The Electric Conductivity $SrBi_2Ta_2O_9$ Capacitors using Rf Magnetron Sputtering Technique

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Abstract : The $SrBi_2Ta_2O_9$ thin films are deposited on Pt-coated electrode($Pt/TiO_2/SiO_2/Si$) using RF magnetron sputtering method. The ferroelectric properties of SBT capacitors with annealing temperatures were studied. Through the x-ray diffraction analysis and the scanning electron microscopy (SEM), it could be observed that crystallization of the SBT thin film started around 650℃ and complete crystallization was accomplished around 750℃and grains grew from a small spheric form to rod-like. For the leakage current density of the SBT capacitor depending upon various annealing atmospheres, capacitor annealed in the oxygen atmosphere showed the most excellent characteristic, and they were respectively about 2.13 x 10^{-9} [A/㎠] at 5V and 340.

Key Words : $SrBi_2Ta_2O_9$(SBT), thin films, RF magnetron sputtering

1. INTRODUCTION

A Bi layer-structured thin film is drawing attention as a fatigue-free film, and studies of this film are under way in many research institutions. The SBT thin film is mainly formed by coating as substrate with a solution of 2-ethylhexanatesolution, which is a carboxylate, followed by heat treatment of coating a substrate.[1] The SBT film has so far been heat treated at temperatures as high as 800℃ for 1 hour in oxygen atmosphere, which is more than 100℃ higher than the 650℃ at which PZT is heat treated.[2] Therefore lowering of the heat-treatment temperature for the SBT film is desired. Recently, some workers tried low-temperature formation of SBT films.[3] SBT thin films are knows to have a superior endurance property and a small coercive field after crystallization at high temperatures around 700-800℃.[4]

However, the crystallization process and fatigue characteristics over 10^{10} cycles have not been investigated for SBT thin films formed at lower temperatures less than 800℃ and few investigations have been directed at overcoming the problems though developmentof raw materials.[4] Here, we report microstructure and electric properties of ferroelectric $SrBi_2Ta_2O_9$ ceramics deposited on Pt-coated electrode (Pt $/TiO_2/SiO_2/Si$) substrate using RF magnetron sputtering technique.

2. EXPERIMENTAL

The SBT target was processed by mixing $SrCo_3$, Bi_2O_3, and Ta_2O_5 powders, calcining the mixed powders at 1000℃, and then pressing the calcined powders in a 2*in*. The pressed target was sintered for 1h at 1000℃ in ambient air. The composition of the ceramic target was $SrBi_2Ta_2O_9$. All substrates were thoroughly cleaned in a series of organic solvents and distilled water prior to film deposition. The detailed sputtering conditions of SBT thin films are summarized in Table1.

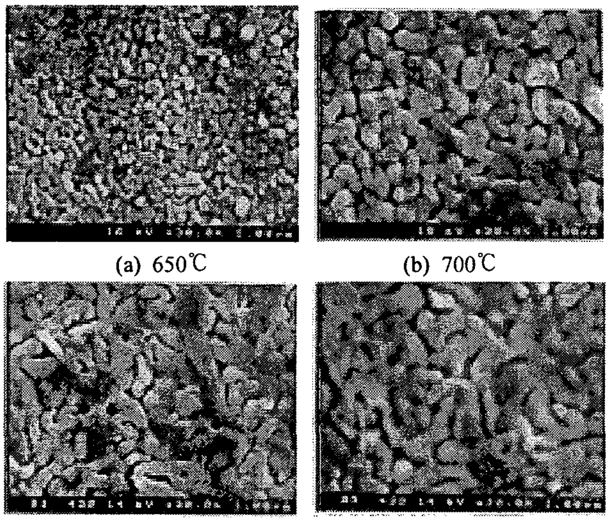
Table 1. Table 1. Sputtering condition of SBT thin films.

sputtering condition	values
target	SBT(2 inch)
substrate	p-type $Pt/TiO_2/SiO_2/Si(100)$
base pressure	5×10^{-6}[Torr]
working pressure	2×10^{-2}[Torr]
RF power	100[W]
annealing temperature	650-800℃
Ar : O_2	1 : 1
annealing time	30[min]

Using this wafer as a substrate, we formed a SBT thin film of 300nm thickness and a top electrode of 0.1mm diameter by sputtering using a metal mask. The typical film thickness was about 300[nm], measured by an Nanospec. The crystallography of the films was analyzed X-ray diffraction. Surface morphology were examined by Field-Emission Scanning Electron Microscope (FE-SEM). The ferroelectric characterization of the capacitors was measured by using a RT66A ferroelec trictester(Radiant Technologies). The electrical measure ments were perfor med using HP 4192A impedance analyzer and HP4155A semiconductor parameter analyzer.

3. RESULTS and DISCUSSIONS

In order to observe the structure and surface of the crystal grain, the x-ray diffraction pattern of the SBT thin film as deposited at 400℃ and then annealed at 600℃ ~ 850℃ was shown in Fig. 1. It could be observed from such figure that as the annealing temperature was more increased (105), the peak was more increased, and when the annealing temperature was over 750℃, it was hardly increased .


(a) 650℃ (b) 700℃

(c) 750℃ (d) 800℃

Photo 1. SEM micrographs of SBT capacitor with annealing temperatures

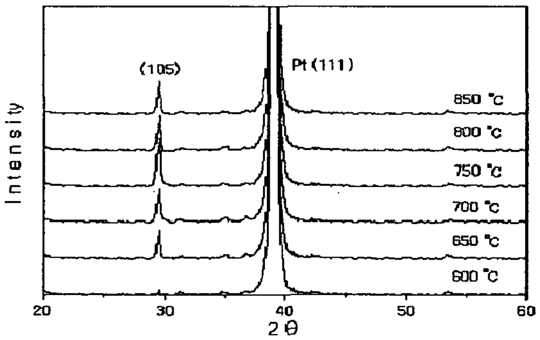


Fig.1. X-ray patterns of SBT thin films with annealing temperatures

Photo 1 showed the micro structure of the SBT thin film surface depending upon various annealing temperatures in the oxygen atmosphere. As can be seen in such photo, all specimens have very fine and compact crystal grains.

Fig. 2 shows a change in the leakage current density of the SBT capacitor depending upon the annealing temperature in the oxygen atmosphere. When the annealing temperature was increased from 650℃ to 750℃, the SBT capacitor showed the leakage current density value in the range of 10^{-9} to 10^{-7}[A/㎠] and the almost similar I-V characteristics. In the SBT thin film annealed at 750℃, the leakage current density value was about 2.13 x 10^{-9} [A/㎠] at 5V.

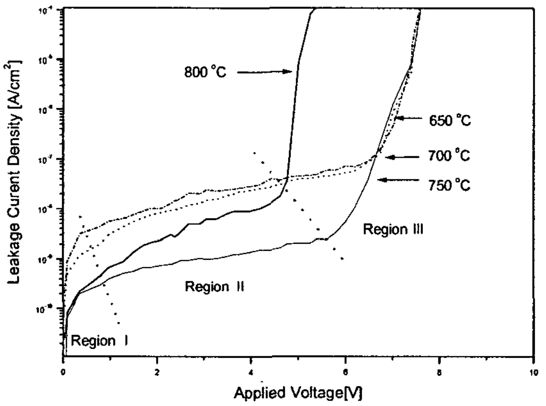


Fig. 2. Leakage current densityes of SBT capacitors with annealing temperatures in oxygen atmosphere

Therefore, the voltage-current characteristics as obtained from this study can be discussed in respect of 3 domains divided as shown in Fig. 2. And the results of discussing the conductive mechanism of each domain are as follows:

(1) Region I

The current in this domain is increased almost in a straight line depending upon the applied electric field, and as can be known from the ionic conduction theoretical expression, when the electric field is a low electric field ($eEa \ll kT$), $J \propto E$. Therefore, the current density of this domain can be explained by the Ohm's law that the current density is in proportion to the electric field.

(2) Region II

In Domain II, there occurred a phenomenon that the current, which contributes to conduction as intergranular impurities (ions or electrons) are deeply trapped and intergranular dipolesare polarized by the applied field from an external source so that they contribute to conduction, and if such polarization is almost accomplished, even if the electric field is increased, the leakage current gets to be slowly saturated.

(3) Region III

It can be seen that in this domain, as the applied electric field is increased, the current is sharply increased to lead to breakdown in the end. It is thought that this phenomenon occurs because tunneling occurs between a grain and another grain after carriers are completely trapped in the depletion layer inside the intergranular layer, the dielectrics.

Fig.3 shows that the Schottky barrier is formed by a donor, wherein E_c, E_F and E_T are respectively a conduction band, a Fermi level and a trap level. Also, $\xi=E_c$, E_F V_1 indicates a decrease in the potential barrier height in the negative (-) side; V_2indicates an increase in the potential barrier height in the positive (+) side; and Φ is a potential barrier height.

Therefore, if the energy band structure is examined in case the electric field is applied, it is thought that the SBT-family ceramic thin film used in this study has formed a structure that a part constituting a grain and each capacity and resistance of the oxidation layer between the crystal grain and the grain boundary layer and the dielectric layer of the crystal grain boundary are combined in a 3-dimensional mesh phase.

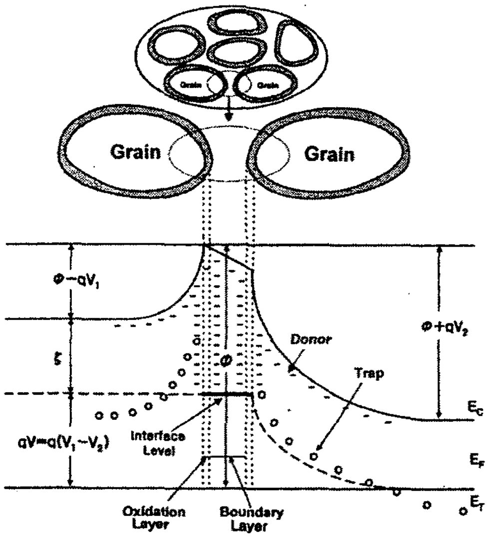


Fig. 3. Energy band structure of boudary layer applied voltage

So, in case any voltage is applied to both ends of the electrode, the potential barrier height gets to be changed. It can be, therefore, thought that the potential distribution as shown in Fig. 5 is available.

From the band structure as shown in Fig. 3, ionized donors, trapped electrons or various impurities forming a boundary level can be considered as factors affecting conductive characteristics.

4. Conclusions

The results of studying ferroelectric characteristics and electric characteristics of the $(Sr_{0.7}Bi_{2.3})Ta_2O_9$capacitor manufactured by the RF magnetron sputtering method depending upon annealing atmospheres are as follows:

1) It could be observed in the SBT thin film annealed in the oxygen atmosphere that the completest crystallization was accomplished around 750℃ and grains grew in the rod-like.

2) In the SBT thin film subsequently annealed in the oxygen atmosphere at 750℃, the most excellent characteristics were shown, and the remnant polarization ($2P_r$) value and the coercive electric field (E_c) were respectively about 12.40[μC/㎠] and 30[kV/cm]. Also, the excellent fatigue characteristic that it was little aged even after 10^{10} cycles of switchings was shown.

3) For the leakage current density and the dielectric constant of the SBT capacitor depending upon various annealing atmospheres, capacitor annealed in the oxygen atmosphere showed the most excellent characteristic, and they were respectively about 2.13 × 10^{-9} [A/㎠] and 340.

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