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Evaluation of Piezoelectric Ta_2O_5 Thin Films Deposited on $SrTiO_3$ Substrates

チタン酸ストロンチウム基板上への圧電性Ta_2O_5薄膜の成膜と評価

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1. Introduction

An *X*-axis-oriented tantalum pentoxide (Ta_2O_5) piezoelectric thin film has a strong piezoelectric property and a high dielectric constant.[1] Kakio, one of the authors, and colleagues found the optimum deposition conditions for obtaining a strong preferential (200) orientation and a high electromechanical coupling factor K^2 for a Rayleigh-type surface acoustic wave (R-SAW) on a synthetic fused silica (SiO_2) glass substrate. However, a large propagation loss (*PL*) for the R-SAW or bulk wave occurs in an oriented Ta_2O_5 thin film.[2,3] By utilizing single-crystal Ta_2O_5 thin films, a reduction in *PL* can be expected. Our group previously reported the fabrication of crystalline Ta_2O_5 thin films on sapphire substrates by epitaxial growth.[4] However, the reduction of *PL* has not been confirmed.

In this study, strontium titanate ($SrTiO_3$:STO) substrates were used for epitaxial growth because the lattice constant of STO is close to that of orthorhombic Ta_2O_5 (β-Ta_2O_5), which has piezoelectricity.[5] The epitaxial growth of β-Ta_2O_5 using an STO substrate was examined, and the crystallinity and R-SAW propagation properties of the samples were evaluated.

2. Sample Fabrication

Ta_2O_5 thin films were deposited on STO(100) and STO(110) substrates using an RF magnetron sputtering system with a long-throw sputter cathode under the sputtering conditions shown in **Table I**. A SiO_2 substrate was also used for comparison. **Figure 1** shows the process of sample fabrication. First, without applying O_2 radical power, a Ta_2O_5 thin film having a thickness of approximately 0.3 μm was deposited as a buffer layer so that the Ta_2O_5 thin film was not preferentially oriented along *X*-axis. Next, with the O_2 radical power set to 150 W to obtain a piezoelectric Ta_2O_5 thin film, a Ta_2O_5 epitaxial thin film having a thickness of approximately 3.3 μm was deposited. The total film thickness *h* was 3.6 μm.

3. Evaluation of Crystallinity

First, the degree of orientation was evaluated from X-ray diffraction (XRD) patterns using a CuKα X-ray source. **Figure 2** shows the XRD patterns of a Ta_2O_5/STO(100) sample (A), a Ta_2O_5/STO(110) sample (B), and a Ta_2O_5/SiO_2 sample (C). Compared with the diffraction intensity of the Ta_2O_5(200) plane of sample (C), those of samples (A) and (B) are about 6 and 25 times higher, respectively. Therefore, it was found that highly oriented Ta_2O_5 thin films can be deposited on STO substrates. However, the diffraction angles 2θ corresponding to the (200) plane of samples (A) and (B) are different from that of the Ta_2O_5/SiO_2 sample (C). The difference is considered to be due to the in-plane lattice arrangement, as mentioned later. Moreover, the Ta_2O_5 thin film of sample (B) was observed to have two lattice plane spacings around the (200) plane. In addition, since the strongest peaks of the (200) plane of samples (A) and (B) appeared at a lower diffraction angle than that of the Ta_2O_5/SiO_2 sample (C), there is a possibility that the piezoelectricity of samples (A) and (B) is lower than that of the Ta_2O_5/SiO_2 sample.[2]

Next, the in-plane crystallinity of the Ta_2O_5 thin films was evaluated by using a pole figure plot. **Figure 3** shows the measured pole figures of these samples. Poles corresponding to {201} were observed for samples (A) and (B). Regarding the symmetry of the poles, samples (A) and (B) have a fourfold symmetrical peak and a twofold symmetrical peak respectively, while sample (C) has a ring-shaped pattern. It is considered that sample

Table I. Sputtering conditions for Ta_2O_5 thin films.

Gas ratio (Ar : O_2)	30 : 10
Gas pressure [Pa]	0.75
Substrate heating [°C]	800
RF power (Ta) [W]	150
O_2 radical power [W]	0 → 150
Total deposition time [h]	4.2

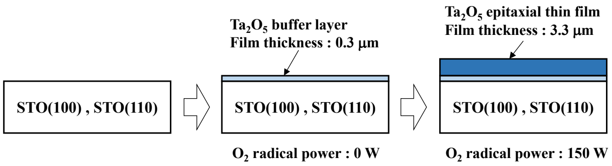

Fig. 1 Process of sample fabrication.

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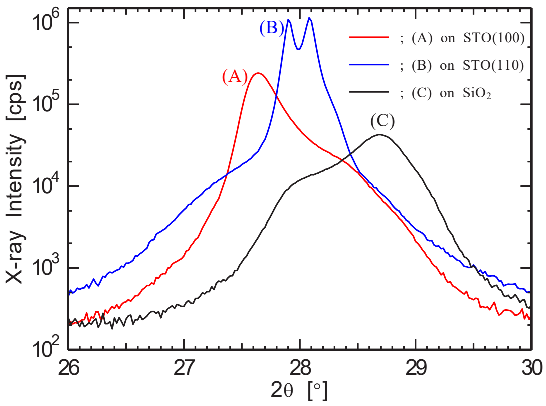
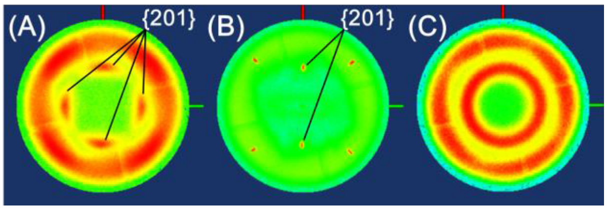


Fig. 2 XRD patterns of Ta_2O_5(200) plane.



(A) STO(100), (B) STO(110), and (C) SiO_2 samples.

Fig. 3 Pole figures.

(A) has two lattice arrangements orthogonal to each other and sample (B) has a single arrangement. On the other hand, sample (C) has no in-plane lattice arrangement.

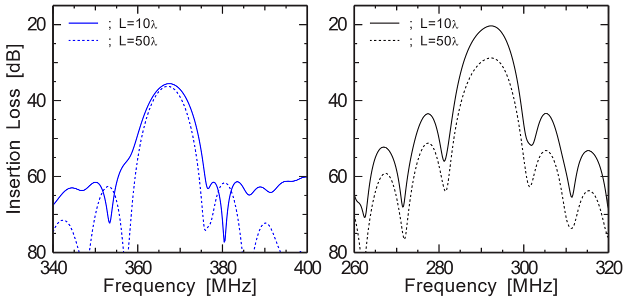
From the above results, the possibility of the homoepitaxial growth of β-Ta_2O_5 on an STO substrate was demonstrated. In particular, it was found that a high-crystallinity Ta_2O_5 thin film was deposited on the STO(110) substrate.

4. Evaluation of SAW properties

Interdigital transducers (IDTs) with a period λ of 8 μm and N=30 finger pairs were fabricated on the above samples by photolithography using an Al film, then the piezoelectricity and propagation properties of the Ta_2O_5 thin films were evaluated by measuring the R-SAW propagation properties.

The frequency responses of these samples with h/λ=0.45 were measured using a network analyzer. **Figure 4** shows the frequency responses of samples (B) and (C), and **Figure 5** shows the minimum insertion loss *MIL* as a function of the propagation length *L* of these samples. The *PL* of the zeroth mode were measured from the *MIL* vs *L* relationships to be 0.11 dB/λ for sample (A), 0.02 dB/λ for sample (B), and 0.21 dB/λ for sample (C). Therefore, the Ta_2O_5 thin films deposited on the STO substrates had a smaller *PL* than the Ta_2O_5/SiO_2 sample. However, the *MIL* values of samples (A) and (B) were larger than that of sample (C).

The coupling factor K^2 was measured from the admittance of the IDTs. For samples (A) and (B), the enhancement of K^2 can be expected because β-Ta_2O_5 has piezoelectricity. However, the K^2 values of samples (A) and (B) were about 0.1%, while that of sample (C) was 0.87%. Therefore, although the crystallinity of the Ta_2O_5 thin films of samples (A) and (B) was high, the piezoelectricity was low. The low piezoelectricity of the crystalline Ta_2O_5 thin films on the STO substrates is considered to be due to the nonuniformity of the polarization direction.



(B) STO(110) sample. (C) SiO_2 sample.

Fig. 4 Frequency responses.

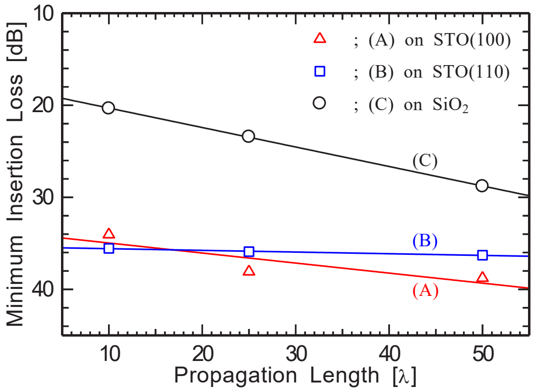


Fig. 5 Minimum insertion loss vs propagation length.

5. Conclusions

In this study, Ta_2O_5 thin films were deposited on $SrTiO_3$(100), $SrTiO_3$(110), and SiO_2 substrates using an RF magnetron sputtering system, and the crystallinity and R-SAW propagation properties of the samples were evaluated. The possibility that the Ta_2O_5 thin films were crystallized to orthorhombic Ta_2O_5 with piezoelectricity on $SrTiO_3$ substrates was demonstrated. The *PL* of Ta_2O_5 thin films deposited on $SrTiO_3$ substrates was smaller than that of the film deposited on a SiO_2 substrate; however, their piezoelectricity was lower than that of the Ta_2O_5/SiO_2 sample. As the next step, we will apply a polarization process to Ta_2O_5 thin films to enhance their piezoelectricity.

References

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