The Comparison of Optical Properties Between Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ and Ba$_{0.75}$Sr$_{0.25}$TiO$_3$ Thin Films As The Light Sensors Application

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Abstract. An investigation has been carried out to determine the optical properties of Barium Strontium Titanate (BST) thin films, with different chemical composition, namely Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ and Ba$_{0.75}$Sr$_{0.25}$TiO$_3$. BST thin films that were prepared by the Chemical Solution Deposition (CSD) method and was coated on an Indium Tin Oxide (ITO) substrate using the Spin Coating method at a speed of 3000 rpm for 30 seconds. BST thin films have been characterized using optical microscopy, UV-vis spectrophotometer and X-Ray Diffraction (XRD). The results obtained that the thickness of BST thin films with the composition of Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ and Ba$_{0.75}$Sr$_{0.25}$TiO$_3$ were 42.7 μm and 28.152 μm respectively, the refractive index value of 2.31 and 2.30 respectively, and they had the gap energy of 3.4 eV and 3.3 eV respectively. From the data obtained data with notes using the same method and treatment, thin film with the chemical structure composition of Ba$_{0.75}$Sr$_{0.25}$TiO$_3$ was declared superior for the usageas photodiode sensors.

1. Introduction

Porous nanomaterials of BaTiO$_3$ have various applications in electro optics, laser, frequency doubling, high capacitor memory cell, MEMS, MLC’s, sensors, waveguide, etc [1]. Barium Strontium Titanate Ba$_x$Sr$_{(1-x)}$TiO$_3$ is a solid solution between BaTiO$_3$ and SrTiO$_3$ which posses different Ferroelectric Curie temperature Tc depending on the value of (x). BST has wide range of applications depending on Curie temperature and Dielectric properties, and BST is used in communications especially in microwave tunable circuits, phase shifter, waveguides, antennas, MOSFET, MLCCs and Varactor [2]. At room temperature, the composition of BST has the highest dielectric constant [3]. The more Ba-rich phases are ferroelectric and tetragonal at room temperature, whereas the more Sr-rich phases have lower dielectric constants. BST has the perovskite structure ABX$_3$, its derived high dielectric constant from an ionic displacement and therefore, it differs from lower dielectric constant material such as SiO$_2$, which experience an electronic displacement only by changing the applied voltage [4]. Optical absorbance of BST thin films are in the range of ultraviolet that is visible to infrared. Therefore, BST thin films can be utilized as a temperature and light sensors [5]. Photodiode can be used as light sensor that can generate electric current when it is exposed in a bright light. This can work as p-n semiconductor. Even though a photodiode can be regarded as a solar battery, but it is usually applied as a sensor to measure light intensity [6].
2. Experimental

2.1. The Preparation of Barium Strontium Titanate Solution

Barium Strontium Titanate (BST) was synthesised by using CSD method [6]. There are two types of BST solutions formed, namely BST with the chemical structure of Ba$_{0.75}$Sr$_{0.25}$TiO$_3$ and Ba$_{0.75}$Sr$_{0.25}$TiO$_3$.

Based on the chemical equilibrium reaction, we know as:

\[
0.25\text{Ba}(\text{CH}_3\text{COO})_2 + 0.75\text{Sr}(\text{CH}_3\text{COO})_2 + T_i(\text{C}_12\text{H}_28\text{O}_4) + 28O_2 \rightarrow \text{Ba}_{0.75}\text{Sr}_{0.25}\text{TiO}_3 + 16\text{CO}_2 + 17\text{H}_2\text{O}
\]

and the second reaction as

\[
0.75\text{Ba}(\text{CH}_3\text{COO})_2 + 0.25\text{Sr}(\text{CH}_3\text{COO})_2 + T_i(\text{C}_12\text{H}_28\text{O}_4) + 28O_2 \rightarrow \text{Ba}_{0.75}\text{Sr}_{0.25}\text{TiO}_3 + 16\text{CO}_2 + 17\text{H}_2\text{O}
\]

From the chemical equilibrium reaction, we know the weights for each element for thin film Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ as follows: Barium Asetat powder [Ba(CH$_3$COO)$_2$, 99%] = 1.125 gram; Strontium Asetat [Ba(CH$_3$COO)$_2$, 99%] = 3.339 gram; Titanium Isoprosida [Ti(C$_{12}$O$_{28}$H$_{28}$), 99.999%] = 5.677 gram; 2-metoksietanol solution [H$_2$H$_4$O$_2$, 99%] = 2.5 ml.

And the weights for each element for thin film Ba$_{0.75}$Sr$_{0.25}$TiO$_3$ as follows: Barium Asetat powder [Ba(CH$_3$COO)$_2$, 99%] = 3.825 gram; Strontium Asetat [Ba(CH$_3$COO)$_2$, 99%] = 1.113 gram; Titanium Isoprosida [Ti(C$_{12}$O$_{28}$H$_{28}$), 99.999%] = 5.677 gram; 2-metoksietanol solution [H$_2$H$_4$O$_2$, 99%] = 2.5 ml.

The work procedure was carried out by inserting Barium Acetate and strontium acetate into a 2-methoxyethanol solution, then it was stirred using a magnetic stirrer on a hot plate within 90 minutes. In the 30 minute process, dropped slowly a solution of Titanium Isoprosida, while continuing the stirring process. Titanium Isoprosida solution was plunged in the last process because it had the properties of freezing solution. Until we got a yellowish-colored solution, then it was heated at 200°C on a hot plate within 20 minutes.

2.2. The Preparation of Thin Film of Barium Strontium Titanate

While the Fabrication of BST thin films, BST solutions was covered on a substrate Indium Tin Oxide (ITO) with the size of 2cm x 2cm, using the Spin Counting which was rotated at a speed of 3000 rpm for 30 seconds, and then, the BST thin film that has formed on the ITO substrate was heated at the temperature of 100°C on the hot plate, with the intention of removing solvents and other organic compounds that might still be present in the thin films. The ITO substrate used in this study had a resistance of 30-40 ohms. Then, annealing process at 300°C for 8 hours was conducted using the Carbolite RHF1600 furnace, which aimed at diffusing the BST solution to the substrate by giving heat treatment. The treatment of annealing at different temperatures would give the result in different characterizations in terms of crystal structure, thickness, and grain size.

3. Results and Discussions

3.1. Characterization of Films Thicknesses

From several samples of BST thin films that successfully coated on the ITO substrate, it was characterized using an optical microscope to measure the thickness of the BST thin film layer that had been coated on the ITO substrate. Two of the best samples were chosen to represent BST thin films with the composition of Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ and Ba$_{0.75}$Sr$_{0.25}$TiO$_3$.

The results of the characterization by using an optical microscope obtained that the thickness of the thin film Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ and Ba$_{0.75}$Sr$_{0.25}$TiO$_3$ were 42.7 µm and 28.152 µm respectively. It could be seen on Figure 2.
3.2. Absorbance, Reflectance and Transmittance Characteristic

The optical characterization of the samples was performed by using UV-vis spectrophotometer. The optical properties determined the absorption of light range and light intensity of the BST thin film. Tests were carried out from in the range of visible light of 300 nm to 900 nm. The results of absorbance relation to the wavelength were shown on figure 4. The absorption event only occurs if the wavelengths of the incoming light spectrum correspond to the energy needed by the electrons which are bound to the outer shell of the BST film layer to make transition into higher energy levels. Figure 4 showed that the absorbance of light on BST thin films worked on the scale wavelengths of 350 nm to 800 nm.

The data result from the investigation on the optical absorbance on the BST films $Ba_{0.25}Sr_{0.75}TiO_3$ and $Ba_{0.75}Sr_{0.25}TiO_3$, were plotted in a diagram shown in the figure 3. It was shown that the films absorb light from the wavelength around 350 to infrared 900 nm. It proved that the films had potential applications for a light sensor as well as a temperature sensor. In the range of the wavelength between 350 nm to 500 nm, the BST films had the smallest absorbance values, and then, on the range of wavelength from 500 nm to 800 nm, the absorbance value went up gradually.

If a beam of light passes through a homogeneous medium, a part of the incoming light will be absorbed, and some will be reflected, while the rest is transmitted. In practice, the value of reflected light is very small, it is around (~4%), so for practical purposes, the transmittance value is usually the
opposite of the absorption value, by ignoring the value of reflectance. Figure 4 showed the reflectance value of the BST thin films.

The transmittance spectrum that was produced from the BST thin film indicated the inverse of the absorbance value, so that if the absorbance value decreased, the transmittance value would increase in the wavelength range of 350-500 nm, and would decrease again until it reached a stable position for the wavelength range of 500 nm - 900 nm. For overall thin film of Ba$_{0.75}$Sr$_{0.25}$TiO$_3$ compositions, it had the ability to transmit higher light when it was compared to the thin film Ba$_{0.25}$Sr$_{0.75}$TiO$_3$.

The refractive index value indicates the optical characteristics of the thin films ability to carry on a photon energy and as an anti-reflection. The determination of the refractive index was found at the absorbance peak at the beginning of the electron transition. Figure 6 showed that Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ thin films has a refractive index value of 2.31, while the thin film of Ba$_{0.75}$Sr$_{0.25}$TiO$_3$ has a refractive index value of 2.30, so it did not have a significant difference. Besides, based on Figure 6, the value of the refractive index for both BST thin films increases as well as the increase in the photon energy. The smaller the value of the refractive index, the better the film was in continuing the photon energy.

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The determination of band gap energy using the method of Tauc Plot, conducted the exploration on the part of curve linear that cut the photon energy axis, and the intersection at x-axis from the extension of curve linear part was the band gap energy of the materials used [7]. Figure 7 and Figure 8 showed the gap energy values of BST thin films for the composition of Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ and Ba$_{0.75}$Sr$_{0.25}$TiO$_3$. Each of them had a gap energy value of 3.4 eV and 3.3 eV. BST film with a composition of Ba$_{0.75}$Sr$_{0.25}$TiO$_3$ had a greater band gap energy when compared to BST film with a composition of Ba$_{0.25}$Sr$_{0.75}$TiO$_3$. It showed that the BST thin film Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ had the ability to absorb light when compared to the layer thin film of Ba$_{0.75}$Sr$_{0.25}$TiO$_3$. A smaller band gap value made it easier for electrons to be jolted from the valence band to the conduction band, so that more electrons were in the conduction band, while the valence band occurred hole. Electrons which were excited when subjected to photon energy carried by light, made the conduction band more negatively charged, whereas the valence band was more positively charged due to the lack of electrons. The differences in charge carriers from the two potential conditions at the p-n junction state would result in a current in the external circuit. The smaller the energy gap of a semiconductor material, the easier the electric current to flow in the material.

3.3. Characterization of BST Thin Films

The characterization of crystal structures in BST films using X-Ray Diffraction (XRD), with a radiation source from Cu which had a wavelength of 1.5406 Å. The data obtained from the XRD characteristic test was a graph of the relationship between the diffraction angle 2θ with the intensity of light. Each peak appeared indicated a field with a certain orientation. The diffraction patterns of Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ and Ba$_{0.75}$Sr$_{0.25}$TiO$_3$ was shown on figure 9. The diffraction patterns for Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ showed the peaks with the positions (2θ) were about 26°, 30°, 39°, 40°, 41° and 51°. While thin film of Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ showed the peaks with (2θ) were about 25°, 31°, 36°, 36°, 45°, and 49°.

The diffraction pattern that showed the highest peak of the thin films of Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ and the film of Ba$_{0.75}$Sr$_{0.25}$TiO$_3$ that were in the crystal plane (100) might happen because the crystal plane (100) was the majority crystal field, so that the results of X-ray diffraction underwent superposition for the same superposition phase.

![Figure 9. The diffraction pattern of BST Films](image)

| Film Composition | Crystalinity (%) | FWHM | Crystal Size (nm) |
|------------------|-----------------|------|------------------|
| Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ | 87.79 | 0.2676 | 3.02 |
| Ba$_{0.75}$Sr$_{0.25}$TiO$_3$ | 87.33 | 0.2676 | 3.03 |
4. Conclusion
The optical characterizations showed that the overall absorbance percentage of the BST thin films had the light absorption area on almost the entire range of the visible light spectrum even to the infrared range. The measurement agreement was that all of BST films showed a photodiode characteristic. The absorbance and reflectance measurement on both of BST thin films gave a conclusion that the thin film of Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ was the best material in absorbing the light, it’s meant that the BST thin film Ba$_{0.75}$Sr$_{0.25}$TiO$_3$, could be good material for the light sensor.

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