# 3Pa3-3

# Evaluation of $Ta_2O_5$ Piezoelectric Thin Film Prepared on Pt/Si Substrate at Low Deposition Rate

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## 1. Introduction

With the shift of mobile communication systems to higher frequencies and wider bandwidths, piezoelectric materials with higher velocity, higher coupling factor ($K^2$), and lower loss are required for the development of high-performance frequency filters using surface acoustic waves (SAWs) and bulk acoustic waves (BAWs). An *X*-axis-oriented tantalum pentoxide ($Ta_2O_5$) piezoelectric thin film fabricated by sputtering has piezoelectricity comparable to that of ZnO thin films and high dielectric constant[1]. The methods of depositing single-crystal $Ta_2O_5$, which is expected to have a higher $K^2$ and a lower propagation loss than the oriented thin film, have been investigated.

We deposited $Ta_2O_5$ thin films on platinum (Pt)/Si and strontium ruthenate ($SrRuO_3$) substrates (SRO/Pt/Si substrate) using an RF magnetron sputtering system. From the pole figure plots, we determined that λ-$Ta_2O_5$ without piezoelectricity grew on the Pt/Si substrate and that β-$Ta_2O_5$ with piezoelectricity grew on the SRO/Pt/Si substrate. In addition, the $Ta_2O_5$ thin film was crystallized to a greater extent at a lower deposition rate (0.4 μm/h). The $Ta_2O_5$ thin film formed at a normal deposition rate (0.8 μm/h) to a film thickness of 6.5 μm was dominated by the *X*-axis-oriented film and exhibited a larger $k_t^2$ than the epitaxial film[2].

In this study, we examined the crystal structure and bulk acoustic wave (BAW) propagation properties of $Ta_2O_5$ thin films prepared at low deposition rates on Pt/Si and SRO/Pt/Si substrates.

## 2. Deposition of $Ta_2O_5$ thin films and evaluation of crystallinity

$Ta_2O_5$ thin films were deposited on Pt(100)/Si and SRO/Pt/Si substrates using an RF magnetron sputtering system[1] at a substrate temperature of 700°C (thickness $h_t$: 7.0 μm). The degree of orientation of the samples was evaluated from X-ray diffraction (XRD) patterns. The XRD patterns measured for the two samples are shown in **Fig. 1**. For both samples, the preferential orientation of monoclinic $Ta_2O_5$(100) was observed. However, the $Ta_2O_5$/Pt/Si sample shows a weak peak near 37°, which was not observed for the *X*-axis-oriented $Ta_2O_5$ films, indicating that the $Ta_2O_5$ epitaxial thin film was grown governed by the lattice plane of Pt, as in the case of the normal deposition rate[2]. On the other hand, for the $Ta_2O_5$/SRO/Pt/Si sample, no peak was observed around 37°, and the growth of an epitaxial film could not be determined from the XRD pattern.

Then, the fluctuation of the plane orientation was evaluated by measuring rocking curves using the same X-ray diffractometer. The measured rocking curves of the two samples are shown in **Fig. 2**. The full widths at half-maximum (FWHMs) corresponding to the $Ta_2O_5$(200) peak for the $Ta_2O_5$/Pt/Si and $Ta_2O_5$/SRO/Pt/Si samples were 4.9° and 6.9°, respectively, which are smaller than those of the *X*-axis-oriented $Ta_2O_5$ films. Therefore, there is the possibility of the growth of epitaxial film in both samples, as in the case of the normal deposition rate[2].

The in-plane crystallinity of the $Ta_2O_5$ thin films was evaluated on the basis of pole figure plots. The diffraction angle 2θ of the multipurpose X-ray diffractometer was set to 37°. The measured pole figures of the two samples are shown in **Fig. 3**. The peaks were observed on the same circumference at the tilt angles χ=40° and 69°. These peaks correspond to β-$Ta_2O_5$(201) and β-$Ta_2O_5$(111)[3], respectively. The peak intensity at $h_t$=7.0 μm was higher than that at $h_t$=2.6 μm, indicating that crystallinity improves with increasing film thickness, unlike in the case of at the normal deposition rate.

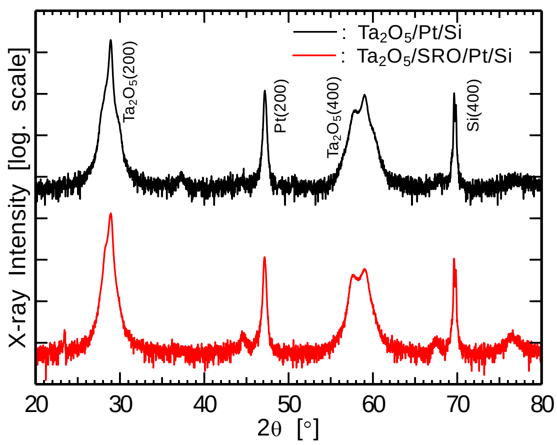


Fig. 1 XRD patterns of $Ta_2O_5$/Pt/Si and $Ta_2O_5$/SRO/Pt/Si samples.

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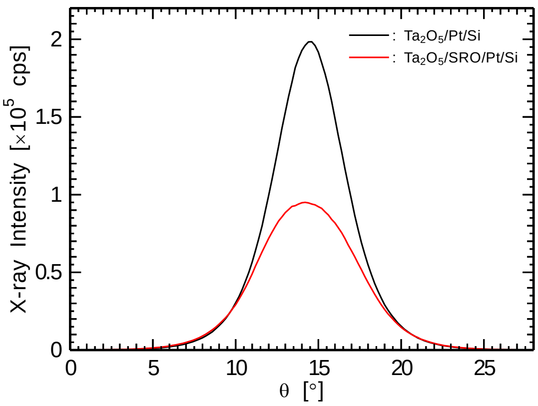


Fig. 2 Measured rocking curves of $Ta_2O_5$/Pt/Si and $Ta_2O_5$/SRO/Pt/Si samples.

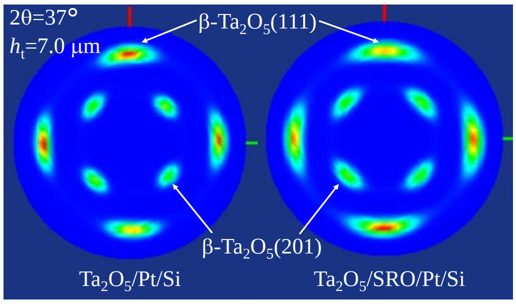


Fig. 3 Measured pole figures of $Ta_2O_5$/Pt/Si and $Ta_2O_5$/SRO/Pt/Si samples.

## 3. Evaluation of BAW propagation property

The properties of high-overtone bulk acoustic resonators (HBARs) were evaluated. The HBAR evaluated had a top electrode of Au film deposited on the above samples and a bottom electrode of Pt. The measured conversion loss and the theoretical value after equivalent circuit fitting of HBARs are shown in **Fig. 4**. **Table I** shows the phase velocity ($v$) and electromechanical coupling factor ($k_t^2$) values determined by fitting a theoretical curve calculated using Mason's equivalent circuit model[4].

$v$ was 5,200 m/s for both samples, and $k_t^2$ values were 0.96% and 1.44% for the $Ta_2O_5$/Pt/Si and $Ta_2O_5$/SRO/Pt/Si samples, respectively. Both $k_t^2$ values were larger than that of the $Ta_2O_5$/SRO/Pt/Si sample deposited at a normal rate, in which the *X*-axis-oriented film was dominant. The larger $k_t^2$ with improved crystallinity suggested that a film mainly composed of β-$Ta_2O_5$ was deposited.

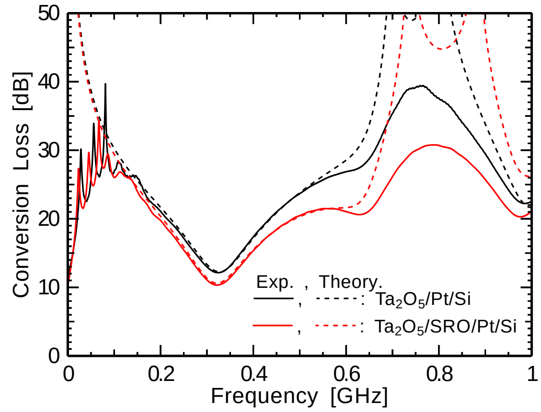


Fig. 4 Frequency responses of HBARs.

## 4. Conclusions

The piezoelectric $Ta_2O_5$ thin films were deposited on Pt/Si and SRO/Pt/Si substrates at low rates using an RF magnetron sputtering system. The orientation and BAW propagation properties were evaluated.

For low deposition rates, β-$Ta_2O_5$ grew on both Pt/Si and SRO/Pt/Si substrates. In both cases, the crystallinity improved with increasing film thickness. This result was different from the films deposited at normal deposition rate: λ-$Ta_2O_5$ grew on the Pt/Si and *X*-axis-oriented $Ta_2O_5$ became dominant on SRO/Pt/Si substrate in thicker films.

The evaluated results of HBAR response indicated that the epitaxially grown β-$Ta_2O_5$ films deposited at a low deposition rate exhibited larger $k_t^2$ values than those of the samples with *X*-axis-orientation owing to the higher crystallinity.

## Acknowledgements

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## References

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Table I BAW propagation properties of $Ta_2O_5$/Pt/Si and $Ta_2O_5$/SRO/Pt/Si samples.

| Sample | Deposition rate | $Ta_2O_5$ film thickness | Phase velocity $v$ [m/s] | Electromechanical coupling factor $k_t^2$ [%] |
|---|---|---|---|---|
| $Ta_2O_5$/Pt/Si | Low | 7.0 | 5,200 | 0.96 |
| $Ta_2O_5$/SRO/Pt/Si | Low | 7.0 | 5,200 | 1.44 |
| $Ta_2O_5$/SRO/Pt/Si[2] | Normal | 6.5 | 5,000 | 0.56 |