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Fabrication and Evaluation of Highly Oriented Ta_2O_5 Piezoelectric Thin Films Prepared by RF-Magnetron Sputtering
高周波スパッタリング法による高配向 Ta_2O_5 圧電薄膜の作製と評価

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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_2O_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_2O_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_2O_5 thin films were deposited under a condition of a low target consumption and the orientation and the K^2 for the Rayleigh-type SAW were evaluated. In addition, the Ta_2O_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_2O_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_2O_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.

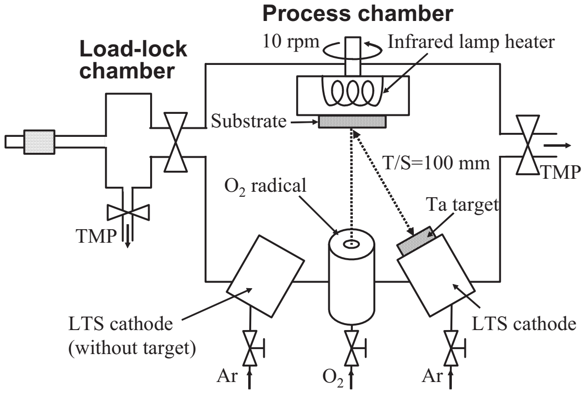

Fig. 1 Configuration of RF-magnetron sputtering system.

Table I Sputtering parameters.

Substrate	SiO_2, Si, MgO
Substrate temperature (˚C)	650 ~ 750
Gas flow rate, Ar : Ar : O_2 (ccm)	30 : 3 : 6 ~ 10
Gas Pressure (Pa)	0.75
Target-substrate distance T/S (mm)	100
Target power (W)	150
O_2-radical power (W)	150
Deposition time (h)	5
Film thickness (μm)	2.50 ~ 6.45
Deposition rate (μm/h)	0.50 ~ 1.29

3. Deposition on SiO_2 substrate

The degree of orientation was evaluated from X-ray diffraction (XRD) patterns using a Cu-Kα 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 λ 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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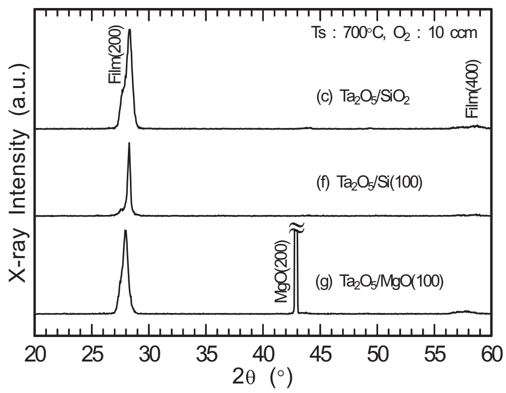

Fig. 2 XRD patterns of Ta_2O_5 thin films deposited on (c) SiO_2, (f) Si and (g) MgO.

Table II Measured coupling factor K^2.

	Substrate	Ts (°C)	O_2 (ccm)	h (μm)	h/λ	K^2 (%)
(a)	SiO_2	700	6	6.45	0.323	0.94
(b)	SiO_2	700	8	5.40	0.270	0.93
(c)	SiO_2	700	10	4.20	0.210	0.88
(d)	SiO_2	650	10	2.71	0.136	0.29
(e)	SiO_2	750	10	2.84	0.142	0.35
(f)	Si	700	10	2.50	0.125	0.26
(g)	MgO	700	10	4.50	0.225	0.23 1.42*

*1st mode

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[2] 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_2O_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%.

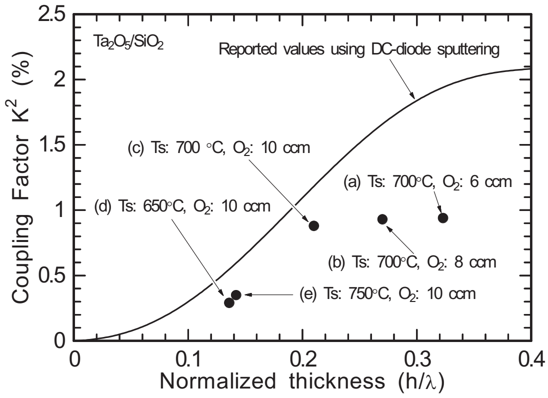

Fig. 3 Measured coupling factor K^2 of IDT/Ta_2O_5 thin film/SiO_2 samples.

5. Deposition on MgO(100) substrate

The Ta_2O_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_2O_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_2O_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/λ of 0.225.

References

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