Thin Film Production and Characterization  
$\text{Ba}_{1-x}\text{Sr}_x\text{TiO}_3\ (x = 0.9)$ for Capacitor Applications

Rahmi Dewi$^{1*}$, TS Luqman Husain S$^1$, Krisman$^1$, Zuhdi2 and Hamdi$^1$

$^1$Department of Physics, Pekanbaru, Indonesia  
$^2$Faculty of Teacher Training and Education, Pekanbaru, Indonesia

*Corresponding author: Rahmi Dewi, Department of Physics, Indonesia

Submission: January 16, 2019; Published: January 24, 2019

Abstract

The thin films of Barium Strontium Titanate (BST) material of $\text{Ba}_x\text{Sr}_x\text{TiO}_3$ were fabricated using sol-gel method and annealed at temperature $600^\circ\text{C}$, $650^\circ\text{C}$ and $700^\circ\text{C}$ to obtain its crystalline structure. The thin films of BST were characterized using FESEM, XRD and Impedance spectroscopy. The results of characterization use FESEM at temperature of $600^\circ\text{C}$, $650^\circ\text{C}$ and $700^\circ\text{C}$ to obtain its crystalline structure. The thin films of BST were characterized using FESEM, XRD and Impedance spectroscopy. The results of characterization use XRD with the temperature annealing of angle $10.26^\circ$ at temperature $600^\circ\text{C}$, $650^\circ\text{C}$ and $700^\circ\text{C}$ to obtain the intensity 244, 280 and 300. The characterization uses Spectroscopy Impedance to obtain the values complex capacitance and dielectric constant are inversely proportional to the frequency and while the loss of dielectric values are proportional to the frequency. At frequency $100\text{Hz}$ with of the temperature $600^\circ\text{C}$, $650^\circ\text{C}$ and $700^\circ\text{C}$ obtaining the complex capacitance of values which are $5.59481 \times 10^{-11}$ F; $7.73048 \times 10^{-11}$ F and $9.38054 \times 10^{-11}$ F. The dielectric constant values are $6.3215$; $8.7350$ and $10.5994$. The loss of dielectric values is $0.0234$; $0.0069$ and $0.0066$. The increasing temperature annealing the thickness value, the complex capacitance, the constant of dielectrics and the losses of dielectrics are increasing.

Keywords: Barium strontium titanite; Sol-gel method; XRD; FESEM; Impedance spectroscopy

Introduction

The development of the era of many changes that occurs in materials is often studied by scientists of science. Ferroelectric is one of the unique materials to be studied and researched. Commonly used ferroelectric thin film materials include Barium Strontium Titanate (BST), Barium Titanate (BaTiO$_3$) and Strontium Titanate (SrTiO$_3$). The BaSrTiO$_3$ material in the last year is highly reviewed and developed, from the above-mentioned ferroelectric thin films $\text{Ba}_x\text{Sr}_x\text{TiO}_3$ which acts as a dielectric to increase the capacitance value of the capacitor [1]. This study is a study for the manufacture of BST thin film from a mixture of Barium Carbonate, Strontium Carbonate and Titanium Isopropoxide with a composition ratio of Ba and Sr 0.1:0.9 or can be written $\text{Ba}_{0.1}\text{Sr}_{0.9}\text{TiO}_3$. The treatment is made by sol gel method or with CSD model, then continuous spin coating and annealing process at temperature $600^\circ\text{C}$, $650^\circ\text{C}$ and $700^\circ\text{C}$. Light sensor made of thin film material $\text{Ba}_x\text{Sr}_x\text{TiO}_3$ on Si substrate (100) p-type by means of chemical-assisted chemical solution deposition (CSD) method [2].The capacitor is one of the electronic devices that play an important role in the electronics circuit. The value of the capacitor depends on how much charge can be stored. This dependence leads to a capacity already limited to the capacitor. The capacitance of a capacitor can be increased by a dielectric material in the capacitor [3]. BST is a perovskite material based on Barium Titanate (BaTiO$_3$) [4]. Figure 1 shows the perovskite crystal structure of the BST ferroelectric material [5].

The nature of the perovskite structure of the BST is due to a form with a concomitant with 3.951Å. This situation coincides with the BaTiO$_3$ crystalline structure (a = 3.991Å and c = 4.0108Å) and SrTiO$_3$ (a = 3.897Å) with Ba and Sr being at zero. The Ti ion is at the center and the three oxygen atoms are at the center of the face. This structure will cause the Ba$^{2+}$ ions in BaTiO$_3$ to be replaced by Sr$^{2+}$ ions. Ti$^{4+}$ ions and O$^{2-}$ ions in BaTiO$_3$ will exchange places at the c-pipe where the Ba$^{2+}$ ion is in an almost symmetrical position. Sr$^{2+}$ ions, Ti$^{4+}$ and O$^{2-}$ ions in SrTiO$_3$ remain unchanged in the structure SrTiO$_3$ estimates [6]. CSD or sol gel techniques are one of the simplest and easiest ways of making nanoparticles. The usefulness of this method allows us to design the desired material at low temperatures and as an alternative to conventional methods [7].

Copyright © All rights are reserved by Rahmi Dewi.
These thin films will be characterized using X-ray Diffraction, FESEM and Impedance Spectroscopy, where the characterization using FESEM to obtain the thickness of the sample and characterization using impedance spectroscopy to obtain the value of the dielectric constant can be calculated using the equation:

\[ \varepsilon' = \frac{\varepsilon'd}{\varepsilon_0 A} \]  

(1)

The dielectric constant \( \varepsilon' \) is a measure of the ability of a material to store a relative charge in a vacuum chamber [8]. The value of complex capacitance \( C^* \) at a given frequency is obtained through the relationship:

\[ C^* = \frac{1}{j\omega\varepsilon''} \]  

(2)

Research Methodology

This research is done by using some experimental method. The sample was prepared using a sol-gel method placed on a glass substrate using a spin coater and annealing at temperatures of 600 °C, 650 °C and 700 °C while for BST capacitor characterization using XRD, FESEM and Impedance Spectroscopy. Figure 2 shows the flow diagram of the research conducted in the manufacture of BST capacitors. The structure of thin film of BST is shown in Figure 3.

![Flow Diagram](image)

**Figure 2:** BST capacity building diagram.

![Thin film structure BST](image)

**Figure 3:** Thin film structure BST.

Results and Discussion

XRD characterization results can be seen in Figure 4 (a) shows the absence of the resulting diffraction peak against the 2θ angle. Without the temperature treatment the annealing structures can be amorphous. The sample has no crystal field but is amorphous [9]. The orientations (010) and (110) contained in the thin film \( \text{PbZr}_{0.625}\text{Ti}_{0.375}\text{O}_3 \) (PZT) were lost by treatment without annealing [10]. Figure 4b shows the resulting diffraction peak at a 2θ angle. Samples subjected to annealing temperature treatments have a crystal structure. Annealing temperature increases cause the atomic radius to increase in size so that the density becomes increased [11]. The intensity is proportional to the annealing temperature [12].
Figure 4: XRD characterization charts a.300 ; b.600, c.650 and d.700 °C temperatures.

Figure 5: The magnification of the diffraction peak range (110).

Figure 5 represents the magnification of the range at the diffraction peak 110 against the angle 2θ, the image shows a angular distance difference due to the different compositions where (a) is the result of the study of thin film Ba$_{0.1}$Sr$_{0.9}$TiO$_3$ having an angle value of 2θ at the diffraction peak 110 (110) i.e. 30.1° with annealing temperature 600 °C, 650 °C and 700 °C, while (b) is the result of the study of the thin film Ba$_{0.5}$Sr$_{0.5}$TiO$_3$ having an angle value of 2θ at the diffraction peak (110) i.e. 32.1° with annealing temperature 650 °C, 700 °C and 800 °C. The composition difference of x=0.4 resulted in an angle of 2θ having a difference of 2.1°. The result of data calculation using match3! shown in Table 1. Characterization using FESEM can be seen in the following Figure 6(a-c).

Table 1: Effect of annealing temperature on intensity at 2 theta.

| No | 2θ (°) | θ | $d_{th}$ (Å) | Grid Parameters a (Å) | hkl | Intensity 600 °C | Intensity 650 °C | Intensity 700 °C |
|----|-------|---|-------------|-----------------------|-----|------------------|-----------------|-----------------|
| 1  | 21.2  | 10.6 | 4.186       | 4.1086                | 100 | 244              | 280             | 300             |
| 2  | 30.1  | 15.05 | 2.960       | 4.186                | 110 | 1045             | 1085            | 1105            |
| 3  | 37.16 | 18.58 | 2.417       | 4.186                | 111 | 373              | 393             | 410             |
| 4  | 43.22 | 21.61 | 2.092       | 4.184                | 200 | 302              | 312             | 320             |
| 5  | 50.63 | 25.3 | 1.812       | 4.159                | 210 | 152              | 182             | 199             |
| 6  | 55.6  | 27.22 | 1.656       | 4.127                | 211 | 456              | 486             | 498             |
FESEM characterization of annealed samples at temperatures of 600 °C, 650 °C and 700 °C produces thicknesses of Ba$_{0.1}$Sr$_{0.9}$TiO$_3$ capacitors. Figure 6(a-c) samples of BST annealing at temperatures of 600, m; 53.59nm and 87.09nm. Enhancement temperature annealing causes the size of BST layer thickness to be greater [14]. Annealing temperature increases cause the size of the BST constituent particles to be larger so that the atoms in it are more orderly and solid [15]. Characterization using Impedance Spectroscopy in order to determine the complex capacitance and dielectric constant to frequency.
to know the value of complex capacitance, dielectric constant and
dielectric loss. Values obtained at temperatures of 600 °C, 650 °C and
700 °C are shown in Figures 7-9 which are bode plot graphs i.e.
the relationship between complex capacitance, dielectric constant
and dielectric loss to frequency. Figures 7-9 are graphs of complex
capacitance bode plot, dielectric constant and dielectric loss to fre-
quency. Temperature 600 °C, 650 °C and 700 °C at 100Hz frequen-
cy of complex capacitance of 5.59x10⁻¹¹F, 15x10⁻¹¹F and 25x10⁻¹¹F.
The dielectric constant value is 6.32, 14.73 and 23.59. Dielectric
loss value is 0.045; 0.11 and 0.16. The same frequency of complex
capacitance values increases as a result of annealing temperature
increases [16]. The dielectric constant increases with increasing
annealing temperature from 550 °C to 800 °C [17]. The frequency
rises from 100 Hz to 1MHz, dielectric decreases and dielectric loss-
es increase sharply [18].

**Figure 9:** Graph of bode plot dielectric loss to frequency.

**Conclusion**

The XRD characterization shows intensity value increases with
increasing annealing temperature and the resulting structure is
cubic. FESEM characterization produces thickness. The thickness
is directly proportional to the temperature. The characterization
of impedance spectroscopy results in the value of complex
capacitance, dielectric constant inversely proportional to the
frequency. Dielectric loss is directly proportional to frequency.

**Acknowledgment**

The author would like to thank to Universitas Riau (UNRI) and
members of materials group at Universitas Riau for their advice and
help.

**References**

1. Siekandar R, Irmsyahdan Irzaman (2013) Temperature sensors-
based material film ferroelectric Ba₀.₅Sr₀.₅TiO₃ (BST) Assisted Azmega
8535 Microcontroller. Journal of Biophysics 9(2): 1-12.
2. Huriauwati F, Erawan K, Irzaman (2016) Pengujian film tipis Ba₀.₅Sr₀.₅TiO₃
(BST) as an electronic circuit assisted light sensor. IJFK 2(2): 61-64.
3. Tipler A, Paul (2001) (3rd edn), basic physics. Erlangga, Jakarta,
Indonesia.
4. Tukimin (2012) Perovskite (Ba, Sr) TiO₃ material impedance
spectroscopy study at high temperature. Thesis of the Faculty of
Mathematics and Natural Sciences, University of Indonesia, Indonesia.
5. Jona F, dan Shirane G (1993) Ferroelectric crystals. Dover Publication,
Inc., New York, USA.
6. Samantaray CB, Sim H, dan Hwang (2005) first-principles study of
electronic structure and optical properties of barium strontium titanates
(BaₓSr₁₋ₓTiO₃). Applied Surface Science 250: 146-151.
7. Dharmawan, W dan DiahSusanti (2012) Measurement of co gas
sensitivity from wo3 material results of sol gel and calcination process
against variation in concentration and operational temperature. POMITS
Technical Journal 1(1): 1-5.
8. Rahmi D, Krisman, Kahroniat, Fauziana (2014) Characterization of
ferroelectric material microstructure BaₓSr₁₋ₓTiO₃ (BST) with variation in
temperature annealing. Indonesian Journal of Physics 53(18): 70-71.
9. Dorris M (2013) Effect of grain size on perovkite BaTiO₃, impedance
material spectroscopy. Universitas Indonesia Depok, Indonesia.
10. Umiati NAK, Irzaman, Maman B, Barmawi M (2001) Annealing effect
on growth of ferroelectric thin films PbZr₀.₆₃Ti₀.₃₇O₃ (PZT). Indonesian
Physical Contributions 12(4): 96-98.
11. Liman J, Budi H, Tantan TR, Umi T, Muhammad K, et al. (2015) Thin film
characteristics test BaₓSr₁₋ₓTiO₃ on corning glass substrates 7059.
Indonesian Physics Journal 55: 45-48.
12. Waseda Y, Eiichiro M, Kozo Shinoda (2011) X-ray diffraction
crystallography. Introduction example and solved problems. Sendai:
Springer.
13. Xiao B, Vitaliy A, Hongrui L, Emmanuel R, Jacob L, et al. (2009) Effect
of large strain on dielectric and ferroelectric properties of BaₓSr₁₋ₓTiO₃
thin film. Applied Physics Letters, pp. 95-98.
14. Zhu X, Lu S, Chan HLW, Choy CL, Wong KH (2003) Microstructural And
dielectric properties of compositionally graded (BaₓSr₁₋ₓTiO₃ thin films
prepared by pulsed layer deposition. Applied Physics A Material Science
and Processing 76(2): 225-229.
15. Gridhann NV, Jayavel R, Ramasami P (2001) Structural, morphological
and electrical studies on barium strontium titanate thin films prepared
by sol-gel technique. Crystal Research Technology 36(1): 65-72.

How to cite this article: Rahmi D, TS Luqman H S, Krisman, Zuhdi, Hamdi. Thin Film Production and Characterization BaₓSr₁₋ₓTiO₃ (x = 0.9) for Capacitor Applications. Res Dev Material Sci. 9(4). RDMS.000717.2019. DOI: 10.31031/RDMS.2019.09.000717
16. Macdonald JR (1987) Impedance spectroscopy. John Wiley and Sons, Inc., New Jersey, USA.

17. Fu C, Chuanren Y, Hongwei C, Liye H, Yingsin W (2005) Ferroelectric properties of Ba\textsubscript{0.6}Sr\textsubscript{0.4}TiO\textsubscript{3} thin film with different grain size. Materials Letters 59(2-3): 330-333.

18. Wu Di, Aidong L, Huiqin I, Xiaobo Y, Chuanzhen G, et al. (2000) Preparation of \(\text{Ba}_{0.9}\text{Sr}_{0.1}\text{TiO}_3\) thin film by sol-gel method with rapid thermal annealing. Applied Surface Science 165(4): 309-331.