Barium Strontium Titanate Thin Film Growth with rotational speed variation as a satellite temperature sensor prototype

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Abstract. Barium Strontium Titanate (BST) is a promising material for sensor devices such as temperature and infrared sensor. BaₓSr₁₋ₓTiO₃ thin films with affordable Si substrate were prepared by chemical solution deposition method and spin coating technique for 30 seconds with variation in rotation speed (3000 rpm, 5500 rpm and 8000 rpm). A high baking temperature at 850°C has been used for 15 hours during the annealing process. The thickness of BST film was calculated via gravimetric calculation. USB 2000 VIS-NIR was used to characterize the optical properties of BST thin film. The obtained reflectance curve showed that the most reflected wavelengths were in the range of 408-452 nm respectively. The result of the optical film characterization is very important for further development as a sensor in satellite technology.

1. Introduction
Barium Strontium Titanate (BST) material is one material which in recent years have intensively studied and developed [1-3]. BaₓSr₁₋ₓTiO₃ (BST) is a material that has a dielectric constant and a high charge storage capacity. Barium Strontium Titanate having a dielectric constant in excess of 1000 in bulk form, a key challenge for the semiconductor industry is to maintain the high dielectric constant properties of BST while integrating the material in thin film form into IC’s [4]. Ferroelectric material has the ability to change the direction of its internal electricity, can be spontaneously polarized and show hysteresis effects associated with the shift dielectric in response to an internal electric field. Piezoelectric properties can be applied as microactuator and sensors, such as infrared sensors and electro-optical properties to be applied to the light sensor [5], polarizability properties can be applied as a non-volatile random access memory [6]. In the process of preparing the film, there are several methods used [7], such as sol-gel method [8], pulsed laser ablation deposition method [9], sputtering method [10], MOCVD method [11] and chemical solution deposition methods [12]. Barium strontium titanate preparation methods may be using equipment that is quite simple, cost-effective and carried out in a relatively short time. In this work, we chose a chemical solution deposition method because of its superiority to control the films stoichiometry with good quality and the procedure is relatively easy [13].
2. Materials and Methods

The substrate used is a p-type silicon. The substrate cut into a square with a size of 1 cm x 1 cm 24 pieces. After the cutting process, followed by washing using distilled water. In the experimental work, barium acetate (99 %, Aldrich-243671), strontium acetate (99.995 %, Aldrich - 41283) and titanium isopropoxide oxide (99 %, Aldrich-21642200) were used as precursor materials for the BST synthesis and 2.5 ml of 2-methoxy ethanol as a solvent to obtain 1 M. Then all the solution were stirred with a Branson 2510 ultrasonic stirrer for 90 minutes [14].

The chemical formula of BST thin film as follow:

\[ 0.5\text{Ba(Ch}_3\text{COO)}_2 + 0.5\text{Sr(Ch}_3\text{COO)}_2 + \text{Ti(C}_12\text{H}_28\text{O}_4) + 22\text{O}_2 \rightarrow \text{Ba}_{0.5}\text{Sr}_{0.5}\text{TiO}_3 + 17\text{H}_2\text{O} + 16\text{CO}_2 \]

2.1 Thin film growth and annealing process

The hatching process from a homogeneous solution was done using chemical solution deposition methods (CSD) which has been developed for the growth of perovskite thin films [15]. Si substrate (100) p-type that has been poured by \text{Ba}_{0.5}\text{Sr}_{0.5}\text{TiO}_3 solution was rotated using a spin coater at 3000 rpm, for 30 seconds. The hatching process and Si (100) p-type substrate rotation performed three times droplets with a pause for one minute in each hatching [16]. Thin films that have gone through the process chemical solution deposition, further in-annealing using Nabertherm furnace at a temperature of 850°C for 15 hours [17]. This procedure was repeated for rotational speed of 5500 rpm and 8000 rpm.

2.2 Optical characterization of thin film BST

Evaluation of optical properties such as reflectance values conducted to observe the light reflection spectrum of the thin film Barium Strontium Titanate. The light source used was visible light, while the tool used in this test was a UV-Vis Spectroscopy Ocean Optics USB 2000. Analysis of the reflectance values in the form of calculation of the energy gap and the refractive index. Energy gap is obtained by creating plotting the relationship between:

\[ \text{ln} \left( \frac{R_{\text{max}} - R_{\text{min}}}{R - R_{\text{min}}} \right) \text{ to } h\nu \]

Extrapolation performed on the curve that has the highest gradient and cutting h\nu axis. Values were cut h\nu axis represents the value of energy gap. Meanwhile, the refractive index is obtained through equation:

\[ n = \frac{1 + \sqrt{R}}{1 - \sqrt{R}} \]  

3. Result and Discussion

From the plots in Fig.1 it can be observed that the thickness of BST was obtained using gravimetric methods. The film thickness (d) can be calculated from actual (m) mass deposited onto substrate, (\rho) density of BST (6.02 g/cm3), and the area of the film (A) [18, 19].

\[ d = \frac{m}{\rho A} \]

The variation of spin coater rotation speed in thin films preparation process led to changes in the thickness of BST film. Although the changes that caused by rotation speed was not significant, but small changes affected the absorption coefficient (\alpha) of the thin film. The value of the energy gap was affected by the value of coefficient absorption [20].
According to Irzaman, the duration of annealing hold time could affect the crystal structure, crystal morphology regularity compilers, and thickness of BST film [21].

The optical properties are measured in the light wavelength region of 400 to 1000 nm. The principal optical properties measured are the reflectance spectrum. It is used to calculate the band gap range of the BST. The energy band gap value calculated using Tauc method from the reflectance data.

![Figure 1. Film thickness](image1)

![Figure 2. Reflectance spectrum of BST](image2)
Figure 3. BST energy gap for 3000 rpm

Figure 3, 4 and 5 shows the relationship of optical properties to band gap energy of each sample to prove the film was semiconductor material. Energy gap is obtained by creating plotting the relationship between. The method is just plotting a curve of $(\alpha h\nu)^{1/2}$ to $hv$. Extrapolation performed on the curve to obtain the corresponding value of energy gap.

Figure 4. BST energy gap for 5500 rpm
Figure 5. BST energy gap for 8000 rpm

The relationship between semiconductor photon absorption coefficient and photon energy incident on the semiconductor film. Assuming that $n=1/2$ it could be used to calculate the energy band gap of $\text{Ba}_{0.5}\text{Sr}_{0.5}\text{TiO}_3$ that is grown on Si substrates. Several studies that have been carried out previously indicate that the absorption coefficient is equal to $\ln \left[\frac{(R_{\text{max}}-R_{\text{min}})}{(R-R_{\text{min}})}\right]$ as shown in equation (1). From the graph in figure 3, 4 and 5 it could be seen that the energy band gap values for BST uses varying the rotational speed of 3000 rpm, 5500 rpm and 8000 rpm are 1.52 eV, 3.05 eV and 3.2 eV respectively. The discrepancy of energy band gap widths are probably due to the varying the rotational speed of chemical solution deposition methods process that make the crystal expand. These values are in accordance to high photon energy in the short wavelength (about 2 to 3 eV). This result is not too different from earlier study of $\text{Ba}_{0.5}\text{Sr}_{0.5}\text{TiO}_3$ energy band gap [22]. Figure 3, 4 and 5 shows the results of the band gap energy is still within in the range of semiconductor energy band gap value. From these results, it seems that if the rotational speed is increased there will be an increase in the band gap energy with the value in the range of semiconductors value range.

4. Conclusions

$\text{Ba}_{0.5}\text{Sr}_{0.5}\text{TiO}_3$ thin film (BST) which is grown on the substrate Si (100) p-type by CSD method uses varying the rotational speed of 3000 rpm, 5500 rpm, 8000 rpm, has been successfully created. Variation of spin coating rotational speed serves to establish the orientation of BST film crystal structure that coincide with the thickness of the crystal substrate. The crystal structure is denser and the energy band gap become narrower which makes it suitable to be applied as a temperature sensor. The energy gap and the refractive index have been successfully analyzed using the reflectance method. The results of the analysis using reflectance method produces a wavelength range of 450 to 750 nm with energy gap are obtained in the range of 1.52 eV to 3.2 eV. Band gap energy values of the films showed that $\text{Ba}_{0.5}\text{Sr}_{0.5}\text{TiO}_3$ was in the range of semiconductors value. The designed BST thin film proved to be sufficient a promising potential as a sensor in terms of optical properties characterization for the satellite technology.

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5. References

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