Effect of Temperature to Fabrication Cigs Solar Cell Using the Sputtering Method

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Abstract. Copper-indium-gallium diselenide (CuInGaSe2) or CIGS is one of the most promising materials for thin film solar cell applications. CIGS solar cells were deposited by sputtering method on ZnO/ZnS/CIGS/Mo arrays. Various parameters in sputtering greatly influence the efficiency of CIGS solar cells such as temperature. Thermal parameters are used to compare the effect of the CIGS layer on optimizing the efficiency of CIGS solar cells. The results show that the CIGS layer deposited using temperature has a crystalline structure, besides that the resulting efficiency is also higher than CIGS solar cells deposited without temperature, namely 0.177%.

1 Introduction

The need for electrical energy which continues to increase so far is still sourced from fossils, so that alternatives are needed to use renewable energy sources, one of which is solar energy. Solar energy or sunlight is a potential energy source to be developed because it is environmentally friendly and the number is unlimited. Almost all of the earth's surface receives sunlight optimally, so the use of solar energy as a renewable energy source becomes an important alternative to meet energy needs [1]. Solar energy can be converted into electrical energy through a device called a solar cell [2]. Solar cells convert solar energy into a form of electrical energy following the photovoltaic principle, by absorbing photon energy at a specific wavelength that will excite some of the electrons in a material to the outer energy band [3].

There are several types of solar cells such as silicon solar cells, thin films made from combinations of groups I-III-IV such as CIGS, and solar cells made of organic materials or dye-sensitized solar cells (DSSC) [4]. Silicon based solar cells have a high efficiency of 23% but tend to be environmentally unfriendly and expensive manufacturing costs, DSSC is environmentally friendly but low efficiency and has not been widely mass produced [5]. CIGS solar cells have high enough efficiency, high absorption, can last a long time, can be

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produced on a large scale, and production costs are more economical than silicon solar cells [6].

Copper Indium Gallium Selenide (CIGS) is a member of the chalcopyrite I-III-IV2 group of semiconductors used as light-absorbing agents in solar cells [7]. Copper Indium Gallium Selenide (CIGS) has a direct band gap of 1.04-3.50 eV [8], a high absorption coefficient, moderate surface recombination rate and good radiation properties [9]. The efficiency of CIGS solar cells on a lab scale is quite high at 20%. CIGS solar cells consist of several layers, namely substrate, absorber layer, buffer layer, and window layer. The material usually used in the substrate is glass coated with molybdenum as back contact, CIGS as absorber layer, CdS and ZnS as buffer layer, and ZnO as window layer [10]. In addition, CIGS with characteristics that are stable against photodegradation, makes CIGS a candidate that can be mass-produced [11].

Currently, various methods have been developed in CIGS filmmaking. Such as co-evaporating [12], sputtering [13], electrodeposition [14], spin coating [9], and heating-up [15]. Of these methods, sputtering is the most superior method because it produces a uniform microstructure and good electrical properties [16]. This is also evidenced by the efficiency produced by the sputtering method is also higher. In 2022, H Rahmawati., et all have conducted research on CIGS fabrication using SeO_2 as selenium with the elecroptrodeposition method resulting in an efficiency of 0.04% where the resulting efficiency is still very low [17]. The spin coating method has also been used to characterize CIGS/ZnO by ASP Dewi in 2022 and resulted in an efficiency of 0.3%, this efficiency is also still low [9]. Research on CIGS solar cells with sputtering method has also been carried out such as Johannes et all in 2018 revealed that CIGS sputtering method solar cells have an efficiency of 20% [18]. Slawomir and Ewelina in 2020 produced 19.2% efficiency from CIGS solar cells with temperatures above 400 °C and pressures of 1.5 Pa [19]. Yanan Li et al., 2019 also stated that temperatures above 400 °C in the CIGS solar cell manufacturing process cause increased recombination [20].

From these several journals it can be concluded that the sputtering method is the most efficient than other methods and temperatures of more than 400 °C with sputtering methods in CIGS can reduce efficiency and thicken the layer, even though the optimal CIGS layer thickness is around 2.1 μm [21]. So, to improve optical and electrical properties without thickening the layer, heating outside the sputtering process is needed. Heating in the sputtering process serves to make it easier for CIGS particles to stick to the substrate, while heating outside the sputtering process can provide more energy for CIGS particles to form crystals. Thus, in this study, an analysis was carried out on the influence of temperature given during the CIGS coating process.

2 Method

2.1 Material

Alcohol, Commercial ITO Substrate, Deionized Water, Wipes, Copper Indium Gallium Diselenide (CIGS) target 99.99% diameter 6 cm, Molybdenum target (Mo) 99.99% diameter 6 cm, Cadmium Sulfide (CdS) target 99.99% diameter 6 cm, Zinc Oxide (ZnO) target 99.99% diameter 6 cm.

2.2 Research Variables

The independent variable used in this study was the temperature variation in the CIGS layer when outside the sputtering process (0℃ and 100 ℃). The dependent variables in this study are structural properties, optical properties, and solar performance of CIGS cells. The control variables in this study were: washing treatment of glass substrates; type of material; Mo, CIGS, CdS, and ZnO coating time, and sputtering-based ITO/ZnO/ZnS/CIGS/Mo substrate coating process.

2.3 Research Procedure

2.3.1 ITO Substrate Cleaning

The ITO substrate was washed with aceton solution and deionized water using an ultrasonic cleaner for 5 min each. After that, the ITO substrate is placed on clean tissue and dried.

2.3.2 ITO/ZnO/ZnS/CIGS/Mo deposition by sputtering method

The process of coating ITO/ZnO/ZnS/CIGS/Mo substrates by sputtering method, which on parameters according to Table 1. After the CIGS coating process, reheating is carried out using furnace of 0 ℃, 100 ℃. Then proceed the sputtering of the Mo layer.

Table 1. Parameter Sputtering.

	Time (minutes)	**Power (Watts)**	**Pressure (Pa)**	**(DC/RF)**	**Temperature (℃)**
ZnO	60	60	1,0	RF	0
ZnS	45	60	1,1	RF	0
CIGS	120	40	5,7	RF	200
Mo	30	40	4,3	DC	100

2.3.3 CIGS Solar Cell Performance Measurement, and Data Analysis Characteriation XRD

X-Ray Difractometer (XRD) characterization aims to determine the phase of a material, crystal structure and crystal size carried out on Mo film, CIGS film with its variations, CdS film and ZnO film.

2.3.4 Uv-Vis Characterization

Uv-Vis characterization aims to identify absorbance and band gap films performed on Mo films, CIGS films with their variations, CdS films and ZnO films.

2.3.5 SEM characterization

SEM characterization was carried out to determine the morphology, composition and thickness carried out on Mo film, CIGS film with its variations, CdS film and ZnO film.

2.3.6 CIGS Solar Cell Performance Measurement

Measurement of solar cell efficiency of ITO/ZnO/ZnS/CIGS/Mo substrate was carried out using a solar simulator with an intensity of 100 mW/ with an active area of 0.25cm^2 x 0.25cm^2.

3 Result and Discussion

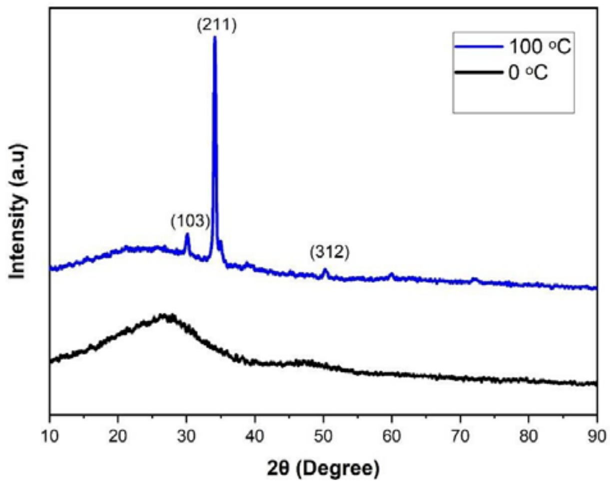

Fig. 1. Diffraction pattern of CIGS coating on glass substrate

Figure 1. Shows the peak yield of X-ray diffraction at CIGS on glass substrates with temperature variations of 0℃ and 100℃ At temperature 0 the results of X-ray diffraction show an amorphous phase, this can occur because the temperature used is too low so that CIGS particles lack energy to become crystals. ℃CIGS layers with temperatures of 100 ℃ are located in planes (103), (211), and (321). The HKL position with the highest diffraction peak intensity in the field (211) is located at 34.99°C The diffraction peak in the image has a fairly large widening pattern, indicating that the crystal size is small. Small crystal sizes have a finite field of X-ray reflectors. Conversely, if the widening pattern is narrow enough, then the size of the large crystal grains. CIGS layers are generally depositioned at a high substrate temperature (Tsub) of more than 550°C. The main peak in the CIGS layer lies in the plane (112)℃ at 26.91℃ but in the CIGS layer with a temperature of 100 has not yet appeared, this is because the diffraction peak of the CIGS field (112)℃ requires a temperature of about 300 to form completely. It can be concluded that with increasing annealing temperature in the CIGS layer increases the crystallinity of the film due to the reduction of defects.

The crystal grain size in the CIGS layer temperature of 100 is ℃ found using the Scherrer equation, which is 19.39 nm. The result of this size calculation has a smaller size the value compared to CIGS produced in the previous study by Riaz et.al [20] was ~40 nm and was almost the same in Badgujar et.al study [21] from 15 – 20 nm. The grain size is possible due to the influence of temperature at the time of growth of CIGS particles, because changes in temperature at the time of growth will change the FWHM value as well as the average size of crystal grains.

Characterization of the UV-Vis spectrophotometer was performed to determine the absorption of CIGS film which can be seen in Figure 2. The absorption value of cigs decreases with wavelength only. This proves the absorption characteristics of CIGS materials. Based on the results of characterization, all samples with different temperature variations have relatively the same absorption value. Based on the absorption graph against the wavelength of the film, CIGS has the strongest excitonic absorption at a wavelength of ~400 nm. This ectonic absorption peak identified that the CIGS film has good optical properties and strong exciton energy.

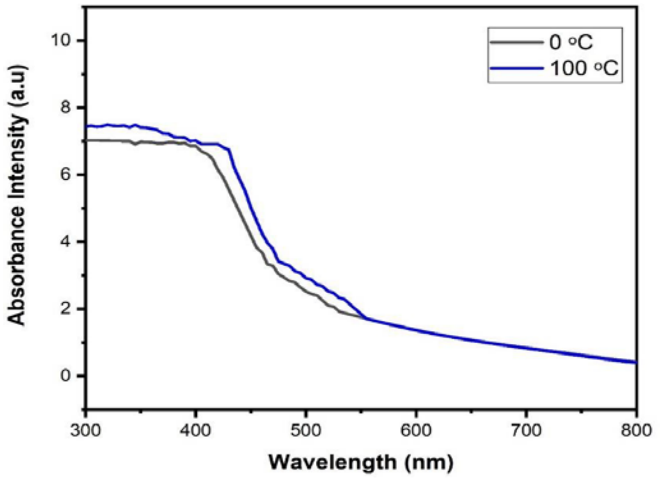

Fig. 2. CIGS absorbance spectrum

In addition to measuring absorbance, Uv-Vis characterization results can also identify the band gap or *band gap* of a semiconductor using the *Tauc Plot Vs* $ahv2$. hv *The band gap absorber layer* material is an important parameter for solar cells, as it is the minimum energy required for electrons to move from the valence band to the conduction band. In *the semiconductor band gap*, the photogeneration process also occurs. In the chalcopyrite alloy system Cu(In, Ga, Al)(Se,S)2, the band gap varies from 1.04 eV to about 3.5 eV [11]. Figure 3 and Table 2 show the *band gap* obtained from the results of the *Tauc Plot* $ahv2$ Vs hv CIGS absorber layer for various variations of the layer.

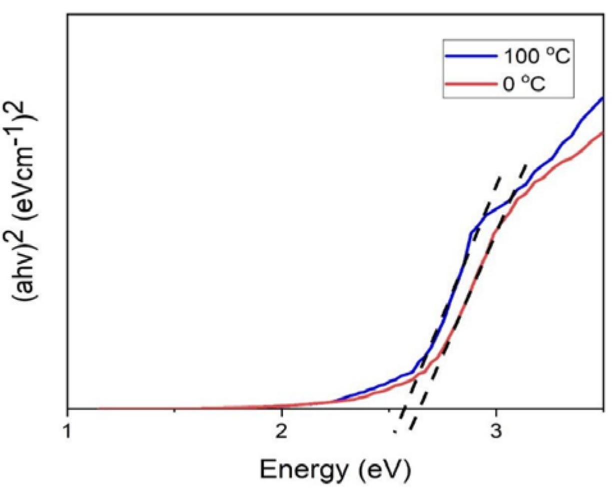

Fig. 3. Band gap of the CIGS absorber layer

Table 2. CIGS absorbance peaks and band gaps.

Sampel	Absorbance (nm)	*Band gap* (eV)
0 °C	400.55	2.65
100 °C	430.64	2.58

Based on Figure 3 and Table 2, the band gap of the CIGS absorber layer with temperatures 0°C and 100°C is 2.65 eV and 2.58 eV. The band gap CIGS absorber layer for all variations is in the range of 1.04 eV to about 3.5 eV, so it can be confirmed that the resulting CIGS film can be used as an absorber layer on solar cells.

CIGS solar film performance at several temperature variations was identified using the KEITHLEY 2400 and a solar simulator with a power input of 100 mWcm-2. This measurement can identify efficiency along with other parameters such as Isc, Jsc, Voc, Fill factor, Pmax, Imax, and Vmax as well as solar cell photoresponsiveness. The following is the result of the analysis of the performance of CIGS solar cells at temperatures 0°C dan 100°C.

Table 3. Parameter efficiency of CIGS.

Parameter	CIGS 0°C	CIGS 100°C
Isc (mA)	0.095	0.072
Jsc (mAcm^{-2})	0.190	0.145
Voc (V)	0.180	0.177
Fill factor	4.510	8.080
Efficiency (%)	0.154	0.177
Pmax (mW)	0.077	0.088
Imax (mA)	0.091	0.071
Vmax (V)	0.850	1.250

Based on Table 3, the efficiency of CIGS solar cells at a temperature of 0 is 0.154% and 100 is 0.177%. °C°C. The application of temperature can affect the resulting efficiency although the results are not much different, low temperatures are not able to reduce CIGS elements optimally.

4 Summary

CIGS film is depositioned with RF magnetron sputtering with temperature variations in furnaces 0 °C and 100°C. It can be concluded that samples at a temperature of 100°C show are located in the fields (°C103), (211), and (321), the crystal grain size is about 19.39 nm. The wavelength of the CIGS film in both variations has absorption at a wavelength of ~400 nm. Efficiency of CIGS solar cells at a temperature of 0°C is 0.154% and 100°C is 0.177%.

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