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A novel chemical solution deposition method suitable for high-yield fabrication of 50 nm-thick $SrBi_2Ta_2O_9$ capacitors

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1. Introduction

Ferroelectric Random Access Memory (FeRAM) is one of the most promising non-volatile memories because of its high operation speed and low power consumption. Among various ferroelectric materials, $SrBi_2Ta_2O_9$ (SBT) has attracted much attention because of its fatigue-free property and low coercive field. Even in case of SBT, the ferroelectric film is required thinner than 50 nm for operation of FeRAM lower than 1 V. However, it is very difficult to form SBT capacitor with sub-50 nm in thickness[1-3], because of the short circuit problem between the top and bottom electrodes. In order to avoid the short circuit problem, we use in this study a Bi-deficient SBT layer as a protective layer for making the film surface smooth in the chemical solution deposition method, and show that SBT capacitors with about 50 nm in this thickness can be fabricated with a high yield.

2. Experiment

The first SBT layer was formed by spin-coating sol-gel solution (Mitsubishi Materials Corp.) on a $Pt/Ti/SiO_2/Si$ structure. The composition of the solution was Sr:Bi:Ta = 0.9:2.2:2. After drying it on a hotplate at 180 °C, rapid thermal annealing was conducted at 750 °C for 1 min in O_2 atmosphere. Next, the second layer was deposited and dried at 180 °C in vacuum of 5 Pa and annealed at temperatures ranging from 600 °C to 750 °C for 1 min. This layer was found to be Bi-deficient due to evaporation of Bi atoms during vacuum-drying, and the surface morphology was very smooth compare with the first layer, as shown in fig 1. After formation of Pt top-electrode, crystallization annealing was conducted for 30 min at 750 °C. During this process, excessive-Bi atoms in the first layer were found from secondary ion mass spectrometry (SIMS) to diffuse to the second layer and an SBT film with a uniform composition and smooth surface was obtained, as schematically shown in fig. 2.

3. Result and discussion

Table Ⅰ shows yields of 55 nm-thick SBT capacitors with 200 μm in the diameter of top-electrode. No ferroelectric properties were measured for 100 capacitors when the conventional method without the Bi-deficient layer was used. On the other hand, almost identical polarization vs. voltage (P-V) characteristics were obtained for 87 capacitors when the Bi-deficient top layer of about 15 nm was formed and annealed at 600 °C. The fabrication yield was found to decrease to 15 % when the second layer was annealed at 750 °C. These results suggest that the yield of SBT is strongly related to the roughness of the top surface. Figure 3 shows the P-V hysteresis and the leakage current density characteristics of a 55 nm-thick SBT film with a protective layer. As can be seen from these figures, remanent polarization (Pr) of this SBT film is 5.6 $\mu C/cm^2$, and the leakage current density at 1 V (Pr-saturation voltage) is on the order of 10^{-8} A/cm^2.

In order to further optimize the ferroelectric properties, the atomic composition in the film shown in Fig. 3 was investigated using X-ray fluorescence spectrometry (XRF). The atomic ratio was Sr:Bi:Ta = 0.9:2.01:1.97. We can see from comparison with the composition in the sol-gel solution (0.9:2.2:2) that many Bi atoms were evaporated during the vacuum drying process. Then in order to compensate the loss of Bi atoms, the atomic composition was changed to 0.9:2.4:2 and a new SBT film with 55 nm in thickness was formed using the same deposition and crystallization method, in which the atomic ratio (0.9:2.17:1.94) was close to that in the sol-gel solution used in the first experiment. Figure 4 shows P-V characteristics of two samples with the above composition ratios. As can be seen from the figure, the Pr value was enlarged from 5.6 $\mu C/cm^2$ to 8.3 $\mu C/cm^2$ and the squareness of the hysteresis loop was improved. Moreover, the saturation voltage of 1 V was unchanged, as shown in Fig. 4 (b).

Using the same method, we also succeeded in forming a 45 nm-thick SBT film, in which the Pr value was 4.0 $\mu C/cm^2$.

4. Conclusion

We proposed a novel chemical solution deposition method to form SBT thin films in which Bi-deficient top layers were formed as protective layers. In this method, the surface flatness of the film was realized using a Bi-deficient layer and the overall composition was adjusted using diffusion of Bi atoms in subsequent crystallization annealing. It is expected that 50 nm-thick SBT capacitors can be produced with a high yield using this method.

Reference

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[3] M. Lim et al., Appl. Phys. Lett. Vol. 81, 1863 (2002)

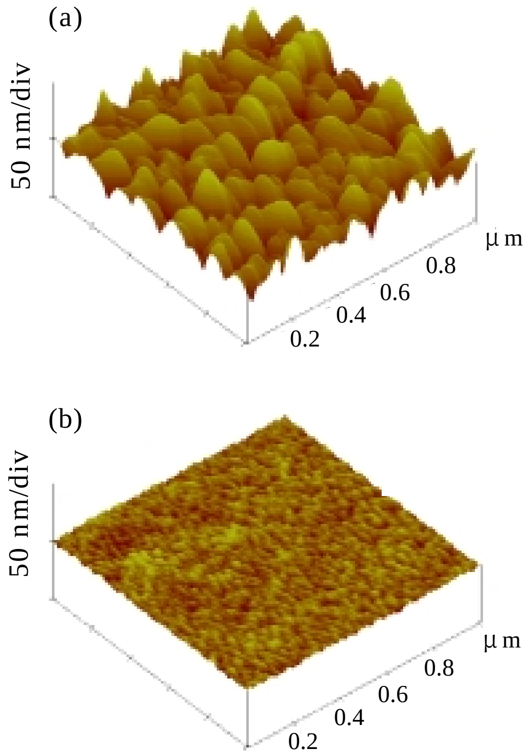

Fig. 1 AFM images of SBT film surfaces

(a) 1st layer and (b) 2nd (Bi-deficient) layer

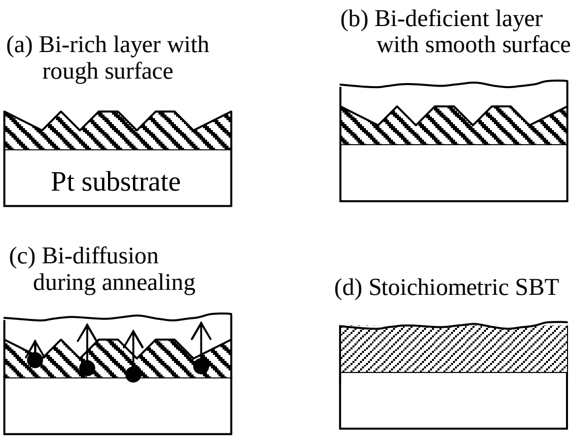

Fig. 2 Fabrication Process

Table Ⅰ. Yields of 55 nm-thick SBT capacitor with the diameter of 200 μm

SBT films	Yield of capacitor
Without protective layer (conventional method)	0/100
With protective layer (700 °C)	15/100
With protective layer (600 °C)	87/100

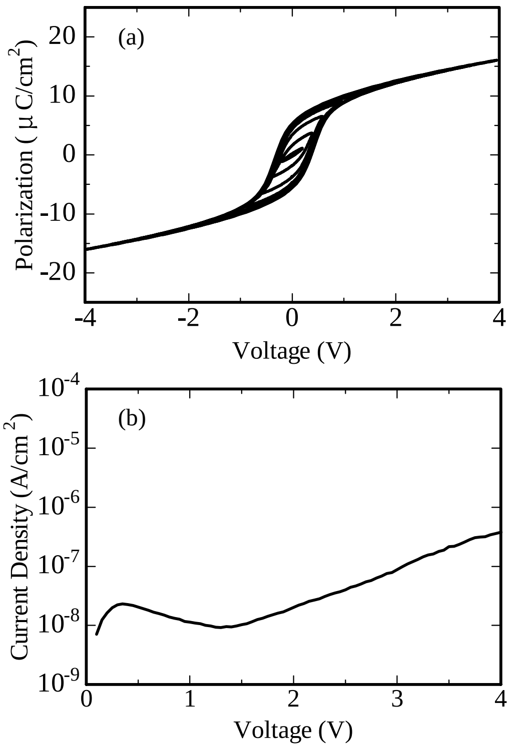

Fig.3 Electric properties of a 55 nm-thick SBT thin film

(a) P-V hysteresis loop and (b) leakage current density

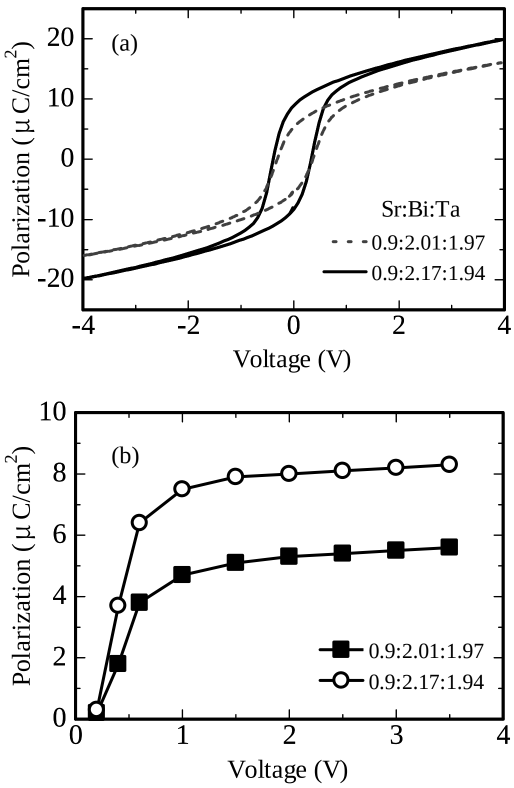

Fig.4 Bi-composition dependence of

(a) P-V hysteresis loop and (b) Pr saturation property