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Evaluation of Piezoelectric Ta_2O_5 Thin Films Deposited on Ta Oxide Film

Ta 酸化膜上への圧電性 Ta_2O_5 薄膜の成膜と評価

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1. Introduction

An *X*-axis-oriented tantalum pentoxide (Ta_2O_5) piezoelectric thin film has a strong piezoelectric property and a high dielectric constant.[1] However, there is a problem that a large propagation loss for the Rayleigh-type SAW (R-SAW) or bulk wave occurs in the oriented Ta_2O_5 thin films.[2,3]

By utilizing the single crystallization of Ta_2O_5 thin films, a reduction in propagation loss can be expected. In the deposition of Ta_2O_5 thin films using an RF magnetron sputtering system with a long-throw sputter (LTS) cathode, we repoted that a hexiagonal Ta_2O_5 (called the δ phase, δ-Ta_2O_5[4]) thin film with (203) orientation was produced on *c*-plane sapphire (*c*-Al_2O_3) by epitaxial growth.[5] However, since δ-Ta_2O_5 belongs to the 6/*mmm* point group without piezoelectricity, no increase in coupling factor and no major improvement in propagation loss were observed.[5] On the other hand, Gnanarajan and Lam reported that an epitaxial orthorhombic twinned Ta_2O_5 film with (201) orientation was fabricated by the low-pressure thermal oxidation of epitaxial tantalum (Ta) films on the *R*-plane of sapphire (*R*-Al_2O_3) substrates.[6] However, the piezoelectricity and SAW properties were not evaluated.

In this study, for the *R*-Al_2O_3 substrate, homoepitaxial growth of the Ta_2O_5 thin film using an oxide Ta thin film (TaO_x) as a buffer layer was examined, and the crystalline and R-SAW propagation properties of the thin films were evaluated.

2. Sample Fabrication

The sample was fabricated using the RF magnetron sputtering system. First, a metal Ta thin film with a thickness of 70 nm was deposited on the *R*-Al_2O_3 substrate in an atmosphere gas of only Ar (30 ccm) at 700 ˚C, and the metal Ta thin film was oxidized in the chamber in an atmosphere gas of Ar and O_2 (30:10 ccm) for 10 min at 700 ˚C. Next, the Ta_2O_5 film was deposited on the TaO_x thin film for 6 h at 700 ˚C under similar sputtering conditions to those in the previous report[5]. The total film thickness h was 3.0 μm.

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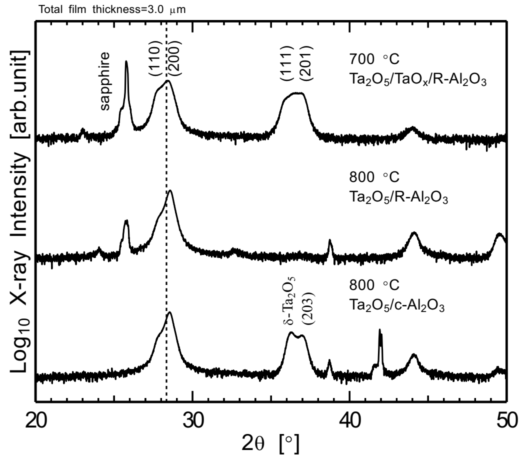

Fig. 1 XRD patterns of Ta_2O_5 thin films deposited on TaO_x/*R*-Al_2O_3, *R*-Al_2O_3, *c*-Al_2O_3.

3. Evaluation of Crystallization

First, the degree of orientation was evaluated from X-ray diffraction (XRD) patterns using a CuKα X-ray source. **Figure 1** shows the XRD pattern of the Ta_2O_5/TaO_x/*R*-Al_2O_3 sample and the plane directions of orthorhombic Ta_2O_5 (called the β phase, β-Ta_2O_5). For comparison, the XRD patterns of the Ta_2O_5 thin films with h of 3.0 μm deposited on *R*-Al_2O_3 and *c*-Al_2O_3 substrates without buffer layer using the same sputtering conditions (800 ˚C) were also shown in Fig. 1.

The preferential (200) orientation was observed for each sample. On the other hand, for the Ta_2O_5/TaO_x/*R*-Al_2O_3 sample, a peak at approximately 2θ=37˚ was observed. There was no peak at approximately 37˚ for the Ta_2O_5/*R*-Al_2O_3 sample without buffer layer. A peak at approximately 37˚ of the Ta_2O_5/*c*-Al_2O_3 sample without buffer layer corresponds to the diffraction angle of the (203) plane of the δ-Ta_2O_5.[5]

Next, the in-plane crystallinity of the Ta_2O_5 thin film was evaluated from transmission electron microscopy (TEM) diffraction patterns. **Figure 2** shows the TEM patterns. The *R*-Al_2O_3 sample with the TaO_x buffer layer was observed like a four-fold symmetry pattern [Fig. 2(a)]. It was different from the *R*-Al_2O_3 sample without buffer layer, in which a ring-shape pattern was observed [Fig. 2(b)]. Therefore, there is a possibility that a part of the Ta_2O_5 film was crystallized by using the TaO_x buffer layer.

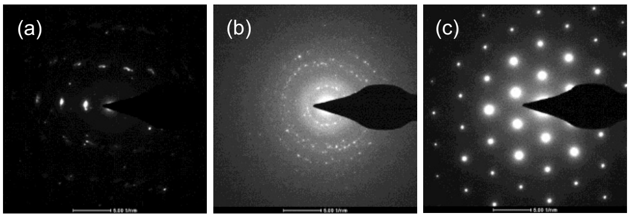

Fig. 2 TEM patterns of Ta_2O_5 thin films deposited on (a) TaO_x/R-Al_2O_3, (b) R-Al_2O_3, (c) c-Al_2O_3.

On the other hand, the pattern of the R-Al_2O_3 sample with buffer layer was also different from the c-Al_2O_3 sample, in which a six-fold symmetric pattern was observed [Fig. 2(c)]. Furthermore, the peak at approximately 37° in the XRD pattern of the Ta_2O_5/TaO_x/R-Al_2O_3 sample in Fig. 1 corresponds to the diffraction angle of the (111) and (201) planes of the β-Ta_2O_5 (2θ=36.67°, 37.05°).

From the above results, the possibility of the homoepitaxial growth of the β-Ta_2O_5 on TaO_x buffer layer was demonstrated. However, from the bright-field image obtained by TEM, a polycrystalline structure with various grain sizes was observed in the Ta_2O_5 thin film of the Ta_2O_5/TaO_x/R-Al_2O_3 sample.

4. Evaluation of SAW Properties

Interdigital transducers (IDTs) with a period λ of 20 μm and 30 double-finger pairs were fabricated on the deposited film using an Al film so that the SAW propagation direction could be set as the Y-axis of Al_2O_3, namely, R-Y and Z-Y (c-plane) Al_2O_3. The propagation length between the center of the input and that of the output IDT was 80 λ.

The frequency responses of each sample with h/λ=0.150 measured using a network analyzer were shown in **Fig. 3**. The zeroth and first modes of the R-SAW were observed for the each sample. The insertion loss IL of the Ta_2O_5/TaO_x/R-Al_2O_3 sample was significantly larger than those of the samples without the TaO_x buffer layer because the Ta_2O_5 thin film deposited on the TaO_x buffer layer was a polycrystalline thin film.

Figure 4 shows the coupling factor K^2 measured from the admittance of the IDT. For the Ta_2O_5/TaO_x/R-Al_2O_3 sample, the enhancement of K^2 can be expected because β-Ta_2O_5 must have piezoelectricity. However, as also shown in Fig.4, the K^2 values of the Ta_2O_5/TaO_x/R-Y Al_2O_3 sample with h/λ=0.150 were approximately half that of the Ta_2O_5/R-Y sample. This was considered to be due to the polycrystalline structure of the Ta_2O_5 thin film on the TaO_x buffer layer.

On the other hand, for the first modes on R-Y and Z-Y Al_2O_3 samples, the value of K^2 of 1.8 % and the phase velocity of approximately 5,000 m/s were obtained at h/λ=0.225. Furthermore, it was found that the Ta_2O_5/R-Y Al_2O_3 samples had a larger K^2 than the Ta_2O_5/Z-Y Al_2O_3 samples. This is because the X-axis-oriented Ta_2O_5 thin film and the (203)-oriented δ-Ta_2O_5 thin film were mixed in the deposited thin film on the Z-Y Al_2O_3 substrate.

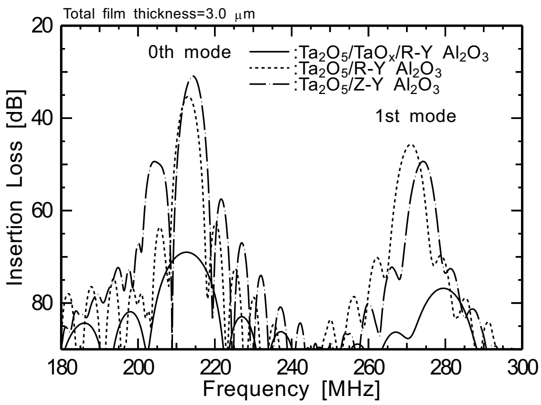

Fig. 3 Frequency responses of each sample with h/λ=0.15.

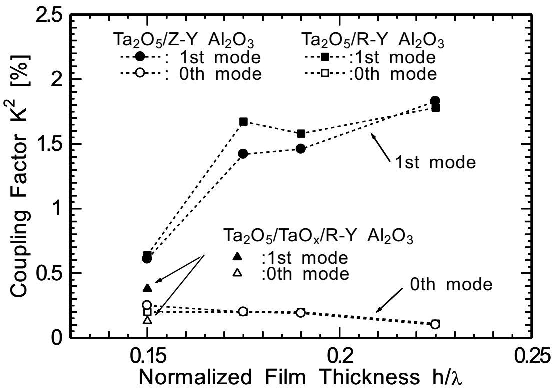

Fig. 4 Measured coupling factor K^2 values.

5. Conclusion

For the R-Al_2O_3 substrate, homoepitaxial growth of the Ta_2O_5 thin film using the TaO_x buffer layer was examined, and the crystalline and R-SAW propagation properties of the thin films were evaluated. The possibility that a part of the Ta_2O_5 film was crystallized to the orthorhombic β-Ta_2O_5 with piezoelectricity due to the homoepitaxial growth was demonstrated. Unfortunately, no major improvement in propagation properties was observed upon the crystallization because the Ta_2O_5 thin film on the TaO_x buffer layer was polycrystalline structure.

References

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