Electrical Conductivity and Surface Roughness Properties of Ferroelectric Gallium Doped $Ba_{0,5}Sr_{0,5}TiO_3$ (BGST) Thin Films

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Abstract

$Ba_{0.5}Sr_{0.5}TiO_3$ (BST) and gallium doped BST (BGST) thin films were successfully deposited on p-type Si(100) substrates. The thin films were fabricated by the chemical solution deposition (CSD) and spin coating method, with 1.00 M precursor and spinning speed of 3000 rpm for 30 seconds. The post deposition annealing of the 9 films were carried out BST without gallium (BGST 0%) annealing 850^{O}C, BGST 0% annealing 900^{O}C, BGST 0% annealing 950^{O}C, BGST 5% annealing 850^{O}C, BGST 5% annealing 900^{O}C, BGST 5% annealing 950^{O}C, BGST 10% annealing 850^{O}C, BGST 10% annealing 900^{O}C, BGST 10% annealing 950^{O}C for 15 hour in oxygen gas atmosphere, respectively. The resistance and electrical conductivity of the grown thin films are characterized by I-V converter, meanwhile surface roughness of the grown thin films are characterized by atomic force microscopy (AFM) method. The electrical conductivity of the grown thin films BGST due to semiconductor. The results show that resistance and electrical conductivity of the thin film have strong correlation to the annealing temperature, concentration dopant and surface roughness.

Keywords : Electrical conductivity, surface roughness, BST, dopant gallium, AFM.

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1. Introduction

Ferroelectric $BaTiO_3$ (BT), $Ba_{0.5}Sr_{0.5}TiO_3$ (BST), $PbZr_{0.5}Ti_{0.5}O_3$ (PZT) thin films are well known as dielectric materials. They have been used as capacitors and high density dynamic random access memory (DRAM) due to their high dielectric constant and high capacity of charge storage [1-4] and ferroelectric solar cell [5]. BT and BST films can be formed by various methods, such as CSD [1-4], metal organic chemical vapor deposition (MOCVD) [6,7], rf sputtering [3, 8, 10] and Pulsed Laser Ablation Deposition (PLAD) [11]. CSD method is of particular interest because of its good control of stoichiometry, ease of fabrication and low temperature synthesis. Since it is relatively new, hence a greater understanding is required before the film quality can be optimized. It was reported that CSD derived thin films are thermodinamically stable [4].

Gallium oxide doped barium strontium titanate has been of immense interest in the use of ferroelectric solar cell (FSC) [5]. The electrical conductivity properties of the materials can be tailored by varying the concentration of the dopant and annealing temperature. Since the sensors performance significantly depend on these properties, the FSC performance can then be optimized.

In this paper we report on the fabrication of 0 % 5 %, 10 % gallium oxide doped barium strontium titanate thin films by CSD with 1.00 M precursor. The electrical conductivity properties using I-V converter characterization, meanwhile surface roughness of the grown thin films are characterized by atomic force microscopy (AFM) method. The electrical conductivity properties of the grown films related to the dopant gallium oxide, annealing temperature and surface roughness are described.

2. *Methodology*

BGST 5 % solution was obtained using 0.160 g barium acetic [Ba($CH_3COO)_2$, 99 % purity] + 0.131 g strontium acetic [Sr($CH_3COO)_2$, 99 % purity] + 0.355 g titanium isopropoxide [Ti($C_{12}O_4H_{28}$), 99.999 % purity] + 0.030 g gallium oxide as precursor in 1.25 ml 2-methoxyethanol [$H_3COOCH_2CH_2OH$, 99.9 %]. While BGST 10 % solution was obtained using 0.160 g barium acetic [Ba($CH_3COO)_2$, 99 % purity] + 0.131 g strontium acetic [Sr($CH_3COO)_2$, 99 % purity] + 0.355 g titanium isopropoxide [Ti($C_{12}O_4H_{28}$), 99.999 % purity] + 0.060 g gallium oxide as precursor in 1.25 ml 2-methoxyethanol [$H_3COOCH_2CH_2OH$, 99.9 %]. After 2 hours of agitating, a thicken solution with a milky appearance was produced. After a filtering process a clear solution was obtained. The solutions obtained, contain 1.00 M BGST 0 %, 5 %, 10%, respectively. The solutions were then spin coated on 10 mm x 10 mm *p*-type Si (100) substrates with speed of 3000 rpm for 30 seconds . The post deposition annealing of the films were carried out in a Nabertherm Type 27 model furnace at 850^{o}C, 900^{o}C, 950^{o}C for 15 hours in an oxygen atmosphere [12,13]. The electrical conductivity of the grown thin films were characterized by I-V converter, and surface roughness of the grown thin films are characterized by atomic force microscopy (AFM) method Model JEOL SPA300/400.

3. *Results and Discussion*

Figures 1 shows 3-dimensional images using AFM method of the thin films annealed at temperatures 900^{o}C. The surface roughness and grain size for BGST 5 % thin film annealed at 900^{o}C were more homogenous, compared to BST and BGST 10 % thin films. The rms surface roughness for BST, BGST 5 %, BGST 10 % are 1.813 nm, 1.773 nm, 6.991 nm, respectively, whereas the grain size (mean diameter) are 276.8 nm, 250.8 nm, 250.8 nm. Observation indicates a homogenous surface obtained for BGST 5 % at 900^{o}C. It can be seen that the introduction of Ga into BST resulted in the improvement of the surface roughness and mean diameter grain size (smaller surface roughness and mean diameter grain size). Many applications of the surface roughness and mean diameter grain size of nanofabrication techniques now require the production of nanowires. The nanowires could be used in a near feature as components of technology to create electrical circuits out of compounds that are capable of being formed into extremely small circuit (electronic, opto-electronic and nanoelectromechanical devices and as leads for biomolecular nanosensors). Instead of tunneling current, AFM techniques are capable to detect the interatomic forces that occur between a cantilever probe tip and a sample. Normal imaging forces are in the 1 - 50 nanonewton range and cantilever deflections of less than 0.1 nm can be detected (nanoscale) [14,15,16].

Figures 2 shows the electrical conductivity classification (insulator, semiconductor, conductor) [17]. The exact relation between resistance (*R*) and the electrical conductivity (σ), those relations are given by equation (1) :

$$R = \frac{L}{\sigma A} \tag{1}$$

Figures 3 and 4 show resistance and electrical conductivity for BST, BGST 5 %, BGST 10 % thin films annealed at 900^{o}C using I-V converter method. Using equation (1) and Figure 2, the electrical conductivity of the grown thin films BGST due to semiconductor (30.00 S/cm until 31,25 S/cm.). In fact, increasing annealing temperature from 850^o C to 950^o C would be increase electrical conductivity. Because angular velocity 3000 rpm for 30 seconds was low enough and continued annealing at 850^{o}C for 15 hours, so that the form of surface roughness as in Figure 1. That condition form of thin films was discontinue and heterogen because of insulating phase between grain size film, so that need higher thermal energy to move charges from one void to another void. If it compared with annealing at 950^{o}C it would result decreasing insulating phase. The results show that resistance and electrical conductivity of the thin film have strong correlation to the annealing temperature, concentration dopant and surface roughness. Such electrical characteristics are suited for ferroelectric devices such as ferroelectric sensor, ferroelectric solar cell (FSC) and dynamic random access memory (DRAM).

4. *Conclusions*

Fabrication of BST, BGST 5 %, BGST 10 % thin films were carried out by spin coating at 3000 rpm for 30 seconds, and then annealing at 850^{o}C, 900^{o}C, 950^{o}C, for 15 hours. The results show that resistance and electrical conductivity of the thin film have strong correlation to the annealing temperature, concentration dopant and surface roughness. with optimum structure obtained at 900^{o}C.

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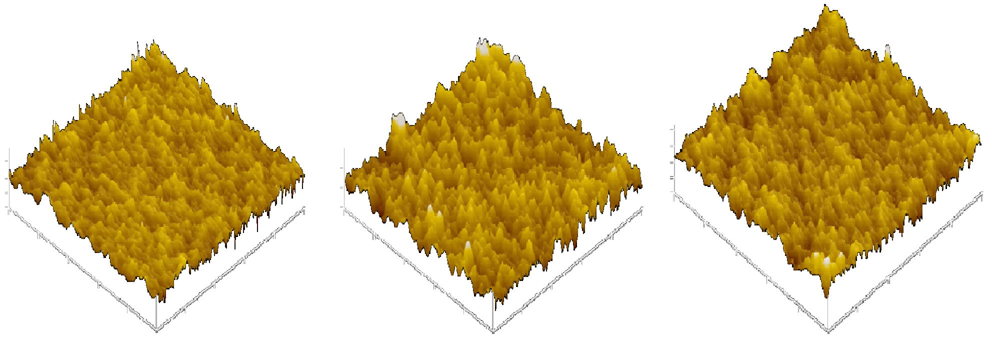

(a) (b) (c)

Figure 1. The 3-dimensional images using AFM of BGST 10 % thin films for the analysis area of 5000 nm x 5000 nm at Ø = 45^o, Θ = 30^o at 900^{o}C,
(a) BST (b) BGST 5 % (c) BGST 10 %

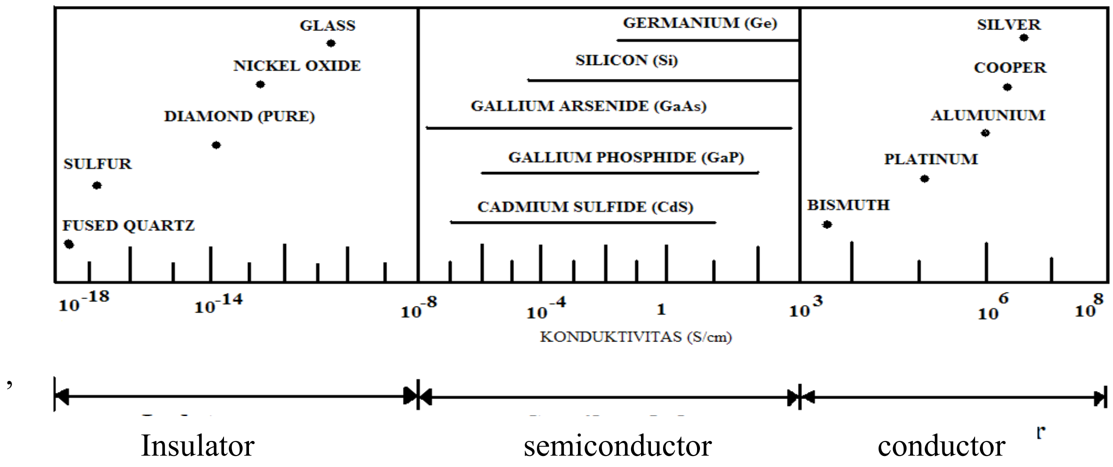

Figure 2. The electrical conductivity classification (insulator, semiconductor, conductor) [17].

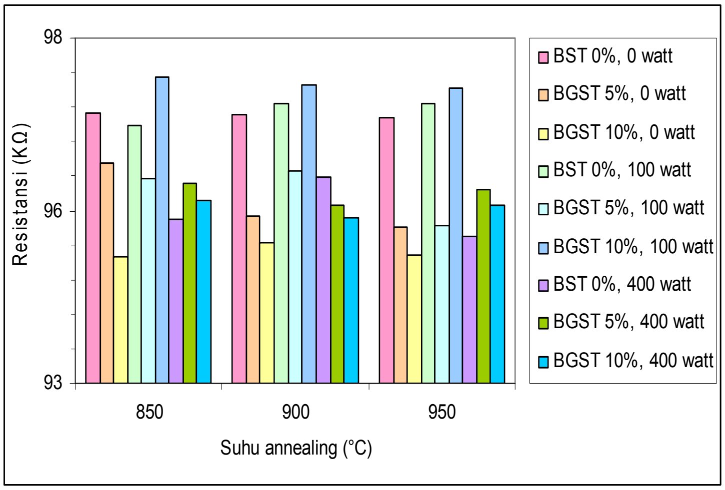

Figure 3. The resistance measured
BST, BGST 5%, and BGST 10% thin films

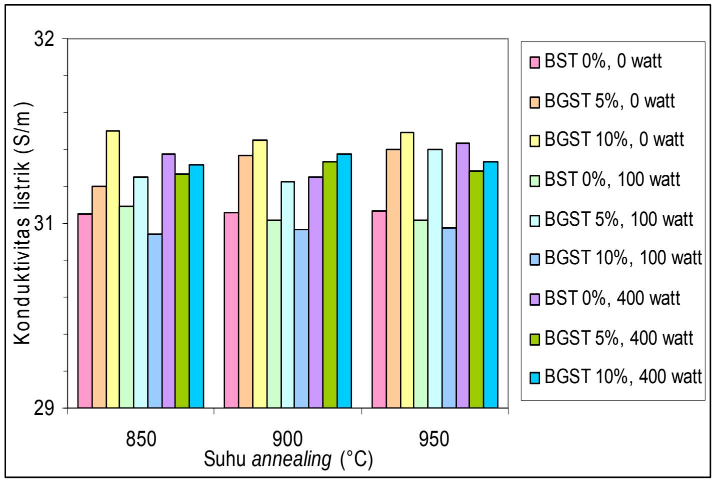

Figure 4. The electrical conductivity calculated using equation (1) BST, BGST 5%, and BGST