

# Enhance the Photocurrent of Cu/n-Cu<sub>2</sub>O Solid State Solar Cell Using Coconut Shell Activated Carbon (CAC) as Upper - Electrode

M. V. W. Samarakkody<sup>1</sup>, N. W. P. S. Perera<sup>1</sup>, P. G. D. C. K. Karunarathna<sup>1</sup>, C. A. N. Fernando<sup>1\*</sup>

<sup>1</sup>Nano Technology Research Laboratory, Department of Electronics, Faculty of Applied Sciences, Wayamba University of Sri Lanka, Kuliypitiya, Sri Lanka.

\*Corresponding Author: canfernando9@gmail.com

**Abstract:** Coconut shells are used for production of activated carbon. In this research, alkaline-bio scoured coconut shell powder was subjected to one step pyrolysis activation by using Phosphoric acid. The acid treated coconut shell particles were fed into a tube furnace with a heating rate of 10 °C min<sup>-1</sup> until the temperature reached at 360 °C and dwell time 15 min in N<sub>2</sub> atmosphere. Next, they were cooled into room temperature. A thin film of n-Cu<sub>2</sub>O was fabricated by immersing a well cleaned copper sheet in a 10<sup>-3</sup> M HCl solution for 60 h. CAC was placed on Cu/n-Cu<sub>2</sub>O substrate and ITO conductive glass plate was placed to fabricate Cu/n-Cu<sub>2</sub>O/CAC/ITO solid state photovoltaic cell. Here, CAC acts as an upper electrode, separate photo-generated charge carriers and enhance photocurrent. BET surface area analysis, diffuse reflectance spectra, photocurrent action spectra, time development of photocurrent and SEM morphology were used to analyse the prepared samples.

**Keywords:** Activated carbon, BET, Coconut shell, n-Cu<sub>2</sub>O.

## I. INTRODUCTION

In the 21<sup>st</sup> century, the oil prices have been increased due to the rapid depletion of resources. Therefore, there are no more reliance on coal, oil and natural gas. Today many researches are focused on the renewable energy sources and it provide promising alternatives. Wind turbines, wave and tidal power, solar cells, solar thermal, hydropower, biomass-fired electricity and biomass-derived liquid fuels are some of renewable source technologies. However, among of all these renewable energy, solar energy is the most promising energy source since it is readily available. The most popular and commercially available type of solar cell is silicon-based solar cell. But the manufacturing cost is very high. Therefore, this research study focuses on fabricating a solar cell by using low cost method.

Due to the special chemical and physical properties of metal and their oxides, recently numerous researches have

been reported. Therefore, in this study Cu metal was used to fabricate the Cu<sub>2</sub>O layer. Cuprous Oxide (Cu<sub>2</sub>O) has many advantages such as direct bandgap structure, suitable bandgap (1.9-2.2 eV), non-toxic, inexpensive and abundant source material [1-2]. Also Cu<sub>2</sub>O is used in many applications such as gas sensing, photovoltaic (PV), catalysis and dilute magnetic semiconductors [3]. As reported, many methods were used to synthesize p-type Cu<sub>2</sub>O and only few methods for n-type Cu<sub>2</sub>O [4-9]. Therefore, in the present work n-type nano crystalline Cu<sub>2</sub>O layer was synthesized by a simple chemical method and here we demonstrate the photocurrent enhancement of Cu<sub>2</sub>O thin film using coconut shell activated carbon.

Coconut shell activated carbon (CAC) is a highly available and eco-friendly material, which used for catalytic supports, capacitors, gas storages for biomedical engineering, battery electrodes and solar cells [10-11]. The proper characteristics of activated carbon are high surface area, porous structure, pore volume and surface functional groups [12-13]. In present study, activated carbon is used for solar application as an upper electrode [14-15].

Here, we demonstrate a remarkable photocurrent enhancement in Cu<sub>2</sub>O thin film after fabricating CAC as an upper electrode. The proposed structure for Cu/n-Cu<sub>2</sub>O/CAC photoelectrode will be discussed from diffused reflectance spectra, photocurrent action spectra, and SEM. Also, BET surface area analysis and ash content calculation were used to characterize the CAC.

## II. EXPERIMENTAL

### A. Preparation of CAC Powder

Phosphoric acid (H<sub>3</sub>PO<sub>4</sub>) chemical activation one step pyrolysis methods were used for production of activate carbon from coconut shells. Cleaned small coconut shell pieces were milled at 550 rpm for 12 min to obtain the micro range particles. After Scouring, shell particles were leached with phosphoric acid and sonicated. Sonicated particles were put into the muffle furnace at 110 °C for 5 h.

Coconut shell pieces were fed into the tube furnace with a constant Nitrogen flow rate of 10 until the temperature was reached a range between 400 °C to 450 °C. At a selected temperature between 360 °C to 370 °C, the samples were kept inside the tube furnace for 15 min and subjected to a nitrogen flow. After pyrolysis, carbon was removed from the furnace and allowed to cool down to the room temperature. Again that granular particles were milled at 550 rpm for 30 min to convert the powder form CAC.

**B. Preparation of Cu/n-Cu<sub>2</sub>O/CAC Photoelectrode**

Well-cleaned copper sheet (1 x 3 cm<sup>2</sup>) was immersed into a 10<sup>-3</sup> M HCl solution at room temperature. The immersing time was controlled the amount of growth of n-Cu<sub>2</sub>O (gcm<sup>-2</sup>) on Cu substrate. After fabricating Cu/n-Cu<sub>2</sub>O substrate, 3 mg of coconut shell activated carbon (CAC) were deposited on n-Cu<sub>2</sub>O layer to form Cu/n-Cu<sub>2</sub>O/CAC photoelectrode. After ITO conductive glass plate was placed on top of Cu/n-Cu<sub>2</sub>O/CAC photoelectrode as shown in schematic diagram in Fig. 1.

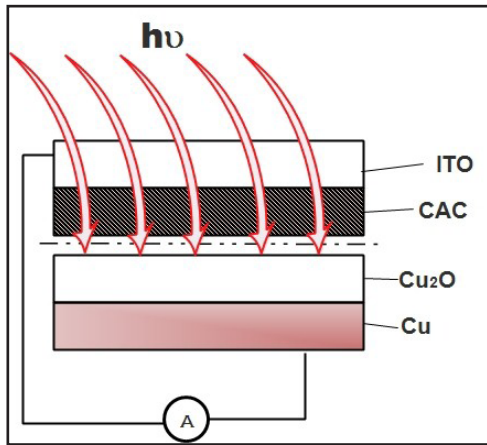


Fig. 1: Schematic Presentation of the Thin Film Photovoltaic Device Structure: Cu/n- Cu<sub>2</sub>O/CAC/ITO

**C. Experimental Techniques**

Coconut shell small pieces were grounded by using Fritsch supreme line Pulverisette 7 ball mill. Rocker Soner 203 H Ultra-sonic heat bath was used for cavitation. Proximate analysis was measured by according to ASTM-D stranded. Defuse reflectance spectra were measured by using Shimdzu 1800 UV Spectrophotometer. The surface morphology of the samples were observed using Scanning Electron Microscope (SEM) Zeiss Evo LS15.

**III. RESULTS AND DISCUSSION**

**A. CAC Characterization**

Fig. 2 shows the nitrogen adsorbent and de adsorbent curve. Nitrogen adsorption isotherms were measured at -196 °C on an ASAP 2010 volumetric analyzer. Prior to adsorption measurements, all samples were out gassed under vacuum at

200 °C for 2 h. The shape of curve shows that chemically treated activated carbon has meso pores size range. It reveals that more adsorbent side available in surface of activated carbon. The BET surface area Value and ash content of produced activated carbon show in Table I. BET surface area of CAC is 825 (m<sup>2</sup>/g). This adsorption values are directly related with porosity of carbon and same as commercially developed one. The ash content of CAC is 2 %.

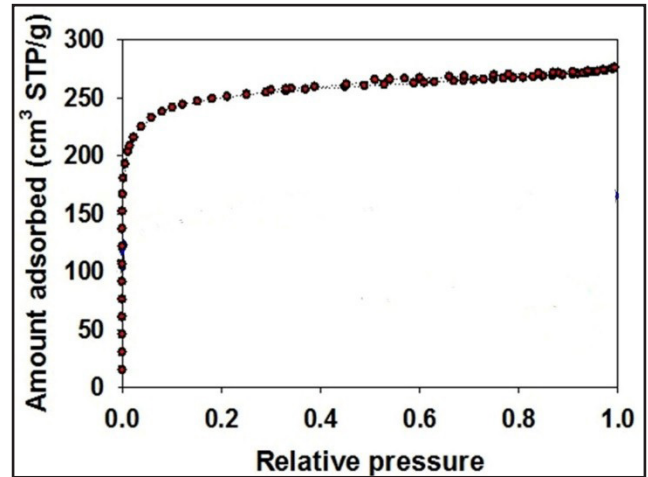


Fig. 2: Nitrogen Adsorption Isotherm of Coconut Shell Activated Carbon

TABLE I: BET SURFACE AREA VALUES OBTAINED FOR THE COCONUT SHELL SAMPLE STUDIED

Content	S <sub>BET</sub> (m <sup>2</sup> /g)	Ash Content
Coconut Shell	825	2 %

**B. The Growth Mechanism of n-Cu<sub>2</sub>O Nano Surface Layer on Copper Substrate**

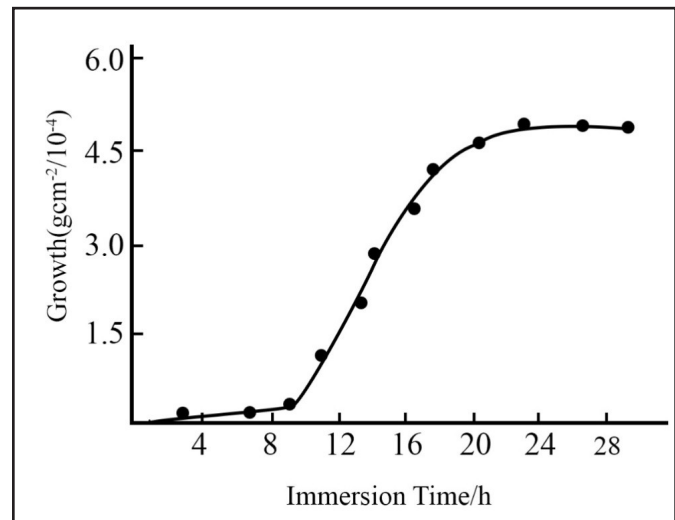


Fig. 3: Growth Rate of Cu<sub>2</sub>O Layer on Cu Plate

Fig. 3 shows the variation of growth of n-Cu<sub>2</sub>O layer on copper plate with the immersion time for this preparation method.

Initial growth stage of  $\text{Cu}_2\text{O}$  layer is not fast with immersing time. After 9 h, growing amount is gradually increased and reached to a saturation level at 24 h. These phenomena can be explained as follows. Initially, in HCl solution the concentration of  $\text{Cu}^{2+}$  is very low until HCl gradually dissolves sufficient copper from the copper substrate. The growth of  $\text{Cu}_2\text{O}$  layer increases rapidly and saturates after dissolving considerable amount of copper into the solution forming  $\text{Cu}^{2+}$  ions.

### C. Diffuse Reflectance Spectra and the Photocurrent Action Spectra

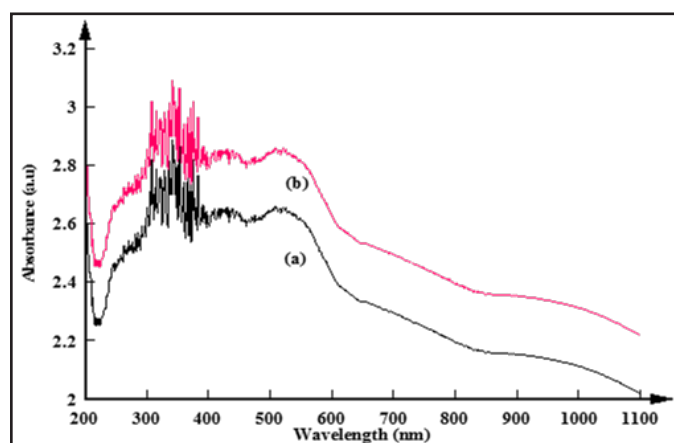


Fig. 4: Diffuse Reflectance Spectra for (a)  $\text{Cu/n-Cu}_2\text{O}$  (b)  $\text{Cu/n-Cu}_2\text{O/CAC}$

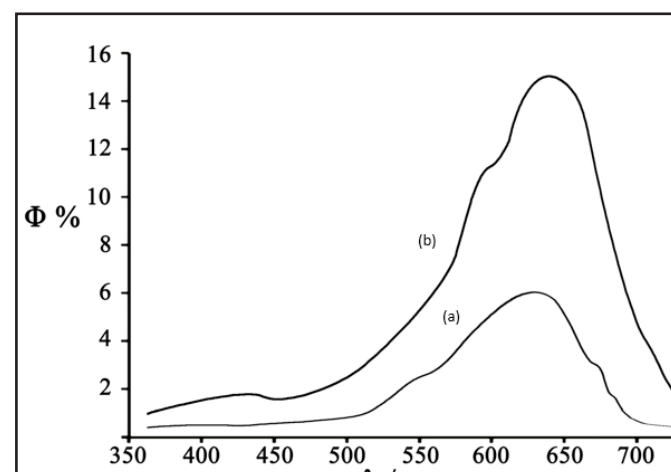


Fig. 5: Photocurrent Action Spectra for (a)  $\text{Cu/Cu}_2\text{O}$  and (b)  $\text{Cu/Cu}_2\text{O/CAC}$

Fig. 4 shows the diffuse reflectance spectra of  $\text{Cu/n-Cu}_2\text{O}$  and  $\text{Cu/n-Cu}_2\text{O/CAC}$ . The shape of the graph (a) and graph (b) were resembled with each other because when introducing CAC on  $\text{Cu/n-Cu}_2\text{O}$  layer, there is no transformation made. It proves that CAC served as an upper electrode to collect the photo charge carriers. The estimated bandgap from the absorption edge

corresponding to the light absorption of  $\text{n-Cu}_2\text{O}$  is  $\approx 1.98$  eV ( $\lambda \approx 625$  nm). Photocurrent action spectra for  $\text{Cu/n-Cu}_2\text{O}$  and  $\text{Cu/n-Cu}_2\text{O/CAC}$  are shown in Fig. 5. According to the figure, the maximum photocurrent can be observed corresponding to the absorption edge of diffuse reflectance spectra ( $\lambda \approx 625$  nm) and it further confirms that the photocurrent generation is due to the light absorption of  $\text{n-Cu}_2\text{O}$  semiconductor. Therefore, the highest photocurrent enhancement is observed due to introducing the CAC layer on  $\text{Cu/n-Cu}_2\text{O}$  substrate.

### D. The Time Development of Photocurrent of $\text{Cu/n-Cu}_2\text{O/CAC/ITO}$

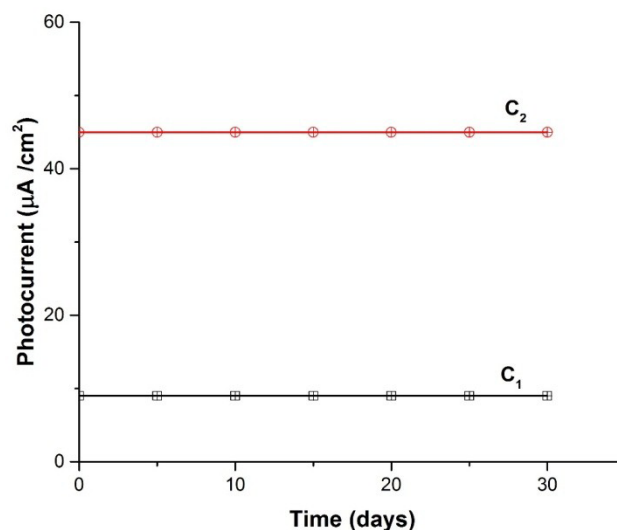


Fig. 6: Time Development Curves for (a)  $\text{Cu/Cu}_2\text{O}$  and (b)  $\text{Cu/Cu}_2\text{O/CAC}$

Time development of photocurrent under visible range light for  $\text{Cu/n-Cu}_2\text{O}$  (C1) and  $\text{Cu/n-Cu}_2\text{O/CAC}$  (C2) are shown in Fig. 6. Maximum stability can be seen in both curves and steady state photocurrent increases after introducing CAC. Meso size pore structure of CAC supports to move the excited electrons from  $\text{Cu}_2\text{O}$  to CAC layer and separate photo-generated electrons and subsequently absorb the visible light. Then the recombination of photo-generated charge carriers is suppressed. Meso pore size carbon particles in the  $\text{Cu}_2\text{O}$  upper layer can act as collection spot to transfer the photo-generated carriers to the ITO glass plate to flow the photocurrent. This shows that the CAC is act as an upper electrode for solar cells.

### E. SEM Micrographs

Scanning electron micrograph shown in Fig. 7 can confirm the surface morphology of  $\text{Cu}_2\text{O}$  is nano size. Micrograph of the thin film is uniform and consists crystals in Nano range. This morphology can be explained that uniform nano surface produced on top of the Cuplate.

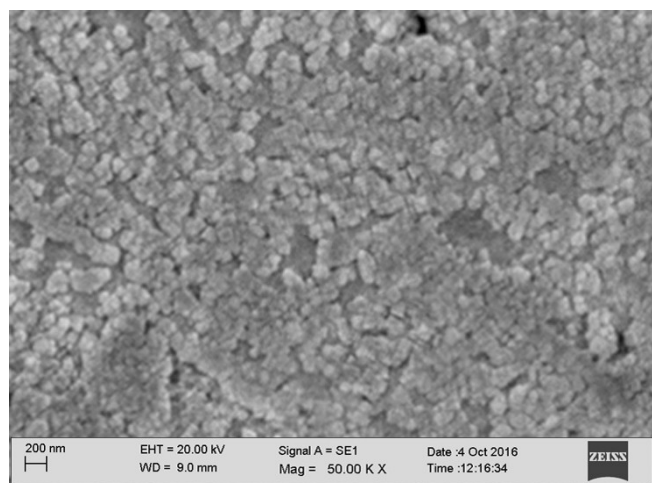


Fig. 7: SEM Image of the Top View for Cu/n-Cu<sub>2</sub>O Substrate

#### IV. CONCLUSION

The photocurrent enhancement was observed in Cu/n-Cu<sub>2</sub>O/CAC photoelectrode compared with Cu/n-Cu<sub>2</sub>O. The photocurrent enhancement can be seen after including CAC due to increment of contact between Cu/n-Cu<sub>2</sub>O and ITO and it serves as upper electrode. Significant stability was observed in Cu/n-Cu<sub>2</sub>O/CAC solid state photovoltaic cell.

#### ACKNOWLEDGMENT

National Research Council of Sri Lanka (NRC) is acknowledged for providing the equipment grant No-26 for this research program. National Science Foundation (NSF) of Sri Lanka is also acknowledged partly providing a research grant nano-01.

#### REFERENCES

- [1] J. N. Nian, C. C. Hu, and H. Teng, "Electrodeposited p-type Cu<sub>2</sub>O for H<sub>2</sub> evolution from photoelectrolysis of water under visible light illumination," *International Journal of Hydrogen Energy*, vol. 33, no. 12, pp. 2897-2903, 2008.
- [2] T. Mahalingam, J. S. P. Chitra, J. P. Chu, S. Velumani, and P. J. Sebastian, "Structural and annealing studies of potentiostatically deposited Cu<sub>2</sub>O thin films," *Solar Energy Materials and Solar Cells*, vol. 88, no. 2, pp. 209-216, 2005.
- [3] B. P. Rai, "Cu<sub>2</sub>O Solar Cells: A Review," *Solar Cells*, vol. 25, pp. 265-272, 1988.
- [4] R. S. Toth, R. Kilkson, and D. Trivich, "Preparation of large area single-crystal cuprous oxide," *Journal of Applied Physics*, vol. 31, no. 6, pp. 1117-1121, 1960.
- [5] M. O'Keeffe, and W. J. Moore, "Electrical conductivity of monocrystalline cuprous oxide," *The Journal of Chemical Physics*, vol. 35, no. 4, pp. 1324-1328, 1961.
- [6] A. P. Young, and C. M. Schwartz, "Electrical conductivity and thermoelectric power of Cu<sub>2</sub>O," *Journal of Physics and Chemistry of Solids*, vol. 30, no. 2, pp. 249-252, 1969.
- [7] H. L. McKinzie, and M. O'Keeffe, "High temperature hall effect in cuprous oxide," *Physics Letters A*, vol. 24, no. 3, pp. 137-139, 1967.
- [8] L. Wang, and M. Tao, "Fabrication and characterization of p-n homojunctions in cuprous oxide by electrochemical deposition," *Electrochemical and Solid-State Letters*, vol. 10, no. 9, pp. H248-H250, 2007.
- [9] C. A. N. Fernando, T. M. W. J. Bandara, and S. K. Wethasingha, "H<sub>2</sub> evolution from a photoelectrochemical cell with n-Cu<sub>2</sub>O photoelectrode under visible light irradiation," *Solar Energy Materials and Solar Cells*, vol. 70, no. 2, pp. 121-129, 2001.
- [10] G.-W. Sun, C. Wang, L. Zhan, W.-M. Qiao, X.-Y. Liang, and L.-C. Ling, "Influence of high temperature treatment of activated carbon on performance of supercapacitors," *Journal of Materials Science and Engineering*, vol. 2, no. 12, pp. 41-48, 2008.
- [11] A. Kay, and M. Grätzel, "Low cost photovoltaic modules based on dye sensitized nanocrystalline titanium dioxide and carbon powder," *Solar Energy Materials and Solar Cells*, vol. 44, no. 1, pp. 99-117, 1996.
- [12] D. H. Jurcakova, M. Seredych, G. Q. Lu, and T. J. Bandoz, "Combined effect of nitrogen-and oxygen-containing functional groups of microporous activated carbon on its electrochemical performance in supercapacitors," *Advanced Functional Materials*, vol. 19, no. 3, pp. 438-447, 2009.
- [13] A. Aygün, S. Y. Karakaş, and I. Duman, "Production of granular activated carbon from fruit stones and nutshells and evaluation of their physical, chemical and adsorption properties," *Microporous and Mesoporous Materials*, vol. 66, no. 2, pp. 189-195, 2003.
- [14] K. Imoto, K. Takahashi, T. Yamaguchi, T. Komura, J. I. Nakamura, and K. Murata, "High-performance carbon counter electrode for dye-sensitized solar cells," *Solar Energy Materials and Solar Cells*, vol. 79, no. 4, pp. 459-469, 2003.
- [15] Z. Huang, X. Liu, K. Li, D. Li, Y. Luo, H. Li, W. Song, L. Chen, and Q. Meng, "Application of carbon materials as counter electrodes of dye-sensitized solar cells," *Electrochemistry Communications*, vol. 9, no. 4, pp. 596-598, 2007.