INTEGRATED VISIBLE LIGHT SENSOR BASED ON THIN FILM FERROELECTRIC MATERIAL Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ to MICROCONTROLLER ATMega8535

Heriyanto Syafutra$^1$, Irzaman$^1$, I Dewa Made Subrata$^2$

$^1$Department of Physics, FMIPA Bogor Agricultural University (IPB)
$^2$Agricultural Engineering, FATETA Bogor Agricultural University (IPB)
Kampus IPB Darmaga, Bogor 16680, Indonesia
e-mail: hsyafutra@yahoo.com

ABSTRACT

Thin films base of ferroelectric materials Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ (BST) at a concentration of 1 M was made by using chemical solution deposition (CSD). The thin films were grown on the substrate of Si (100) p-type and annealed at a temperature of 950°C. The BST has a small reflectance at the green area. The photocurrent and electric conductivity of thin films increased with increasing intensity. The diode characteristic curve formed on the current-voltage characteristics and the shift of the diode characteristics curve when treated in dark to light conditions. This indicates BST are a photodiode. BST had been integrated in the ATMega8535 microcontroller as light meter for measuring the light intensity in units of Wm$^{-2}$, in which BST as a light sensor.

Keywords: Thin Film, BST, Light Intensity, Light Sensor, Microcontroller.

INTRODUCTION

The development of chemical solution deposition (CSD) processes for perovskite thin films dates back to the mid-1980s. Perovskite materials display a wide range of properties that make them attractive for a variety of electrical ceramic applications [1]. Perovskite barium strontium titanate (BST) materials are very attractive due to their large electro-optic coefficient making them useful for opto-electronic devices [2]. Thin films BST can be produced using sol-gel method [3;4;5].

This research attempt to manufacture thin film ferroelectric material Ba$_{0.25}$Sr$_{0.75}$TiO$_3$ (BST) at 1 molar concentration with 950°C annealing temperature, and integrated to a microcontroller for visible light sensor application.

EXPERIMENTAL METHOD

The precursors for the BST solution were Strontium acetate [Sr(CH$_3$COO)$_2$, 99%], Barium acetate [Ba(CH$_3$COO)$_2$, 99%] in powder and Titanium isopropoxide [Ti(C$_{12}$H$_{28}$O$_4$), 99.999%] in liquid. 2-methoxyethanol [H$_2$COCH$_2$CH$_2$OH, 99%] was a solvent and Si (100) p-type was a substrate. Strontium acetate, Barium acetate and Titanium Isopropoxide were mixed together in 2-methoxyethanol solvent for 1 hour and vibrated by ultrasonic 22kH.
The precursor was dropped into the surface of a substrate and was spinned at 3000 rpm for 30 seconds and as 3 time deposition using spin-coater. The thin film was annealed at a temperature of 950°C with a temperature rise of 1.7°C/minute and was held for 15 hours at a temperature of 950°C. It was then put into contact with 99.999% Aluminum for anode and cathode of thin film.

Characterization of absorbance was done using UV-VIS Spectrophotometer Ocean Optics USB 1000 in the visible wavelength (350-1000 nm). The current-voltage tests were done using Keithley's SourceMeter family 2400. Photo-current was measured by inverting amplifier circuit current to voltage with 1 MΩ feedback resistor, and 5V for voltage reference. Electrical conductivity of BST was measured by voltage divider method.

RESULTS AND DISCUSSION

As shown in Figure 1, BST thin films have second reflection wavelength region, namely in areas close to the blue violet (421-433 nm) and red region (749-773 nm). In this region, the absorption of the photon energy is very small, because more photons were reflected than were absorbed. Thus, this wavelength region hardly contributed in generating the flow of photons. Reflection properties of BST thin films decreased again in the area close to violet purple, green region (511-527 nm), and into the infrared region. The wavelength of this region will greatly contribute in generating the flow of photons in the BST thin films, because the photon energy at this wavelength is sufficient to excite electron in the valence band into the conduction band of BST thin films. A decrease in the reflection properties of thin films in the infrared region, also allows the BST thin film to be applied to the infrared sensor, not only for the light sensor is shown in this study. The existence absorption of infrared requires for the installation of filters for infrared wavelengths does not contribute in generating the flow if the BST is used only for visible light.

From the measurement of current voltage, BST thin films showed good diode curve in darkness or in bright conditions, as shown in Figure 2. Diode curve indicates the formation of this junction has been the formation of p-type semiconductor substrate with n-type semiconductor. From the measurement of thin films, it is also known to be photodiode, with the characteristic curves that indicated the shift of the diode when given a 578 lux light intensity as shown in Figure 2. So that, this thin film can be applied as a light sensor. The phenomenon of shifting diode curve was because of the additional currents in the conduction band. Additional current in the conduction band is obtained from electrons excitation in the
valence band into the conduction band because the photon energy is greater than the band gap energy.

When BST thin films were subjected to light, it would arise due to the flow of electrons from the valence band excited to the conduction band on n-layer and will create holes in the valence band. Hole in the valence band and electrons in the conduction band will play a role in generating the current in a semiconductor material.

![Figure 2: Current vs applied voltage for BST thin film](image)

Figure 3 shows the graph of the relationship between the intensity of light with photons flows that occurred on BST thin film for annealing temperature of 950°C. Flow of photons will increase with increasing light intensity. Increasing the flow of photons is because more and more charge carrier concentration resulting from excited Hydrated Electrons from the valence band electrons into the conduction band. Electrons in the conduction band move freely under the influence of an electric field so that more electrons are excited into the conduction band causing increased flow.

![Figure 3: Photocurrents of BST thin film](image)

Figure 4 show electric conductivity value of BST thin films increased with increasing light intensity, but not linearly. Significant increase occurred in less than 6000 lux intensity for thin films at annealing temperatures 950°C. Semiconductor material is in the range of \(10^{-8}\) S/cm to \(10^3\) S/cm [6], thus the conductivity BST films are in group semiconductor material.
Electric conductivity increased when light intensity increases because the increasing number of excited electrons from the valence band electrons into the conduction band.

Electrons in the conduction band move freely under the influence of an electric field so that more electrons that are in the conduction band will increase the current flowing, thereby also increasing its electrical conductivity, while resistance value would decrease since conductivity and resistance has an inverse relationship [7]

Figure 5 is a graph of the relationship between output voltages of the amplifier circuit to the intensity of light falling on the surface of BST thin films.

From this picture, the relationship is nonlinear, thus, we have to find similarities that connect the amplifier output voltages values of light intensity. Because this amplifier's output voltage will be input for the microcontroller to be translated into the value of light intensity in units of Wm⁻². From the results of curve fitting in Figure 5, the following equation was obtained.

\[ y = 1.485x^5 - 6.643x^4 + 11.827x^3 - 10.002x^2 + 4.592x + 0.087 \]

where \( R^2 = 0.9950 \). Where \( y \) and \( x \) are respectively the light intensity and output voltages of the amplifier circuit.
Before the signal output from the amplifier is processed by a microcontroller, this signal must be converted into digital signals. ATMega8535 can distinguish 0.00486328 V voltages because it has a resolution of 10 bits = 1024 decimal, and a reference voltage of 4.98 V. Thus the change in output voltage of the amplifier at 0.00486328 V is a new condition to the microcontroller. These new conditions will be interpreted in light intensity value.

Calibration and validation of the results obtained suit the light intensity measurement unit W.m\(^{-2}\) using standard measuring devices and using the microcontroller ATMega8535. Thus, BST thin films with annealing temperature of 950°C can be applied as a visible light sensor as shown in Figure 6 and 7.

![Figure 6: Calibration curve of BST as light sensor](image1)

![Figure 7: Validation curve measurement using microcontroller](image2)

**CONCLUSION**

Sensor-based thin film ferroelectric materials Ba\(_{0.25}\)Sr\(_{0.75}\)TiO\(_3\) has been integrated in a microcontroller ATMega8535 as visible light sensor with units of Wm\(^{-2}\).
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