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Evaluation of Piezoelectric Ta_2O_5 Thin Films Deposited on Sapphire Substrates
サファイア基板上への圧電性 Ta_2O_5 薄膜の成膜と評価

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1. Introduction

An *X*-axis-oriented Ta_2O_5 piezoelectric thin film is a relatively new material developed by Nakagawa and has a strong piezoelectric property similar to that of ZnO thin films and a high dielectric constant.[1-3] In the deposition of *X*-axis-oriented Ta_2O_5 piezoelectric thin films using an RF magnetron sputtering system with a long-throw sputter (LTS) cathode, Kakio, one of the authors, and colleagues found the optimum deposition condition for obtaining a strong preferential (200) orientation and a high coupling factor (K^2) for the Rayleigh-type SAW (R-SAW) on synthetic fused silica (SiO_2) glass substrates,[4] and demonstrated the application of the optimum deposition condition to an FBAR using a Si substrate.[5] However, there is a problem that a large propagation loss for the R-SAW or bulk wave inhabits the oriented Ta_2O_5 thin films.

For the single crystallization of the Ta_2O_5 thin films, in which a reduction in propagation loss can be expected, an investigation involving linear rapid thermal postannealing was reported.[6,7] However, piezoelectricity vanishes owing to depolarization.

In this study, Ta_2O_5 thin films were deposited on sapphire (Al_2O_3) substrates, in which the single crystallization due to an epitaxial growth can be expected, and the crystalline and R-SAW propagation properties were evaluated.

2. Sample Fabrication

Ta_2O_5 thin films were deposited on the *c*- and R-planes of Al_2O_3 (*c*-, R-Al_2O_3) substrates using an RF magnetron sputtering system with an LTS cathode. Sputtering parameters similar to those indicated in the previous report[4] were used.

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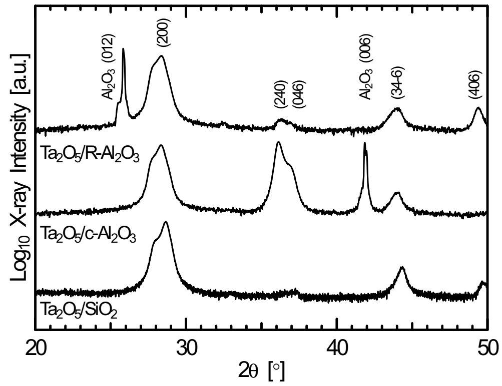

Fig. 1 XRD patterns of Ta_2O_5 thin films deposited on R-Al_2O_3, *c*-Al_2O_3 (no pretreatment), and SiO_2.

The substrate temperature T_S was set to be 800 ˚C because a large K^2 for the R-SAW on a SiO_2 glass substrate was obtained in comparison with that at T_S=700 ˚C. The deposition time was 5 h and the deposition rate was 0.68-0.75 μm/h.

For the surface pretreatment, the Al_2O_3 substrates were etched in acid (H_2SO_4:H_3PO_4 =1:3) at 80 ˚C for 1 h and then annealed in the sputtering gas (Ar:O_2=30:10 ccm, 0.75 Pa) at 800 ˚C for 1 h. Samples subjected to only annealing without pretreatment were also prepared. The film thickness *h* values are shown in **Table I** for all the conditions considered.

3. Evaluation of Crystallization

First, the degree of orientation was evaluated from X-ray diffraction (XRD) patterns using a Cu-Kα X-ray source. **Figure 1** shows the XRD patterns of the Ta_2O_5 thin films deposited on the R- and *c*-Al_2O_3 substrates without pretreatment. The XRD pattern of the Ta_2O_5 thin film deposited on the SiO_2 substrate using the same sputtering conditions

Table I Measured coupling factor K^2 and phase velocity *V* for first mode of R-SAW.

Substrate	Pretreatment	*h* (μm)	*h*/λ	K^2 (%)	*V* (m/s)
R-Y Al_2O_3 (R-plane)	No treatment	2.7	0.135	0.64	5,920
	Annealing	3.0	0.150	1.00	5,640
	Etching+annealing	2.9	0.145	0.73	5,800
Z-Y Al_2O_3 (*c*-plane)	No treatment	2.7	0.135	0.48	6,060
	Annealing	3.0	0.150	0.61	5,920
	Etching+annealing	2.9	0.145	0.78	5,720

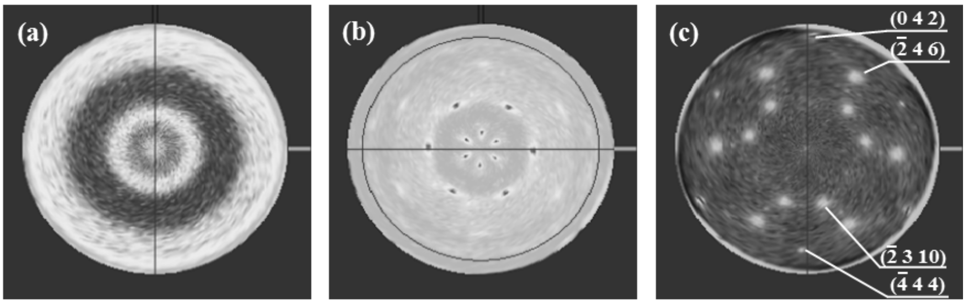

Fig. 2 Pole figures of (a) Ta_2O_5/SiO_2, (b) Ta_2O_5/c-Al_2O_3 (no pretreatment), and (c) c-Al_2O_3.

is also shown in Fig. 1. For the Ta_2O_5/R-Al_2O_3 sample, a preferential (200) orientation similar to that of the Ta_2O_5/SiO_2 sample was observed. For the Ta_2O_5/c-Al_2O_3 sample, a (240) peak was also observed. For samples with pretreatment, XRD patterns similar to that of the corresponding substrate without pretreatment were observed.

Next, the in-plane crystallinity of the Ta_2O_5 thin films was evaluated from pole figures using a Cu-Kα X-ray source (2θ=98.24°, ω=13.43°). For the Ta_2O_5/SiO_2 sample, a ring-shaped pattern was observed, as shown in **Fig. 2(a)**, because the atoms were not arranged in plane. On the other hand, for the Ta_2O_5/c-Al_2O_3 sample (no pretreatment), a spotted pattern, in which poles were arranged at the vertex of a hexagon, was observed, as shown in **Fig. 2(b)**. Since the spotted pattern was different from that of the c-Al_2O_3 substrate (**Fig. 2(c)**), the possibility of the epitaxial growth of the Ta_2O_5 thin films was observed for the first time.

4. Evaluation of SAW Properties

Interdigital transducers (IDTs) with a period λ of 20 μm and 30 single-finger pairs were fabricated on the deposited film using an Al film so that the SAW propagation direction could be set to be the Y-axis of Al_2O_3, namely, Z-Y (c-plane) and R-Y Al_2O_3. **Figure 3** shows the frequency responses of the R-Y Al_2O_3 samples. The zeroth and first modes of the R-SAW were observed for either sample. Relatively high phase velocities, which were measured from the center frequency, were obtained (approximately 6,000 m/s) for the first mode on the Al_2O_3 substrate, as shown in Table I. Unfortunately, no major improvement in the propagation loss for the zeroth mode was observed in comparison with that of the oriented film on the SiO_2 glass substrate.

The measured K^2 values of the first mode obtained from the IDT admittance are also shown in Table I. It was found that the R-Y Al_2O_3 samples had a larger K^2 than the Z-Y Al_2O_3 samples, except the etched and annealed samples. It seems that the samples with pretreatment exhibit a larger K^2 than the samples without pretreatment. However, since K^2 strongly depends on film thickness, samples should be prepared with exactly the same film thickness for each condition or experimental curves should be compared with theoretical curves. For the zeroth mode, K^2 values of 0.21-0.34% were obtained.

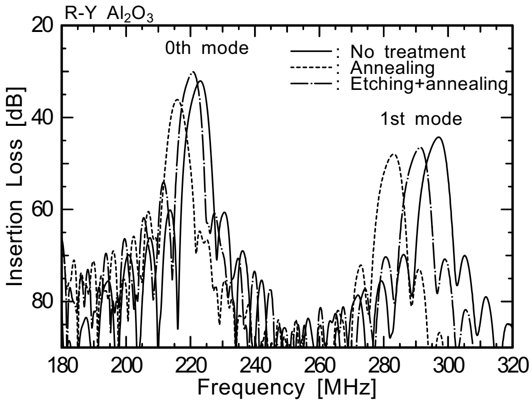

Fig. 3 Frequency responses of IDT/Ta_2O_5/R-Y Al_2O_3 samples.

5. Conclusions

Ta_2O_5 thin films were deposited on Al_2O_3 substrates. From the measured pole figure, the possibility of the epitaxial growth of the Ta_2O_5 thin films was observed for the first time. For the first mode of the R-SAW on a Ta_2O_5/R-Y Al_2O_3 sample with annealing pretreatment, a K^2 of 1.00% and a phase velocity of 5,640 m/s were obtained for a normalized thickness h/λ of 0.150. The identification of the crystal system of the Ta_2O_5 thin films and the relationship between crystallization and propagation loss will be investigated in the future.

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