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Proceedings of Symposium on Ultrasonic Electronics, Vol. 36 (2015)
5-7 November, 2015

Loss Reduction of Longitudinal-type Leaky Surface Acoustic Wave by Loading with ScAlN Thin Film
ScAlN 薄膜装荷による縦型リーキー弾性表面波の低損失化

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1. Introduction

The longitudinal-type leaky surface acoustic wave (LLSAW) has attracted interest for application to high-frequency SAW devices owing to its high phase velocity, which is close to that of a longitudinal bulk wave. However, it exhibits large inherent attenuation owing to the continuous radiation of shear horizontal and shear vertical waves into the substrate.

To solve this problem, the authors' group proposed that the attenuation of an LLSAW can be reduced by loading with an aluminum nitride (AlN) thin film with a higher phase velocity than that of the substrate.[1] However, the electromechanical coupling factor K^2 is reduced owing to the small piezoelectricity of an AlN thin film.

On the other hand, it has been reported that the piezoelectric coefficient of an AlN thin film can be enhanced by doping scandium (Sc) into the AlN thin film.[2] Thus, for the LLSAW, we can expect the decrease in the attenuation and the increase in K^2 simultaneously by loading with an ScAlN thin film.

In this study, we prepared ScAlN thin films using an RF magnetron sputtering system with dual long-throw sputter (LTS) cathodes (ULVAC MPS-2000) using pure Al and Sc targets. We then investigated the effect of loading an ScAlN thin film on the propagation loss (*PL*) of an LLSAW.

2. Deposition of ScAlN thin film

First, ScAlN thin films were deposited on SiO_2 substrates under the sputtering conditions shown in **Table I**. The gas ratio of Ar to N_2 and gas pressure were changed to determine the sputtering conditions for a highly oriented ScAlN thin film, and the orientation was evaluated by X-ray diffraction (XRD) analysis (Rigaku Multiflex). As an example, **Fig. 1** shows the XRD pattern of the sample deposited at a gas ratio of 12 to 8 and a gas pressure of 0.22 Pa. The broad peak of the SiO_2 substrate and the sharp peak of the ScAlN(002) plane were observed at the diffraction angles of 2θ= 15–30° and about 36° for all prepared samples.

Therefore, the deposited ScAlN thin films were determined to be *c*-axis-oriented films. When the gas ratio was 12 to 8 and the gas pressure was 0.22 Pa, the highest peak intensity was obtained.

Table I. Sputtering conditions for ScAlN thin films.

Gas pressure [Pa]	0.22–0.36
Gas ratio (Ar:N_2)	8:12, 10:10, 12:8, 14:6
Substrate heating [°C]	150
RF power (Al) [W]	150
RF power (Sc) [W]	50
N_2 radical power [W]	150
Deposition time [h]	2.0–3.5

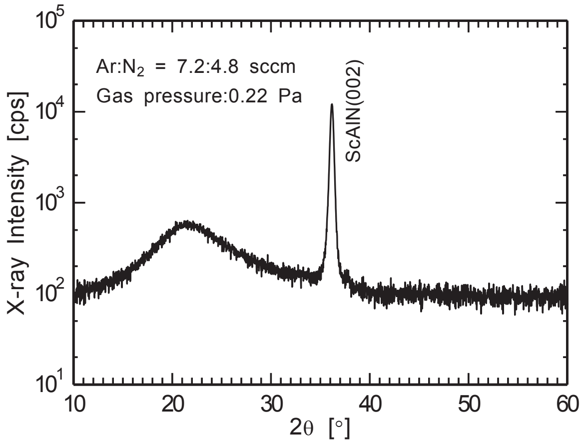

Fig. 1 XRD pattern of ScAlN/SiO_2.

The piezoelectricity of the ScAlN thin film was evaluated using an interdigital transducer (IDT) fabricated on the deposited thin film and measuring a SAW property. However, no SAW excitation was observed. Although the cathode power of the Sc target increased to 150 W, the result was not improved.

Then, ScAlN thin films were deposited on *R*-plane sapphire(*R*-Al_2O_3), (100) and (111) plane silicon ((100)Si and (111)Si), and (100)Si substrates with an oxidation surface layer (SiO_2/(100)Si) substrates. For the *R*-Al_2O_3 and (100)Si substrates, a polycrystalline ScAlN thin film and an amorphous ScAlN thin film were deposited, respectively. On the other hand, the preferentially *c*-axis-oriented ScAlN thin films were obtained on (111)Si and SiO_2/(100)Si substrates. From these results, it was

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found that the orientation of an ScAlN thin film is affected by the lattice plane of the substrate.

Input and output IDTs having the parameters shown in **Table II**, which were fabricated on samples by photolithography using an Al film, and the piezoelectricity of ScAlN thin films were evaluated by measuring a SAW property. **Table III** shows the film thickness h/λ, the degree of orientation, and K^2 of ScAlN thin films on each substrate. The SAW excitation was observed except in the amorphous sample. However, K^2 was lower than 0.1%.

The composition of the deposited ScAlN thin film was analyzed by Rutherford backscattering spectroscopy. It was found that the Sc content of the thin film was about 24%. The reported K^2 of the ScAlN thin film was 1.3% when the Sc content of the ScAlN thin film was 22%.[3] The Sc content of the thin films prepared in this study was not very small. It was considered that the direction of polarization in the ScAlN thin film was not uniformed.

3. Evaluation of LLSAW propagation property

Although no large piezoelectricity of the ScAlN thin film was obtained, we investigated the effect of loading with the $Sc_{0.24}Al_{0.76}$ thin film on *PL* of a LLSAW. First, the IDTs shown in Table II were fabricated, and then an ScAlN thin film was deposited under the optimum sputtering conditions on an *X*-cut 36° *Y*-propagation $LiNbO_3$ (*X*-36°*Y* LN) substrate. The film thickness *h* was determined to be 0.25 λ.[1]

Figure 2 shows the frequency responses between the input and output IDTs measured for finger pairs *N* of 15 and the propagation length *L* of 100 λ. The insertion loss *IL* for the sample with the thin film was about 22 dB less than for the sample without the thin film.

Table II. IDT parameters.

Al thickness [Å]	1,200
Wavelength λ [μm]	4.8
Finger pairs *N*	15, 30
Propagation length *L* [λ]	10, 25, 50, 100
Propagation path	Metallized

Table III. Properties of ScAlN thin films.

Substrate	Orientation	h/λ	K^2 [%]
R-Al_2O_3	Polycrystalline	0.37	0.081
(111)Si	*c*-axis	0.29	0.065
(100)Si	Amorphous	0.21	—
SiO_2/(100)Si	*c*-axis	0.21	0.081

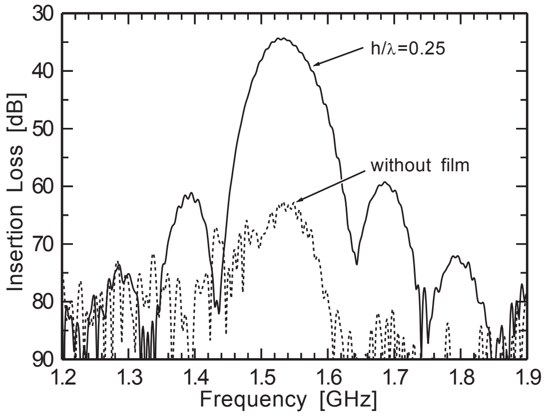

Fig. 2 Frequency responses.

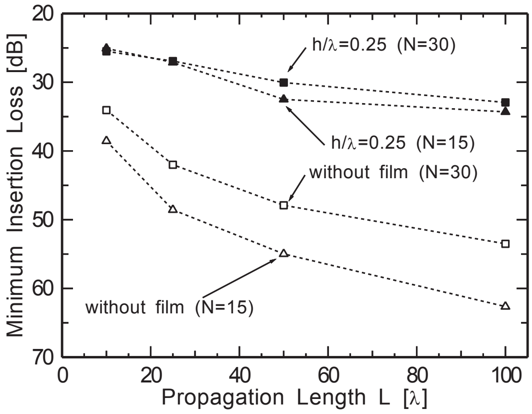

Fig. 3 Minimum insertion loss vs propagation length.

Figure 3 shows the minimum *IL* as a function of *L*. The *PL* was determined to be the slope from 10 λ to 100 λ; the *PL* was reduced from 0.25 and 0.20 dB/λ for the sample without the film to 0.10 and 0.08 dB/λ for that with the film for each *N* of 15 and 30.

4. Conclusions

In this study, first ScAlN thin films were prepared using an RF magnetron sputtering system with dual LTS cathodes, and then the LLSAW propagation properties on *X*-36°*Y* LN with the $Sc_{0.24}Al_{0.76}$ thin film were investigated. The preferentially *c*-axis-oriented $Sc_{0.24}Al_{0.76}$ thin film was obtained; however, the K^2 of this sample was lower than the reported value. The loss reduction of an LLSAW by loading with a $Sc_{0.24}Al_{0.76}$ thin film was observed. As the next step, we will investigate more optimum sputtering conditions for obtaining an ScAlN thin film with a large piezoelectricity.

References

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