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Giant electromechanical coupling in c-axis oriented ScAlGaN films
巨大圧電性 (0001) ScAlGaN 薄膜

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1. Introduction

III nitride materials such as AlN, GaN and InN have been used for a light-emitting diode. A quantum confinement stark effect (QCSE), which causes the decrease in luminance efficiency, occurs due to the piezoelectric fields. Decrease of recombination probability of electrons and holes is induced by QCSE. In addition, piezoelectric fields at heterostructure interface between GaN and AlGaN result in the high carrier density in the 2D electron gas, which make it possible to realize a heterostructure field-effect transistor (HEFT) with high current density. Piezoelectricity of the III nitride material is important for these device performances.

Althogh piezoelectricity of GaN is small, large piezoelectricity in Sc doped GaN was predicted by a first principle calculation[1)]. Experimental piezoelectric properties of ScGaN film have not yet been reported.

We previously reported on the fabrication of c-axis oriented ScAlN film by Sc ingot sputtering method. Electromechanical coupling coefficient k_t value increased with increasing Sc concentration in the film. The highest k_t was estimated to be 0.35 in Sc 43% doped ScAlN film[2)]. The value is 1.2 times as high as that of an AlN single crystal film.

In this study, we prepared ScAlGaN film and AlGaN film by using Sc ingot sputtering method. k_t values of films were estimated.

2. Fabrication of ScAlGaN films

Ga ingots were melted on Al dish in vacuum to prepare AlGa target. 0.045 g -0.054 g Sc ingots (Kojundo Chemical Laboratry, 99% purity) were selected, and ingots (1.0 g) were put on the Ga metal target. Ingot sputtering method makes it possible to change composition of films easily by adjusting the amount of grains on the target. c-axis oriented ScGaN film was deposited by using Sc ingot sputtering method with RF bias as shown in **Fig. 1**. Nitrogen plasma is generated around substrate by applying a RF bias, and nitrogen ion bombardment stimulates nitridation of the films.

Highly (0001) oriented Ti electrode film (100-150 nm, rocking curve FWHM value = 2.5 º) on the silica glass (25 × 50 × 0.57 mm^3) were used as the substrate. Total gas pressure was adjusted to be 0.75 Pa with Ar/N_2=2 gas. The distance from the target to the substrate was set to 24 mm. Film thickness was 5.0 μm and 2.0 μm. RF power applied to the target is 50 W and RF bias power to the substrate is 5 W. We did not bond the target to cold cathode to obtain nitride compound mode surface on Ga metal target. In additionm, pure AlGaN film was prepared under the same condition for comparison.

Stoichiometry of films were estimated by an energy depressive X-ray analyzer (JSM-7001FF, Nihon denshi). Table I shows Sc /Al/ Ga atomic concentration in ScAlGaN and AlGaN film.

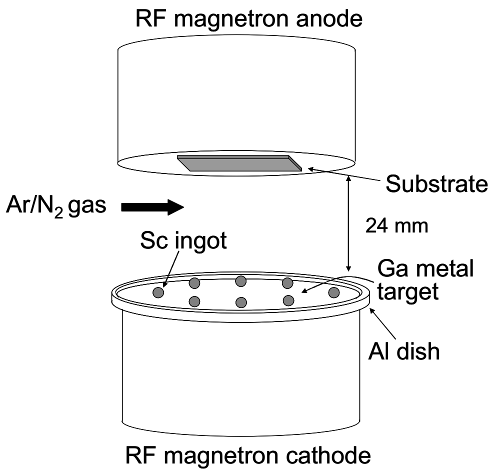

Figure 1. The diagram of Sc ingot sputtering method with RF bias system

Table I Sc /Al/ Ga atomic concentration in ScAlGaN and AlGaN film

	ScAlGaN	AlGaN
Sc (%)	6	---
Al (%)	36	78
Ga (%)	58	22

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3. Evaluation of crystal orientation

The crystal orientation of films was investigated by an X-ray diffraction (XRD). Figure 2 shows the XRD pattern and rocking curve of ScAlGaN film. The (0002) peak was observed around 35º. c-axis was oriented perpendicular to the substrate plane. Full width at half-maximum of rocking curve of ScAlGaN film was estimated to be 4.7º. We could not understand why the curve was split.

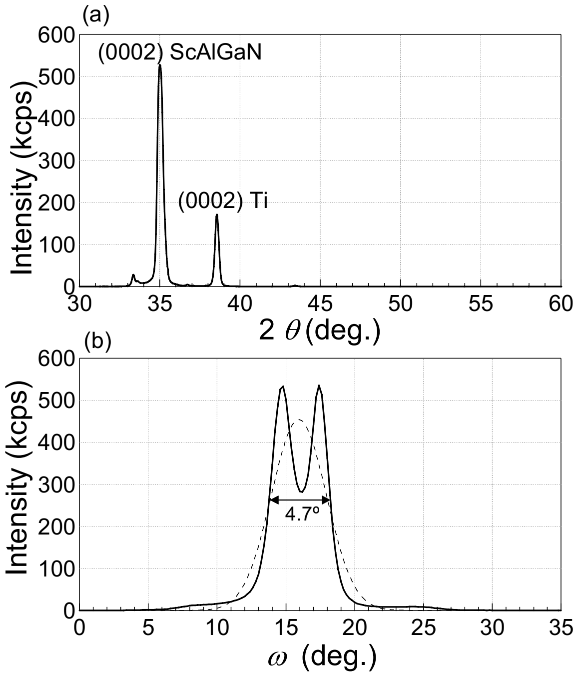

Figure 2. (a) XRD patterns and (b) rocking curve of ScAlGaN film.

4. *k* values of the ScAlGaN film

Cu (100 nm) top electrode films were deposited on suface of films, and top electrode film /piezoelectric film /bottom electrode film /substrate structure (HBAR structure) were fabricated to evaluate k_t value of the film. The value was determined by comparing experimental and theoretical conversion losses of the resonators. Experimental conversion losses were measured by a network analyzer (Agilent Technologies E5071C) with a microwave probe. Theoretical conversion loss was calculated using modified Mason's equivalent circuit model[3)]. Physical constants of ScAlGaN and AlGaN are unknown, therefore velocity of ScAlGaN in the model was assumed to be 96 % of GaN[4)]. Figure 3 shows longitudinal wave conversion losses of ScGaN film and AlGaN film. Resonance frequency was 1 GHz. k_t value of ScAlGaN film were determined to be 0.16.

It is known that k_t value of AlN is decreased by Ga doping. Our previously reported that k_t value of pure AlN film was 0.22. k_t value of AlGaN film in this study was estimated to be 0.12, which may be due to the Ga doping. Meanwhile, k_t value of pure GaN film was reported to be 0.14[5)]. In spite of its high Ga concentration, ScAlGaN film showed relatively large k_t value. As a result, we conclude that enhancement of piezoelectricity of AlGaN can be induced by the Sc doping.

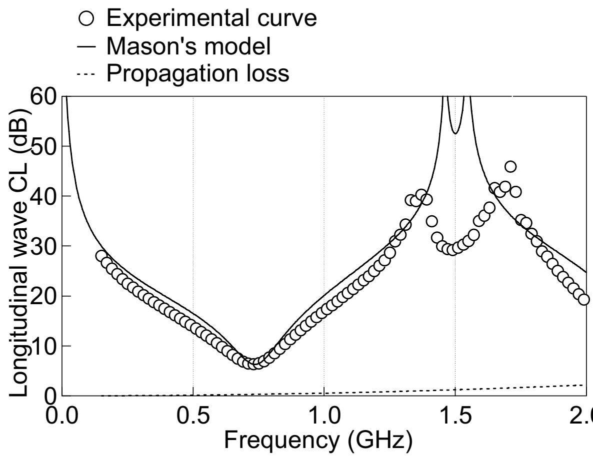

Figure 3. Experimental and theoretical shear wave conversion loss of ScAlGaN film and AlGaN film.

5. Conclusions

In this study, we prepared (0001) ScAlGaN film and (0001) AlGaN film. k_t value of ScGaN film and AlGaN film were estimated to be 0.16 and 0.12, respectively. We demonstrate enhancement of piezoelectricity by Sc doping to AlGaN film.

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