The dielectric tunability of $Ba_{0.6}Sr_{0.4}TiO_3$ thin films deposited by radio-frequency magnetron sputtering

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ABSTRACT

$Ba_{0.6}Sr_{0.4}TiO_3$ (BST) thin films with the thickness of 300nm were deposited on $Pt/SiO_2/Si$ substrates at various deposition temperatures by RF magnetron sputtering technique, and their electric properties were investigated. Due to the high temperature annealing process at substrate temperature of 600 °C, well-crystallized BST film was deposited. The dielectric constant and dielectric loss of the film deposited at 600 °C are 300 and 0.033 at 100 kHz, respectively. Due to the good crystallinity of the BST films deposited by RF magnetron sputtering, high dielectric tunability up to 39.2% is achieved at a low applied voltage of 5V.

Keywords: BST thin films, dielectrics, sputtering

1 INTRODUCTION

Recently, the nonlinear dielectric property of BST thin films has been developed for the applications in high-performance tunable microwave devices such as resonators [1], phase shifters [2,3], filters [4] and antennas [5]. However, many problems still remain in utilizing BST for these applications. In such devices, one of the major challenges encountered for realizing the integration of BST thin films into tunable devices is the simultaneous minimization of the material's dielectric loss and maximization of dielectric tenability [6].

In the past, several techniques have been explored to deposit BST film including metal-organic chemical vapor deposition (CVD) [7], sol-gel processing [8], pulsed laser ablation [9], and radio-frequency (RF) magnetron sputtering deposition [10]. Among these, RF magnetron sputtering technique is the simplest and most versatile for the deposition of smooth, stoichiometric, stable, and electrically textured films (poled) over a large substrate area. Despite several studies on magnetron sputtered BST films under specific routines, an effort to optimize the process parameters through microstructure-property correlation is warranted. Thus, the present study attempts to investigate the effect of deposition temperature on the phase evolution, microstructure and electrical property of the film.

2 EXPERIMENTS

$Ba_{0.6}Sr_{0.4}TiO_3$ (BST) thin films were deposited onto $Pt/SiO_2/Si$ substrates at three different deposition temperatures of 400, 500 or 600 °C using Leybold UNIVEX450B multi-target RF magnetron sputtering system. The three BST films deposited at different temperatures were marked as BST400, BST500 and BST600, respectively. The three films thickness measured by scanning electro microscopy (SEM) cross-section observation was about 300nm.

The phase of the films was identified by a Rigaku x-ray diffractometer (XRD) using Cu *Ka* radiation at room temperature. The dielectric properties of the $Au/BST/Pt/SiO_2/Si$ capacitors were measured at room temperature using a HP4192A impedance analyzer. Leakage current density J as a function of applied electric field E (J-E curve) was measured using a HP4155B Semiconductor Parameter Analyzer.

3 RESULTS AND DISCUSSION

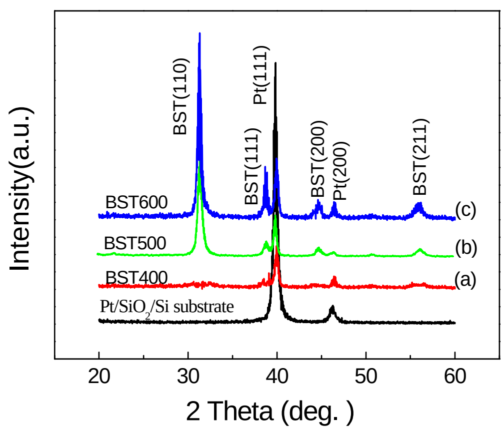

Figure 1: XRD patterns of the BST thin films.

Fig. 1 shows the XRD patterns of the BST thin films deposited on Pt/ SiO_2/Si at different deposition temperatures by RF magnetron sputtering system. As comparison, the XRD patterns of the substrate Pt/SiO_2 /Si are also presented in Fig. 1. The absence of diffraction peaks in XRD pattern of the BST400 film deposited at 400 ^{o}C indicates that the film is amorphous in nature. It is apparent that the BST500 and BST600 films possess a polycrystalline perovskite structure, and all XRD peaks except that of Pt are attributed to cubic $Ba_{0.6}Sr_{0.4}TiO_3$. The crystallinity of the thin films improved with an increase of substrate temperature, indicated by the increase in intensity of the XRD peaks.

Fig. 2 shows the dependence of leakage current density as a function of applied voltage for the three BST films. The leakage current is known to be greatly dependent on the grain structure of the films, and those films with small grain size, smooth surface, and dense microstructure usually

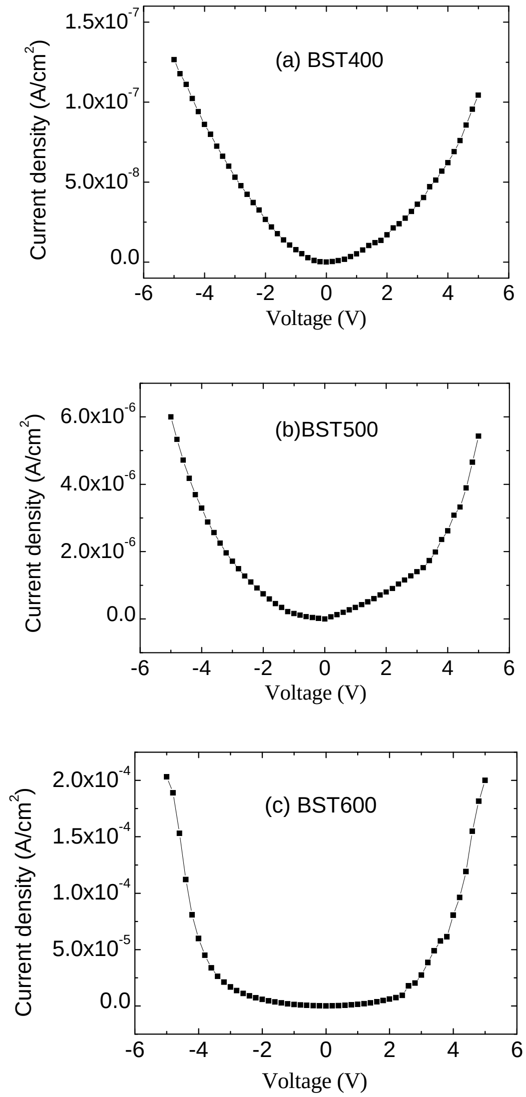

Figure 2: Leakage current density of the BST films

have low leakage current [11]. For the BST400 and BST500 films, when the applied voltage was increased to 5 V, a low leakage current density of 1.25×10^{-7} and 6×10^{-6} A/cm^2 was observed, respectively. A considerable insulating behavior for the two films can be ascribed to their dense microstructure and low defect density. For the BST600 film, a small leakage current (<10^{-5}A/cm^2) is investigated below 100 kV/cm. However, the rapid increase of leakage current from 100 kV/cm indicates the near breakdown of the film. The high leakage current density above 100 kV/cm for the BST600 film, is resulted from the large grain size

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of the BST films and rough surface.

Fig. 3 displays the dependence of dielectric constant as a function of applied voltage for the three BST films. The ε-V curves were measured under a small oscillation signal of 50 mV at 100 kHz. The Curie temperature (T_C) of bulk $Ba_{0.6}Sr_{0.4}TiO_3$ is about 10 °C, so it is in the paraelectric state at room temperature. The ε-V curves of the three BST films deposited by RF sputtering are symmetric along the zero-bias voltage axes and no typical ferroelectric hysteresis

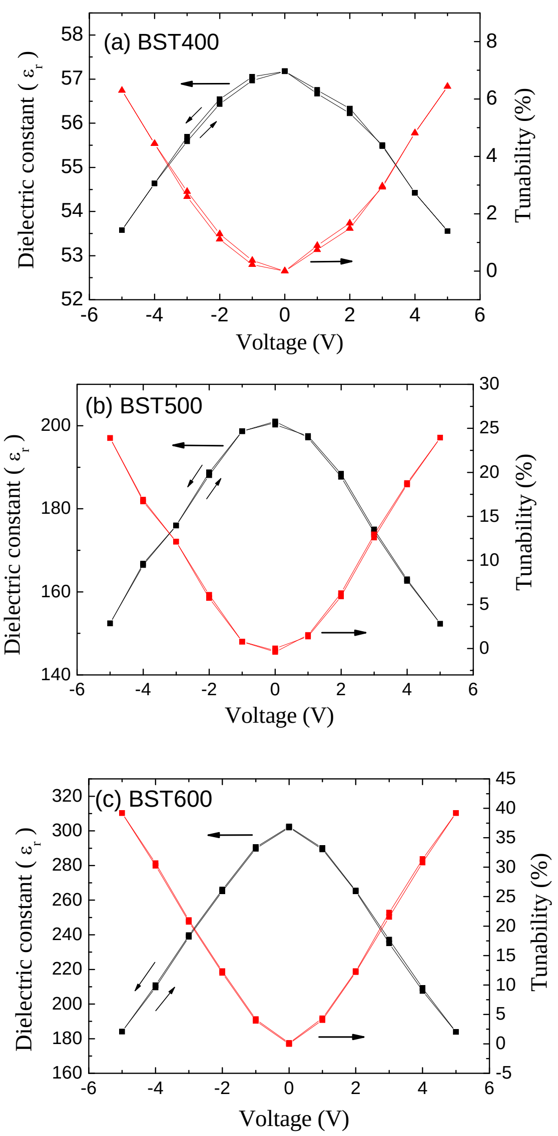

Figure 3: Dielectric constant and dielectric tunability for the BST films

loop is observed. It indicates the paraelectric behavior of cubic perovskite $Ba_{0.6}Sr_{0.4}TiO_3$ thin film at room temperature, which is accordant with the XRD results (Fig. 1). The dielectric constant of the three films (BST400, BST500 and BST600) is 57, 200 and 300, respectively. This indicates good crystallinity increases the permittivity. The dielectric loss of the three films (BST400, BST500 and BST600) is 0.021, 0.027 and 0.033, respectively. Usually, dielectric loss in BST thin films originates from two mechanisms: resistive loss and relaxation loss [12]. Resistive loss mechanism involves energy consumption by the mobile charges in the film, and it is directly connected to the leakage current of the film. The considerable low dielectric loss for the three films is attributed to the fairly low leakage current at a very low voltage (measured under a small oscillation signal of 50 mV).

The dielectric tunability of the film was calculated at an applied voltage of 5 V, in terms of the parameter $\Delta\varepsilon/\varepsilon_0$, where $\Delta\varepsilon$ is the change of dielectric constant relative to zero-bias dielectric constant ε_0. Fig. 3 shows the dielectric tunability of the three BST films as a function of applied voltage. The dielectric tunability of the three films (BST400, BST500 and BST600) at a low voltage of 5 V is 6.3, 23.9 and 39.2%, respectively. This high tunability for BST600 is achieved at a bias voltage as low as 5 V, which is compatible with the voltage requirements of the present semiconductor based systems [13]. The relatively high dielectric constant and high tunability for the BST600 films deposited by RF sputtering are believed to have resulted from the good crystallinity and sufficient solubility of Ba and Sr composition at A site of ABO_3 perovskite structure.

4 CONCLUSIONS

BST thin films have been deposited at different temperatures (400, 500 and 600 °C) using

RF magnetron sputtering technique. The as-deposited BST thin films are well crystallized at the high temperature of 500 and 600 ^{o}C. With deposition temperature increase, the leakage current of the film become larger due to big grain and rough surface, while the dielectric constant increases due to good crystallinity. The dielectric constant and dielectric loss of the BST600 film deposited at 600 ^{o}C at 100 kHz are 300 and 0.033, respectively. High dielectric tunability up to 39.2% for the BST600 film is achieved at a low applied voltage of 5 V, and it is believed to be attributed to the good crystallinity of the BST film deposited by RF sputtering.

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