

Effect Of Cuprous Oxide (Cu_2O) Film Thickness On The Efficiency Of The Copper-Cuprous Oxide ($\text{Cu}_2\text{O}/\text{Cu}$) Solar Cell

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Abstract

Copper-Cuprous Oxide ($\text{Cu}_2\text{O}/\text{Cu}$) Backwall solar cells were fabricated using thermal oxidation method for the Cu_2O thin film deposition. By connecting the cells in an experimental circuit and varying the load resistance from 0Ω to ∞ , the short-circuit current, open-circuit voltage, and maximum power point were determined for each of the cell samples. The fill-factor and efficiency of the $\text{Cu}_2\text{O}/\text{Cu}$ solar cells were determined after which the thickness of the Cu_2O film layer was measured for each of the samples using the gravimetric (weight loss) method. The dependence of efficiency of $\text{Cu}_2\text{O}/\text{Cu}$ solar cell on the oxide film thickness was established. The efficiency was found to increase as the oxide film-thickness decreases, up to a limiting thickness of $26.30\mu\text{m}$ after which the efficiency decreases with decrease in the oxide film-thickness.

Keywords: efficiency, fill factor, maximum power point, open-circuit voltage, short-circuit current, solar cell

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I. INTRODUCTION

Despite the fact that solar cell has been recognized as a major source of renewable electric energy, its use, has continued to be limited by cost. The high cost of solar panels is as a result of the high material and production costs. This has made researchers to now focus attention on new low cost material and production techniques. One of the new techniques currently researched on, is thin film technology. This technology has the potential of greatly reducing the quantity of materials required for a cell and also the high heat energy required for the cell production (Poortmans and Arkhipov, 2006). Some of the materials that can be employed in thin film solar cell production include amorphous silicon, copper indium diselenide, cadmium telluride and cuprous oxide.

Cuprous oxide or Copper (I) oxide (Cu_2O) is an oxide of copper. It is insoluble in water and organic solvents but dissolves in concentrated ammonia solution to form the colorless complex $[\text{Cu}(\text{NH}_3)_2]^+$ which easily oxidizes in air to the blue $[\text{Cu}(\text{NH}_3)_4(\text{H}_2\text{O})_2]^{2+}$. It also dissolves in hydrochloric acid to form HCuCl_2 (a complex of CuCl), while dilute sulfuric acid and nitric acid produce copper (II) sulfate and copper (II) nitrate, respectively (Greenwood and Earnshaw, 1997). Copper (I) oxide is formed as the mineral cuprite in some red-colored rocks. When it is exposed to oxygen, copper will naturally oxide to copper (I) oxide, but this takes extensive time. Artificial formation is usually accomplished at high temperature or at high oxygen pressure. With further heating, copper (I) oxide will form copper (II) oxide.

Some properties of cuprous oxide include

- [1] molecular mass of 143.0g/mol ,
- [2] Density of 6.0g/cm^3 ,
- [3] Brownish-red appearance,
- [4] Cubic structure and,
- [5] Energy band gap of 2.0eV .

Copper (I) oxide is one of the earliest known semiconductors and its potential to be used in semiconductor devices has been recognized since 1920 (Olsen et al 1982). It has optimum, conversion efficiency of order of 12% at room temperature but the best Cu_2O solar cells efficiencies obtained so far have been of the order of 1% (Noguet et al, 1982).

1.1 RESEARCH AIM

Investigating the effect of cuprous oxide film thickness on the efficiency of the $\text{Cu}_2\text{O}/\text{Cu}$ solar cell

1.2 OBJECTIVES

- [1] Fabrication of $\text{Cu}_2\text{O}/\text{Cu}$ Backwall solar cells

- [2] Determination of the thickness of the Cu₂O film of each cell
 [3] Determination of the efficiency of each Cu₂O/Cu cell

II. MATERIALS AND METHODS

2.1 SAMPLE PREPARATION

A copper plate was cut into eight coupons with each having a dimension of 1cm x 1cm. The samples were then thoroughly cleaned and smoothed with the help of glass paper, and by dipping them in a solution of 10g of sodium persulphate dissolved in 250ml of de-ionized water. After dipping in the cleaning solution, the samples were dried between tissue papers.

2.2 OXIDATION PROCESS

When the temperature of the furnace was stabilized at 950°C, the first sample was placed in a ceramic crucible and introduced into the furnace with the help of tongs. The furnace door was closed and the stop clock pressed-on to start oxidation time count. Immediately the oxidation time got to 5 minutes, the sample was brought out, and rapidly quenched in cold de-ionized water to stop further oxidation. The process was repeated for the remaining seven samples but at different oxidation temperatures and times of 970°C/5min for sample 2, 980°C/3min for sample 3, 980°C/4min for sample 4, 1000°C/3min for sample 5, 1050°C/2min for sample 6, 1050°C/3min for sample 7, and 1050°C/4min for sample 8. The oxidation temperature and time were varied so as to obtain different film thicknesses of the cuprous oxide.

2.3 HEAT TREATMENT

The samples were heat treated at the temperature of 500°C and at a time of 1½ hours. This was done by heating the samples up to 500°C in a furnace and allowing them to stay at this temperature for 1½ hours, after which they were quenched in cold de-ionized water. The heat treatment was carried out to increase the conductivity of the Cu₂O.

2.4 ETCHING

Etching was carried out on the samples to remove the copper (II) oxide (CuO) layer which covered the required copper (I) oxide (Cu₂O) on both sides of the copper coupons. A second etching was carried out to remove Cu₂O from one side of the samples.

The etching was carried out as follows:

2.4.1 FIRST ETCHING TO REMOVE THE CuO LAYERS

- [1] The samples were dipped in a solution containing 10gm of FeCl₂, 8gm of NaCl dissolved in 200ml of de-ionized water, and 40cm³ of concentrated HCl.
 [2] The samples were again dipped in a solution containing 10gm of sodium persulphate dissolved in 250ml of de-ionized water to stop further actions of the etchant, and then cleaned in de-ionized water.

2.4.1 SECOND ETCHING

The second etching was then carried out to remove the (Cu₂O) layer from one side of the samples with the help of concentrated nitric acid. Figure 2.1 shows the Schematic diagram of the samples before etching, after the first etching, and after the second etching.

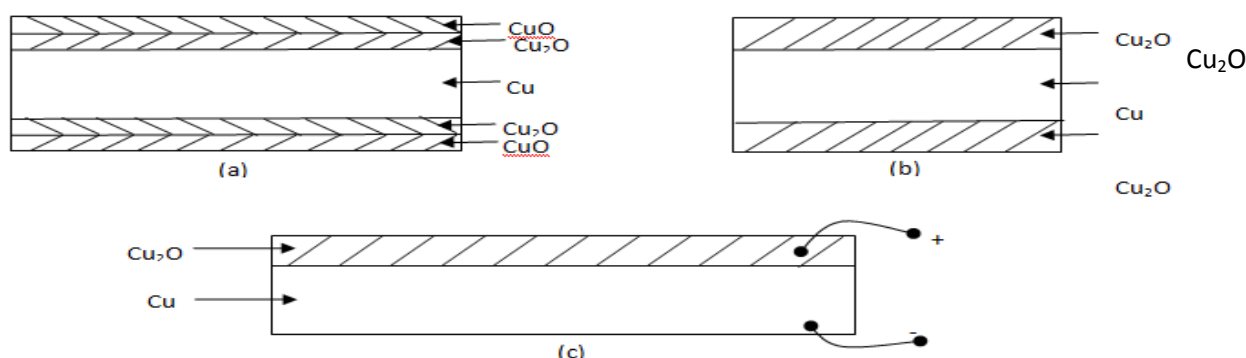


Fig. 2.1 The schematic diagram of the samples

- (a) Before the etching
 (b) After the first etching
 (c) At the end of the fabrication

2.5 MAXIMUM POWER POINT DETERMINATION

The first back wall solar cell was connected in a circuit as shown in Fig. 2.2

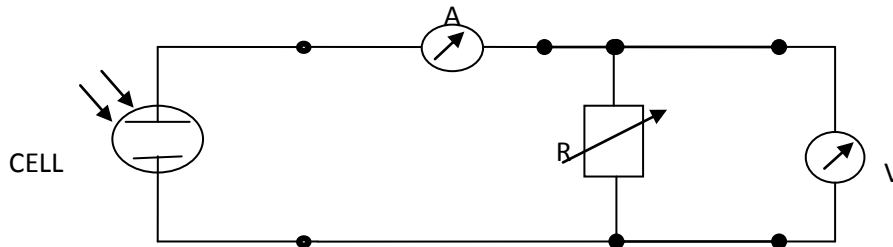


Fig. 2.2 The experimental circuit setup

A = Microammeter

V = voltmeter

R = Rheostat

R was set to zero resistance, and the microammeter and voltmeter readings noted.

This was repeated for values of R = 100Ω, 1KΩ, 5KΩ, 10KΩ, 15KΩ, 20KΩ, 100KΩ, 1MΩ and ∞.

The experiment was repeated with each of the remaining seven cells connected in place.

2.6 THICKNESS MEASUREMENT

The method used for the measurement of the thickness of Cu₂O on Cu was the gravimetric method.

This was done in three steps.

- [1] The cell samples were weighed on a digital meter balance to obtain the mass of Cu₂O/Cu. This was recorded as M₁ for the different cells.
- [2] The cell samples were then dipped in a concentrated hydrochloric acid solution to remove the Cu₂O layers. The chemical reaction is expressed as
- [3] $2\text{Cu}_2\text{O}_{(s)} + 4\text{HCl}_{(aq)} = 2\text{CuCl}_{2(aq)} + 2\text{H}_2\text{O}_{(l)} + 2\text{Cu}_{(s)}$ (2.1)
- [4] The cell samples were again weighed on a digital meter balance to obtain the mass of Cu. This was recorded as M₂ for the different samples.

The difference in mass ($M_d = M_1 - M_2$) was calculated for all the samples to obtain the mass of Cu₂O using the formula

$$t = M/\rho A \quad (2.2)$$

Where t = thickness of Cu₂O on Cu, M = mass of Cu₂O, ρ = density of Cu₂O (= 6.0 gcm⁻³), and A = surface area of the samples (=0.0001m²), the thickness of Cu₂O on Cu was calculated for all the samples.

III. RESULTS

Table 3.1 gives the result of the maximum power point determination experiment for cell sample 1, Table 3.2 gives the summary of the results for all the cell samples, while Table 3.3 gives the result of the thickness measurement experiment.

TABLE 3.1: Results of Maximum Power Point Determination Experiment for Cell 1 (950°C/5min).

R(Ω)	I(μA)	V(mV)	P(μW)
0	280	0.0	0.0000
100	276	4.0	1.1040
1K	264	10.0	2.6400
5K	232	22.5	5.2200
10K	196	32.0	6.2720
15K	144	43.0	6.1920
20K	92	52.2	4.8024
100K	50	56.5	2.8250
1M	4	59.0	0.2360
∞	0	60.0	0.0000

Table 3.2: Summary of the Results of Maximum Power Point Determination Experiment

Cell	Oxidation Condition	I _{sc} (μ A)	V _{oc} (mV)	P _m (μ W)
1	950 ⁰ C/5min	280	60.0	6.2720
2	970 ⁰ C/5min	370	70.4	10.7440
3	980 ⁰ C/3min	423	73.6	13.0720
4	980 ⁰ C/4min	471	80.5	15.4875
5	1000 ⁰ C/3min	518	86.0	17.7600
6	1050 ⁰ C/2min	475	88.2	16.5300
7	1050 ⁰ C/3min	420	91.2	15.7274
8	1050 ⁰ C/4min	325	93.0	12.9860

TABLE 3.3: Results of the Thickness Measurement

S/N	M ₁ (g)	M ₂ (g)	M _a (g)	Thickness(μ m)
1	0.4707	0.4463	0.0244	40.60
2	0.4695	0.4484	0.0211	35.20
3	0.4642	0.4449	0.0193	32.20
4	0.4599	0.4416	0.0183	30.50
5	0.4532	0.4377	0.0158	26.30
6	0.4470	0.4334	0.0136	22.70
7	0.4459	0.4340	0.0119	19.90
8	0.4451	0.4349	0.0102	17.00

3.1 FILL FACTOR AND ENERGY CONVERSION EFFICIENCY

Using the equations

$$\text{Fill-Factor, FF} = \frac{P_m}{V_{oc} * I_{sc}} \quad (3.1)$$

and

$$\text{Efficiency, } \eta = \frac{P_m}{E_1 * A_c} \times 100 \quad (3.2)$$

where P_m = maximum power point, V_{oc} = open circuit voltage, I_{sc} = short circuit current, E₁ = Input light irradiance (= 1000W/m²), and A_c = Surface area of the cell, the fill factor and efficiency of the solar cells were calculated and the results were put in Table 3.4.

TABLE 3.4: Fill Factor and Efficiency of the Solar Cells

Cell	Fill Factor	Efficiency x10 ⁻² %
1	0.37	0.62
2	0.41	1.07
3	0.42	1.31
4	0.41	1.55
5	0.40	1.78
6	0.39	1.65
7	0.41	1.57
8	0.43	1.30

3.2 VARIATION OF ENERGY CONVERSION EFFICIENCY WITH THICKNESS OF THE SOLAR CELLS

From Tables 3.3 and 3.4, the energy conversion efficiency variation with the thickness of the solar cells was realized as given in Table 3.5.

TABLE 3.5: Efficiency variation with thickness

Cell	Efficiency, η X 10 ⁻² %	Thickness (μ m)
1	0.62	40.60
2	1.07	35.20
3	1.31	32.20
4	1.55	30.50
5	1.78	26.30
6	1.65	22.70
7	1.57	19.90
8	1.30	17.00

Figure 3.1 gives the plot of energy conversion efficiency against the thickness of Cu₂O on Cu.

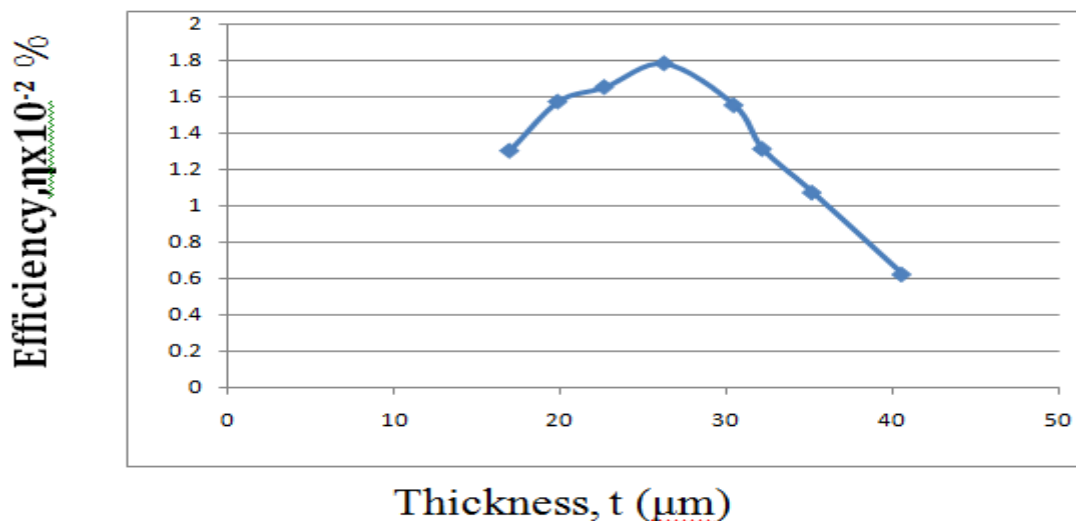


Fig. 3.1 Variation of energy conversion efficiency with the thickness of Cu₂O on Cu

IV. DISCUSSION

A study of Table 3.5 and plot of Fig. 3.1 shows that the efficiency of Cu₂O/Cu solar cell increases as the thickness of the Cu₂O decreases, up to a limiting thickness of 26.30 μm, after which the efficiency decreases as the thickness decreases. This result is supported by the following theoretical projection: The efficiency of a solar cell is a function of the number of created electron-hole pairs that are able to migrate to the space charged region where they are separated. The ability of an electron-hole pair to get to the space charged region without recombination depends on the proximity of the creation point to the space charged region.

The limiting thickness of 26.30 μm belongs to the cell sample oxidized at a temperature of 1000⁰C and time of 3 minutes. It means that the best oxidation condition for Cu₂O on Cu deposition is 1000⁰C/3minutes. The short circuit current, open circuit voltage, maximum power point, fill factor and efficiency of this solar cell are 518 μA, 86.0mV, 17.76 μW, 0.4, and 0.0178%, respectively. The maximum short circuit current and open circuit voltage realized in this work are 518 μA and 93.0mV, respectively. The results obtained in this work are comparable to the results of similar works done on Cu₂O/Cu solar cell. For instance, in the work of Haruna Ali in 2007 on the *fabrication of Cu₂O/Cu solar cell by oxidation method*, he found out that the short circuit current increases as the oxide film thickness decreases, up to a limiting thickness of 23 μm below which the short circuit current decreases with decrease in the oxide film thickness (Haruna, 2007). In Haruna's work, the maximum short circuit current and open circuit voltage realized were 50 μA and 93.10mV, respectively. Therefore, in terms of the maximum short circuit current realized, this work is an improvement on Haruna's work.

V. CONCLUSION

Within the limits of experimental accuracy, it was determined that the efficiency of Cu₂O/Cu solar cell depends on the thickness of the Cu₂O film layer. The efficiency increases as the oxide film thickness decreases, up to a limiting film thickness of 26.30 μm, after which the efficiency decreases as the thickness decreases. This result has the following theoretical support: The efficiency of a solar cell is a function of the number of created electron-hole pairs that are able to migrate to the space charged region where they are separated. The ability of an electron-hole pair to get to the space charged region without recombination depends on the proximity of the creation point to the space charged region. We hereby assert that the limiting thickness of the oxide film as realized in this work is the thickness at which all the created electron-hole pairs get to the space charged region (that is, there is no chance of recombination). A further decrease in the oxide film thickness reduces the number of possible electron-hole pairs that can be created, and consequently decreases the efficiency of the solar cell.

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