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Contriving of Photo-Electrochemical Solar Cell of n-Cds-p-Cu_2S Electrode by Electrical Characterization Method

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Abstract: *This study reports the preparation and electrical characterization of n-type cadmium sulphide (CdS) and p-type copper sulphide (Cu_2S) semiconductor electrodes for photoelectrochemical solar-cell applications. CdS thin films were deposited on glass substrates by chemical bath deposition, and a Cu_2S layer was subsequently formed on the CdS film through ion exchange. The fabricated cell was evaluated under illumination using current–voltage (I–V) measurements. The measured short-circuit current (Isc) was 0.56 mA and the open-circuit voltage (Voc) was 0.615 V. The calculated fill factor was 0.61, while the power-conversion efficiency was 0.14%. Of the electrolyte conditions investigated, 0.25 M sodium chloride containing the $FeCl_3$ redox couple produced the highest recorded Voc and Isc. The results indicate that Cu_2S/CdS electrodes can be produced using solution-based techniques.*

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

1.0 INTRODUCTION

Increasing demand for clean energy has intensified research into effective technologies for converting sunlight into usable energy and storing the energy generated. Current efforts focus on designing effective light-harvesting structures, producing affordable photovoltaic devices, and improving energy-storage systems. Although liquid-junction electrochemical cells have been known for many years, they remain relevant to portable and other electrical applications. Nanostructured materials have also emerged as possible alternatives to conventional photovoltaic devices based on single-crystal semiconductors.

Cu_2S/CdS photovoltaic cells have previously been reported to achieve conversion efficiencies of approximately 9.1%, although their preparation may be difficult and expensive (Guangming et al., 2003). In this work, Cu_2S and CdS films were prepared using chemical bath deposition and an ion-exchange process to examine their potential for solar-energy conversion. Semiconductor metal-sulphide nanoparticles have received considerable attention because of their optical properties and possible applications (Rohit, 2012). Their band structures and strong light absorption make them promising materials for photovoltaic devices.

Nanostructured semiconductors are being investigated for applications in dye-sensitized solar cells, inorganic nanoparticle solar cells, and hybrid nanocrystal–polymer devices. Potential uses also include electronics, data storage, energy storage, catalysis and sensors. In comparison with some conventional crystalline and thin-film technologies, these materials may provide advantages in processing and manufacturing costs (Rohit, 2012). One important challenge is to identify semiconductors with suitable band gaps that can be fabricated in nanostructured forms. Copper sulphide has been studied for this purpose, with a reported bulk band gap of approximately 1.21 eV (Liu et al., 2003), and is often combined with CdS to form a semiconductor heterojunction.

Various methods have been used to prepare Cu_2S/CdS heterojunction films, including vacuum evaporation, sputtering, chemical vapour deposition, physical vapour deposition, spray pyrolysis, electrochemical deposition, dip growth and successive ionic adsorption and reaction. Each method has limitations. Evaporation can make stoichiometric CdS films difficult to obtain, while spray deposition may require high temperatures (Cetinorgu et al., 2006; Liu et al., 2003). Chemical bath deposition is a solution-based technique that can be performed at relatively low temperatures and used with different substrate materials (Dhawale et al., 2008; Li et al., 2010). Thin-film fabrication can also reduce material consumption and certain processing, handling and capital costs (Larea et al., 2009; Gaikwad, 2003). Accordingly, this study used chemical bath deposition and ion exchange to prepare Cu_2S/CdS films and evaluate the electrical characteristics of the resulting photoelectrochemical cell.

2.0 MATERIALS AND METHODS

2.1 MATERIALS

The materials and equipment included microscope glass slides, an 8414JA-153 temperature-controlled stirred water bath, a 78HW-1 magnetic heating stirrer, an Ohaus AR 2140 weighing balance, cadmium chloride, thiourea, potassium hydroxide, ammonium nitrate, sodium chloride, ferric chloride, copper chloride and distilled water.

2.2 SUBSTRATE FORMATION

Microscope slides measuring 25.4 mm × 76.2 mm and 1 mm in thickness served as substrates. They were cleaned successively with carbon tetrachloride, acetone and isopropyl alcohol, with rinsing in distilled water during the cleaning procedure.

2.3 DEPOSITION OF CDS

An aqueous bath was prepared with cadmium chloride (0.02 M), potassium hydroxide (0.5 M), ammonium nitrate (1.5 M) and thiourea with 1.5 M concentration. The solution was placed in a glass beaker in a water bath maintained at 75 °C and stirred (Oliva et al., 2003; Musa, 2007). Glass substrates were secured in Teflon holders and immersed in the bath. Deposition began after thiourea was added and continued for two hours. The substrates were then removed, producing transparent, pale-yellow films with bright surfaces. The films were annealed at 160°C for 30 minutes.

2.4 FORMATION OF Cu_2S

A Cu_2S layer was formed on the CdS-coated substrate through ion exchange, in which cadmium ions in the film were replaced by copper ions from the solution (Sam et al., 2010). A 0.075 M copper chloride solution was prepared in a glass beaker and stirred at 60°C. The CdS-coated substrate was immersed vertically in the solution, this conversion occurred in about one minute. During the process, cadmium ions move from the film into the solution while copper ions enter the film.

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

2.5 FABRICATION OF PHOTO-ELECTROCHEMICAL SOLAR CELL

The cell comprised CdS and Cu_2S semiconductor electrodes, identified as the photo-cathode and photo-anode, respectively. Both electrodes were immersed in a sodium chloride (NaCl) electrolyte. The cell was exposed to light and its open-circuit voltage (Voc) and short-circuit current (Isc) were measured under the stated no-load and short-circuit conditions, both with the electrolyte alone and with a redox couple added. Current and voltage were also recorded while the external load was varied.

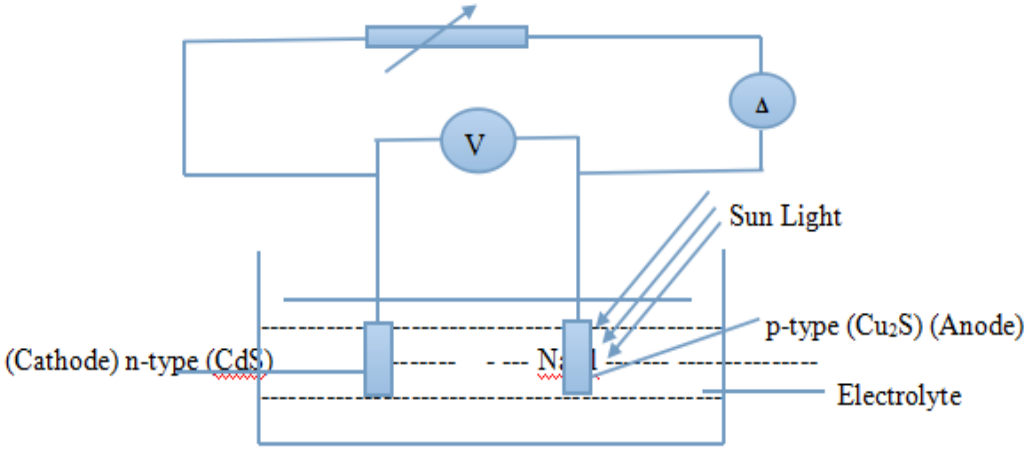


Figure 1: Schematic illustration of the Cu_2S/CdS photoelectrochemical solar cell

In the cell description, Na^+ ions in the electrolyte migrates toward the p-type Cu_2S electrode, while Cl^- ions move toward the n-type CdS electrode as described in the equations below:

$$\text{Overall: } 2NaCl \rightarrow 2Na + Cl_2 \quad (2)$$
$$\text{At the anode: } Na^+ + e^- \rightarrow Na \quad (3)$$
$$\text{At the anode: } 2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad (4)$$
$$\text{At the cathode: } 2Cl^- \rightarrow Cl_2 + 2e^- \quad (5)$$
$$\text{At the cathode: } 2H_2O \rightarrow O_2 + 4H^+ + 4e^- \quad (6)$$

2.6 MEASUREMENT OF CURRENT–VOLTAGE CHARACTERISTICS

The cell was tested both in darkness and under illumination. Two electrolyte conditions were compared: NaCl solution without a redox couple and NaCl solution containing $FeCl_3$. Several NaCl concentrations were examined. The open-circuit voltage and short-circuit current were measured and a variable load resistance was used to record current and voltage under illumination. The resulting I–V curve was used to estimate the cell's external electrical parameters. For the electrolyte containing 0.25 M NaCl and the $FeCl_3$ redox couple, which gave the highest Voc and Isc values, better performance was recorded.

Table 1: Voc and Isc at different NaCl concentrations, with and without $FeCl_3$

NaCl concentration (M)	Voc without $FeCl_3$ (V)	Isc without $FeCl_3$ (mA)	Voc with $FeCl_3$ (V)	Isc with $FeCl_3$ (mA)
0.05	0.302	0.18	0.486	0.24
0.10	0.341	0.24	0.495	0.31
0.15	0.390	0.28	0.512	0.35
0.20	0.455	0.33	0.527	0.43
0.25	0.472	0.37	0.615	0.56

3.0 RESULTS AND DISCUSSION

3.1 RESULTS

After deposition of the CdS film and conversion of its surface layer to Cu_2S by ion exchange, the photoelectrochemical cell was assembled and tested. The I–V characteristics were determined by measuring the current generated at different applied voltages and the resulting curve was used to estimate the cell's main external photovoltaic parameters. Figure 3 presents the illuminated I–V curve for the Cu_2S/CdS cell at room temperature.

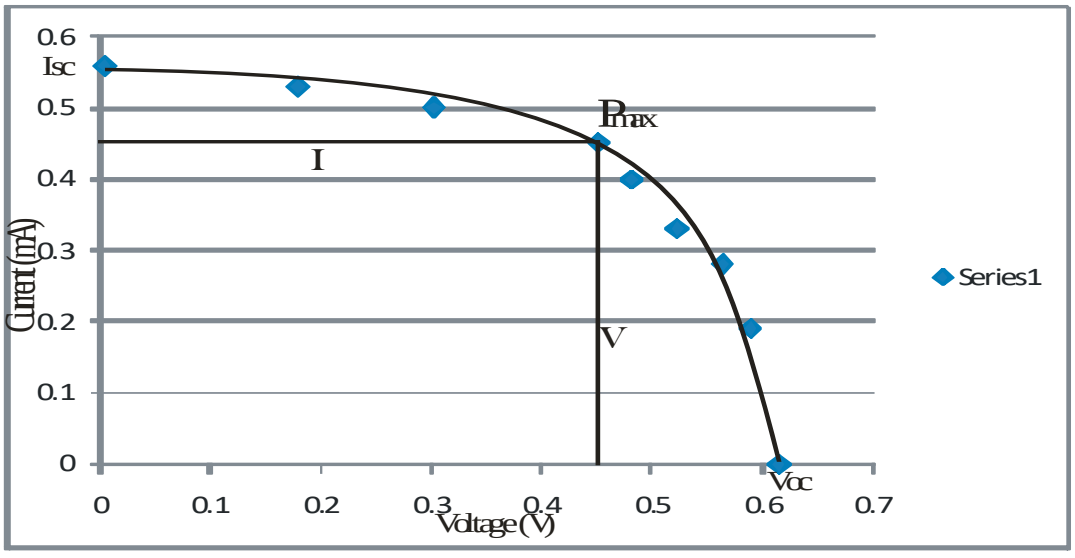


Figure 3: I-V characteristic of Cu_2S/CdS solar cell under illumination at room temperatur.

3.2 DISCUSSION

The cell produced a short-circuit current of 0.56 mA and an open-circuit voltage of 0.615 V. The maximum-power point corresponds to the point on the I–V curve at which the product of current and voltage is greatest. The reported maximum power density was 0.21018 Wm^{-2}, the fill factor was 0.61 and the conversion efficiency was 0.14%. The short-circuit current was lower than the 5.8mA reported for another Cu_2S/CdS thin-film solar cell (Rohit, 2012). The reported fill factor and efficiency were also below the

comparison values of 0.73 and 10.9%, respectively. The result show that both Voc and Isc increased as the NaCl concentration rose across the tested range. At each concentration, the electrolyte containing $FeCl_3$ produced higher Voc and Isc values than the electrolyte without the redox couple. The highest recorded values of 0.615V for Voc and 0.56mA for Isc were obtained with 0.25M NaCl and $FeCl_3$.

4.0 CONCLUSION AND RECOMMENDATIONS

CdS and Cu_2S semiconductor films were prepared by chemical bath deposition and ion exchange, respectively and used to assemble a photoelectrochemical solar cell. Under illumination, the cell generated a short-circuit current of 0.56 mA and an open-circuit voltage of 0.615V. Its fill factor was approximately 0.61 and its conversion efficiency was 0.14%. Of the electrolyte conditions examined, 0.25M NaCl containing the $FeCl_3$ redox couple produced the highest current and voltage. These findings show that Cu_2S/CdS thin-film electrodes can be fabricated through solution-based methods.

It was recommended that, further optimization is required to enhance the photovoltaic performance.

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AUTHOR CONTRIBUTIONS

All authors contributed toward data analysis, drafting and critically revising the paper and agree to be accountable for all aspects of the study.

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