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$CuInSe_2$ THIN FILM FOR SOLAR CELL BY FLASH EVAPORATION

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Abstract

Deposition of thin films for material solar cell $CuInSe_2$ are relatively simple. In this research mainly focused on the use of flash evaporation method, and the material created can then be characterized by optical and electrical properties. The optical characterization is done by X-ray Diffraction (XRD), Energy Dispersive Spectroscopy (EDS), and transmission and reflection by UV-VIS spectrophotometry. Electrical characterization is done by utilizing the Hall effect equipment. From these characterization, the atomic structure, absorption coefficient, energy gap, material type, composition of each elements and the mobility of $CuInSe_2$ can be measured and determined. During process evaporation were carried out at substrate temperatures the range between 20ºC–415ºC.

Keywords: *chalcopyrite, flash evaporation, stochiometric, and thin film*

1. Introduction

Deposition of solar cell material by evaporation has been conducted by many researchers [1-7]. The methods used were flash evaporation, thermal evaporation and co-evaporation. The results were thin film with a thickness of 0.5 µm to 3.7 µm. This research mainly concerned in deposition by using flash evaporation method. By using this method the thin film produced can adhere stronger to a substrate compared to thermal evaporation and co-evaporation method. The material created can then be characterized. The optical and structural characterization is done by X-ray Diffraction, Energy Dispersive Spectroscopy, and measurement on transmission and reflection by UV-VIS spectrophotometry. As the transmission and reflection are known, the absorption coefficient and bandgap can be determined. Electrical characterization is done by measuring the resistance using the Hall effect, and the measurement on the thickness of the thin film was done using the alpha-step equipment. The material has a basic structure of tetrahedric and it's also known as chalcopyrite structure from the diamond family, the value of the lattice crystal parameter is a = b, c/a ≈ 2 and it has a boiling point of 986°C [8,9] with a band gap of 1 eV to 1.7 eV.

2. Methods

The method used to deposit the thin film in this research is by flash evaporation. The starting material was in ingot form [10], it is pounded to a powder with a diameter of 50 µm – 300 µm. Before the process, the evaporation chamber was first cleaned, the substrate was washed using detergent and distilled water. The substrate used was pyrex glass with dimensions of 1.2 cm x 2.4 cm and 2 cm x 2 cm. The material powder was then placed inside a vibrator tube and put inside the evaporation chamber, the chamber was then vacuumed to 10^{-7} Torr and then sealed. Evaporation started, the crucible was heated to temperature of 1200°C-1300°C, at the same time the vibrator tube was running at the speed where the powder would fall only to the crucible. The overall processes can be monitored through the chamber's window. By controlling the speed of the falling powder to the crucible, it is about 15-40 minutes needed for each evaporation. In every evaporation process, the substrate temperatures were changed from

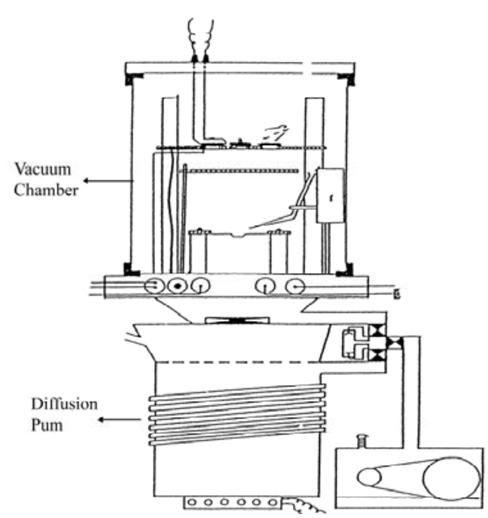

Figure 1. The Flash Evaporation Equipment

20°C up to 415°C. In this research at low substrate temperature (<200ºC) the result both optic and electric characterization are not good and the research consentrate at high substrate temperature in between 270ºC-415ºC. Figure 1 shows the set-up for the flash evaporation equipment.

3. Results and Discussion

Table 1 shows the evaporation parameters that are grains size, substrate temperature and evaporation time of some thin film samples. The thickness of thin film is measured by alpha-step and its result can be seen in last column in this table.

From some evaporation experiments, it is best to keep the diameter of powder grain size on 50 μm, smaller diameter caused the powder not to fall to the crucible during evaporation.

Optical characterization

XRD measurement. The structural characterization is measurement by X-ray Diffraction with different substrate temperatures that are a low substrate temperature from 20°C–60°C and a high substrate temperature from 270°C–400°C. Result on measurement using X-ray Diffraction can be seen on Figure 2 and Figure 3. Figure 2 shows that there are two samples and in each sample the substrate was heated to a temperature of 20°C, and 56°C**.** In Figure 3, shows that there are two samples and in each sample the substrate was heated to a temperature of 270°C and 415°C. From both figures we can conclude that the temperature of the substrate is very important. When the substrate on low temperature is between 20°C–60°C the orientation of crystal peaks are low and weak, occasionally found binary material such as Cu_9In_4. Compared to substrates heated on 270°C–400°C or high temperature, the peak was clearly defined and sharp. This is especially true for orientation crystal peaks (112) with an angle of 2θ = 26.67°; (204) or (220) with an angle of 2θ = 44.41°; and (116) or (312) with an angle of 2θ = 52.50° that is the principal peaks on the material $CuInSe_2$. After determining the peaks through X-ray Diffraction, the material's lattice crystal parameter can then be calculated which are a, c, and c/a. The values of these parameter can be seen on Table 2, especially for thin film exposited at high substrate temperatures. The lattice crystal parameters values calculated, especially c/a, was almost 2, this conclude that the atomic structure produced is a structure of chalcopyrite.

Table 1. Evaporation Parameters on Some Samples

Samples	Grains Size (μm)	T. Substrate (˚C)	Time (min)	Thickness (μm)
1	250 – 300	271	15	0.80
2	150 – 250	293	30	1.40
3	150 – 250	317	30	0.30
4	100 – 150	355	25	1.20
5	150 – 250	389	30	0.50
6	150 – 250	391	40	0.28
7	150 – 250	391	40	1.45
8	150 – 250	293	40	3.30
9	150 – 250	293	40	3.70
10	50 – 250	279	40	2.15
11	150 – 250	313	35	1.20
12	50 – 250	415	30	1.00

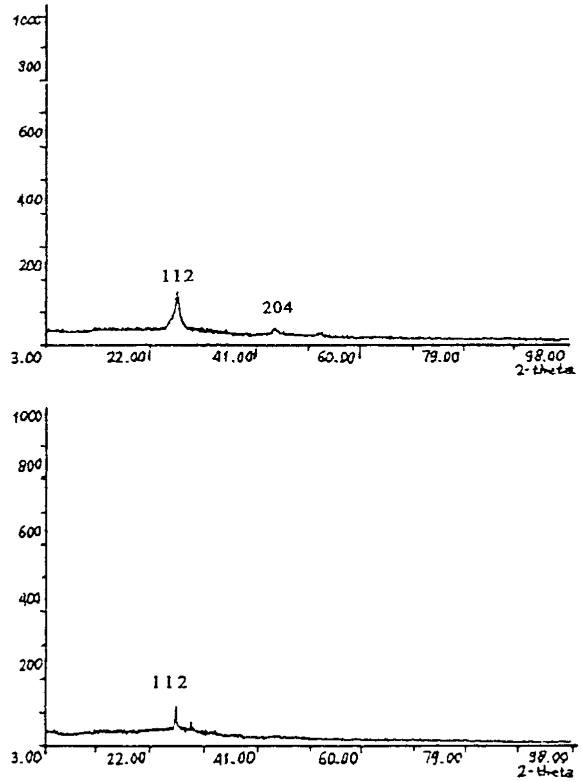

Figure 2. X-ray Results on Low Substrate Temperature

Table 2. Values on a, c, and c/a

Samples	a (Å)	c (Å)	c/a
1	5.7641	11.5963	2.0118
2	5.7675	11.5428	2.0014
3	5.7593	11.5945	2.0132
4	5.7849	11.5906	2.0036
5	5.7894	11.5737	1.9991
6	5.7500	11.6147	2.0200
7	5.7637	11.5924	2.0110

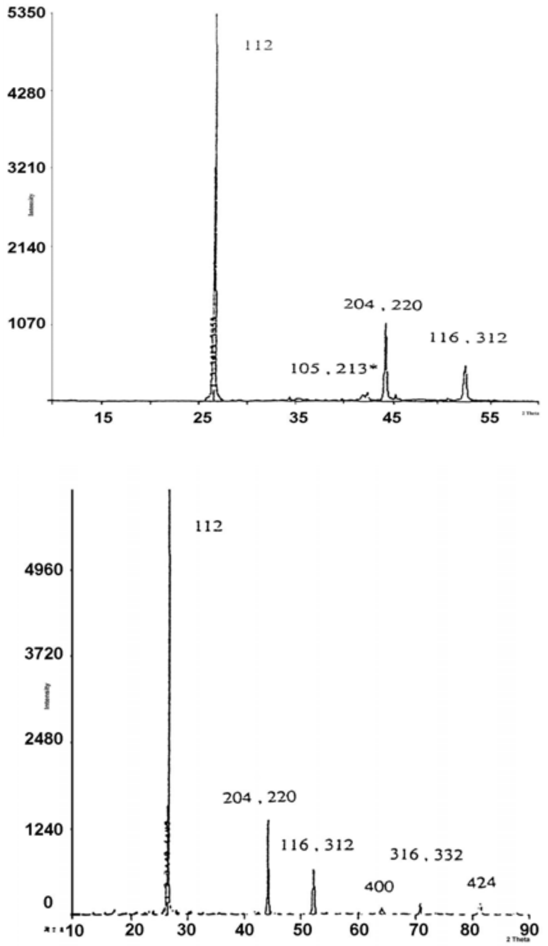

Figure 3. X-ray Results on High Substrate Temperature

EDS Measurement. Composition of each element results using EDS can be seen on Table 3. It shows that the composition of material is close to stochiometric composition, except for samples numbers 5 and 6.

Grain measurement. Grain size measurement on the surface of the thin film using Electronic Microscope (SEM) can be seen on Photo 1. The photo shows that the grain has a diameter between 0.2 μm – 1.2 μm with substrate temperatures 293ºC, 355ºC and 391ºC (samples number 6, 7 and 9 in Table 1) respectively. Grain with bigger diameter of 1 μm, was produced when the substrate temperature was heated on 300ºC – 415ºC. Kazmerski, et al., conclude that the diameter will increase with the increase of substrate temperature [11]. The diameter resulted is 0.2 μm - 0.8 μm and the results gained in this experiment is relatively the same with other research using different methods such as co-evaporation [12,13], flash evaporation, spray evaporation and electrodeposition [14].

Table 3. Composition of Each Element in $CuInSe_2$

Samples	Cu (%)	In (%)	Se (%)
1	20.9	28.8	50.3
2	27.0	29.3	43.7
3	25.9	26.7	47.4
4	19.9	30.9	49.2
5	30.5	24.1	45.4
6	32.0	22.0	46.0
7	25.8	27.4	46.8
8	25.3	26.8	47.9
9	22.9	27.8	49.3
10	24.6	27.7	47.7
11	24.9	27.7	47.4
12	25.3	27.9	46.8

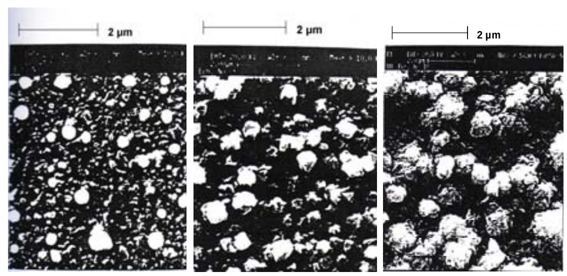

Photo 1. Morphology of Grains Taken from Some Samples

Transmission, reflection and energy gap

Measurements on transmission, and reflection were done using spectrophotometer UV-VS NIR Beckman UV 5270. The measurements were done using wavelength from 0.2 μm to 2.5 μm. The transmission and reflection typical result on high substrate temperature at 415ºC, can be seen on Figure 4. From transmission and reflection results, the bandgaps and absorption coefficients can be calculated [15] as seen on Figure 5 and Figure 6. Figure 5 shows that the absorption coefficient values is between 10^{-3} cm to 10^{-5} cm at substrate temperatures 293ºC, 389ºC, 391ºC and 415ºC (samples number 2, 5, 6 and 12 in Table 1) respectively and with same samples in Figure 5 in Figure 6 shows the energy gaps measured is between 0.95 eV to 1.0 eV. From these results concluded that with the increase substrate temperatures the both values absorbstion coefficient and energy gaps will also increase.

Electrical characterization

By using the Hall effect, the value of resistivity, conductivity type and majority carriers concentration of $CuInSe_2$ [16] can be measured as shown in Table 4. Figure 7 shows the correlation between mobilities, the values of Cu/In and type. This Figure shows that, if the values of Cu/In < 1 the type of materials are n and if the values of Cu/In > 1 the type are p. These results show that almost all samples the type are n except samples 5 and 6 are p.

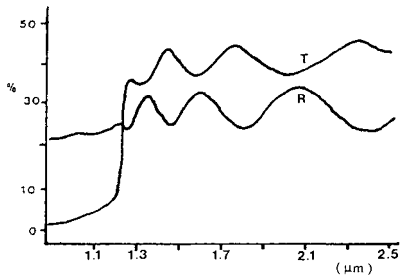

Figure 4. Pattern of Transmission and Reflection

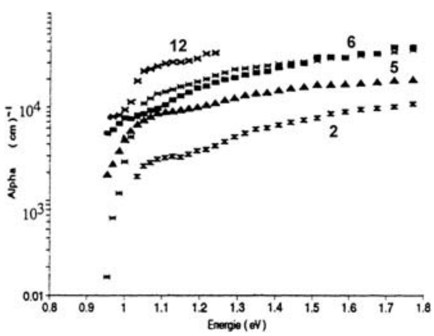

Figure 5. Absorption Coeficient on Several Samples

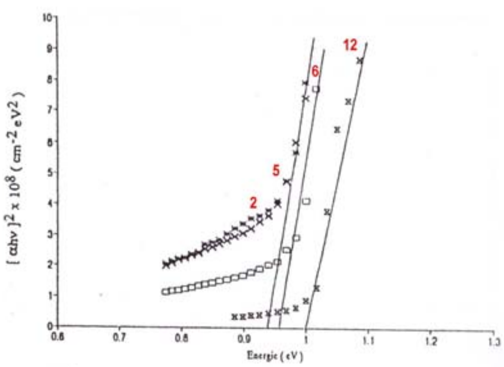

Figure 6. Energy Gap Interpolation on Several Samples

Table 4. Resistivity, Mobility, Material Type and Majority Carriers Values

Samples	Resistivity (Ω-cm)	Type	C.Hall	Mobility (cm^2/V.s)	Carriers Majority (cm^{-3})
1	1.6800	n	69.400	41.400	9.01×10^{16}
2	5.5100	n	76.800	13.900	8.14×10^{16}
3	0.3600	-	99.600	276.000	6.28×10^{16}
4	3.0000	n	154.000	51.200	4.06×10^{16}
5	11.2000	p	25.800	2.310	2.42×10^{17}
6	0.0187	p	0.128	6.850	4.89×10^{19}
7	2.7500	n	0.935	0.340	6.68×10^{18}
8	34.0500	n	9.700	0.279	6.50×10^{17}
9	2.6800	n	13.800	5.140	4.54×10^{17}
10	0.0357	n	0.370	10.250	1.71×10^{19}
11	0.3210	n	2.860	8.900	2.18×10^{18}
12	0.0814	n	0.510	6.290	1.22×10^{19}

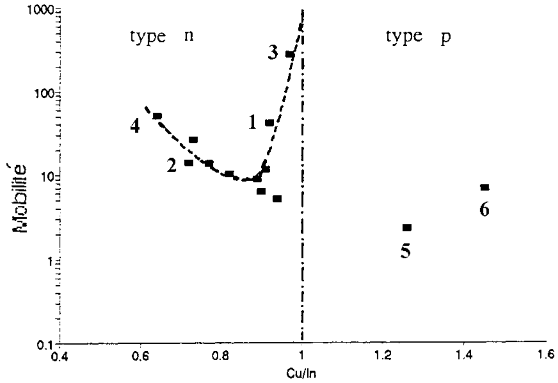

Figure 7. Correlation between Cu/In, Mobility, and Material Type

4. Conclusion

Deposition of base material for solar cell on $CuInSe_2$ in this research is relatively easy by using flash evaporation. The characterization of material on high substrate temperatures (270ºC–415ºC) shows that parameters physics of material such as; lattice crystal a, c and values c/a was almost 2, structure crystal produced is a structured of chalchopyrite, peaks of material at XRD clearly sharp that is the principal peaks $CuInSe_2$, atomic composition of material almost stochiomeric, absorption coefficient values between 10^{-3} Ωcm–10^{-5} Ωcm, bandgap values between 0.95–1.0 eV, type of material almost n, resistivity values between 0.03 Ωcm–34.05 Ωcm and mobility values between 4.06×10^{16} - 4.89×10^{17} cm^2/V.s In low subtrate temperatues especially at temperatures 20ºC and 57ºC the XRD results shows the peaks are low and weak and found binary material such as Cu_9In_4. The Values Cu/In >1, composition of material relatively are not stochiometric. For the future development on this research is basically to produce device solar cell.

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