Mg and Ti Doping Effect in $SrBi_2Ta_2O_9$

Solla Park, Sung-Ho Pak*, Ho-Sung Jun, Chul-Ju Kim
The University of Seoul, Man-Do corporation*

Mg와 Ti doping에 따른 $SrBi_2Ta_2O_9$의 특성 변화

박선라, 백승호*, 전호승, 김철주
서울시립대학교, 주식회사 만도*

Abstract

Ferroelectric Mg-doped SBT and Ti-doped SBT were successfully deposited on $Pt/Ti/SiO_2/Si$ substrate by using a sol-gel solution coating method. The solutions were prepared through out adding the metal alkoxide solutions to SBT solution. The typical hysteresis loop of the films was obtained at 5V. The measured $2P_r$ value were 16.50μC/㎠ for SBT, 18.98μC/㎠ and for Mg-doped SBT, and 17.10μC/㎠ for Ti-doped SBT at an applied voltage of 5V, respectively. And it is found that the leakage current densities are less than 10^{-7}A/㎠ when applied voltage is less than 10.8MV/㎝, which indicates the excellent insulating characteristics.

Key Words : Ferroelectric, Sol-Gel, SBT, Mg-doped SBT, Ti-doped SBT

1. Introduction

SBT($SrBi_2Ta_2O_9$) is one of the most advantageous material for the application in NVFRAMs (Nonvolatile Ferroelectric Random Access Memories).[1] Because SBT materials have low coercive field, low leakage current, long retention, minimal tendency to imprint and specially little fatigue without metal oxide electrode. And SBT appear to maintain good electrical properties even when they are very thin(≤100nm), unlike Pb-based ferroelectirc materials.[2] But this material has some disadvantages. Particularly, SBT's crystallization temperature should be low for high density FeRAM application. And it has low Curie temperature and low remnant polarization than PZT($Pb(Zr,Ti)O_3$).[3] Therefore, many researches for solving these problems have been reported.[4]

In this study, SBT thin film and modified SBT(Mg and Ti doped SBT) thin film were synthesized using a sol-gel method employing mixed alkoxides prepared mixing processes for the improvement of ferroelectric properties. Although the amount of doped metal was not much, doped metals produced some effect on crystallization of total thin film. As doped atoms size variation, the crystal lattice distances of among some of composition atoms were changed. This distance changes induced new several structural distortions. Due to these distortions, doped SBT films have produced good property compared with normal SBT.

2. Experiment

First, SBT[$SrBi_2Ta_2O_9$] sol-gel solution was prepared using strontium acetate [$Sr(CH_3CO_2)_2$], bismuth acetate[$Bi(OOCCH_3)_3$], tantalum ethoxide[$Ta(OC_2H_5)_5$] as precursors. Acetic acid for Bi precursor, and 2-methoxyethanol for strontium and tantalum precursors were used as solvents.

Bismuth salt precursors such as bismuth acetate or bismuth nitrate are not soluble in an alcohol or alkanolamine. It is soluble only with acetic acid.[5]

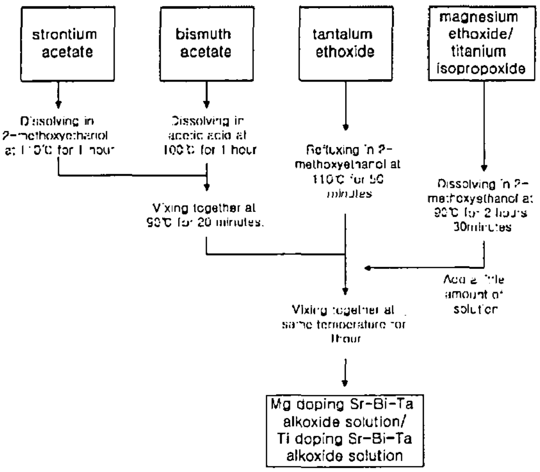


Fig 1. *Flow chart for the preparation of Mg-doped SBT and Ti-doped SBT solution*

And then, the SBT solution was modified with a little amount of magnesium or titanium. Figure 1 shows flow diagram for the preparation of modified SBT solution. For this doping solution, a little amount of magnesium alkoxide solution or titanium alkoxide solution was added to SBT solution in the last solution fabrication processing, respective. All of solutions were filtered out to remove not dissolved impurities.

Each solution (SBT, Mg-doped SBT, Ti-doped SBT sol-gel solution) was spin-coated onto prepared $Pt/Ti/SiO_2/Si$ substrate to deposit thin film. When SBT, Mg doped SBT, and Ti doped SBT were spin-coated on $Pt/Ti/SiO_2/Si$ substrate, the spin coater was rotated at 3000 rpm for 20s. As-deposited film was dried at 400℃ for 10 minutes to remove the organic components and dehydrate. The process was repeated many times to obtain films of the required thickness. So final thickness of each film is about 2500Å. In next step, the deposited films were annealed at 800℃ which is crystallization temperature of SBT. The Annealing of deposited films were practiced in dry oxygen atmosphere for 1 minute using the Rapid Thermal Process (RTP) system to crystallize the films.

In the last process, for electrical measurement, the capacitor structure was fabricated. An aluminum top electrode of capacitor was deposited on the surface of the films using the thermal evaporator. The deposited aluminum electrode thickness was 1500Å.

3. Results and Discussion

The XRD(X-ray Diffraction) patterns of the films grown on Pt ($Pt/Ti/SiO_2/Si(100)$) substrate are shown in Figure 2. The films show highly textured [105] orientation. According to this XRD data, the film crystal orientation was affected by doped metal. Specially, when doped metal was Magnesium, the crystallization of the film was induced better than other films as shown in XRD data. It can be seen that doped metal atoms influenced the film crystallization.

In general, film orientation is an important factor for ferroelectirc properties such as polarization. This is related to direction of dipoles. Therefore, the Mg-doped SBT and Ti-doped SBT can have better ferroelectirc characteristic than normal SBT.

As another physical data, in Figure 3, SEM images of Mg-doped SBT film are shown. The enlargement ratios are 1,400,000 at surface, 840,000 at cross section. The surface morphology of the film shows well-developed grain structure. In the cross-section film image, the film thickness is about 2500Å.

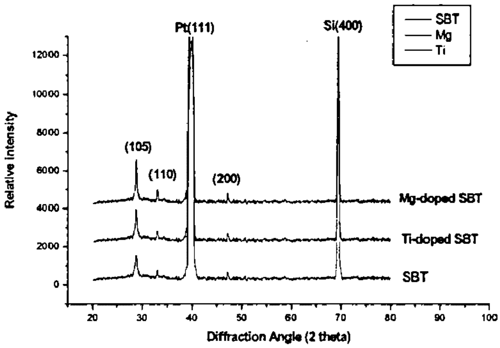
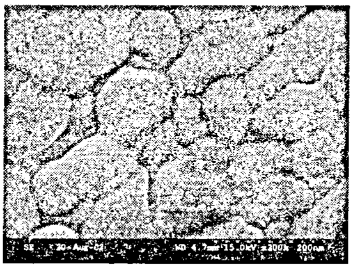


Fig 2. XRD patterns of the films grown on Pt ($Pt/Ti/SiO_2/Si(100)$) substrate

(a) Cross section view of Mg-doped SBT film



(b) Surface view of Mg-doped SBT film

Fig 3. SEM images of Mg-doped SBT film

Figure 4 is shown the ferroelectric hysteresis loops of each film annealed at 800℃. The $2P_r$ were 16.50μC/㎠ for SBT, 18.98μC/㎠ and for Mg-doped SBT, and 17.10μC/㎠ for Ti-doped SBT at an applied voltage of 5V, respectively. Especially, the ferroelectric hysteresis loop properties of the Mg-doped SBT film was good value. This is quite acceptable for non-volatile memory devices. However, since the bottom and top electrode were not same material, the hysteresis loops are poor symmetrical. It can improve by using same material electrode.

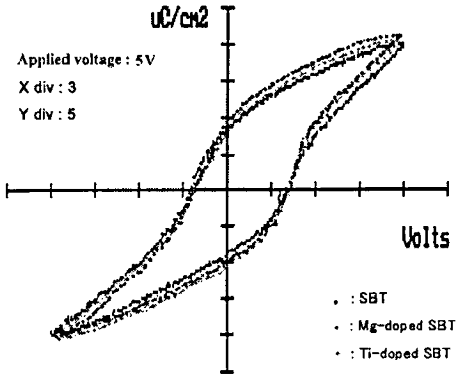
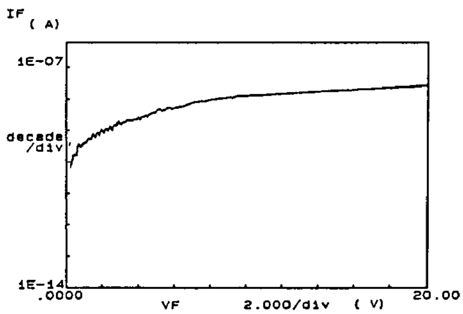
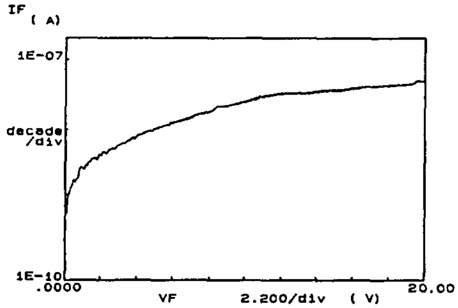


Fig 4. Ferroelectric hysteresis loops of each film annealed at 800℃

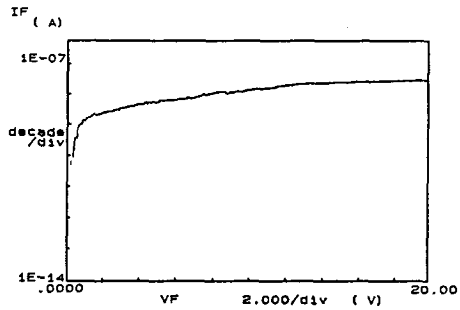
Figure 5 shows the I-V characteristics Al/metal doped-SBT/$Pt/Ti/SiO_2/Si$ measured at room temperature. It is found that the leakage current densities decreased, which indicates the excellent insulating characteristics in films. It is found that the leakage current densities are less than 10^{-7}A/㎠ when applied voltage is less than 10.8MV/㎝, which indicates the excellent insulating characteristics. In especial, the Mg-doped SBT film's leakage current densities is extremely low.



(a) SBT film



(b) Ti-doped SBT film



(c) Mg-doped SBT film

Fig 5. I-V characteristics of films

4. Conclusions

SBT, Mg doped SBT, and Ti doped SBT film using the prepared each sol-gel solution were deposited on Pt substrate. It is found that the ferroelectric properties of metal doped SBT film, especially Mg doped SBT film, is better than those of normal SBT film. From these experiment, it could be seen that the doped metal atoms improve the crystallization of the whole SBT crystal.

In the doped atoms size point of view, crystal lattice distances of some composition atoms were changed. This distance variation produce new structural distortions. Due to these distortions, doped SBT films have good property compared with normal SBT.

Particularly, as experimental results, stated above, Mg-doped SBT film has better characteristics than Ti-doped SBT film. It seems that the Mg atoms are substituted for some Sr atoms and the Ti atoms are substituted for some Ta atoms. Since Mg like Sr has two valence electrons but Ti unlike Ta has four valence electrons, the substitution of Ti-doped SBT film could not show better results than Mg-doped SBT.

References

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