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Preparation and electrical properties of Sm-doped $Bi_2Ti_2O_7$ thin films prepared on Pt (111) substrates

H.T. Sui[a], D.M. Yang[b], H. Jiang[a], Y.L. Ding[a], C.H. Yang[a,c,d,*]

[a]School of Materials Science and Engineering, University of Jinan, Jinan 250022, China
[b]China National Petroleum Offshore Engineering Co. Ltd., Drilling Division, Tianjin 300280, China
[c]Shandong Provincial Key Laboratory of Preparation and Measurement of Building Materials, University of Jinan, China
[d]State Key laboratory of Crystal Materials Shandong University, Jinan 250100, China

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Abstract

Crack-free Sm-doped $Bi_2Ti_2O_7$ (Sm:BTO) thin films with strong (111) orientation have been prepared on Pt (111) substrates using a chemical solution deposition (CSD) method. The structural properties and crystallizations were studied by X-ray diffraction. The surface morphology and quality were examined using atomic force microscopy (AFM). The insulating and dielectric properties were also evaluated at room temperature. The results demonstrate that the Sm:BTO films exhibit improved electrical performances as compared to the pure $Bi_2Ti_2O_7$ thin films and suggest a strong potential for utilization in microelectronics devices.

Keywords: A. Films; B. Microstructure; C. Dielectric properties; C. Electrical properties

1. Introduction

Bismuth titanate ($Bi_2Ti_2O_7$) is of increasing interest because it has many applications in the field of microelectronics, electro-optics and dielectrics due to its relatively high dielectric constant and good insulating property [1–4]. Although $Bi_2Ti_2O_7$ exhibits no ferroelectricity or piezoelectricity, it has a relatively high dielectric constant [5,6]. Therefore, $Bi_2Ti_2O_7$ thin films can be used as materials for storage capacitors in dynamic random access memory (DRAM) and as gate insulators to increase the transconductance of MOSFETS [7]. Besides, $Bi_2Ti_2O_7$ films have also been used as buffer layers to improve the electrical properties of ferroelectric $Pb_{0.85}Sm_{0.1}TiO_3$ [8], $Bi_{3.5}Nd_{0.5}Ti_3O_{12}$ [9] and $BiFeO_3$ [10–11] thin films.

Some articles reported that $Bi_2Ti_2O_7$ materials are easily transformed into other phases at high annealing temperatures [15–17]. However, some researchers discovered that the phase stability of the $Bi_2Ti_2O_7$ thin films was improved owing to the doping of lanthanum ions and the phase structure can be stabilized by ionic modification [18–20]. In this paper, we prepared the $Bi_2Ti_2O_7$ thin films doped with Sm ions (Sm:BTO) on Pt (111) substrates by repeated coating/dying cycles. The structure and surface morphology were analyzed and electrical properties were also reported.

2. Experimental procedure

The Sm:BTO thin films were prepared on Pt (111) substrates using a chemical solution deposition (CSD) method. The precursor solution were prepared using bismuth nitrate ($Bi(NO_3)_3 \cdot 5H_2O$), samarium nitrate ($Sm(NO_3)_3$) and tetrabutyl titanate ($C_{16}H_{36}O_4Ti$) materials according to determinate molar. Glacial acetic acid has been used as solvent and the solution was diluted with 2-methoxythanol to adjust the viscosity. Acetylacetone was added to the solution to keep the precursor solution stable. Dust and other suspend impurities were removed by filtering through a 0.2 μm syringe filter. This is the $(Bi_{0.9}Sm_{0.1})_2Ti_2O_7$ precursor solution of 0.1 M.

*Corresponding author at: School of Materials Science and Engineering, University of Jinan, Jiwei road 106, Jinan 250022, China.
Tel.: +86 531 889736280; fax: +86 531 87974453.
E-mail address: mse_yangch@ujn.edu.cn (C.H. Yang).

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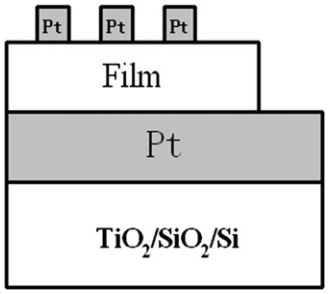

Fig. 1. Schematic diagram of MFM structure.

Then the precursor solution was coated onto Pt (111) substrates by spin coating at 3000 rpm for 30 s. Thickness of the films was controlled through adjusting the viscosity of the solution and the spin speed. The films were heated to 300 °C in air at a rate of 10 °C/min and kept at 300 °C for 20 min to ensure complete removal of solvents, organics and other volatile matters. Then the films were annealed at 600 °C for 5 min in an O_2 atmosphere by rapid thermal processor (RTP). The deposition and heat-treatment procedure were repeated to prepare a desired thickness.

For electrical property measurement, Pt circular dots were deposited by dc magnetron sputtering through a shadow mask on the films as top electrodes and one of corners of film was corrode by the mixture of HNO_3 and HF as bottom electrode to form a MFM configuration as shown in Fig. 1.

FT-IR spectra for Sm:BTO samples with different annealing temperatures was under consideration by the FT-IR. The crystallization of the Sm:BTO thin films was studied by X-ray diffraction (XRD) using a Rigaku D/MAX-γA X-ray diffractometer. The surface image of the films was characterized by atomic force microscopy (AFM). The insulating property was conducted using a pA meter/DC voltage source (HP4140B PA) and the dielectric properties were measured using a LF Impedance Analyzer (HP4192A).

3. Results and discussion

3.1. Crystallization behavior of Sm:BTO films

The infrared-absorption spectrum of Sm:BTO samples have been measured for powder samples dispersed in pressed KBr disks. Fig. 2 shows the infrared (IR) spectrum of powders dried at different temperature in air for 10 min. We can see there are a series of absorptions in the range of 600–950 cm^{-1} at 100, indicating non-decomposition of organic substance. The band at 1385 cm^{-1} is attributed to the characteristic peak of NO_3^- and the band at 1624 cm^{-1} is the –COOH rocking modes. At 300 °C, the absorptions at 3422 cm^{-1} is lower due to the losing some water and ether solvent. Meanwhile, because of the not carbonized completely for organic substance, there exists faint absorption at 1624 cm^{-1}. It was noted that the intensity of band at 3422 cm^{-1} is further weak as the

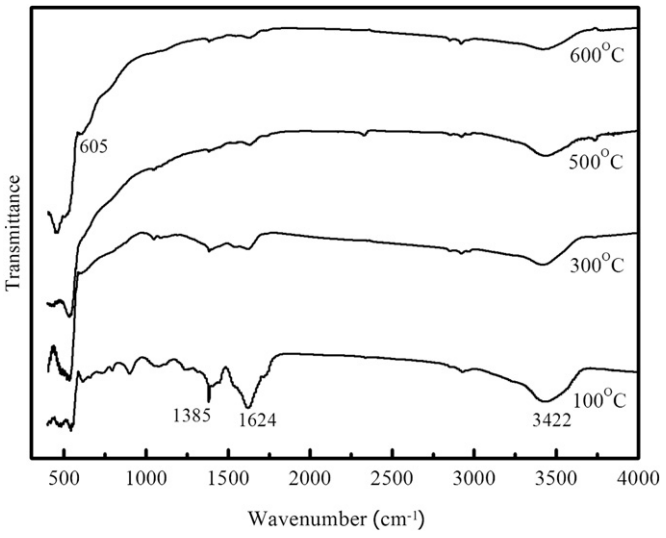

Fig. 2. Infrared spectrum of Sm:BTO precursor powder heated at different annealing temperature for 10 min.

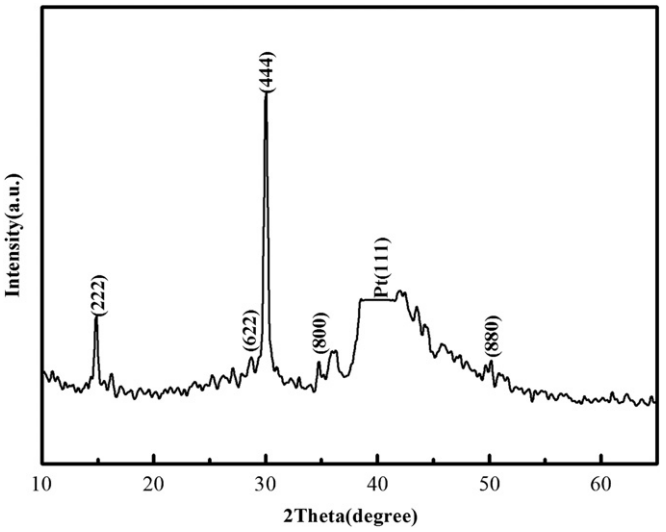

Fig. 3. X-ray diffraction pattern of Sm:BTO films annealed at 600 °C for 10 min.

temperature increasing to 500 °C and almost disappeared when the temperature further increases to 600 °C. At 600 °C, the band in the low wavenumber (500 cm^{-1}–700 cm^{-1}) is attributed to the M–O bonds [21], which comes from the envelop of the photon bands of a metal–oxygen–metal bond from a solid oxide network, for example, V_{Ti-O} = 653–550 cm^{-1} [22]. In addition, the band at 605 cm^{-1} belongs to the Sm–O bonds, which indicates that a large amount Sm:BTO nano-grains form. Fig. 3 shows the X-ray diffraction patterns of Sm:BTO thin films deposited on the Pt substrates annealed at 600 °C for 10 min. The strong and sharp peaks are indications of good crystallization of the films. The interplanar spacing values (d) of the peaks agree well with those of $Bi_2Ti_2O_7$ given in the standard JCPDS data card (no.32–118). Moreover, the strongest peak at (222) and (444) for the