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Investigation of Dielectric Characteristics and Tunability of $Ba_{0.8}Sr_{0.2}TiO_3$

[1]Nurhafizah Ramli, [1]Zaliman Sauli, [1]VithyacharanRetnasamy, [1]They Yee Chin and [2]Hussin Kamarudin

[1]School of Microelectronic Engineering, Universiti Malaysia Perlis (UniMAP), Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
[2]School of Materials Engineering, Kompleks Pusat Pengajian Jejawi 2,Taman Muhibbah, Universiti Malaysia Perlis, 02600 Jejawi, Arau, Perlis, Malaysia.

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ABSTRACT

It's been years ferroelectric materials has become a popular fields for research. Many methods were used for the barium strontium titanate (BST) preparation like sol-gel method, radio frequency (RF) magnetron sputtering, metal organic chemical vapor deposition (MOCVD), pulsed laser deposition, and soft solution processing. In this work, sol-gel method was used for the BST preparation. The main focus in this paper is on the dielectric properties of $Ba_{0.8}Sr_{0.2}TiO_3$. Dielectric constant, dielectric loss and tunability of the $Ba_{0.8}Sr_{0.2}TiO_3$ were done in the experiment. As conclusion, the dielectric constant and tunability exhibit lower value compared the previous work; $Ba_{0.7}Sr_{0.3}TiO_3$. However, $Ba_{0.8}Sr_{0.2}TiO_3$ has a lower dielectric loss.

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INTRODUCTION

Ferroelectricity is an electrical phenomenon of ferroelectric materials may exhibit a spontaneous polarization which the direction of the polarization can be switched by the application of an external electric field. This phenomenon was discovered by J. Valasek in 1920 during his study on the analogy between the magnetic properties of ferromagnetic and the dielectric properties of Rochelle Salt [1]. Then barium titanate, BaTiO3, the first perovskite ferroelectric was discovered in 1942 and 1944 in the United States, Russia and Japan. Further study of $BaTiO_3$ continued and in 1945 and 1946, Von Hippel, and Wul and Goldman demonstrated ferroelectric switching in $BaTiO_3$ and followed by other perovskites, which is $KNbO_3$ and $KtaO_3$ discovered by Matthias in 1949, $LiNbO_3$ and $LiTaO_3$ discovered by Matthias and Remeika in 1949 and $PbTiO_3$ by Shirane, Hishima and Suzuki in 1950 [1]. Barium strontium titanate ($Ba_xSr_{1-x}TiO_3$/ BST) material is one of the ferroelectric material which attract great interest among researchers to study its electrical properties due to high dielectric constant and composition dependent Curie temperature [2, 3]. Barium strontium titanate compounds are the continuous solid solution of barium titanate ($BaTiO_3$) and strontium titanate ($SrTiO_3$). The introduction of Sr atoms to the A site of $BaTiO_3$ lattice substitute the Ba atoms will change the Curie temperature of $Ba_xSr_{1-x}TiO_3$. The Curie temperature of $Ba_xSr_{1-x}TiO_3$ system decreases linearly with the increases of Sr amount in the $BaTiO_3$ lattice which enable the paraelectric-ferroelectric transition temperature to be tailored by adjusting the barium-to-strontium ratio for specific application. Barium strontium titanate (BST) or also known as $Ba_xSr_{1-x}TiO_3$ is a very common ferroelectric materials which play an important roles in many fields. These ferroelectric materials are mostly used in microelectronic devices such as capacitor and memory devices due to its high dielectric constant, low leakage current and high breakdown field. In these recent years, the BST thin films attracted the attention in producing potential application like dynamic random access memories (DRAM), field effect transistor. One of the most important issues in estimating the charge retention capacity of the capacitor is the leakage current of the BST thin films[4-9]. BST is the composition of $BaTiO_3$ and $SrTiO_3$ solid solution. The Curie temperature T_c of $BaTiO_3$ ferroelectric material is 1200C while SrTiO3 is paraelectric material which no ferroelectric phase transition. Therefore, adjusting the ratio of Ba to Sr can control the Curie temperature TC of BST. At room temperature, the solid solution system is known to be in ferroelectric phase when Ba content is in a range of 0.7-1.0, and in paraelectric phase when Ba content is less than 0.7[10, 11].Ferroelectric materials are being widely pushed to the forefront for usages in microelectronic field. In this aspect, taking into consideration of the ferroelectric materials

Corresponding Author: Nurhafizah Ramli, School of Microelectronic Engineering, Universiti Malaysia Perlis (UniMAP), Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
E-mail: vc.sundres@gmail.com

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capability of high dielectric constant function, it has good potential as a capacitance device. Many researches were done on the BST thin films with different ratio, different preparation methods, and different materials. In this works, the focus research is on the $Ba_{0.8}Sr_{0.2}TiO_3$ dielectric properties changes with different thickness layer.

Methodology:

BST solution preparation:

The BST solution was first prepared by synthesize the barium acetate ($Ba(CH_3CO_2)_2$), strontium acetate ($Sr(CH_3CO_2)_2$), and titanium (IV) isopropoxide ($Ti((CH_3)_2CH)_4$). The solvents used in the experiment were glacial acetic acid (CH_3COOH) and 2-methoxyethanol ($C_3H_8O_2$). Sufficient amount of barium acetate and strontium acetate is mixed and stirred using magnetic stirrer in heated acetic acid at 80^0C for 1 hour until obtain clear and transparent solution. Reflux condenser was used to flux the Ba-Sr solution for 2 hours at 120^0C. Then titanium (IV) isopropoxide was dissolved in 2-methoxy ethanol at room temperature and stirred for 1 hour. The prepared Ba-Sr solution then was dropped into Ti solution and stirred at room temperature until get a thicker solution.The prepared solution was refluxed for 30 mins at 120^0C. Filtration was done using nylon microfiber filter to obtain clear yellowish solution of $Ba_{0.8}Sr_{0.2}TiO_3$Figure 1 illustarates the process flow of $Ba_{0.8}Sr_{0.2}TiO_3$ solution preparation.

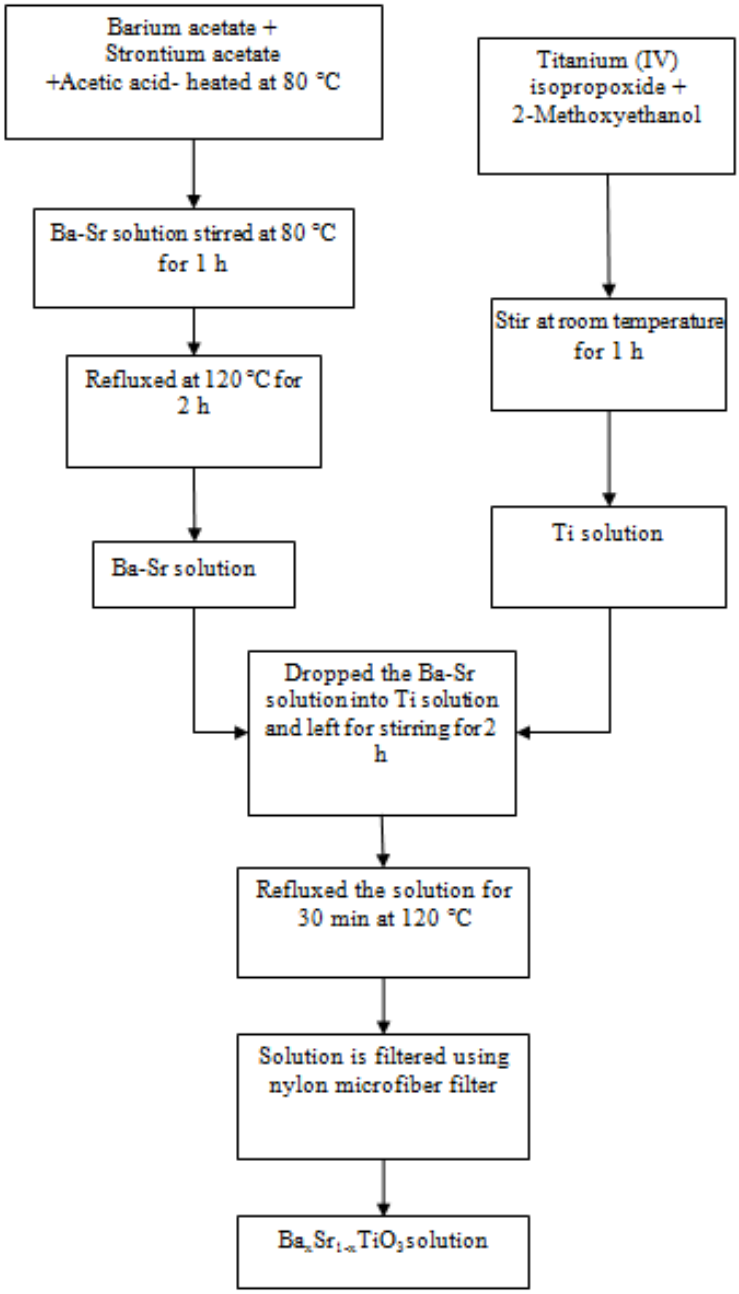

Fig. 1: Process flow of $Ba_{0.8}Sr_{0.2}TiO_3$ solutionpreparation

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$Ba_xSr_{1-x}TiO_3$ solutions Deposition Process:

Deposition processes of $Ba_xSr_{1-x}TiO_3$ solution involve four basic steps. First, substrate surface cleaning processes is important to ensure good wetting and adhesion. Then, dry oxidation process on the silicon sample is to grow thin silicon dioxide. After that, platinum deposition process on SiO_2/Si substrate which was repeated 4 times to get thicker layer of platinum. This process was done due to its stability in oxidizing atmosphere at high temperature and simultaneously maintain its electrical conductivity. The sputtered sample was annealed at 900 ^{0}C for 30 seconds after deposition process to make sure platinum coalesces uniformed. The forth process is the heat treatment process was the thin films are baked on hot plate to vaporize organic solvent. After the processes, the thin films are heated in furnace at 500^{0}C in oxygen atmosphere and repeated till the appropriate thickness. The thin films again were annealed in oxygen atmosphere at 800 ^{0}C to crystallize the thin films. The deposition of $Ba_{0.8}Sr_{0.2}TiO_3$ was repeated 4 times to produce 4 layers thin films which were noted as 1-layer, 2-layer, 3-layer and 4-layer.

RESULT AND DISCUSSION

The variation of dielectric constant (r) of $Ba_{0.8}Sr_{0.2}TiO_3$ thin films for 1 layer, 2 layer, 3 layer and 4 layer film thickness as a function of voltage is shown in Fig. 1 (a), (b), (c) and (d), respectively. The dependence of dielectric constant as a function of voltage shows non-linear character with two peaks switching polarization for all respective layers of $Ba_{0.8}Sr_{0.2}TiO_3$ thin films. The non-linear behavior with butterfly-shaped curves indicates that the $Ba_{0.8}Sr_{0.2}TiO_3$ films exhibit ferroelectric nature with is similar to ε_r -V curves of $Ba_{0.7}Sr_{0.3}TiO_3$.

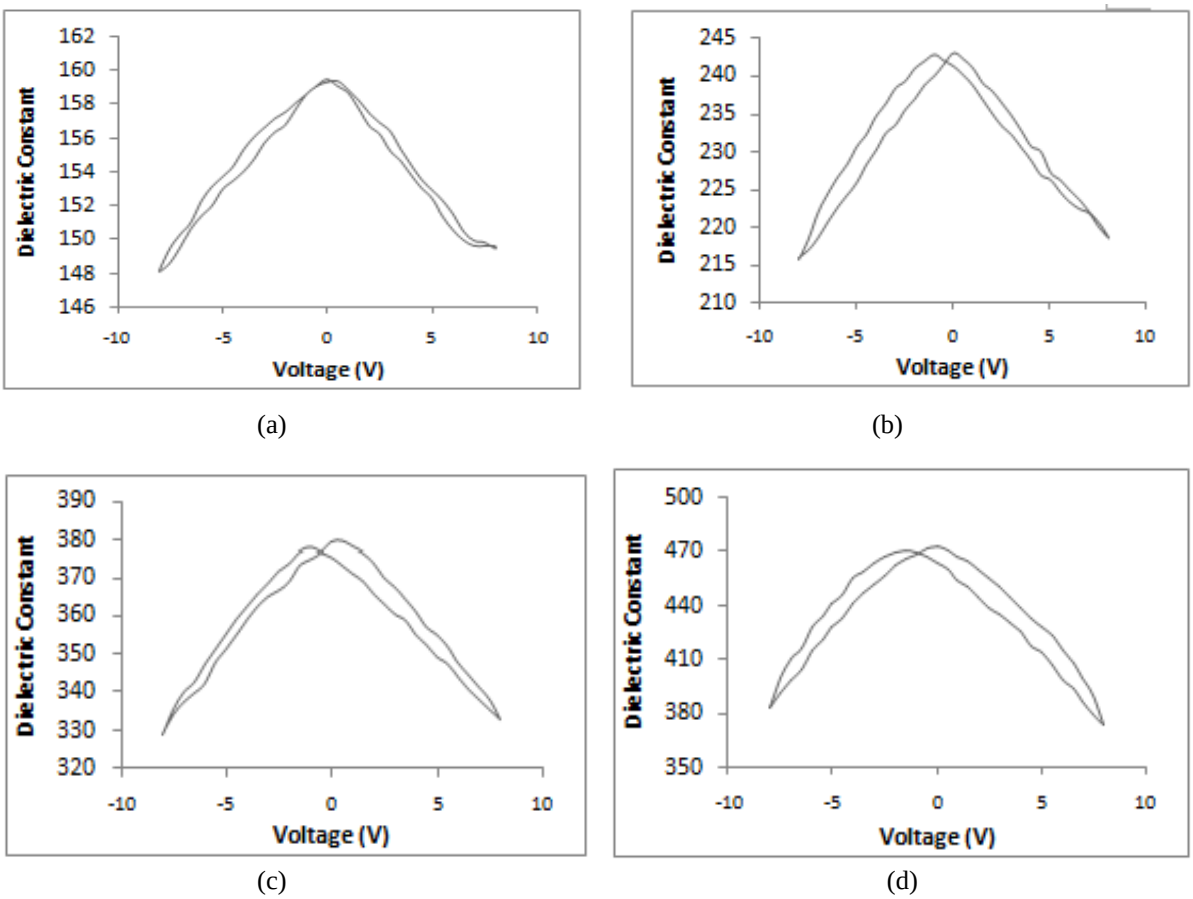

Fig. 1: ε_r-V characteristics of $Ba_{0.8}Sr_{0.2}TiO_3$ thin films with 4 different thickness

The film thickness, grain size, dielectric constant, dielectric loss and dielectric tunability of $Ba_{0.8}Sr_{0.2}TiO_3$ thin films are tabulated in Table 4.10. It has been observed that the dielectric constant at zero voltage increases from 159.51 to 472.63, and the tunability increases from 6.22 to 20.8 % and the dielectric loss increases from 0.0581 to 0.0704 with the increasing of film thickness from 1 layer to 4 layer. $Ba_{0.8}Sr_{0.2}TiO_3$ thin films has a lower dielectric constant compared to $Ba_{0.7}Sr_{0.3}TiO_3$ but higher than $Ba_{0.5}Sr_{0.5}TiO_3$ and $Ba_{0.6}Sr_{0.4}TiO_3$. This can be explained by considering our discussion to the Curie temperature. The Curie temperature is defined as the temperature where the characteristic of thin films transform from ferroelectric to paraelectric or vice versa. The work done by

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Adikary and Chan (2004) and Wu et al. (2001) concurs with these findings, whereby both the Curie temperature for composition of $Ba_{0.5}Sr_{0.5}TiO_3$ and $Ba_{0.6}Sr_{0.4}TiO_3$ are from 0 °C and below[12]. This can be deduced why 0.8 composition of Ba dielectric constant is slightly below 0.7 compositions, the temperature required for $Ba_{0.8}Sr_{0.2}TiO_3$ thin films to function fully as a ferroelectric is approximated around 55 °C. In the case of 0.7 Ba content, its Curie temperature is around room temperature whereby it's at full functional capability as a ferroelectric as to where its dielectric constant at maximum.

Table 1: Film Thickness, Grain Size, Dielectric Constant, Dielectric Loss And Dielectric Tunability Of Ba0.8Sr0.2TiO3 Thin Films

Thickness	Thickness (nm)	Grain Size (nm)	Dielectric constant	Dielectric loss	Tunability (%)
1 Layer	166.30	73.19	159.51	0.058	6.62
2 Layer	250.26	88.68	243.10	0.064	10.05
3 Layer	370.22	96.95	379.31	0.066	12.28
4 Layer	452.46	123.10	472.63	0.070	20.80

Conclusion:

$Ba_{0.8}Sr_{0.2}TiO_3$ is prepared by sol-gel method with 4 different layers.The thickness and grain size of $Ba_{0.8}Sr_{0.2}TiO_3$ thin films increase as the layer increase.Sahooet al. states that properties of multiple layer structures are strongly depend on the multilayer of the thin films[1]. As compared to the previous work, the dielectric constant and tunability of the $Ba_{0.8}Sr_{0.2}TiO_3$ thin films has a lower value. However, $Ba_{0.8}Sr_{0.2}TiO_3$ thin films have a lower dielectric loss as compared to the previous work; $Ba_{0.7}Sr_{0.3}TiO_3$ thin film[13].This phenomenon occur due to the Curie temperature. Adikary and Chan (2004) and Wu et al. (2001) concurs with these findings, whereby both the Curie temperature for composition of $Ba_{0.5}Sr_{0.5}TiO_3$ and $Ba_{0.6}Sr_{0.4}TiO_3$ are from 0 °C and below. This can be deduced why 0.8 composition of Ba dielectric constant is slightly below 0.7 compositions, the temperature required for $Ba_{0.8}Sr_{0.2}TiO_3$ thin films to function fully as a ferroelectric is approximated around 55 °C. In the case of 0.7 Ba content, its Curie temperature is around room temperature whereby it's at full functional capability as a ferroelectric as to where its dielectric constant at maximum.

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