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c-Axis tilted ScAlN films grown on silicon substrates for surface acoustic wave devices

SAW デバイスへの応用に向けて Si 基板上に成長させた c 軸傾斜配向 ScAlN 薄膜

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1. Introduction

ScAlN films exhibit higher piezoelectricity than the AlN films.[1)] Furthermore, recent studies have shown that the appearance of ferroelectricity in the ScAlN films.[2)] Therefore, ScAlN films are currently being investigated to explore their potential for use in elastic wave devices for next-generation mobile networks.

Surface acoustic wave (SAW) devices based on ScAlN film/high velocity substrate (e.g. diamond and 6H-SiC) structure was reported to have higher electromechanical coupling coefficient K^2 than AlN based SAW devices[3)], while they have a disadvantage in cost of the substrate. Conversely, silicon is known as inexpensive substrates and is suitable for device integration. However, bulk acoustic wave (BAW) velocity of the substrate, which contributes to the increase in K^2, is lower in the silicon than in the diamond and 6H-SiC. In previous study, we have shown that the K^2 of SAW propagating on the wurtzite films, which ScAlN films belong to, increase with the c-axis tilt angle.[4)] Therefore, SAW devices using c-axis tilted ScAlN film/silicon substrate structure may exhibit high K^2.

In this study, we reported that results of theoretical analysis of SAW propagating on c-axis tilted ScAlN film/silicon substrate structure and a method for preparing the c-axis tilted ScAlN film on silicon substrate.

2. Theoretical analysis of SAW

Figure 1(a) shows the theoretical analysis model for SAW propagation in $Sc_{0.4}Al_{0.6}N$ film/silicon substrate layered structure. We analyzed K^2 of Rayleigh mode SAW propagation on this structure by Campbell and Jones's method.[5)]

Figure 1(b) and 1(c) show phase velocity in an electrically free surface and K^2 values of Rayleigh mode SAW as functions of normalized ScAlN film thickness H/λ, respectively. c-Axis tilt angle ψ of the ScAlN film is used as a parameter in these figures. The phase velocity approaches about 4600 m/s at ψ = 0° and 90°, and about 4200 m/s at ψ = 30° and 60° from the SAW velocity of silicon substrate as the H/λ increases. This is because the velocity of shear vertical (SV) wave propagating in the ScAlN monolayer is almost equal at ψ = 0° and 90°, and ψ = 30° and 60° due to the symmetry of wurtzite crystal. K^2 of SAW increase as ψ increase in the range of ψ = 0° to 60°. The maximum K^2 is found to be 3.86% at ψ = 60° and H/λ = 0.52. The phase velocity at the point is 4277 m/s. One reason for the increase in K^2 is that the large piezoelectric constant e_{33} of ScAlN contributes to the excitation of the longitudinal wave and SV wave, which are the components of SAW, owing to the c-axis tilt. In

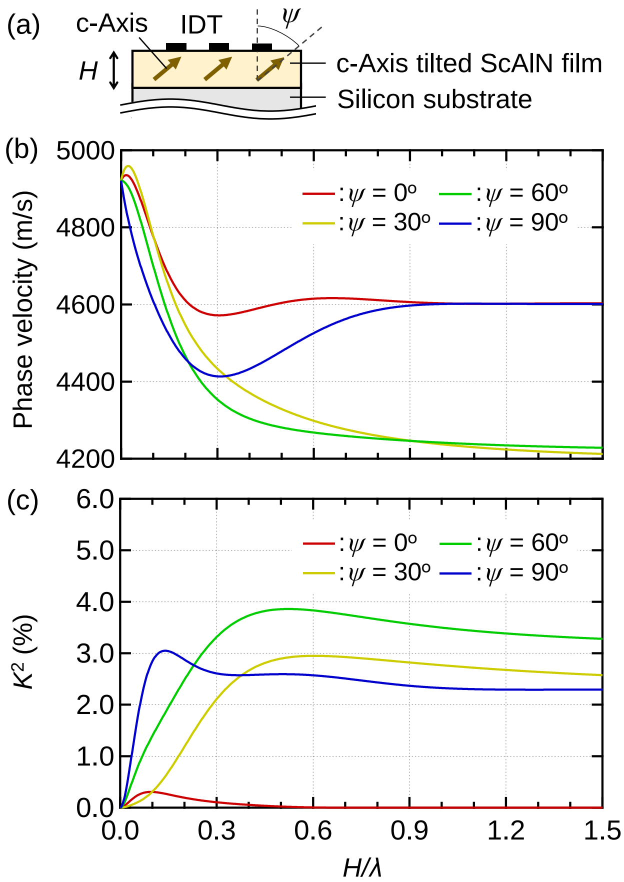

Fig.1 (a) theoretical analysis model for SAW propagation in $Sc_{0.4}Al_{0.6}N$ film/silicon substrate structure. (b) Phase velocity and (c) K^2 of Rayleigh mode SAW as functions of normalized ScAlN film thickness H/λ.

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addition, we analyzed Sezawa mode SAW. However, the K^2 of the Sezawa mode SAW is much smaller than that of the Rayleigh mode SAW. The maximum K^2 is obtained at $\psi = 0^o$, and there was no effect of c-axis tilt of ScAlN films on the increase in K^2. These results indicated that c-axis tilted ScAlN film/silicon substrate structure is suitable for Rayleigh mode SAW devices.

3. c-Axis tilted ScAlN films on silicon substrates

ScAlN films were prepared on (100) silicon substrates by using an RF magnetron sputtering method. Wurtzite films deposited using sputtered particle flux oblique to the substrate surface exhibit c-axis tilted orientation.[6] This feature is demonstrated by self-shadowing effects. Thus, the tilt angle γ of the silicon substrate was set to 60° toward sputtering target surface to take advantage of self-shadowing effect, as shown in **Fig. 2(a)**. In addition, ScAlN films were deposited in $\gamma = 0^o$ for comparison with the sample deposited in $\gamma = 60^o$. As a sputtering target, 80 mm diameter Al disc target (Furuuchi Chemical Co.) on which Sc ingots (JX Nippon Mining & Metals Co.) were placed was used. The total weight of the Sc ingots was 3.2 g. The deposition conditions were set to Ar:N_2-flow ratio of 2:1, gas pressure of 0.6 Pa, and RF power of 200W with 13.56 MHz. The thickness of ScAlN films were controlled to approximately 4 μm, Sc concentrations of them were 30% in this conditions.

The c-axis tilt angle and crystalline orientations of the samples were investigated by x-ray diffraction (XRD) with Cu $K\alpha_1$ radiation. **Figure 2(b)** shows ψ-scan profile curves of the ScAlN (0002) pole of the samples. The angle ψ at the ScAlN (0002) pole corresponds to the c-axis tilt angle. The c-axis tilt angles of the samples prepared with the substrate angles $\gamma = 0^o$ and 60° were 0.2° and 31.7°, respectively. We have determined that the c-axis tilted ScAlN films may have grown on the silicon substrates due to the self-shadowing effect.

The degrees of out-of-plane and in-plane crystalline orientation were evaluated by the full width at half maximum (FWHM) values for the ψ-scan and ϕ-scan profile curves, respectively. The ϕ-scan FWHM values is, however, unable to be measured on the films which c-axis tilt angle is about 0°. The FWHM values for the ψ-scan profile curves in the sample deposited in $\gamma = 0^o$ is 3.2°. The FWHM values of the ψ-scan and ϕ-scan profile curves are 5.9° and 4.7°, respectively, for sample deposited in $\gamma = 60^o$. The both of out-of-plane and in-plane crystalline orientation are relatively high in the sample deposited in $\gamma = 60^o$. The sputtering method using self-shadowing effect is good candidate for preparing c-axis tilted ScAlN films on the silicon substrates.

4. Conclusion

In this study, we have demonstrate theoretically that Rayleigh mode SAW propagating on c-axis tilted ScAlN films/silicon substrate layered structure have higher K^2 than that of the structure using the c-axis oriented ScAlN films. In addition, the c-axis tilted ScAlN films could be grown on a silicon substrates via a sputtering method using self-shadowing effect. In the future, the applications of this c-axis tilted ScAlN films/silicon substrate layered structure to SAW devices is greatly anticipated.

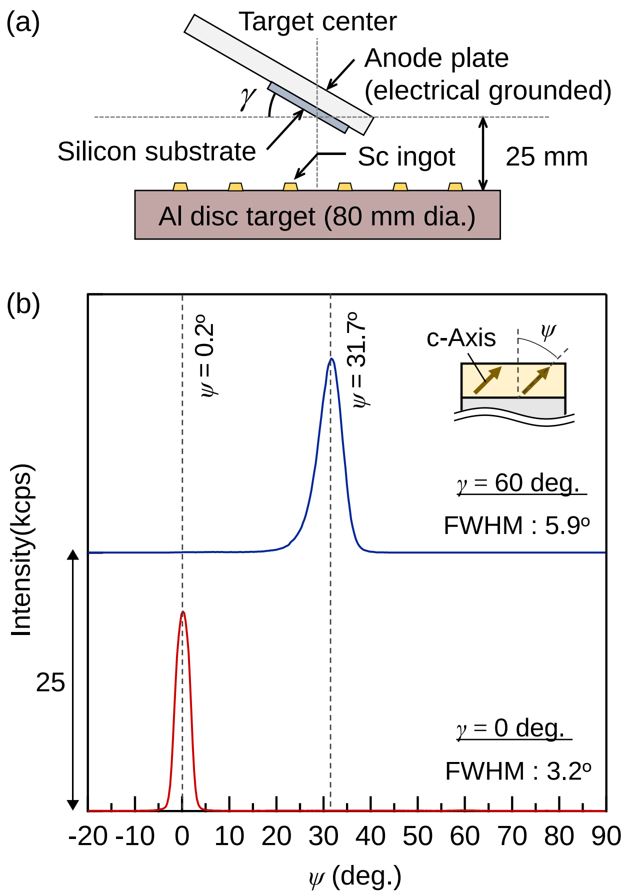

Fig.2 (a) substrate setting above the sputtering target. (b) ψ-scan profile curves of the ScAlN (0002) pole of the ScAlN films on silicon substrate.

References

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