

## Low Cost Electro-deposition of Cuprous Oxide P-N Homo-junction Solar Cell

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**Abstract.** Most of the photovoltaic industry uses wafer of single-crystal and poly-crystal silicon as a material of their photovoltaic (PV) modules. However, the cost of these modules is high due to the material and processing cost. Cuprous oxides (Cu<sub>2</sub>O) have several features that suitable for future photovoltaic applications. Cu<sub>2</sub>O can be prepared with simple methods at very low cost. Cu<sub>2</sub>O p-n homojunction solar cell is a device that converts sunlight to electrical energy, consists of two similar materials for its p-n junction, which is Cu<sub>2</sub>O. The p-type and n-type of Cu<sub>2</sub>O thin films are then fabricated to produce solar cells. Other layers aluminium and glass substrate coated with indium tin oxide (ITO) need to be added as a contact for electrons movement. In this study, p-type Cu<sub>2</sub>O, n-type Cu<sub>2</sub>O and p-n junction are prepared in order to become accustomed for solar cell applications. To achieve the optimum deposition conditions, p-n junction solar cell is prepared by two-steps electrochemical deposition process. The result from x-ray diffraction (XRD) shows that the peak is dominated by CuO (1, 1, 1). P-n junction is in between the p-type and n-type of Cu<sub>2</sub>O layer. Al has the thickness of 427.5nm. The second and the third layer are p and n -type of Cu<sub>2</sub>O, which have the thickness of 106.9nm and 92.3nm, respectively. Finally the thickness of ITO layer is 131.1nm. An absorption experiment at AM1 light is performed in order to get the I-V curves, and in fact, to study the electrical solar cells p-n homojunction. Based on I-V curve test, the level of energy conversion of cell is 0.00141% with fill factor, FF 0.94813 which proved that Cu<sub>2</sub>O p-n homojunction solar cell can be fabricated and produced at very low cost and well function.

### Introduction

Currently the photovoltaic market production is dominated by silicon based solar cell. Due to their fabrication process that required sophisticated and high cost of equipment, the electricity generation cost of silicon based solar cell is difficult to compete with fossil energy. There is exit way to overcome this matter by producing solar cell from cheap material with simple method [1].

Cu<sub>2</sub>O thin films can be prepared with simple methods at a very low cost by using electro-deposition method [2]. The cuprous oxide is formed from non-toxic elements which are copper and oxygen so the supply is easily available in the world [3]. Their absorption coefficient is good for light that have greater energy than energy bandgap. Energy bandgap for cuprous oxide is 1.9eV at room temperature [4]. It has suitable majority carrier mobility and minority carrier diffusion length in the micrometer range. By reducing cost, cuprous oxide has potential to be used in the new generation of dual solar cell which is polycrystalline multi-junction solar cell and intermediate band solar cell [5-6]. Both of these new concepts seem promising to increase solar cell efficiency in the future.

Multi-junction solar cell consist several layers of thin films materials with different energy bands purposely to absorb more solar radiation of light waves [5, 7-8]. Short-wavelength solar radiation will be absorbed on the top layer while the remaining wavelengths of light rays are absorbed by the lower layers. Cuprous oxide thin film with high energy band of 1.9eV can be used as a top layer of this multi-junction solar cell.

In the intermediate band solar cell, more light waves can be absorbed by the existence of an intermediate band in the material. The intermediate band solar cell is formed by doping with impurity elements that will produce a deep energy level in the band gap. In this way the absorption of radiation with energy less than the band gap occurs through two mechanisms. First, when the photon with less energy than the band gap is absorbed, electrons will excite from the valence band to the intermediate band. Then, the absorption of another photon also with less energy than the band gap, electrons will excite from the intermediate band to the conduction band. These mechanisms complete the absorption of electron from valence band to conduction band with less energy than the band gap [9].

Cu<sub>2</sub>O solar cell is a tool that uses to convert sunlight, or magnetic radiation to an electric energy. This p-n junction solar cell consists of two similar materials which are cuprous oxide Cu<sub>2</sub>O the p-type semiconductor. By using electrochemical deposition method, the Cu<sub>2</sub>O can be turned to be n-type Cu<sub>2</sub>O. The optimum oxygen entrance can be achieved by controlling the pH value, temperature and voltage potential value [10]. To facilitate the realization of the main research objective, 3 sub-objectives are defined as below:

- i. To design and fabricate p-type Cu<sub>2</sub>O, n-type Cu<sub>2</sub>O and p-n homojunction Cu<sub>2</sub>O solar cell.
- ii. To determine p-type Cu<sub>2</sub>O, n-type Cu<sub>2</sub>O and p-n homojunction Cu<sub>2</sub>O feature and characteristics as a solar cell.

## Methodology

In this study, p-type, n-type and p-n junctions have been prepared in order to be used for solar cell application. Homo-junction solar cells are made with Cu<sub>2</sub>O electrochemical reduction method to achieve the optimum deposition conditions. Light absorption experiment at AM1 has been conducted to obtain I-V curve, thus the electrical properties of p-n homojunction solar cells can be studied. Crystal characterization was also performed using XRD. By using scanning electron microscopy (SEM) technique the surface, cross-section and microstructure of the film reduction can be characterized [11-12].

## Fabrication of Cu<sub>2</sub>O thin film

Cu<sub>2</sub>O thin film consists of four layers with different materials, i.e., ITO, Cu<sub>2</sub>O n-type, p-type Cu<sub>2</sub>O and aluminum as shown in Fig. 1. Several methods are used to provide these layers. For the first layer, completed ITO that coated with glass substrate is used.

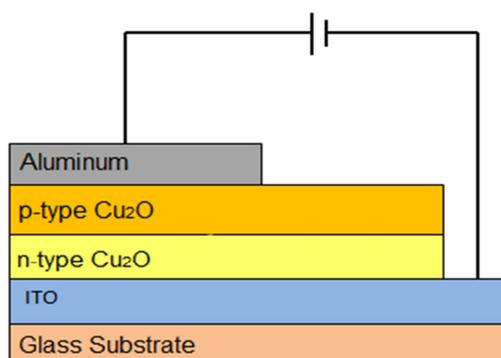


Figure 1 Cross sectional diagram of Cu<sub>2</sub>O thin films solar cell

Electron deposition method is used to produce Cu<sub>2</sub>O layer of n-type and p-type. The electrodeposition process consists of three types of electrodes [10, 13]. In this study, the working electrode (WE) is coated with ITO glass substrate. Reference electrode (RE) is Ag / AgCl / NaCl while platinum sheet as counter electrode (CE)

ModuLab components are used to perform the process of sedimentation. After this process is complete the formed p-n junction can be tested by using I-V test to verify the flow of electrical current in the cells [14- 15].

Surface structure is characterized by using Dino-Lite AM311S to view the structure of ITO layer. This device also been used before and after the deposition process. After that, radio frequency (RF) sputtering machine is performed to grow the aluminum (Al) layer on top of n-type layer. Al layer is used to allow electrons to flow from the p-type layer as ohmic contact.

## Results

**Cu<sub>2</sub>O homojunction thin films.** Fig. 2(a) show the surface of ITO coated the glass substrates. ITO is a transparent overlay when viewed with the naked eye. Fig.2(b) shows the sample surface of ITO layer after the deposition process by using aqueous solution of n-type. Fig.2(c) shows the state of the surface after the deposition process using a solution of p-type layers on n-type. This layer is visible yellow and has a structure like an orange peel.

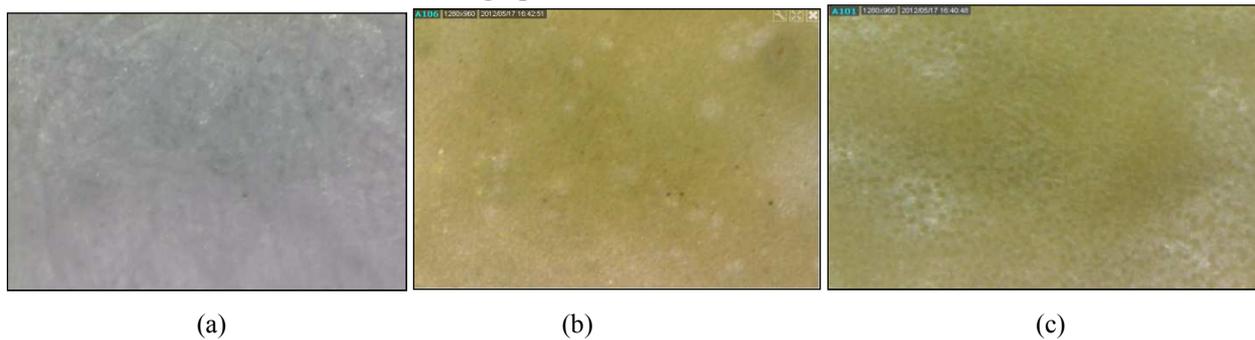


Figure 2 The glass substrate's surface with the (a) layer of ITO, (b) layer of n-type deposited on ITO layer, (c) layer of p-type deposited on n-type layer.

## Analysis and Discussion

**Field Emission Scanning Electron Microscopy (FESEM).** FESEM is performed to obtain the thickness of each layer in Cu<sub>2</sub>O thin film [16]. Based on the Fig.3, the first layer thickness is 427.5nm, 106.9nm second layer, third layer 92.3nm and 131.1nm fourth layer. The cross section shows the uneven layers especially the second layer.

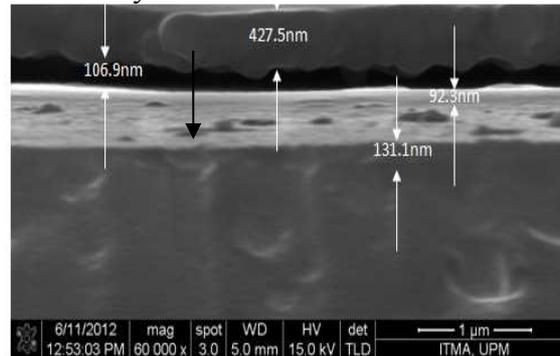


Figure 3 FESEM image that shows the thickness for each layer of Cu<sub>2</sub>O p-n homojunction solar cell.

**Energy Dispersion X-ray Spectroscopy (EDAX).** Fig.4 shows the spectrum of 1,2,3,4, and 5 representing all segments of the Cu<sub>2</sub>O thin films that have been produced in 2μm scale by using EDAX characterization. The summary of the layer thickness in Cu<sub>2</sub>O thin films, as well as type of coating can be seen in Table 9.

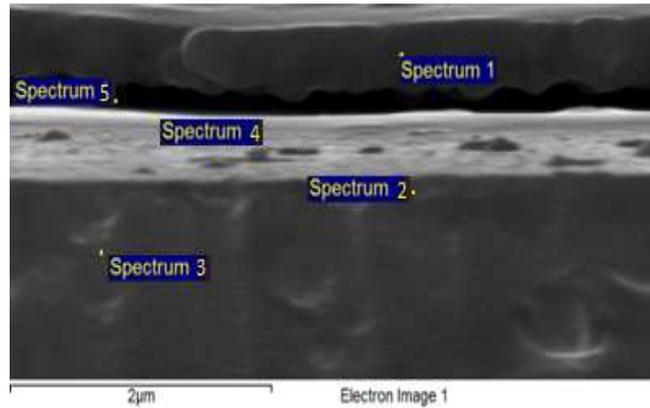


Figure 4 Spectrums representing each layer of  $\text{Cu}_2\text{O}$  thin film.

Table 1 Types of layer and its thickness for each spetrum

Spectrum	Type	Thickness
1	Aluminum	427.5nm
2	ITO	131.1nm
3	Glass Substrate	1.35mm
4	n-type Cuprous Oxide	106.9nm
5	p-type Cuprous Oxide	92.3nm

**X-Ray Diffraction (XRD).** XRD spectra for  $\text{Cu}_2\text{O}$  thin films are shown in Fig.5. Notably, there are some differences peak heights. All tops use the same wavelength which is 1.5406. The most significant peak height of  $\text{CuO}$  with Miller indices (1,1,1). It has the intensity at  $2\theta = 32.4$  a.u 36,595.  $\text{CuO}$  has a value of  $a = 4$ ,  $b = 4$ , and  $c = 4$ . Z value for the  $\text{CuO}$  is 2 with space group Fm-3m (225). Copper oxide,  $\text{Cu}_8\text{O}$  (2,0,0) can also be seen at  $2\theta = 13.7$  au intensity of 44,697 where it is on the right-most peak with Bmm2 space group (38). Z value for  $\text{Cu}_8\text{O}$  is 2. In addition, Al (2,0,0) as a conductive layer can also be seen at  $2\theta = 44,037$  with the intensity of 6.28 au. Al is in the space group C2 / c (15) and has a Z value of 2. The left-most peak represents Cuprite,  $\text{Cu}_2\text{O}$  (1,0,0)[16].  $\text{Cu}_2\text{O}$  has space group Pn.3m (224) at  $2\theta = 11.0$  au and the intensity of 36,595. The low peaks are combination of elements in the glass substrate and ITO layer. For example, at 21,529 and the intensity of  $2\theta = 3.68$  au Indium Tin Oxide or  $\text{In}_4\text{Sn}_3\text{O}_{12}$  elements is involved. The Z value for this element is 3 and has the space group R-3 (148).

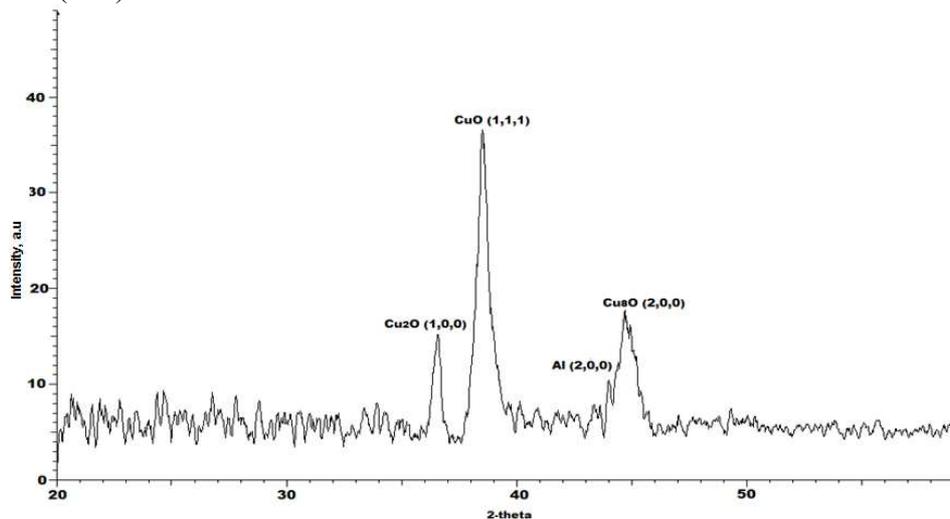


Figure 5 XRD pattern of  $\text{Cu}_2\text{O}$  p-n homojunction solar cell.

**I-V Curve.** Fig. 6 shows the I-V curve results after exposure to light with intensity  $0.1\text{W}/\text{cm}^2$ . Table 2 shows the parameters of IV curve test results. As shown, the surface area of the sample is  $0.5\text{ cm} \times 0.5\text{ cm}$ . Level of efficiency is calculated using the equation (Eq.1) below. The efficiency obtained is 0.00141%.

$$\begin{aligned}\eta &= \frac{P_{max}}{P_{in} \times A} \times 100\% \\ &= \frac{3.518 \times 10^{-7}}{0.1 \times (0.5 \times 0.5)} \times 100\% \\ \eta &= 0.00141\%\end{aligned}\tag{Eq.1}$$

Table 2 I-V curve test results.

Parameter	Value
Area of sample	0.5cm x 0.5cm.
Maximum Power, $P_{max}$	3.518E-7
Maximum voltage, $V_{max}$	0.0024V
Maximum Current, $I_{max}$	0.0001466A
Short Circuit Current, $I_{sc}$	0.0001564A
Open Circuit Voltage, $V_o$	0.0024V
Fill Factor, FF	0.94813

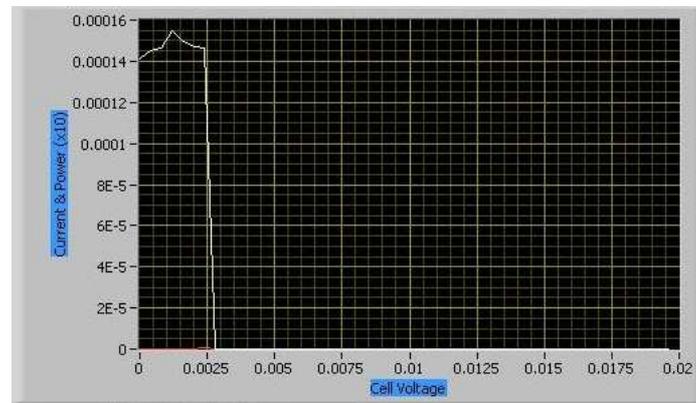


Figure 6 I-V curve test

## Conclusion

Homojunction p-n cuprous oxide thin films have been prepared by electrodeposition method. The thickness of each layer cuprous oxide thin films has been identified. In addition, the feature crystal composition of each layer, the electrical properties and efficiency of Cu<sub>2</sub>O thin films have also been discussed.

Cu<sub>2</sub>O thin films p-n homojunction has 4 layers on the glass substrate. The first layer is ITO on glass substrates. Sediment deposited on ITO layer is a layer of n-type Cu<sub>2</sub>O subsequent deposition of p-type Cu<sub>2</sub>O layer. Conductor layer, a layer of Al, produced on p-type Cu<sub>2</sub>O layer. P-n junctions are between the layers of p-type and n-type of Cu<sub>2</sub>O layer. Al layer thickness is 427.5nm. Next, the second layer and the third layer is p-type and n-type Cu<sub>2</sub>O respectively 106.9nm 92.3nm thick. ITO layer has a thickness of 131.1nm. Cross section shows the uneven layers especially the second layer. This is because the process is not uniform during the deposition method is done.

In terms of crystal characterization, the most significant peak height is CuO (1,1,1), where it has the intensity 32.4 a.u. at  $2\theta = 36.595$  with space group Fm-3m (225) which means the CuO is in cubic form. Copper oxide, Cu<sub>2</sub>O (2,0,0) can also be seen at  $2\theta = 13.7$  au intensity of 44,697 where it is on the right-most peak with Bmm2 space group (38). In addition, Al (2,0,0) as a conductive layer can also be seen at  $2\theta = 6.28$  au intensity of 44,037. Al is in the space group C2 / c (15). The left-most peak represents Cuprite, Cu<sub>2</sub>O (1,0,0). Cu<sub>2</sub>O has space group Pn.3m (224) at  $2\theta = 11.0$  au and the intensity of 36,595. Low peaks resulting are a combination of elements in the glass substrate and ITO layer. For example, at 21,529 and the intensity of  $2\theta = 3.68$  au the elements involved is Indium Tin Oxide or In<sub>4</sub>Sn<sub>3</sub>O<sub>12</sub>. Z value for this element is 3 and has the space group R-3 (148). By using I-V curve test the electrical characterization of solar cells is done. The level of energy conversion efficiency of cells derived from this test is 0.00141% with fill factor, FF 0.94813.

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