with quadrupole mass spectrometer, as shown in **Fig. 1**. Sc-put Al target or Sc-embedded Al target was used as a sputtering target.

**Figure 2** shows the ion energy distributions of $CN^-$ in each target condition. A large number of negative ions at 100-170 eV was observed with the Sc-put Al target. The highly-energetic negative ions decreased with Sc-embeded Al target as expected.

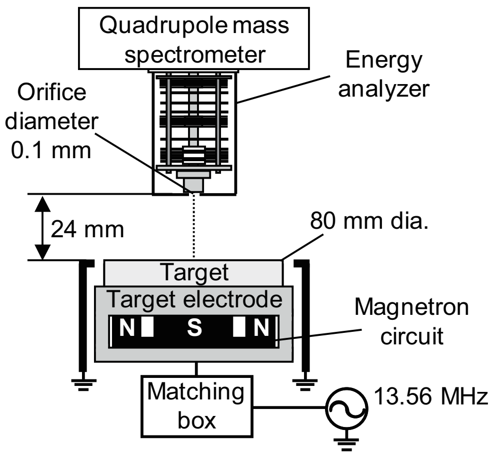


Fig. 1 Measurement system of the negative-ion-energy distributions in an RF magnetron sputtering apparatus.

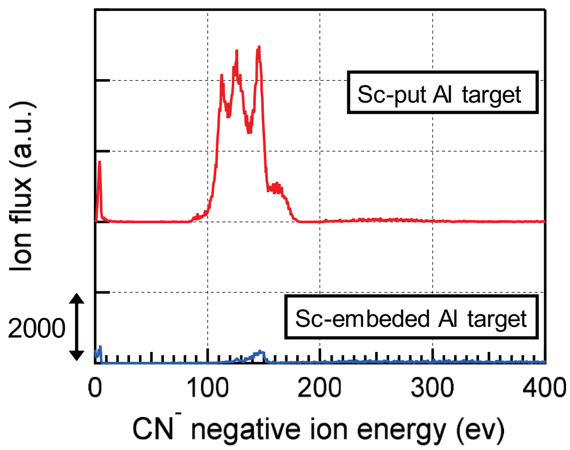


Fig. 2 Energy distributions of $CN^-$ entering the substrate during the sputtering depositions.

## 3. ScAlN Film Growth

ScAlN film samples were grown on Ti/silica glass substrates by an RF magnetron sputtering in the same conditions of the ion energy measurements. The substrate was set at the surface of the energy analyzer in Fig. 1.

The crystalline orientations were determined by XRD analyses. **Figure 3** shows AlN(0002) *ω*–scan rocking curves in the ScAlN film sample with Sc-put Al target and Sc-embedded Al target. the intensity and FWHM value were improved by cooling Sc ingots. It was corresponded to decrease of ion bombardment.

Next, HBARs consisting of Cu electrode/ScAlN film/Ti electrode/silica glass were fabricated. Longitudinal mode BAW was observed using inverse Fourier transform of reflection coefficients ($S_{11}$) in the HBARs by a network analyzer. Conversion losses of the HBARs were calculated from a Fourier transform of the first echo in the longitudinal wave. Then, Theoretical curves were calculated by one-dimensional mechanical transmission line model using Mason's equivalent circuit. Electromechanical coupling coefficient $k_t^2$ was estimated by the minimum conversion loss of the HBAR. **Figure. 4** shows the frequency responses of the longitudinal mode conversion losses of the samples. The CL of the fundamental mode at Sc-embedded Al target was lower than that at Sc-put Al target. Therefore, the electromechanical coupling was improved by cooling Sc ingots. It was also corresponded to decrease of ion bombardment.

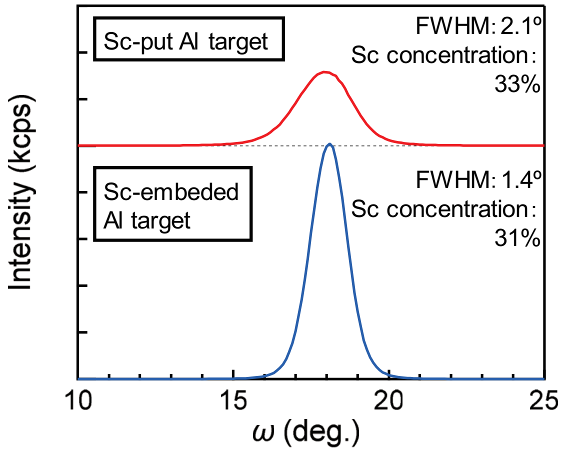


Fig. 3 AlN(0002) *ω*-scan XRD patterns of the ScAlN samples.

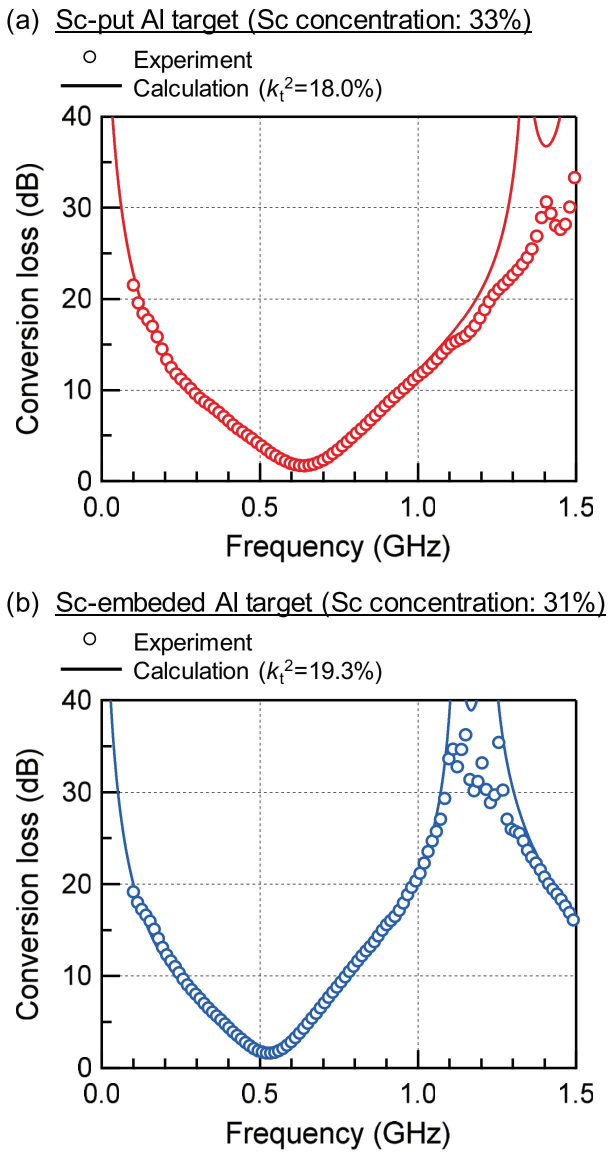


Fig. 4 Frequency responses of the longitudinal-mode conversion losses of ScAlN film samples with (a) a Sc-put Al target and (b) Sc-embedded Al target.

## 5. Conclusions

We measured the negative ion energy distribution, and also measured crystalline orientations and piezoelectric properties of ScAlN films. In this study, the amount of ion bombardment was the smaller in the condition with Sc-embedded Al target. Crystalline orientation and electromechanical coupling were improved with decreasing negative ion bombardment. Therefore, investigation of negative ion bombardment is an effective method for ScAlN film growth with high Sc concentration.

## References

1. S. Takayanagi, and T. Yanagitani: Proc. 2017 IEEE Int. Ultrasonics Symp., 2017, p. 1.
2. C. Takata, S. Takayanagi, T. Yanagitani, and M. Matsukawa: presented at IEEE IUS 2014, P3C2-2.