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Effect of Deposition Time on CIGS/TiO_2 Solar Cell Fabrication Using PVD Sputtering Method

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ABSTRACT

The CIGS (Copper Indium Gallium Selenide) thin film solar cells have been widely studied for a long time and have achieved an important position in the photovoltaic (PV) market. CIGS is one of the most promising materials for thin film solar cell applications. In this study, a thin film synthesis process was carried out on an ITO (Indium Tin Oxide) substrate using CIGS and TiO_2 (titanium Dioxide) with deposition time variations of 30. 45 and 60 minutes using the PVD DC (Physical Vapor Deposition Direct Current) Sputtering method. Based on the test results, there was a shift in the diffraction peak along with the addition of the TiO_2 layer, which indicated that the crystallization of ITO began to decrease and the TiO_2 peak began to appear at deposition times of 45 minutes and 60 minutes. The formation of polycrystalline indicates good crystallization and surface uniformity. The highest layer thickness was obtained at a deposition time of 60 minutes, which was 426 nm, due to the particle agglomeration process on the substrate surface. The larger the particle agglomerates formed, the thicker the layer on the substrate surface. The results of the UV-Vis (Ultraviolet Visible) spectrophotometer test also showed that the overall band gap energy value corresponds to the ideal value for photovoltaic thin films, namely in the range of 1.04 eV to 3.5 eV.

KEYWORDS: *CIGS, TiO2, PVD sputtering, Thin film, Solar cell.*

NOMENCLATURE

PVD	Physical Vapor Deposition
DC	Direct Current
ITO	Indium Tin Oxide
CIGS	Copper Indium Gallium Selenide
TiO_2	Titanium dioxide
SEM	Scanning Electron Microscopy
UV-Vis	Ultraviolet Visible

1. INTRODUCTION

Copper Indium Gallium Selenide (CIGS) has been studied for the past five decades. CIGS coatings are the most promising for producing high-efficiency absorption. The highest efficiency absorption generally uses vapor deposition techniques [1]. CIGS exhibits high performance due to its chemical stability, high absorption capacity, non-toxicity, and good transport properties. This indicates that further development of CIGS for solar cell technology is still very possible [2]. CIGS-based solar cells are considered one of the most promising solar cells due to their high efficiency and low production costs. In addition, they also have excellent durability and stability. Due to their flexibility and light weight, they can also be an attractive choice [3]. The absorption coefficient of CIGS is very high, around of 105 cm^{-1} in the visible spectrum of sunlight [4].

Titanium oxide (TiO_2) is an attractive semiconductor oxide with a wide band gap, good optical properties, and chemical stability [5]. When exposed to light, the holes in titanium dioxide develop a high potential that can oxidize organic materials [6]. TiO_2 is known to have a suitable band gap for photocatalytic processes, thus facilitating excitation of electrons to the conduction band, thus optimizing the absorption of ultraviolet light [7]. Several techniques commonly used to create thin layers on TiO_2 are deposition methods such as sol gel, atomic layer deposition, electro deposition, and deposition with sputtering techniques [8].

The sputtering deposition method is the most attractive and simple compared to other methods [9]. The thin film deposition (PVD) technique involves the evaporation or atomization of material from a solid source, usually called a target. The target to be used as a coating is decomposed using ionized gas molecules, causing the target atoms to release their electrons and become the plasma. To obtain good sputtering results, sufficient ion energy is required and directed to the target surface to eject atoms from the material. The ejected atoms must be able to move freely towards the substrate [10].

Thin films have various ranges in thickness, from a few atomic layers to a few microns. Surface properties and the transition zone between the substrate and the deposited material were change as a result of this process. Conversely,

substrate properties can also affect film properties. PVD techniques aim to improve coating properties and deposition rates while maintaining initial surface cleaning to prevent contamination [11]. Atomic deposition can occur in a vacuum, gas, plasma, or electrolyte environment. The vacuum environment in the deposition chamber also significantly reduces gas contamination during the deposition process [12].

In previous research, photovoltaic was made using the DSSC method using TiO_2 on an FTO substrate. TiO_2 is an n-type semiconductor so it can function as a collector and electron distributor. The nanostructure in TiO_2 allows the light absorption process to be more abundant and efficient [13]. While CIGS is a p-type semiconductor that functions to capture electrons carried by the n-type. So it will form a p-n junction layer which is needed in semiconductor applications in solar cells [14].

This study combines CIGS and TiO_2 thin layers with the aim of obtaining the characteristics, surface thickness, and band gap energy of ITO substrates coated with CIGS and TiO_2 at various TiO_2 deposition times of 30, 45, and 60 minutes.

2. RESEARCH METHOD

2.1 ITO Substrate Preparation and Deposition Process

The deposition process begins with the preparation of the ITO substrate, as shown in Figure 1. This involves alternating washing with alcohol solutions to remove contamination. This soaking is carried out in an ultrasonic cleaner bath for 5 minutes, after which the substrate is dried with a dry tissue paper.

After the washing process, a pre-vacuum was performed on the substrate using a pressure of 2 x 10-2 torr for 15 minutes with the entire Argon (Ar) gas flowing in the chamber with a pressure of 2.5 x 10-2 torr. Next, the deposition process was carried out using PVD DC Sputtering with the deposition parameters used being 71 watts, DC-Bias 800 V, and a distance of 3 cm from the target material. The deposition process begins using the CIGS target material for 60 minutes to form the first layer, then a re-deposition process was carried out using TiO_2 target material with variations of 30, 45, and 60 minutes.

2.2 Testing Process

The testing stage on substrates that have been coated with CIGS and TiO_2 was carried out using X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and UV–Vis Spectrophotometry tests as shown in Figure 2. XRD testing was conducted at the ITB Nanoscience and Nanotechnology Research Center using Bruker D8 Advance type X-Ray Diffraction (XRD) with the aim of identifying elements and compounds formed in the CIGS and TiO_2 layers. The XRD testing range used was using a diffraction angle of 2θ, which is around 0° - 95°. XRD parameters was used after obtaining graph of the test results and identified with the help of the Joint Committee on Powder Diffraction Standards (JCPDS) database software.

SEM testing was conducted at the ITB Nanoscience and Nanotechnology Research Laboratory. The instrument operates by firing an electron beam to determine surface thickness. The voltage used ranges from 0 to 30 kV and uses a silicon drift detector (SDD) type. ITO samples coated with CIGS and TiO_2 were analyzed in cross-section to observe the layer thicknesses formed from varying deposition times.

UV–Vis Spectrophotometry testing was conducted at the ITB Nanoscience and Nanotechnology Research Center using a UV–Vis Spectrophotometer type 220. The spectrometer is used to measure the intensity of light that can be absorbed by a sample at a certain wavelength. The wavelength range used in this study is 200–800 nm. The measurement principle used is transmission which produces output in the form of absorbance power.

Figure 1: Substrate preparation and deposition process

Figure 2: CIGS/TiO_2 coating testing process

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3. RESULT AND DISCUSSION

3.1 XRD Characterization Results Analysis

The results of XRD analysis on ITO substrates coated with CIGS and CIGS- TiO_2 showed diffraction peaks at angles of 21.4, 30.5, 35.4, 51.0, and 60.6, respectively corresponding to the area (211), (222), (400), (440), and (622) of ITO (JCPDS data file No: 06-0416), 26.8, 44.6, 52.9, respectively corresponding to the area (112), (220), (321) of CIGS (JCPDS data file No: 35-1102), and 25.270, 36.910, 37.771, 38.528, 48.010, 53.849, 55.037, 62.073, 62.649, each corresponding to the area (101), (103), (004), (200), (105), (211), (204) of TiO_2 (JCPDS data file No: 00-004-0477). Based on the XRD test results, the following diffraction peaks were obtained.

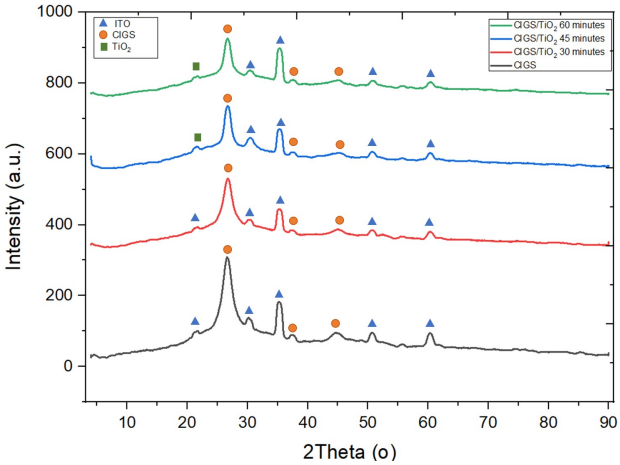

Figure 3: Results of XRD test analysis on CIGS and CIGS- TiO_2 layers

Based on Figure 3, the formation of the area (211) around the angle of 21.4 has a less sharp peak than ITO. The peak shift begins to occur when given the treatment of adding a layer of TiO_2 where it begins to shift at an angle of 25.270 which is the peak of TiO2. This shows that it begins to shift to the right which indicates that the crystallization of ITO begins to decrease. While the TiO_2 peak that begins to appear is shown at the TiO_2 deposition time of 45 minutes and 60 minutes. A sharp peak at around 26.8 with a weak peak at 44.6, indicates the formation of a tetragonal chalcopyrite structure CIGS [12]. The most intense peak at 26.8 indicates a polycrystalline CIGS alloy with the formation of a (112) plane with a tapered peak. Small angles and tapered peaks indicate stress modification in the material, resulting in a more homogeneous and dense layer [15]. The formation of polycrystalline CIGS indicates good crystallization and surface uniformity [16]. This indicates that the crystallization of CIGS increases. The thin CIGS layer that shows a more intense and sharp diffraction peak is the CIGS layer without TiO_2.

3.2 Thickness analysis using SEM

SEM testing is performed using the cross-section method to determine the thickness of a layer. This test uses 10,000 x magnifications for each layer.

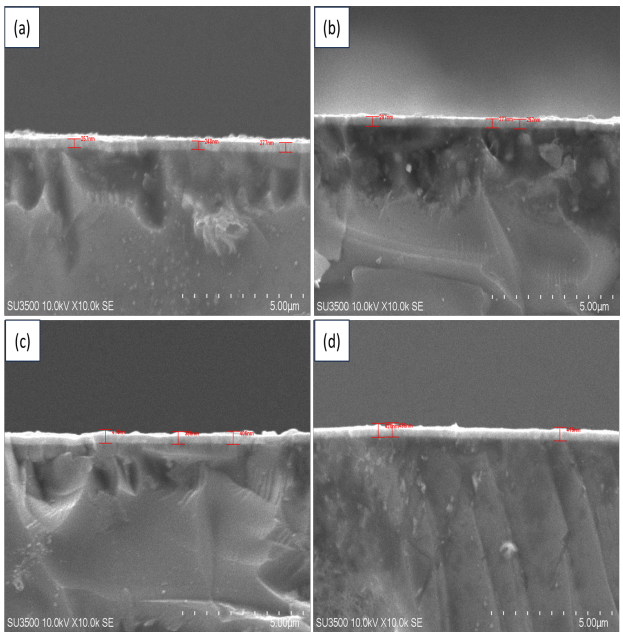

Figure 4: (a) CIGS morphology, image (b) CIGS/ TiO_2 30 min morphology, image (c) CIGS/ TiO_2 45 min morphology, and image (d) CIGS/ TiO_2 60 min morphology

In Figure 4(a),(b),(c),(d) it can be seen that the layer formed by the sputtering method produces a dense morphology and experiences an increase in thickness along with the increase in deposition time. The particle agglomeration process on the substrate surface can affect the thickness of the CIGS- TiO_2 layer, where the larger the particle clumps formed, the thicker the layer on the substrate surface (biological). The layer thickness values vary and show an increase along with the increase in deposition time as seen in Table 1. The highest layer thickness was obtained at a deposition time of 60 minutes, which was 426 nm. The decrease in thickness in the CIGS- TiO_2 layer shown at a deposition time of 30 minutes was 290.33 nm. The lowest thickness of all variations was shown in the CIGS layer without TiO_2, which was 260.67 nm. The thickness of the layer is one of the important parameters in determining the performance of the resulting cell device [17]. A thicker thin layer can increase light absorption with the possibility of increasing charge recombination simultaneously [18].

Table 1: Results of coating thickness on ITO substrate

No	Sample	Layer Thickness (nm)
1	CIGS without TiO_2	260.67
2	CIGS - TiO_2 30 min	290.33
3	CIGS - TiO_2 45 min	402.67
4	CIGS - TiO_2 60 min	426.00

3.3 Optical Properties of CIGS-TiO2 Thin Films Using UV-Vis Spectrophotometry

UV-Vis Spectrophotometry tests on CIGS/ TiO_2 thin films were conducted to determine the film's absorption spectrum. The absorption spectrum in this study was measured in the range of 200–800 nm, where the UV spectrum (200–400 nm) and the visible spectrum (400–800 nm) were measured.

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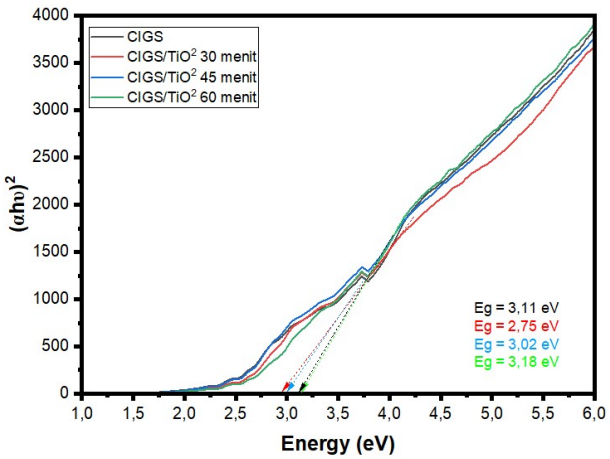

Figure 5: Band Gap Energy of CIGS and CIGS Coatings with TiO_2

Based on Figure 5, the UV-Vis characterization results identify the band gap of a semiconductor using the Tauc vs $\alpha h\nu 2$ plot. $h\nu$ The band gap absorber layer material is an important parameter for solar cells, because it is the minimum energy required for electrons to move from the valence band to the conduction band. The photogeneration process also occurs in the semiconductor band gap. Based on Figure 15, the band gap energy value for the CIGS layer without TiO_2 is 3.11 eV, CIGS - TiO_2 30 minutes is 2.75 eV, CIGS - TiO_2 45 minutes is 3.02 eV, and CIGS-TiO2 60 minutes is 3.18 eV.

Based on this, it can be interpreted that the formed layer has a good light radiation absorption area in the UV region. This sharp bend indicates that the TiO_2 particles deposited in the form of a layer begin to be detected by UV light [19]. This also indicates that the CIGS - TiO_2 thin layer has the ability to absorb UV-A light radiation at a band gap varying from 1.04 eV to around 3.5 eV [20].

4.0 CONCLUSION

In this study, the peak shift began to occur when the TiO_2 layer was added, indicating that the ITO crystallization began to decrease and showed that the TiO_2 peak began to appear at 45 and 60 minutes of deposition time. The highest layer thickness was obtained at 60 minutes of deposition time, which was 426 nm. The particle agglomeration process on the substrate surface can affect the thickness of the CIGS- TiO_2 layer, where the larger the particle clumps formed, the thicker the layer on the substrate surface will be. The band gap energy value for the CIGS and TiO_2 layers is in the range of 1.04 eV to 3.5 eV. Based on this, it can be interpreted that the layer formed has a good light radiation absorption area in the UV region. So the process of forming a thin layer of CIGS/ TiO_2 makes it possible to become a candidate for photovoltaic in the future.

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