Fabrication and Evaluation of Highly Oriented Ta$_2$O$_5$ Piezoelectric Thin Films Prepared by RF-Magnetron Sputtering

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1. Introduction

For the development of high-performance piezoelectric devices, such as surface acoustic wave (SAW) and film bulk acoustic resonator (FBAR) devices, piezoelectric thin films with high coupling, high stability, low loss, and high frequency are required. An X-axis-oriented Ta$_2$O$_5$ piezoelectric thin film is a relatively new material developed by Nakagawa, one of the authors, and has a strong piezoelectric property similar to that of ZnO thin films and a high dielectric constant.$^{1,2}$ Investigations on the preparation conditions to improve the properties have been carried out.$^{3,5}$

The authors reported that, the X-axis-oriented Ta$_2$O$_5$ piezoelectric thin films were deposited on a SiO$_2$ substrate using an RF-magnetron sputtering system with a metal Ta target and an O$_2$-radical source.$^6$ It was found that supplying the RF power to O$_2$-radical source markedly enhanced the preferential (200)-axis orientation, increased the electromechanical coupling factor ($K^2$), and reduced the surface roughness. However, a reduction of the piezoelectric property was observed as the deposition rate decreased due to a consumption of the Ta target.

In this paper, the Ta$_2$O$_5$ thin films were deposited under a condition of a low target consumption and the orientation and the $K^2$ were clearly observed. When the O$_2$ flow rate of 10 ccm, the preferential (200)-axis orientation was not observed.

In this paper, the Ta$_2$O$_5$ thin films were deposited on Si and MgO substrates. These structures can be expected to be used for an FBAR device and to have a higher phase velocity, respectively.

2. Sputtering parameters of Ta$_2$O$_5$ thin films

Figure 1 shows the configuration of the RF-magnetron sputtering system with long-throw sputter (LTS) cathodes and the O$_2$-radical source used for the deposition of the Ta$_2$O$_5$ thin film on SiO$_2$, Si(100), and MgO(100) substrates.

The sputtering parameters are shown in Table I. A metal Ta target with 50 mm diameter was used and the distance between the target and the substrate was 100 mm. The substrate temperature $T_S$ was varied from 650°C to 750°C. The RF power applied to the cathode and the radical source was 150 W. The Ar atmosphere gas flow rates for the two cathodes with/without the target were 30:3 ccm, respectively, and the O$_2$ flow rate of the O$_2$-radical source was varied from 6 to 10 ccm, while the atmosphere gas pressure was fixed to 0.75 Pa. The deposition time was 5 h and the deposition rate ranged from 0.50 to 1.29 µm/h.

3. Deposition on SiO$_2$ substrate

The degree of orientation was evaluated from X-ray diffraction (XRD) patterns using a Cu-K$_\alpha$ X-ray source. Figure 2 shows the XRD pattern of sample (c) with $T_S$ of 700°C and the O$_2$ flow rate of 10 ccm. The preferential (200)-axis orientation was clearly observed. When the O$_2$ flow rate was varied from 6 to 10 ccm, the major change in the orientation was not observed.

Interdigital transducers (IDTs) with a period $\lambda$ of 20 µm and 30 single-finger pairs were fabricated on the deposited film using an Al film. The $K^2$ for the

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Rayleigh-type SAW was evaluated from the measured admittance property using network analyzer. The measured $K^2$ corresponding to the above-mentioned sputtering parameters are shown in Table II and Fig. 3. For a comparison, the reported values of $K^2$ using a DC-diode sputtering system are also shown in Fig. 3. The deposition rate decreased as the O$_2$ flow rate increased. The $K^2$ for sample (c) with $T_s$ of 700°C and the O$_2$ flow rate of 10 ccm was measured to be 0.88% and was about 75% of the reported value. In addition, the values of $K^2$ of the sample (d) with 650°C and (e) with 750°C were 0.29% and 0.35%, respectively. The piezoelectric property was observed at least in this temperature range. These values were 50–60% of reported values. However, there is possibility to be included the effect of the target consumption because the deposition rate was relatively low.

4. Deposition on Si(100) substrate

The Ta$_2$O$_5$ thin film was deposited on Si(100) using the same sputtering parameter as sample (c). The XRD pattern of sample (f) is shown in Fig. 2. The full width at half maximum of the peak (FWHM) was less than half of that of the thin film deposited on SiO$_2$ (c). The measured $K^2$ was 0.26%.

5. Deposition on MgO(100) substrate

The Ta$_2$O$_5$ thin film was deposited on MgO(100) as sample (g) in the same way. As shown in Fig. 2, the FWHM of the (200) peak was slightly less than that of sample (c). The $K^2$ for the 1st mode of the Rayleigh-type SAW was measured to be 1.42% and was 1.6 times larger than that for the 0th mode of sample (c) with almost the same film thickness. The measured phase velocities for the 0th and 1st modes were 3,694 and 5,126 m/s, respectively. The latter was about twice of that for the 0th mode of sample (c).

6. Conclusions

The X-axis-oriented Ta$_2$O$_5$ piezoelectric thin films were deposited using an RF-magnetron sputtering system. When the SiO$_2$ substrate temperature was 700°C and the O$_2$ flow rate was 10 ccm, the measured $K^2$ was about 75% of the reported value. In the deposition on Si(100), the higher orientation was observed. Moreover, for the 1st mode of the Rayleigh-type SAW on the Ta$_2$O$_5$/MgO(100), the $K^2$ of 1.42% and the phase velocity of 5,126 m/s were obtained for the normalized thickness $h/\lambda$ of 0.225.

References