FABRICATION AND ELECTRICAL CHARACTERIZATION OF PHOTOELECTROCHEMICAL SOLAR CELL OF n-CdS-p-Cu_2S ELECTRODE

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ABSTRACT

This paper presents fabrication and characterization of p-type Cu_2S and n-type CdS semiconductor electrodes for photo-electrochemical solar cell applications. The n-type cadmium sulphide was deposited on glass substrate by chemical bath deposition process at a temperature of 75^0C for 2hours. The chemical bath consisted of Cadmium Chloride, Potassium Hydroxide, Ammonium Nitrate and Thiourea with concentration of 0.02M, 0.5M, 1.5M, and 0.2M respectively. The p-type copper (II) sulphide was formed on the CdS layer using a solution consisting of copper chloride. The values obtained for photovoltaic parameters of the photo-electrochemical cell are the short-circuit current (I_{sc}) 0.56mA, open-circuit voltage (V_{oc}) 0.615V, fill factor (FF) 0.61 and efficiency (η) 0.14%.

Keywords: *Chemical bath deposition, CdS-Cu_2S, Photo-electrochemical solar cell*

1.0 Introduction

The demand for clean energy technologies has spurred academic and commercial interest in new and efficient ways to capture and store sunlight. Concerted efforts are now being directed towards both the design of light harvesting assemblies, construction of economically viable solar cells, and the development of efficient energy storage devices. Even in the age of nanotechnology, century-old liquid junction electrochemical cell plays a pivotal role in our daily lives by delivering portable energy to everything from mobile phones to automobiles. In recent years, the concept of utilizing nano-material-based architectures in light energy conversion devices has emerged as an alternative to single-crystalline based photovoltaic devices. It was found that Cu_2S/CdS photovoltaic cells have solar energy conversion efficiency of 9.1% but they are difficult to prepare and have high cost (Guangming *et al.,* 2003). In this work, Cu_2S and CdS nano-particles have been synthesized using chemical bath deposition method and ion exchange chemical route to prepare a thin film of Cu_2S/CdS for investigation of its potential as solar cell. The synthesis and characterization of nano-particles of semiconducting metal sulfide have been intense field of research due to the interesting optical properties and potential applications of this compound (Rohit, 2012). Their unique band character, high extinction coefficients and impact ionization effects suggest that these materials are promising light absorbers for solar cells. Semiconductor nano-structures are promising building blocks for future generation of photovoltaic devices, such as dye sensitized solar cells, all inorganic nano-particle solar cell, and hybrid nano-crystal polymer composite solar cells (Rohit, 2012). Such materials are promising candidates in electronics, data storage, energy storage, catalysis and sensors. All of these could offer processing, scale, and cost advantage when compared with conventional single crystal and thin film solar cells (Rohit, 2012). One of the most challenging aspects in this area is to find a semiconductor material with a suitable band gap, near 1eV for conventional, single-gap devices, which can be made in nano-structured form. Here, we explore a candidate material satisfying these requirements: copper (II) sulfide (Cu_2S). Cu_2S is an indirect gap semiconductor with a bulk band gap of 1.21eV (Liu *et al.,* 2003). It is used in combination with cadmium sulfide (CdS) as a solar cell material. Different methods with different chemical reagents have already been used for the preparation of Cu_2S/CdS hetero-junctions films. Such methods include vacuum evaporation, sputtering and chemical methods such as chemical vapor deposition, physical vapor deposition, spray pyrolysis, electrochemical deposition, dip growth, successive ionic adsorption and reaction. But there are some problems in each method. For example, it is difficult to obtain a stoichiometric CdS film by evaporation technique, and a high temperature is required in spray deposition method (Cetinorgu *et al.,* 2006 and Liu *et al.,* 2003). The technique is a low temperature deposition method, and does not limit the choice of the substrate material (Dhawale *et al.,* 2008 and Li *et al.,* 2010). Thin film modules are promising for their manufacturing owing to reduced material cost, energy, handling and capital costs (Larea *et al.,* 2009). Reduction of cost of thin film cells is achieved by minimizing the amount of materials used, application of an inexpensive material processing method and the use of inexpensive mounting arrays (Gaikwad, 2003). In this work, Cu_2S and CdS nano-particles have been prepared using chemical bath deposition method and ion exchange chemical route, and thin film of Cu_2S/CdS has been investigated as solar cell.

2.0 Materials and Method

2.1 Materials

Microscope glass slide, 8414JA-153, stirred water bath, 78HW-1 magnetic heating stirrer, weighting balance (Ohaus AR 2140), Cadmium Chloride (CdCl), Thiourea $(NH_2)_2CS$, Potassium Hydroxide (KOH), Ammonium Nitrate (NH_4NO_3), Sodium Chloride (NaCl), ferric Chloride $FeCl_3$ and distilled water were used.

2.2 Substrate Formation

Microscope glass slide of dimension 25.4mm x 76.2mm and 1mm thick are used as the substrates cleaned with carbon tetrachloride, acetone, and isopropyl alcohol and rinsed with distilled water in each step.

2.3 Deposition of CdS

The aqueous solution containing the following molar concentration of reactant was prepared; 0.02M cadmium chloride ($CdCl_2$), 0.5M potassium hydroxide (KOH), 1.5M ammonium nitrate (NH_4NO_3), and 1.5M thiourea ($CS(NH_2)_2$) are prepared using distilled water (Oliva *et al.*, 2003). The chemical bath solution was contained into a glass beaker and immersed into a water bath control at 75^0C. The solution was agitated using stirrer which was placed inside the mixed solution (Musa, 2007). The glass substrates were supported by Teflon holders and immersed in the bath solution. The Film starts forming when thiourea was added and deposition was maintained for 2 hours. The sample was removed at the end of the time from the bath solution. The resulting transparent and pale yellow films obtained on the substrate having bright surface, was then annealed at 160^0 C for 30 minutes.

2.4 Formation of Cu_2S

For the ion exchange process, Cu_2S layer was formed on CdS layer via ion exchange of Cd by Cu (Sam *et al.*, 2010). The solution consists of 0.075M of copper chloride (CuCl) which was prepared in a glass beaker and placed on magnetic heating stirrer, the solution was agitated and the temperature was fixed at 60^0C. The CdS sample are vertically immersed into the solution to let exchange of the Cd by Cu, the complete thickness was converted to Cu_2S. This was reported to occur in 1minute (Sam *et al.*, 2010). In order to form Cu_2S thin layer on CdS substrate by the ion exchange method, Cd ions have to migrate from substrate to the ion exchange solution and replace with Cu ions which migrate from solution to the substrate. The chemical reaction is as follows:

$$CdS + 2CuCl \rightarrow Cu_2S + CdCl_2 \quad (1)$$

2.5 Fabrication of Photo-Electrochemical Solar Cell

The electrolytic cell consists of a photo-cathode (CdS) and photo-anode (Cu_2S) semiconductors working electrodes. Both electrodes were immersed in electrolyte (NaCl solution). The cell was kept under illumination, where the open circuit voltage $V_{oc,}$ and short circuit current $I_{sc,}$ were measured under no load condition for only the electrolyte and the addition of redox couple of the photo-electrochemical solar cell. Later, different values for the voltage V, and current I, of the cell were also measured by varying the load.

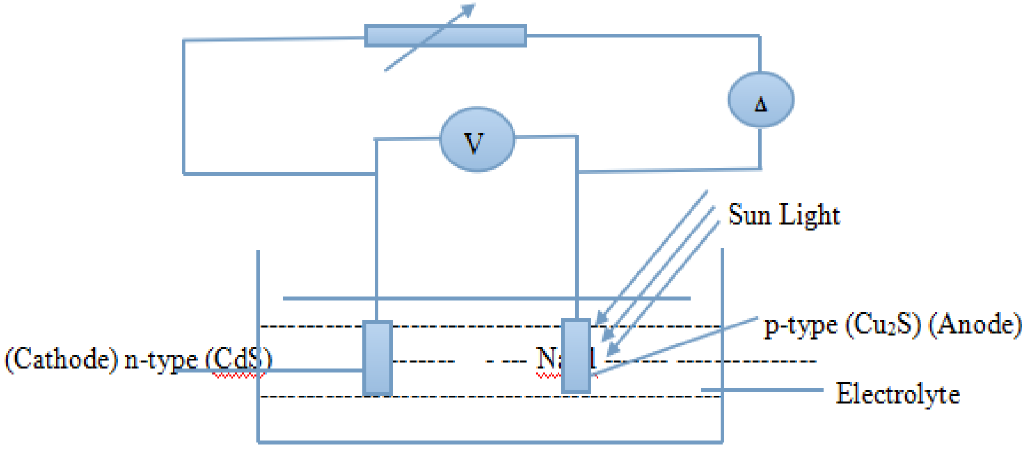

Figure1. Illustration of the Fabrication Cu_2S/CdS photo-electrochemical Solar cell

Figure 1 shows an idealized diagram of a photo-electrochemical Solar cell, in which an aqueous solution of sodium chloride is use as the electrolyte. The Na^+ ions migrate toward the p-type (Cu_2S) semiconductor electrode and the Cl^- ions migrate toward the n-type (CdS) semiconductor electrode. But, now there are two substances that can be reduced at the anode: Na^+ ions and water molecules. Two sets of

2.6 Reaction of the Electrolyte Solution

$$2NaCl \rightarrow 2Na + Cl_2 \quad (2)$$

At the Anode:

$$Na^+ + e^- \rightarrow Na \quad (3)$$

$$2H_2O + 2e^- \rightarrow H_2 + 2H0^- \quad (4)$$

At the Cathode:

$$2Cl^- \rightarrow Cl_2 + 2e^- \quad (5)$$

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^- \quad (6)$$

2.7 Current-Voltage Characteristics Measurement

The constructed Photo-electrochemical solar cell was used for testing current-voltage characteristic measurement without illumination (in dark) and under illumination. Two sets of different electrolytes; one with 2moles of redox couple ($FeCl_3$) and the other one without redox couple were prepared during the experiment with different molar concentrations as shown in table 1. The open circuit voltage and the short circuit current were measured. Variable load resistance was used to record the current-voltage values under illumination. The current-voltage characteristic curve was plotted and used to obtain the solar cell external electrical parameters. The photo-electrochemical cell solar cell performance was better for electrolyte of 0.25M containing redox couple ($FeCl_3$), because of its higher values of the V_{oc} and I_{sc}.

Table 1. Values of V_{oc} and I_{sc} under different concentration of sodium chloride with and without addition of 2moles of redox couple ($FeCl_3$).

Electrolyte concentration (NaCl)	Electrolyte (NaCl)		Electrolyte (NaCl) + Redox Couple ($FeCl_3$)	
	V_{oc} (V)	I_{sc} (mA)	V_{oc} (V)	I_{sc} (mA)
0.05M	0.302	0.18	0.486	0.24
0.10M	0.341	0.24	0.495	0.31
0.15M	0.390	0.28	0.512	0.35
0.20M	0.455	0.33	0.527	0.43
0.25M	0.472	0.37	0.615	0.56

3.0 Results And Discussion

After successful deposition of CdS layer and formation of Cu_2S layer on CdS via ion exchange of Cd by Cu, then followed by the fabrication of photo-electrochemical solar cell, the current-voltage(I-V) Characteristics curve measuring the values of current produced under various applied potentials used to obtain the solar cell external electrical parameters are shown in the figure 3.

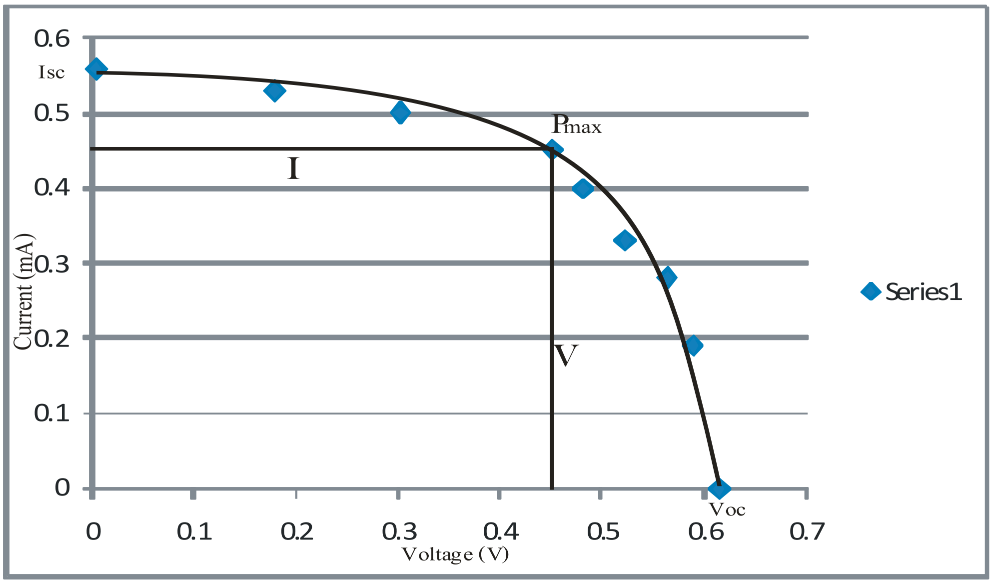

Figure 3: I-V characteristic of Cu_2S/CdS solar cell under illumination at room temperature.

The short circuit current of the cell is substantially lower when compared with that of (I_{sc},) 5.8mA obtained for high efficiency and cost effective Cu_2S/CdS thin-film solar cell (Rohit, 2012). The cell exhibits the short circuit current I_{sc} of 0.56mA, and the open circuit voltage V_{oc} of 0.615V. The point along the I-V curve, which maximizes power, is labeled P_{max}. Approximate points for V_{oc}, I_{sc}, and P_{max} are labeled in figure 3. The parameters extracted are the short circuit current (I_{sc}) of 0.56mA, open circuit voltage (V_{oc}) of 0.615V, maximum power density (P_{max}) of 0.21018Wm^{-2}, fill factor (FF) of 0.61 and Power conversion efficiency (η) of 0.14%. Obviously, the weak value of this cell is low value of fill factor and the efficiency when compared with the (FF) 0.73 and (η) 10.9% obtained for high efficiency and cost effective Cu_2S/CdS thin-film solar cell (Rohit, 2012). This may be due to the series resistance.

3.1 Conclusion

The study presents the synthesis of CdS and Cu_2S nano-particles by chemical bath deposition method and their application in solar cells. A thin film CdS was prepared on a glass substrate and then a film of Cu_2S was also formed on the CdS thin film using ion exchange process. The current-voltage under illumination resulted in (I_{sc}) of 0.56mA and (V_{oc}) of 0.615V. Efficiency of the cell is 0.14% and fill factor around 0.61. The results show the reasonable efficiency of thin film Cu_2S-CdS electrodes.

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