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Piezoelectric properties of c-axis highly tilted AlN films
高角度傾斜配向 AlN 膜の作製と圧電特性

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1. Introduction

Shear mode piezoelectric films are attractive for use in shear mode film acoustic resonators (FBARs) and SH-SAW devices. c-axis tilted AlN films is one of the good candidate for these applications because they expected to have large quasi-shear mode electromechanical coupling (k'_{15} =0.26 at 28º tilt angle for single crystal [1,2]). In previous work, using c-axis tilted AlN films, Wang et. al. have reported shear mode FBARs [1], and several authors have also been reported shear mode FBAR liquid (bio-) sensors [3,4]. However, large k'_{15} value expected in single crystal have not been obtained. This may be due to lack of the alignment and density in the crystal grain structure in the films. In this study, we provide a quantitative evaluation of the crystalline orientation using X-ray pole figure analysis. Structural properties of c-axis tilted AlN films are predicted by the result of longitudinal wave and shear wave conversion loss characteristics.

2. Film deposition

c-axis tilted AlN films (1.2-3.6 μm) were fabricated using planer RF magnetron sputtering system having 60 mm diameter cathode with neodymium magnetron. Al electrode film (0.2 μm) on silica glass (25×100×0.5 mm^3) were used as the substrate. Substrate was set parallel to the Al metal target plane. Substrate to target distance was adjusted to 30 mm. 23 ccm pure N_2 gas with 0.4 Pa was introduced during the deposition. Two samples A and B, respectively, with 450 ºC and without heating substrate during the deposition, were prepared.

3. Crystallographic properties

3-dimensional crystalline orientations of samples were determined by XRD pole figure analysis. **Figure 1** shows (0002) pole figure of sample B measured at the 95 mm from anode center. (0002) pole observed at ψ =45.0º and ϕ =92.6º indicates that c-axis in the sample tilts 45º to the substrate normal. On the other hand, XRD peaks in pole figure and XRD patterns were significantly weak in the sample A. This shows that any crystallization did not occur in sample A.

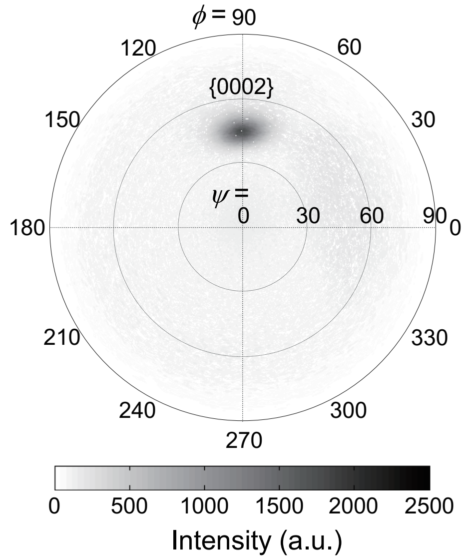

Fig. 1 (0002) pole figure of sample B measured at 95mm from anode center.

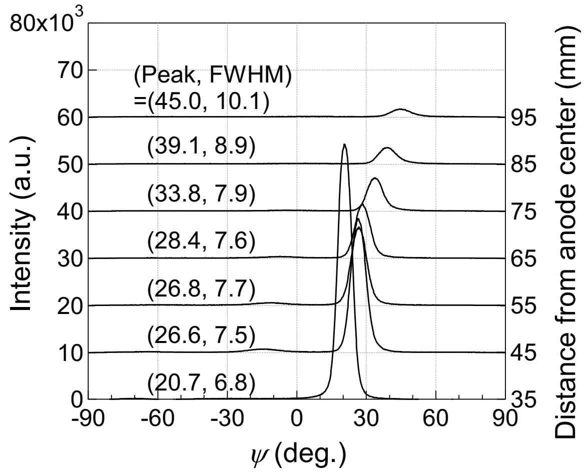

Fig. 2 ψ-scan profile curves as a function of the distance from anode center for the sample B fabricated without heating during the deposition.

Peak value and FWHM of the ψ-scan profile curve in the pole figure indicates c-axis tilt angle and degree of out-of plane orientation. ψ-scan curves of the sample B as a function of distance from anode center were shown in **Fig. 2**. We can see that c-axis tilt angle increases with an increase of the distance from the anode center.

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4. Piezoelectric properties

To measure electromechanical coupling coefficient of the samples, composite resonator structure was fabricated by evaporating Cu films (0.2 μm) on the samples as a top electrode. Conversion losses of the resonators were measured by network analyzer (Agilent Technologies, E5071C) with microwave probe [5]. Acoustic wave excitation were almost not observed in the sample A. **Figure 3** shows the longitudinal wave and shear wave conversion losses of the sample B measured at 55 mm and 80 mm from anode center.

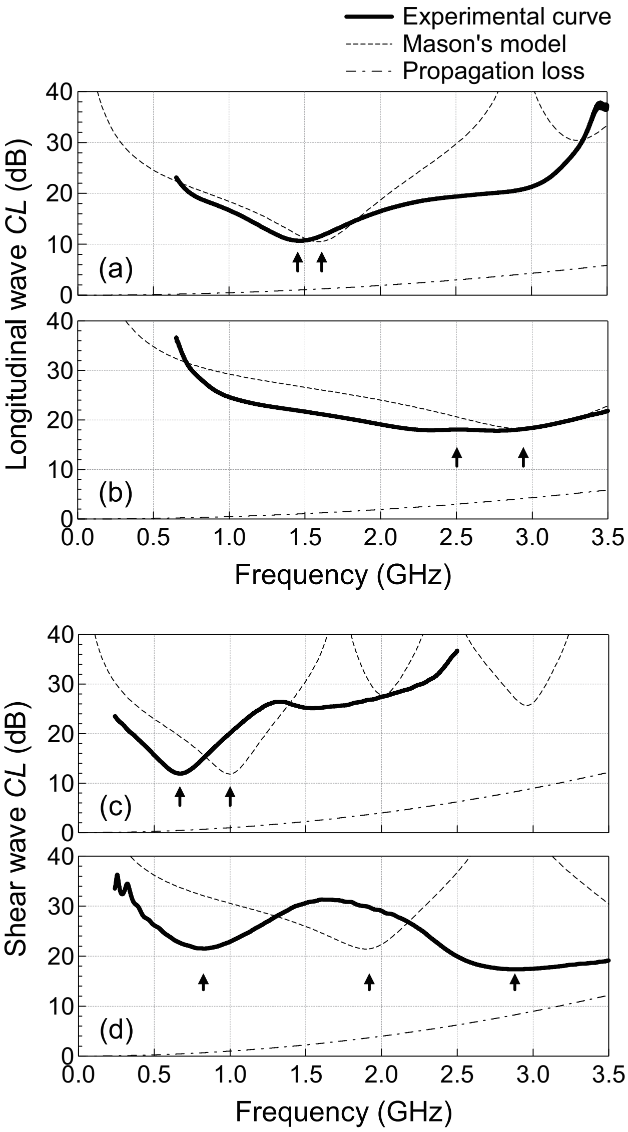

Fig. 3 Longitudinal wave conversion losses (CL) at (a) 55 mm and (b) 80 mm and shear wave conversion losses (c) 55 mm and (d) 80 mm in the sample B. Propagation losses in the silica glass substrate were subtracted.

Theoretical curve were calculated by using Mason's equivalent circuit model including the effect of c-axis tilt angle and electrodes. By comparing experimental curves with the theoretical curves, k'_{15} values were determined. k'_{15} value in the sample B at 55 mm was found to be 0.11. In spite of its relatively good crystalline orientation, this value is only 40 % of the value in single crystal.

In longitudinal wave curve shown in **Fig**. 3 (a) and (b), we can see relatively small discrepancy in resonant frequency (frequency at minimum point of the curves) between theoretical and experimental one, whereas, in shear wave curves in (c) and (d), large discrepancies were observed. This implies decrease of shear wave velocity, and this probably caused by the fiber structure in the films. Shear stiffness is likely to be sensitive to the void between columnar grains. In highly tilted film (45º tilt, 80 mm **Fig**. 3 (d)), 1/4 and 3/4 wavelength resonance were observed rather than half-wavelength resonance, indicating that acoustic impedance in the films is lower than that in the silica glass substrate.

Pritosh and Srolovitz have shown that such a highly tilted columnar structure induces decrease of film density (void between columnar grains) because of the shadowing effect [6]. Also, as shown in **Fig. 4**, porous columnar structure was observed in the films. This structure is a probable reason for decreasing k'_{15} value in the tilted films.

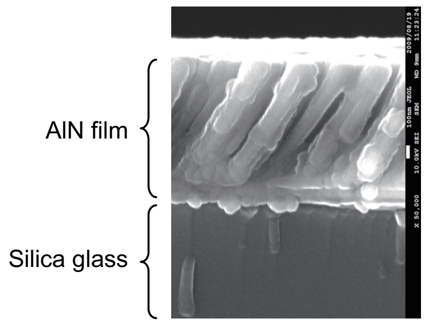

Fig. 4 Cross sectional SEM image of the sample B.

3. Conclusions

Quantitative evaluations of the 3-dimensional crystalline orientation and piezoelectric properties have been performed for c-axis highly tilted AlN films. Resultant k'_{15} value of 0.11 is small despite its good crystalline orientation. This may be due to the porous columnar structure in the films.

References

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