Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp276-277

Sputtered $Pb(Zr,Ti)O_3$ piezoelectric films for MEMS application

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1. Introduction

Ferroelectric materials based on lead, such as lead zirconate titanate (PZT), have been intensively investigated for application in MEMS devices such as actuator and sensors, since they have large piezoelectric coefficients and electromechanical coupling coefficients, which may further enhance the performance of sensing and actuation devices. These applications require reliable manufacture worthy thin-film process technologies that are new-frontier technical fields for the perovskite ceramic oxides and high value of piezoelectric coefficient e_{31} for good performance of MEMS devices. Furthermore, in actuator devices, since driving voltage is high, higher breakdown voltage is required. One of the difficulties in PZT film deposition by sputtering method is to keep the stability in the lead content which is volatile element and deposition rate with the passage of sputtering time. Another would be how to obtain higher piezoelectric coefficient e_{31} and higher breakdown voltage of PZT film for high-performance device. In this paper, some key technologies for perovskite oxide thin-film production including production tool technologies, their performances of sputtering, and improvement of properties of PZT film will be introduced.

2. Experimental Procedure

A multi-chamber type mass production sputtering systems for electronic devices SME-200E (ULVAC) equipped with an exclusive sputtering module was used. When insulating PZT film adhered to the shields of the ground potential, charge-up occurred, the impedance of the system changed, plasma was pushed to the center of the chamber, exposure to plasma was enhanced, and as a consequence, Pb content within film is reduced. As shown in Fig.1, in order to stabilize the status of plasma, we installed a stable anode, that is, an anode that avoided charge-up due to the adhesion of insulating PZT film and maintained the role as an anode [1]. We also note that *post in-situ treatment* [2] has been recently established, aiming to improve crystalline quality and piezoelectric coefficient in our PZT films.

PZT films have been deposited on 8inch diameter $Pt(111)/TiO_X/SiO_2/Si$ substrates. The PZT films were deposited under Ar/O_2 mixed gas atmosphere of 0.5 Pa. Substrate temperature was heated up to 550°C. PZT films were deposited with relatively high growth rate about 3.8 μm/h and these thicknesses was 2.0 μm. The ceramic target with Zr/Ti ratio of 52/48, in which 30 mol% excess PbO was added for the compensation of the lead re-evaporation from the films, was used in order to obtain PZT films near the stoichiometric composition. After the PZT deposition, top electrode 100 nm-thick Pt was deposited by the dc sputtering method to measure electrical and piezoelectric properties.

For the measurement of the piezoelectric properties of the PZT films, Rectangular beams (cantilevers) with the size of about 25 mm (2.5 cm) × 3 mm short title 9 were prepared. Displacement in these films was simultaneously observed using the laser doppler vibrometer (Graphtec AT-3600) which was attached to a ferroelectric test system.

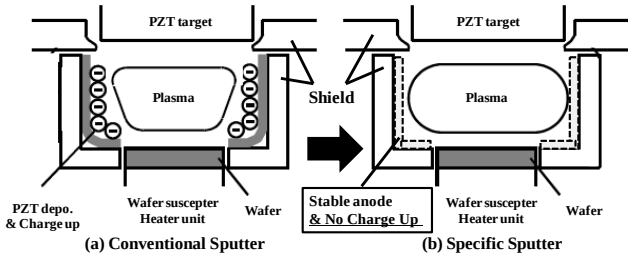

Figure 1. Before and after installation of stable anode.
(a)Conventional Sputter (b) Specific Sputter

Table1. Sputtering condition of PZT

Sputtering tool	SME-200E (ULVAC,Inc)
Target	$Pb(Zr_{0.52}Ti_{0.48})O_3$,300φ
RF POWER	2.5kW
Temperature	580 deg.C
Deposition rate	3.8 μm/h
Thickness	2.0 μm
Substrate	8-inch $Pt/TiOx/SiO_2/Si$

3. Results and Discussions

Fig.2 shows relationship between Pb composition and repeatability. As can be seen from the fig.3, the change in the Pb composition was 1.0±0.6% and uniformity of within wafer was less than ±0.6% by the evaluation until end of target life (total wafer; 400 pieces). Fig.3 shows relationship between deposition rate and repeatability. The change in the deposition rate was 3.8 μm/h±1.4% and uniformity of within wafer was less than ±3% by the evaluation until end of target life (total wafer;400 pieces). As a result that a stable anode was installed, stability of Pb content and deposition rate within film in continuous sputtering has been confirmed.

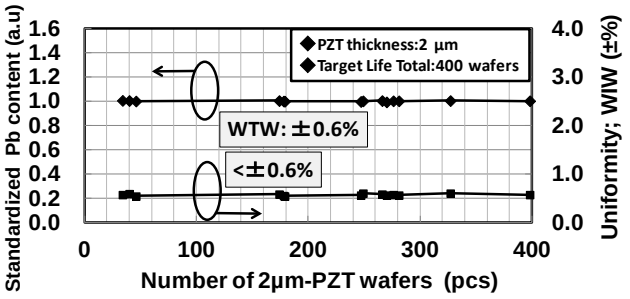

Figure 2. Stable transition of Pb content within film in continuous sputtering

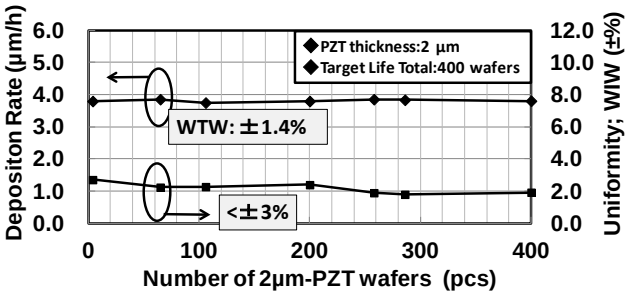

Figure 3. Relationship between deposition rate and repeatability by the evaluation until end of target life.

Fig.4 shows film thickness dependence of crystalline property of PZT film deposited on 8-inch Pt/TiOx/SiO_2/Si substrate of (a) 1 μm (b) 2 μm (c) 3 μm. In all film thickness, the pyrochlore phase cannot be detected, and PZT film oriented PZT(001)/(100) preferably. As film thicknesses of PZT increased, peak intensity of PZT(110) became weak. It was reported that there was close relationship between crystal orientation and the piezoelectric coefficient of PZT film, and the piezoelectric coefficient e_{31} of PZT(001)/(100) oriented was larger than that of PZT(110) and PZT(111) oriented [3, 4, 5].

Fig.5 shows film thickness dependence of piezoelectric coefficient of PZT film. PZT film thickness increased, piezoelectric coefficient became high. This result was corresponding to the crystal orientation of PZT film as shown in Fig.4. In a film thickness of 3um, it was confirmed that the piezoelectric coefficient was -18.8 C/m^2, which is remarkably improved compared to e_{31} of -8.4 C/m2 as previously reported [6].

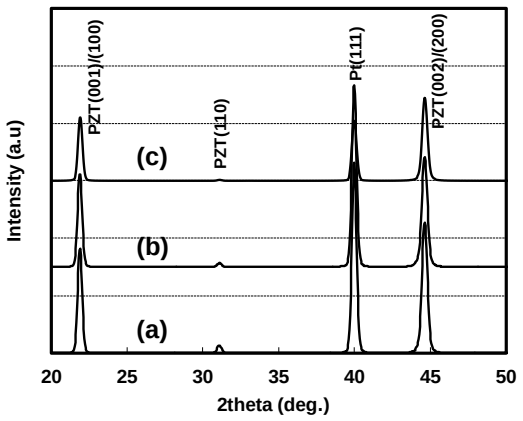

Figure 4.Film thickness dependence of crystalline property of PZT film deposited on 8-inch Pt/TiOx/SiO_2/Si substrate.
(a) 1 μm (b) 2 μm (c) 3 μm

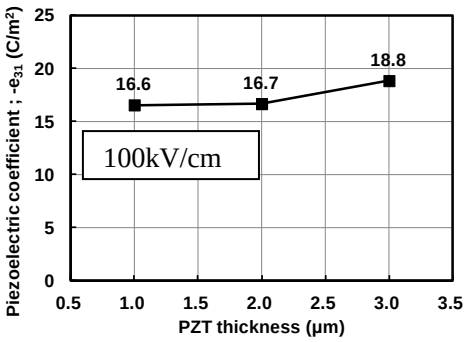

Figure 5. Film thickness dependence of piezoelectric coefficient of PZT film deposited on 8-inch Pt/TiOx/SiO_2/Si substrate.

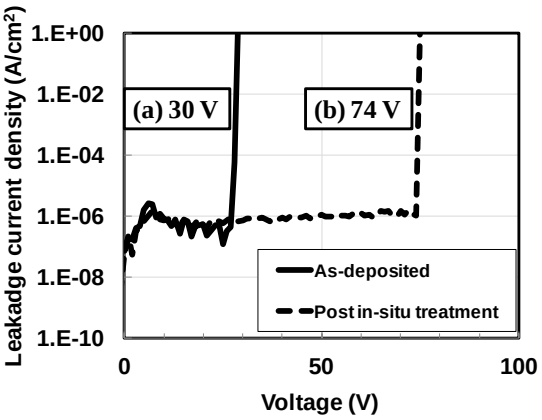

Figure 6. Breakdown voltage of 2 μm-PZT film.
(a) as-deposited (b)post in-situ treatment.

Fig.6 shows breakdown voltage of 2 μm-PZT film of (a) as-deposited (b) post in-situ treatment. Breakdown voltage of PZT film was improved to 74 V from 30 V by post in-situ treatment.

4.Conclusions

In this study, PZT films were deposited on 8-inch substrate using mass productive sputtering tool. The results obtained in this study are as follows; (1) As a result that a stable anode was installed, stability of Pb content and deposition rate within film in continuous sputtering and (2) very high piezoelectric coefficient e_{31} of -18.8 C/m^2 and high breakdown voltage of 74 V was achieved.

We have established both mass production capability and advanced process capability to realize MEMS application such as actuator and sensors.

References

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