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c-Axis tilted ScAlN film on sapphire substrate for SAW devices with high electromechanical coupling

高い電気機械結合係数を持つ SAW デバイスに向けた c 軸傾斜 ScAlN 膜/サファイア基板の作製

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1. Introduction

Surface acoustic wave (SAW) devices are widely utilized for current mobile phones because of their high reproducibility, high driving frequency, lower loss, wider bandwidth and so on. Electromechanical coupling coefficient K^2 is essential parameter for wider filter bandwidth and a minimum insertion loss.

ScAlN films are attractive for SAW devices with high K^2. In previous study, we simulated K^2 in c-axis tilted $Sc_{0.4}Al_{0.6}N$ film/diamond substrate[1)]. The K^2 of the c-axis tilted film was increased, compared with that of the c-axis- normally-oriented film. However, it is difficult to perform experiments because diamond substrates are so expensive.

In this study, K^2 of SAWs in c-axis tilted ScAlN film/R-sapphire substrate were theoretically analyzed. According to the result, c-axis tilted ScAlN films were grown on sapphire substratres.

2. Theoretical analyses

The K^2 of SAWs in c-axis tilted $Sc_{0.4}Al_{0.6}N$/R-sapphire structure were theoretically analyzed as functions of normalized film thickness H/λ and c-axis tilt angle ψ by using the Farnell and Adler's method[2)]. The SAW propagation direction was parallel to c-axis tilt plane.

Figure 1 (a) and **(b)** shows surface plots of the calculated K^2 values of Rayleigh mode SAW and second mode (Sezawa) SAW, respectively. High K^2 in Rayleigh mode SAW were found to be 3.9% (phase velocity V = 5521 m/s) at H/λ = 0.20 and ψ = 90° and 3.7% (V = 4317 m/s) at H/λ = 0.92 and ψ = 54°. On the other hand, high K^2 was not found in Sezawa mode SAW.

We tried to prepare c-axis tilted ScAlN films whose c-axis tilt angle ψ is more than 30°. Relatively high K^2 over 3.0% is expected.

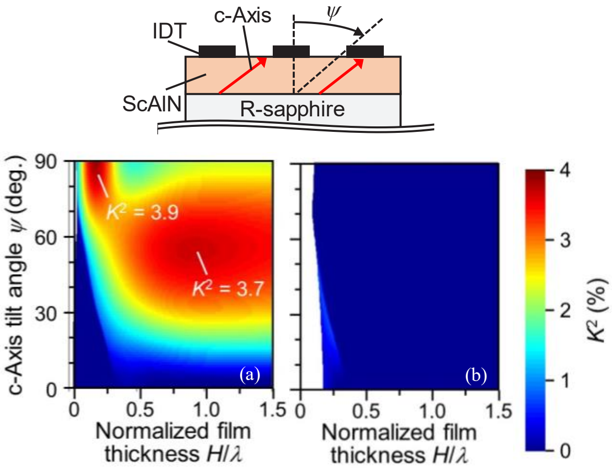

Fig. 1 Contour plots of the calculated K^2 values of (a) the Rayleigh mode SAW and (b) the second mode (Sezawa) SAW with $Sc_{0.4}Al_{0.6}N$ film/R-sapphire.

3. Film growth of c-Axis tilted ScAlN

ScAlN films were grown on R-plane sapphire substrates (10×10×0.5 mm^3, CRYSTAL GmbH) by a Sc ingot RF magnetron sputtering. Metallic Sc grains (2.3 g in total, Kojundo chemical laboratory) on Al metallic disk was used for the sputtering target. Sc concentration of 24% is expected in this condition. The deposition conditions were optimized to the process gas pressure of 0.45 Pa, the argon-to-nitrogen ratio of 2, and the RF power of 200 W. The substrate tilt angle γ to the target surface plane was adjusted to be 0° ,45° and 60° at 25 mm, as shown in **Fig. 2**.

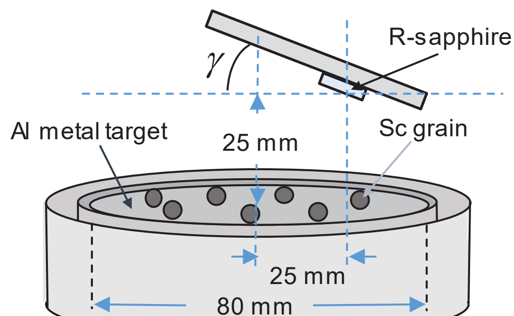

Fig. 2 RF magnetron sputtering system for c-axis tilted ScAlN films growth.

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Film thickness of three ScAlN samples at γ = 0°, 45° and 60° were 3.9 μm, 5.6 μm, and 3.7 μm, respectively. The crystalline orientation of ScAlN samples were measured by an X-ray diffraction (PANalytical, X'Pert Pro MRD). **Figure. 3** shows the profile curves of AlN(0002) ψ-scan XRD of the ScAlN samples. A c-axis-normally-oriented film was grown in the sample at γ = 0°. On the other hand, c-axis tilt angle ψ increased with increasing the substrate tilt angle γ. c-Axis tilt angles ψ of the samples at γ = 45° and 60° was 26.4° and 33.1°, respectively. Therefore, the c-axis-33°-tilted ScAlN film was obtained on the R-plane sapphire. The XRD peak intensity in the c-axis-33°-tilted film was, however, weak, as compared with that c-axis-normally film.

The ψ-scan FWHM of the c-axis-33°-tilted film, which indicate the distribution of the c-axis tilt angle, was 6.0°. The ϕ-scan FWHM, which indicate the dispersion of the plane direction, was 6.4°. The AlN(0002) pole figure was also measured, as shown in **Fig. 4**. The in-plane direction of the c-axis approximately corresponds to the a-plane direction of the R-sapphire substrate.

4. SAW excitation

IDT electrodes were fabricated on the c-axis-33°-tilted ScAlN film. The fingers of the IDT electrode were perpendicular to the c-axis of the ScAlN film. An IDT electrode was composed of 40 finger pairs with the wavelength (λ) of 8 μm and aperture length of 400 μm. H/λ was 0.46 in the sample structure.

The insertion loss (S_{21}) of the IDT /c-axis-33°-tilted ScAlN/R-sapphire measured by a network analyzer (Agilent Technologies, E5071C) Rayleigh mode SAW excitation was observed at 578 MHz. The minimum insertion loss (S_{21}) was 34.4 dB. One probable reason of the large insertion loss is the low XRD peak intensity of the ScAlN film. To obtain a lower insertion loss device, highly crystalized ScAlN film is necessary.

5. Conclusion

SAW propagation properties of the c-axis-tilted ScAlN/R-sapphire were theoretically analyzed. As the result, K^2 values of more than 3.0% were found in c-axis tilted angle of over 30°. c-Axis-33°-tilted ScAlN film was obtained at the substrate tilt angle of 60° to the target plane in the sputtering. Although the Rayleigh SAW excitation was observed with the film sample, the insertion loss was 34.4 dB. Further optimization of film deposition conditions of ScAlN is expected.

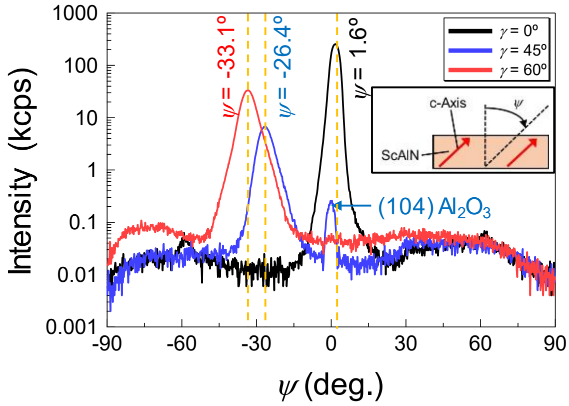

Fig. 3 Profile curves of AlN(0002) ψ-scan XRD of the ScAlN samples at γ = 0°, 45° and 60°.

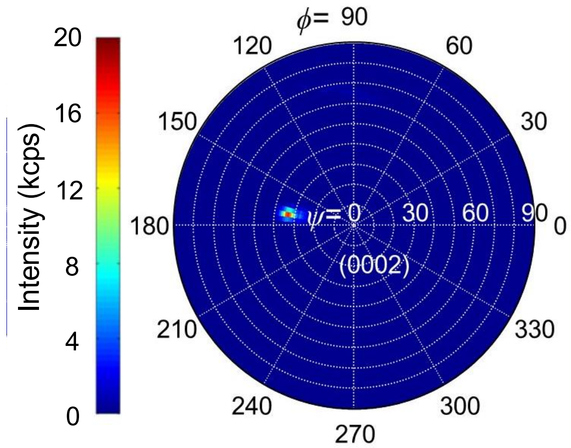

Fig. 4 AlN(0002) pole figure of the ScAlN sample at γ = 60°.

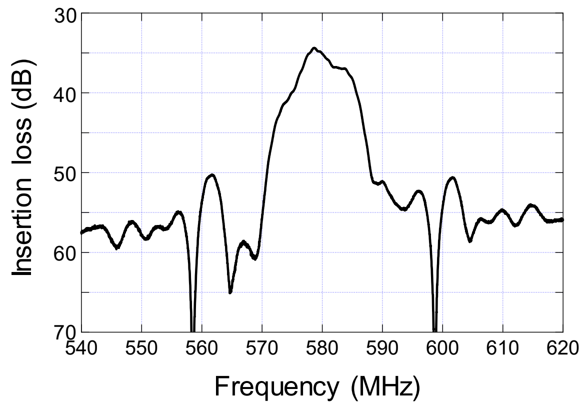

Fig. 5 Insertion loss (S_{21}) characteristics obtained from IDT /c-axis-33°-tilted ScAlN /R-sapphire structure.

References

1. K. Hashimoto, S. Sato, A. Teshigahara, T. Nakahara, and K.Kano:IEEE Trans. Ultrason. Ferroelectr. Freq. Control 60 (2013) 637.
2. S. Takayanagi, et al, presented at *IEEE IUS 2016*,P3-B2-1.
3. G.W. Farnell and E. L. Adler: in *Physical Acoustics*, eds. W.P. Mason and R. N. Thrston (Academic Press, New York, 1972) Vol. 9, p.35.