Effect of negative ion bombardment increased in low-pressure sputtering deposition on piezoelectric properties of ScAlN thin films

低圧スパッタ成膜において増大する負イオン照射が ScAlN 薄膜の圧電性に及ぼす影響

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1. Introduction

ScAlN films are known to have piezoelectric properties much larger than AlN films. [1)] Therefore, the ScAlN films are attracting attention as a piezoelectric material for GHz acoustic wave devices.

ScAlN films can be deposited using a RF magnetron sputtering method. However, when the Sc concentration of the ScAlN films is increased, there is a problem that the quality of the film such as crystallinity and piezoelectric properties is deteriorated. One of the causes is negative ion bombardment. Sc used as a sputtering target is known for a rare metal and contains a small amount of impurities such as oxygen O and carbon C. Due to such impurities, negative ions are generated during sputtering deposition. Then, they bombard to the substrate in a large amount with high energy, resulting in the deterioration of the film quality. [2,3)]

In low-pressure sputtering deposition, thermalization and scattering of sputtered particles are reduced, so that the film quality is improved, whereas negative ions bombardment to the substrate increase. [4,5)] In this study, we demonstrated that the piezoelectric properties of ScAlN films were deteriorated by the negative ion bombardment increased in low-pressure sputtering deposition.

2. Measurement of negative ion

Species and energy distributions of negative ion reaching the substrate were measured during ScAlN deposition by an energy analyzer with quadrupole mass spectrometer (PSM003, Hidden Analytical). As a sputtering target, an Al disc target (Furuuchi Chemical Corp) with 3.6 g Sc ingots (Great Western Mineral Group) putted on the surface was used. The orifice plate of the energy analyzer was placed 25 mm above the target surface. The deposition conditions were set to the argon-to-nitrogen ratio of 2 and the RF power of 200 W with 13.56 MHz.

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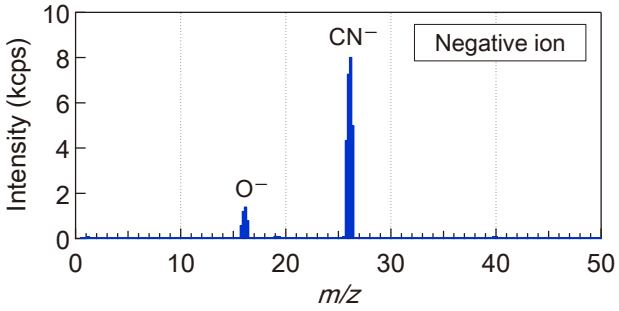

Fig. 1 Mass spectra of negative ions at sputtering pressure of 0.56 Pa.

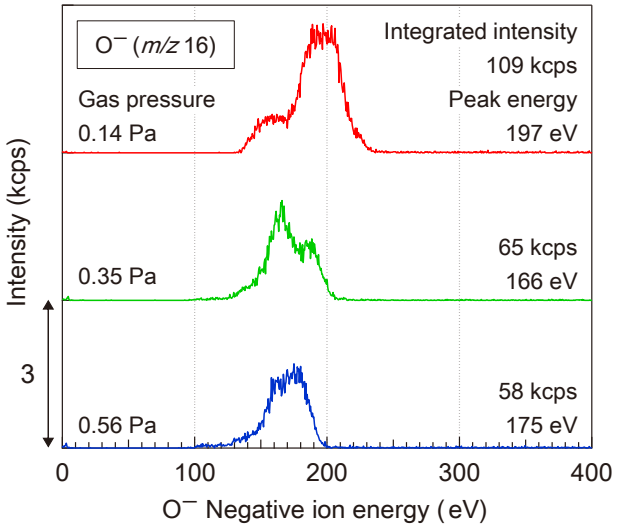

Fig. 2 Energy distribusions of O^- negative ion (*m/z* 16) at sputtering pressure of 0.14, 0.35 and 0.56 Pa.

First, the species of negative ions entering the substrate were identified by a mass spectrometry. **Figure 1** shows mass spectra of negative ions at the 0.56 Pa. Two strong peaks at *m/z* 16 and 26 were observed. The previous studies showed that oxygens and carbons contained in Sc ingots became O^- and CN^- respectively. Thus, *m/z* 16 and 26 were presumed to O^- and CN^- respectively.

Energy distributions of O^- and CN^- were then measured at 0.14, 0.35 and 0.56 Pa. **Figure 2** shows the energy distribution of the O^- negative ions. In addition, their integrated intensity and peak energy

in each energy distribution are also showed. Those results indicated that negative ions bombard to the substrate in a large amount with high energy in low-pressure sputtering deposition. The energy distributions of CN^- negative ions followed similar trends with that of O^- negative ions.

3. Piezoelectric properties of ScAlN films

ScAlN films were deposited on Al/silica glass substrates by an RF magnetron sputtering method at the sputtering pressure of 0.14, 0.35 and 0.56 Pa. The substrates were set on the orifice plate of the energy analyzer.

From XRD patterns, it was found to exhibit (0001) preferred orientations in all ScAlN samples. However, the peak intensity of ScAlN(0002) decreased with decreasing the pressure.

High-overtone bulk acoustic wave resonators (HBARs) consisting of Cu top electrode / ScAlN film / Al bottom electrode / silica glass substrate were then prepared to investigate piezoelectric properties of ScAlN films. **Figure 3** shows the frequency responses of the experimental and theoretical longitudinal mode conversion losses of the HBARs that were measured by a network analyzer (Agilent Technologies, E5071C). The theoretical curves were calculated by one-dimensional mechanical transmission line model using Mason's equivalent circuit. The electromechanical coupling coefficient k_t^2 of ScAlN films were evaluated by comparing experimental and theoretical conversion losses of HBARs using ScAlN film as piezoelectric layer. As shown in **Fig. 3**, the k_t^2 of ScAlN films decreased with decreasing the pressure. This indicates that the piezoelectric properties of ScAlN films were deteriorated in low-pressure sputtering deposition.

As mentioned above, the film quality improves in low-pressure sputtering deposition. In sputtering deposition of AlN films at low pressure, it was found that the film quality improved.[4] However, the piezoelectric properties of ScAlN films were deteriorated. Therefore, it is revealed that the ion bombardment increased at low pressure adversely affects the crystal growth of the ScAlN film and deteriorates its piezoelectric properties.

4. Conclusion

In this study, we demonstrated that the piezoelectric properties of ScAlN films are deteriorated by the negative ion bombardment increased in low-pressure sputtering deposition. In order to improve the quality of ScAlN thin films, it is necessary to discuss the effect of negative ion bombardment on the crystal growth, including deposition conditions.

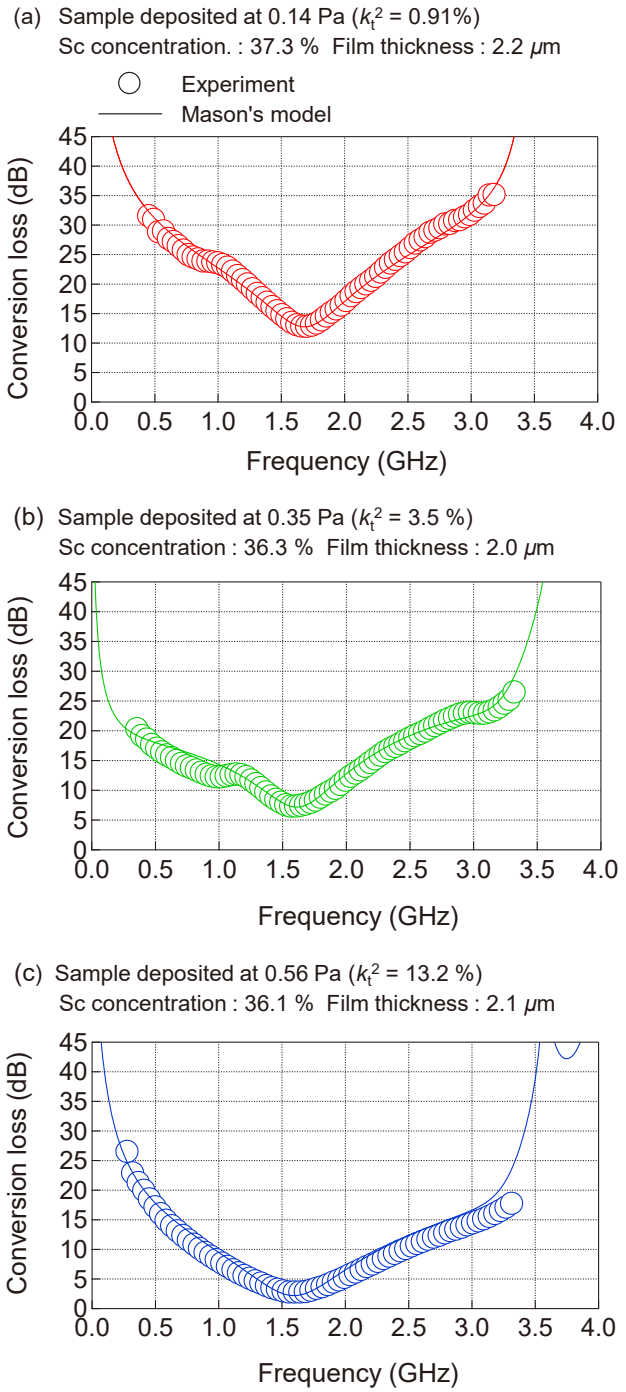

Fig. 3 Longitudinal-mode conversion losses of ScAlN films deposited at sputtering pressure of (a) 0.14, (b) 0.35 and (c) 0.56 Pa.

References

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