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Deposition of Highly Oriented Ta_2O_5 Piezoelectric Thin Films on Silicon for Fabricating Film Bulk Acoustic Resonator Structure by RF Magnetron Sputtering

Ta_2O_5 薄膜/Si 基板を用いた圧電薄膜共振子の作製

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1. Introduction

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. The orientation and Rayleigh-type SAW properties such as electromechanical coupling factor (K^2) were evaluated. Substrate temperature and O_2 flow rate dependence were investigated, and optimum sputtering condition was obtained.[6] In addition, the Ta_2O_5 thin films were deposited on Si and MgO substrates[7]. These structures can be expected to be used for an film bulk acoustic resonator (FBAR) device and to have a higher phase velocity, respectively.

In this paper, the FBAR using Ta_2O_5 thin film/Si substrate structure was fabricated and the resonant characteristic was evaluated.

2. Deposition on Si Substrate

Figure 1 shows the configuration of the RF-magnetron sputtering system with long-throw sputter (LTS) cathodes and the O_2-radical source. The sputtering parameters were the same as reported previously.[6] The substrate temperature T_S and the Ar/O_2 flow rate were 700˚C and 33:10 ccm, respectively.

It was necessary to form a silicon oxide film on a Si substrate as an etch stop layer before the Ta_2O_5 thin film was deposited so that the FBAR structure could be fabricated by Si anisotropic etching. Therefore, the orientation and piezoelectricity of the Ta_2O_5 thin film deposited on the silicon oxide film formed on Si substrate were evaluated and compared with those of a sample using an unprocessed Si substrate.

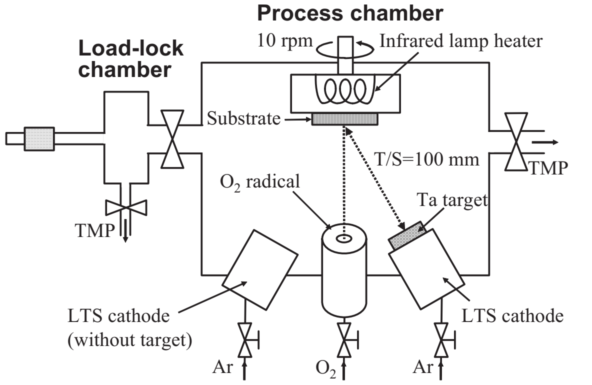

Fig. 1 Configuration of RF-magnetron sputtering system.

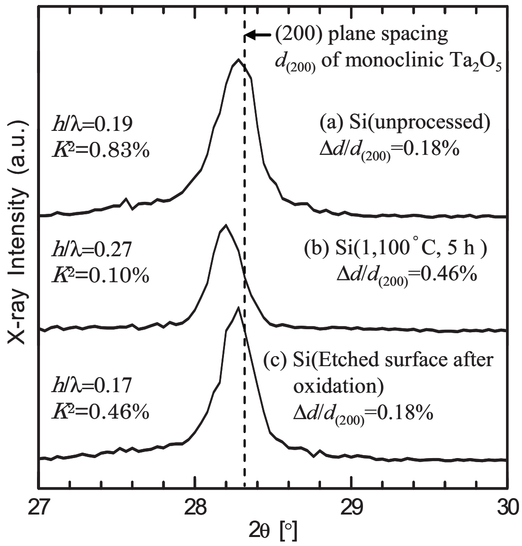

Fig. 2 XRD patterns of Ta_2O_5 thin film.

First, a silicon oxide film with a thickness of 900 nm was formed on the upper and lower surfaces of a Si(100) substrate (300 μm thickness) by heating at 1,100˚C for 10 h in a wet O_2 atmosphere. Next, a Ta_2O_5 thin film of 5.4 μm thickness was deposited on the substrate under optimum sputtering conditions[6]. The degree of orientation was evaluated from X-ray diffraction (XRD) patterns using a Cu-Kα X-ray source. 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. K^2 for the Rayleigh type SAW was evaluated from the measured admittance property using a network

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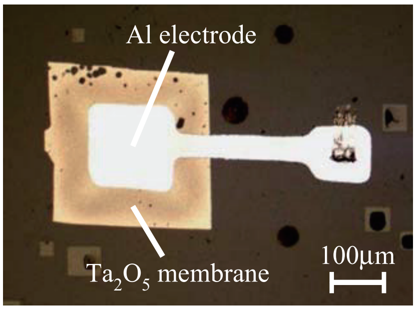

Fig. 3 Microscope image for FBAR sample.

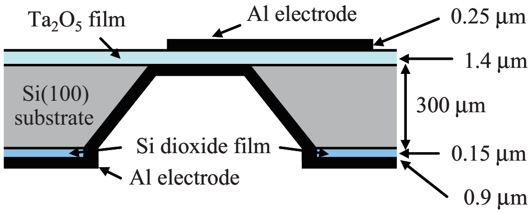

Fig. 4 Cross section view of FBAR sample.

analyzer.

Figure 2 shows XRD patterns of the sample using the unprocessed Si substrate (a) and the sample using a Si substrate with the silicon oxide film (b). The (200) peak of sample (b) appeared at a smaller diffraction angle than that of the (200) plane of monoclinic Ta_2O_5. As also indicated in Fig. 2, the measured K^2 of sample (b) was smaller than that of sample (a). The similar phenomenon of the piezoelectricity decreasing when the (200) plane spacing slightly increases was observed for the deposition of a Ta_2O_5 thin film on a SiO_2 substrate.[6]

Therefore, a process in which the Ta_2O_5 thin film itself was used as an etch stop layer was adopted because the Ta_2O_5 thin film was confirmed to be not etched by a solution of potassium hydroxide (KOH) at 50°C, which was used for anisotropic etching. Thus, the silicon oxide film formed on the upper surface was completely etched using room -temperature buffered hydrogen fluoride (BHF) after the silicon oxide film was formed. The Ta_2O_5 thin film was deposited on the exposed Si surface to form sample (c). A smaller shift of the diffraction angle of the (200) peak and greater piezoelectricity than those of sample (b) were observed, as shown in Fig. 2. These fabrication conditions were adopted for fabricating an FBAR structure in the next section.

3. Fabrication of FBAR Using Ta_2O_5/Si Structure

First, a Ta_2O_5 thin film with 1.4 μm thickness was deposited on an exposed Si surface after etching the silicon oxide film on the upper surface. Next, Ta_2O_5 thin film diaphragms of 300×300 μm^2 area were fabricated by first etching an array of square windows of 550×550 μm^2 in the silicon oxide film on the lower surface using room-temperature BHF for 30 min and then selective Si etching using KOH solution at 50°C for 40 h until the Ta_2O_5 thin film was reached. Finally, an Al film was deposited on the upper/lower surfaces as electrodes. The upper electrode (Ta_2O_5 thin film side) was fabricated so that the size of the electrode matched the membrane, and a feeding electrode pad with a busbar was then fabricated. **Figures 3 and 4** show a microscope image and a cross-section view of the FBAR sample, respectively.

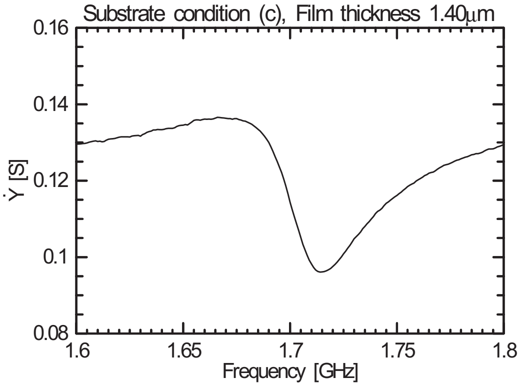

Fig. 5 Admittance property of FBAR sample.

Figure 5 shows the measured admittance property of the FBAR sample using a network analyzer. Although the admittance ratio was small (3.0 dB), a resonance response corresponding to a longitudinal bulk wave with a phase velocity of approximately 4,700 m/s was observed at 1.7 GHz. The coupling factor k_t^2 was evaluated to be 7.0% from the resonance and antiresonance frequencies.

4. Conclusions

An FBAR with a Ta_2O_5 thin film/Si substrate structure was fabricated. The resonant characteristic was observed at 1.7 GHz for the sample, which had a film thickness of 1.4 μm. The coupling factor k_t^2 and the admittance ratio were measured to be 7.0% and 3.0 dB, respectively.

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