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# ScAlN multilayer second overtone mode resonator fabricated by $Al_2O_3$ ingot sputter deposition

## $Al_2O_3$粒スパッタ法よる(0001)配向 ScAlN 薄膜の極性制御と極性反転共振子

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### 1. Introduce

AlN has good chemical stability, high power handling capability, heat conductivity, velocity, and Q factor. AlN film is suitable for SAW device and film acoustic resonator applications.

As shown in Fig. 1 (a), c-axis tends to orient normal to substrate plane, and N-polar film is normally formed in AlN film grown on a silica glass by sputtering method. Larson III et al reported polarization inversion in AlN film on fresh Al seed layer[1)]. Polarization control by surface of various substrate, surface processing and the insertion of buffer layer were reported for epitaxial III-nitride single crystalline films[2)]. However, fabrication of the polarization inverted multilayer structure[3)] shown in Fig. 1 (c) is impossible in these methods which utilize the bottom surface properties because polarization of after the 2nd layer can not be controlled. Al-polar AlN film growth (Fig. 1 (b)) without depending on the bottom surface properties makes it possible to obtain the structures such as Fig. 1 (c) and (d)[4)]. A resonator with single piezoelectric layer excites fundamental mode resonance, whereas, the polarization inverted multilayered film resonator can excite high orvetone mode resonance. High overtone mode resonator enables high operating frequency and high power handling capability.

On the other hand, significant increase of piezoelectricity was recently found in Sc doped AlN films[5)]. We previously reported on the fabrication of c-axis oriented ScAlN films by Sc ingot sputtering method. Thickness extensional mode electromechanical coupling coefficient $k_t$ was estimated to be 0.35 in $Sc_{0.34}Al_{0.66}N$ film. The $k_t$ value was 1.2 times as high as that of an AlN single crystal[6)].

In this study, we report on the polarization control of c-axis oriented ScAlN films by ion beam irradiation, without depending on the bottom surface properties. Second overtone mode resonator consiting of polarization inverted multilayered ScAlN film was obtained.

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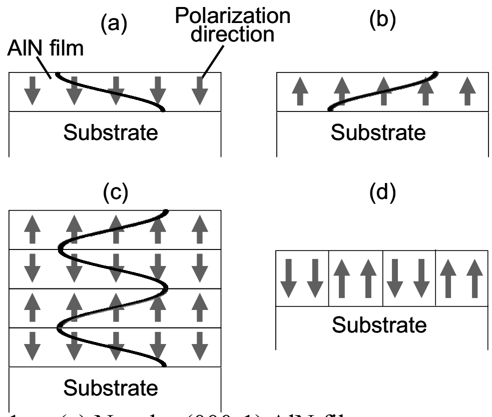


Fig. 1 (a) N-polar (000-1) AlN film
(b) Al-polar (0001) AlN film
(c, d) Potential polarization inverted structure

### 2. Deposition method

First, ScAlN film on fresh Al seed layer was prepared according to the Larson III's report, but unusual Al-polar film was not obtained. However, we fortunately found second overtone resonance, indicating polarization inversion, in other experiments of Sc ingot sputtering[6)]. In this experiment, Sc ingots were left for a long time in air. Oxygen may be adsorbed on the surface of ingots. We then considered that negative oxygen ion generated by sputtering Sc ingots and slight ion beam irradiation to substrate affected to polarization of ScAlN film. It is well-known that high energetic negative oxygen ion is generated by the sputtering of oxidized target. To verify this assumption, Sc (1.0 g) and $Al_2O_3$ (0.03 g) ingots were put on the center of 2" Al target, and c-axis oriented ScAlN film was fabricated on highly oriented Ti electrode film / silica glass by RF magnetron sputtering. ScAlN film without $Al_2O_3$ ingot was prepared for comparison. In addition, ScAlN film with $Al_2O_3$ ingot was fabricated on ScAlN film without $Al_2O_3$ ingot to obtain two layered polarization inverted ScAlN film.

The crystal orientation of films was examined by an x-ray diffraction pattern and rocking curves, and as a result, c-axis was normal to substrate plane in all samples. FWHM of rocking curves of ScAlN films with and without $Al_2O_3$ ingot were 3.8 º and 3.4 º, respectively.

Stoichiometry of ScAlN films were estimated by an energy dispersive x-ray spectroscopy. Sc / Al atomic concentration ratio was approximately 1 / 5 in all samples.

## 3. Polarization of ScAlN films

Cu top electrode was deposited on ScAlN films, and compressive stress was applied to top electrode by the probe, to generate the piezoelectric response (squeeze test). Polarization was determined from sign of the piezoelectric response measured by an oscilloscope. Fig 2 shows the piezoelectric responses of ScAlN films. Negative amplitude was observed in ScAlN film without $Al_2O_3$ ingot when compressive stress was applied. In contrast, positive amplitude was observed in ScAlN film with $Al_2O_3$ ingot. From these results, this polarization inversion may be caused by ion beam irradiation from $Al_2O_3$ ingot.

The polarization of film surface was also determined by a nonlinear dielectric microscope[7]. The polarization of ScAlN film without $Al_2O_3$ ingot exhibited Al polar, whereas, ScAlN film with $Al_2O_3$ ingot exhibited N polar. These results corresponded with the result of previous squeeze test.

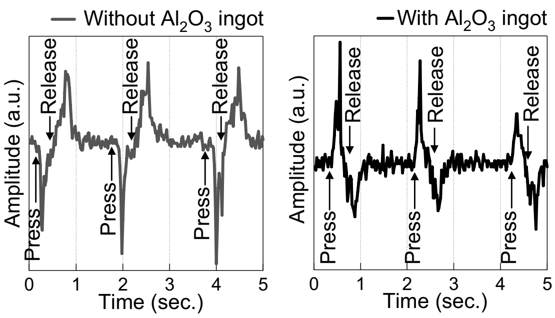


Fig. 2 Piezoelectric responses of ScAlN films by applying compressive stress

## 4. Piezoelectric propertied

HBAR structure was fabricated by evaporating top electrode Cu film on the surface of films. The longitudinal wave conversion loss of the resonators were measured by a network analyzer to estimate $k_t$ of ScAlN films and to evaluate polarization inversion in two layered ScAlN film. Fig. 3 (a), (b) and (c) show the longitudinal wave conversion loss for single layered ScAlN films without and with $Al_2O_3$ ingot, and two layered ScAlN film, respectively. Fundamental mode resonance around 2 GHz was observed in single layered ScAlN films. $k_t$ of films without and with $Al_2O_3$ ingot are determine to be 0.23 and 0.21, respectively, by comparing the experimental curve with the theoretical one. Fundamental mode resonance at 1 GHz was suppressed, and excitation of second overtone mode resonance was observed at 2.3 GHz in two layered ScAlN film. The experimental curves agree well with the theoretical one. The theoretical curves were calculated by using Mason's equivalent model including the effect of polarization inversion. These results show polarization inversion in two layered ScAlN film.

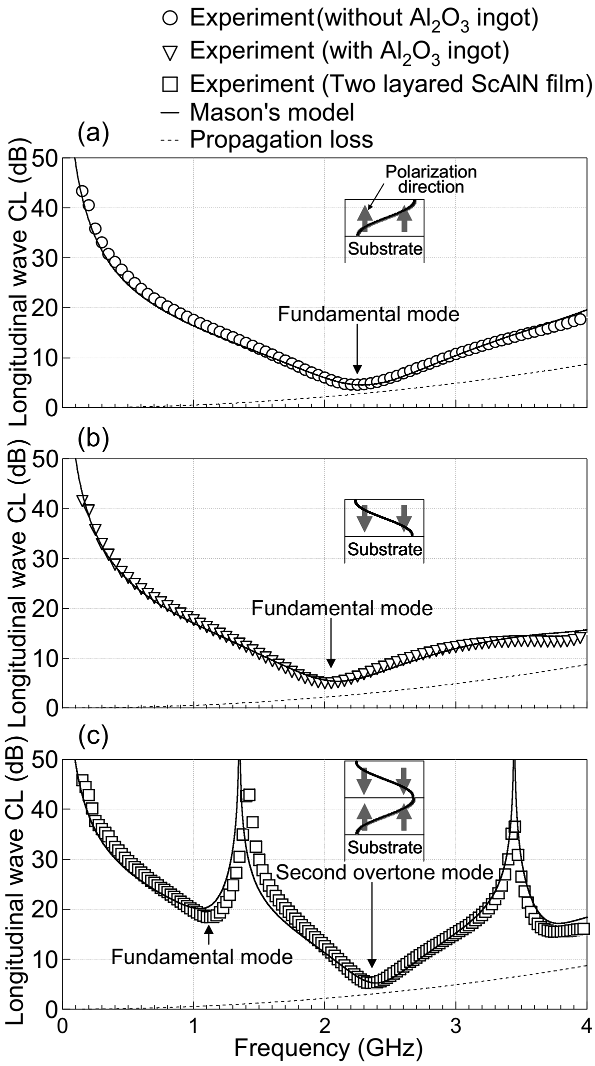


Fig. 3 Longitudinal wave conversion loss (CL) for single layered ScAlN films (a) without and (b) with $Al_2O_3$ ingot, and (c) two layered ScAlN film

## 5. Conclusion

Polarization of ScAlN films was successfully controlled by negative oxygen ion beam irradiation. Two layered polarization inverted ScAlN film resonator was obtained, and second overtone mode resonance was observed.

## References


1. J. D. Larson III, et al., in Proc. IEEE Ultrason. Symp., **1**, (2010), 719..
2. M. Sumiya and S. Fuke, MRS Internet J. Nitride Semicond. Res., **9**, (2004), 1.
3. 中村僖良, 日本音響学会誌, **56** (8), (2000), 579.
4. E. Milyutin, et al., J. Vac. Sci. Technol. B, **26**(6), (2010), L61.
5. M. Akiyama, et al., Adv. Mater., **21**(5), (2008), 593.
6. N. Suganuma, et al., Proc. Piezo. Mater. Devices. Symp., (2012), 199.
7. S. Kazuta, et al., Jpn. J. Appl. Phys., **39**, (2000), 3121.