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Study of a Sr_2RuO_4 thin film in a PZT device as a top electrode for application as a piezoelectric sensor

Gye-Youg Lee[a], Dong-Guk Cho[a], Caroline Sunyong Lee[a,*] and Moon-gi Jeong[b]

[a]*Hanyang University, Division of Materials and Chemical Engineering, Ansan, 426-791, Korea*
[b]*LG Electronics Institute of Technology, Devices and Materials Laboratory, Seoul 137-724, Korea*

This study evaluates the properties of a lead zirconium titanate (PZT) capacitor using a top electrode of strontium rutanate (SRO). Sr_2RuO_4 has similar properties to that of $SrRuO_3$ that has been previously studied but Sr_2RuO_4 was not used in PZT capacitors due to the difficulties to grow it as a thin film. In this study, Sr_2RuO_4 was used as a top electrode for a PZT capacitor and its phase was verified using XRD. Moreover, it was found from SEM analysis that interfaces between Sr_2RuO_4 and PZT was much smoother than the interface between PZT and RuO_2 which has conventionally been used as a top electrode in a PZT capacitor. Finally, the hysteresis curve using SRO as a top electrode showed that the curve was well saturated despite of its small remnant polarization value. Therefore, this PZT capacitor using SRO as a top electrode showed good potential to be used as a sensor.

Key words: SRO(Strontium rutanate), PZT(Lead zirconate titanate) capacitor, Top electrode, Hysteresis curve, Sr_2RuO_4.

Introduction

The electrodes of lead zirconium titanate (PZT) devices provide the means by which electrical energy is delivered by the piezoelectric effect. There have been studies of electrodes that could improve the piezoelectric effect of these devices [1-4]. Usually, a metal is used as an electrode material because it has high electrical conductivity. However, one problem with metal electrodes is the diffusion of oxygen from the PZT to the metal which causes a problem with fatigue. This can result in a change in the PZT structure since the oxygen concentration is reduced. Recent efforts to resolve this problem have involved using alternative top electrodes such as RuO_2, $SrRuO_3$, and IrO_2 [1-6].

In this study, Sr_2RuO_4(SRO) has been tried as a top electrode to replace the conventional top electrode. SRO has been considered as a possible top electrode for PZT because its lattice constant is 4.04 Å for both a and b, and these values are very similar to that of RuO_2 which is 4.49 Å. $SrRuO_3$ is being considered as an electrode material for PZT capacitors because of its similar lattice constants. Moreover, $SrRuO_3$ has a pseudo-cubic perovskite structure with a lattice constant of 3.91 Å and a similar structure to that of PZT. In this study, Sr_2RuO_4 which has a lattice constant of 3.87 Å is being considered as a top electrode for PZT capacitors and a good interfacial property is expected due to very similar lattice constants to that of PZT. As shown in Fig. 1, Sr_2RuO_4 exhibits relatively good conductivity. Moreover, Sr_2RuO_4 is thermally stable even at 1200 K [7, 8, 9]. Regardless of these good reasons for its choice, development of Sr_2RuO_4 as a top electrode has been delayed due to difficulties of its film growth.

*Corresponding author:
Tel : +82-31-400-5221
Fax: +82-31-417-3701
E-mail: sunyonglee@hanyang.ac.kr

Experimental procedures

To study Sr_2RuO_4 as a top electrode for a PZT capacitor, a simple structure of a PZT capacitor was fabricated using the process flow shown in Fig. 2.

First, a 20-nm-thick Ti adhesion layer followed by a 100-nm thick Pt bottom electrode was deposited on a Si wafer. Then a 200-nm-thick layer of PZT was coated on this structure using a sol-gel method, and a 100-nm-thick layer of SRO was deposited at 450 °C. The target used for sputtering was $SrRuO_3$. Finally, the PZT with its top electrode was patterned using a dry etching method.

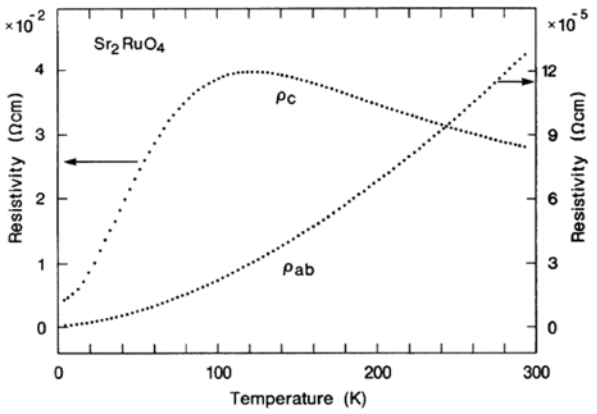

Fig. 1. Resistivity of Sr_2RuO_4 [7].

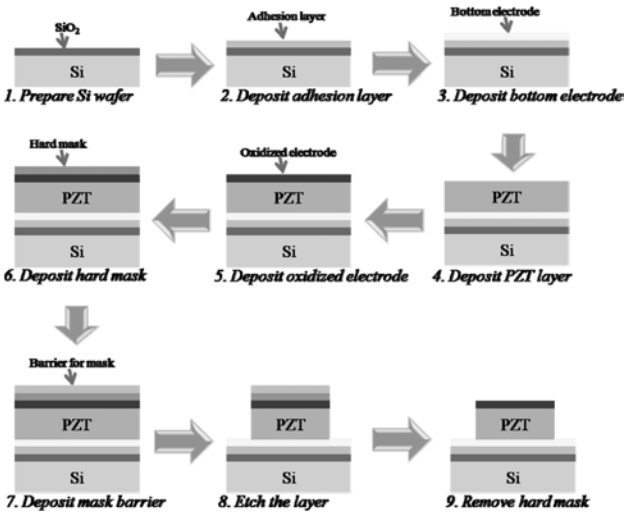

Fig. 2. Process flow for sample fabrication.

After that, this structure was annealed for 10 minutes at 600 °C for phase stabilization. Fig. 3 shows an optical image of the fabricated PZT capacitor. The area of the top electrode was approximately 6.4 cm^2. XRD was used to detect the phase in the SRO layer. SEM was used to observe the interface between SRO and PZT. A TF analyzer 1000 (aixACCT, Inc.) was used to study the hysteresis curve of the PZT capacitor to determine whether SRO can be used as a top electrode or not, and to detect any sign of PZT degradation.

Results and Discussion

Fig. 4 shows the XRD results to verify the phase of Sr_2RuO_4 thin film which was deposited on PZT film. As shown on the left hand side of Fig. 4(a), the peak for Sr_2RuO_4 was not detected due to the comparatively large peaks for Si and Pt. However, when these peaks were magnified by 400x as shown on the left hand side of Fig. 4(b), a peak for Sr_2RuO_4 was detected. Since XRD detects the peak from crystallized materials using X-rays and the relative peak gives an indication of the amount of a particular phase, the

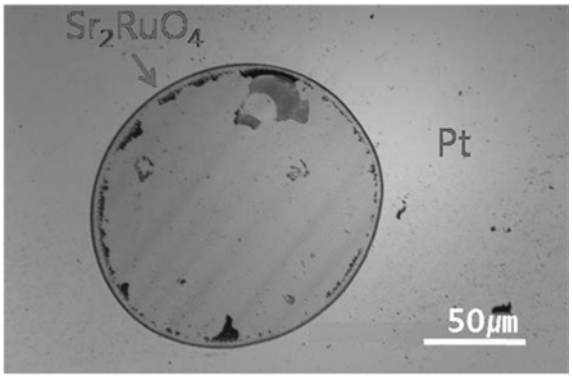

Fig. 3. Optical image of a PZT capacitor using Sr_2RuO_4 as the top electrode (top view).

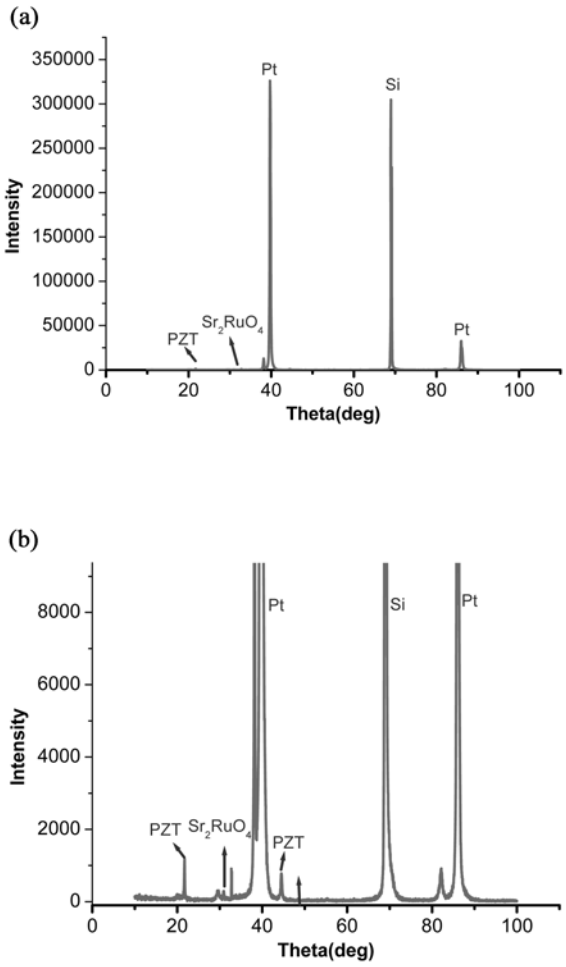

Fig. 4. XRD data of Sr_2RuO_4; (a) as and (b) peaks magnified by 400X.

detection of a peak indicates the presence of a phase regardless of its small intensity. Therefore, thin film deposition of Sr_2RuO_4 was verified successfully. Although a $SrRuO_3$ target was used for the deposition, Sr_2RuO_4 was obtained mainly because this film was deposited at 450 °C while the stable formation of $SrRuO_3$ is at 500 °C [14].

Fig. 5(a) shows an SEM image of a RuO_2 top electrode which has been conventionally used as a top electrode [10] and Fig. 5(b) shows a cross section of a Sr_2RuO_4 thin film which was deposited over a PZT film. As shown in Fig. 5, RuO_2 showed columnar growth and a distinct interface between the RuO_2 and PZT layer was observed. However, the interface between Sr_2RuO_4 and PZT as shown in Fig. 5(b) was hard to detect indicating that the growth of the Sr_2RuO_4 film on top of PZT film has been successful. This successful growth of Sr_2RuO_4 on the PZT film was possible due to the similar lattice constant values for PZT and Sr_2RuO_4.

Finally, a TF-analyzer was used to observe the characteristics of a PZT capacitor using Sr_2RuO_4 as the top electrode. As shown in Fig. 6, the hysteresis curve was well saturated and symmetrical with a remnant polarization value of 1.5 mC/cm^2. Moreover, this result shows that the PZT capacitor was not degraded during the fabrication

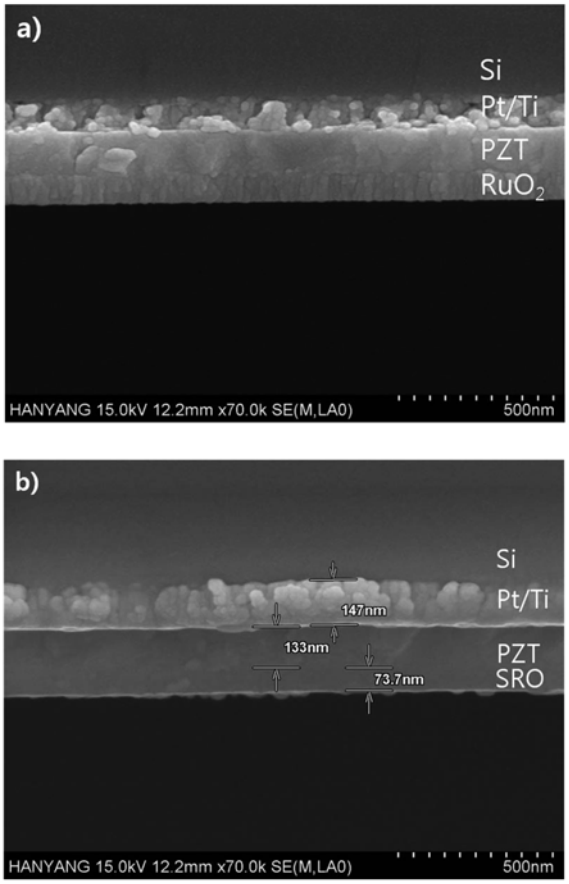

Fig. 5. SEM images (cross sectional view) of thin films deposited on a PZT capacitor; (a) RuO_2 thin film, (b) Sr_2RuO_4 thin film.

process. The small remnant polarization value is not useful for application as a PZT actuator where relatively large remnant polarization values are required. However, the symmetry of this curve is crucial for its application as a sensor where very small differences in charge generation need to be detected.

Conclusions

Several electrode materials to improve PZT capacitors have recently been studied. In this study, Sr_2RuO_4 has been evaluated as a top electrode material for a PZT capacitor by verifying its phase, observing its interface with PZT and its hysteresis curve.

As a result of the deposition from a $SrRuO_3$ target at 450 °C, a thin film Sr_2RuO_4 was obtained and from a cross-sectional view by SEM, a much smoother interface between Sr_2RuO_4 and PZT than the interface between RuO_2 and PZT was obtained. Moreover, the hysteresis curve using Sr_2RuO_4 as a top electrode was well saturated and symmetrical. The PZT capacitor was not degraded during the fabrication process. Due to its small remnant polarization values, this capacitor might not be useful as an actuator but using this capacitor as a sensor is possible due to its hysteretic properties.

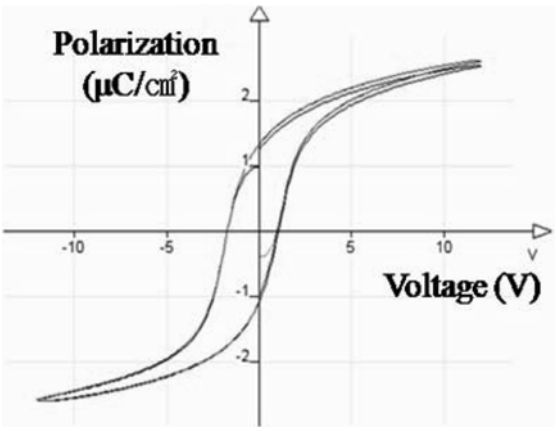

Fig. 6. Polarization-voltage (P-V) curve of a PZT cantilever using Sr_2RuO_4 as a top electrode.

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