Photocurrent Enhancement of Cu/p-CuSCN/n-Cu_2O Quantum Dot (QD) Novel Solid State Photovoltaic Cell with Coconut Shell Activated Carbon (CAC) as the Upper Electrode

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Abstract: p-CuSCN was sensitized by n-Cu_2O quantum dots (QDs) to fabricate a new solid state photovoltaic cell. QDs of n-Cu_2O were deposited by boiling Cu/p-CuSCN photoelectrodes in a 1M $CuSO_4$ solution to form Cu_2O QDs on p-CuSCN. Boiling periods controlled the n-Cu_2O quantum dot size. Activated coconut shell charcoal (CAC) was introduced on top of the Cu_2O as the upper electrode and finally ITO glass was placed on CAC to fabricate the device.

Keywords: n-Cu_2O, p-CuSCN, Quantum dots.

I. Introduction

As the fossil fuel supplies have been decreasing, energy preservation and alternative energy sources are expected to sustainable development [1]. The most accessible alternative energy source is the sun [2]. Solar energy can be used to generate the electricity by photovoltaic effects of solar cells. High efficiency, low cost and easily fabricate solar cells are good candidates to exhibit the solar energy [3].

Wide band gap semiconductors are attractive materials due to their capability for applications in photovoltaic devices [4]. CuSCN is the one of most talented wide band gap (~3.0 eV) p-type semiconductor because it has high chemical stability [5]. According to the literature, by applying suitable dye on the CuSCN can be make a usable solar cells. But the main disadvantage in dye sensitized solar cell is the photo degradation. Therefore now a days dyes are replaced with the quantum dots (QDs). QDs are also semiconductors which have diameter approximately between 2-10 nm and its size and the shape of the individual crystal are closely related to their electronic characteristics [6]. In this study we used n-Cu_2O QDs to enhance the photocurrent of p-CuSCN [7]. Scientific investigation of Cuprous oxide (Cu_2O) thin films are inexpensive, attractive and non-toxic semiconducting material with a band gap of ~2.0 eV which is an excellent candidate for window material for solar cells [8, 9].

For further enhancement of the photocurrent, coconut shell activated carbon (CAC) is used in this study because it is a low cost, highly available and eco-friendly material. Catalytic supports, capacitors, gas storages for biomedical engineering, sensors, battery electrodes and solar cells are some widely used applications of CAC [10, 11]. For all these applications, electrical conductivity is a highly important parameter [12]. Since carbon can enhance the catalytic activity and conductivity, it use as a counter electrode for solar cells.

From this study p-CuSCN is sensitized from n-Cu_2O QDs with CAC as the upper electrode for the first time. Fabrication procedure of the device, photocurrent measurements with n-Cu_2O amount fabricated on p-CuSCN and with CAC concentration as the upper electrode are presented.

II. Experimental

A. Preparation of CAC Powder

The coconut shell charcoal was activated by using steam method [13] and to produce CAC powder grinded it for 2 hour using Fritsch supreme line pulverisette 7 Ball Mill. To measure the surface area of the CAC powder, Iodine number was determined using the standard test method ASTM D 4607.

B. Preparation of Cu/p-CuSCN/n-Cu_2O QD / CAC Photo Electrode

The outer impurity layer in copper plate (1 cm × 4 cm) was removed by sand paper and cleaned with distilled water. Copper plate was further cleaned ultrasonically. The well cleaned copper plates were immersed in a solution containing 0.1 M KSCN, 0.1 M acetic acid and 1 M acetone (pH-value ≈ 3.5) for 30 minutes to prepare p-CuSCN layer [14]. Then, resultant Cu/p-CuSCN substrate was boiled in a 1 M $CuSO_4$ solution for different time intervals to obtain an n-Cu_2O QDs layer on top of the p-CuSCN layer [8].

A thin film CAC was deposited on top of the Cu/p-CuSCN/n-Cu_2O layer and ITO glass plate was placed on the CAC to fabricate the Cu/p-CuSCN/n-Cu_2O QD / CAC solid state photo voltaic cell as shown in Fig. 1.

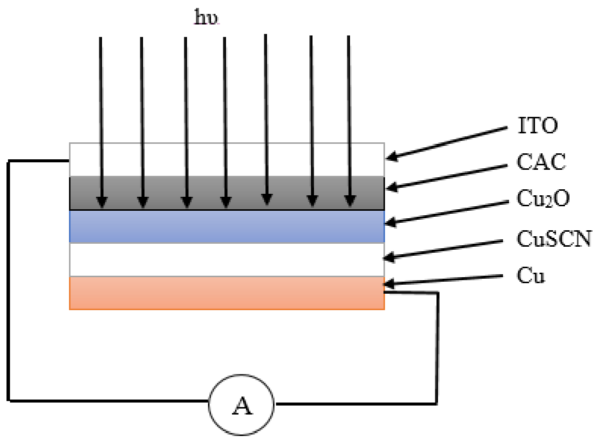

Fig. 1. Schematic structure of Cu/p-CuSCN/n-Cu_2O/CAC thin film solar cell

C. Experimental Techniques

Analytical grade chemicals and double distilled water were used for experiment. Defuse reflectance spectra were measured by using a Shimdzu 1800 UV Spectrophotometer. Particle size distribution of CAC was measured using a Fritsch Analysette 22 Nano Tec Plus.

III. Results and Discussion

Fig. 2 shows the variation of the photocurrent of the solid state photovoltaic cell for various boiling time intervals of Cu/p-CuSCN electrode in the 1M $CuSO_4$ solution. It is clearly seen, that the photocurrent enhances initially with the increase of boiling time. It is interesting to mention that the maximum photocurrent occurs when the boiling time is nearly 15 min. The reason for the sharp photocurrent maximum at 15min boiling period, may be due to the formation of Cu_2O QDs by sensitizing p-CuSCN enhancing light absorption of Cu_2O QDs. It should be mentioned that after 15 min boiling period photocurrent decreases with increase of boiling time up to 30 min period and after 30 min period the photocurrent found to increase again and maximizes at 35 min boiling period. This observation can be explained as follows. When the boiling period increases more than 15 min the size of the QDs may be increased forming Cu_2O larger crystals suppressing the sensitization process. Further increment of boiling period the grain sizes of Cu_2O may increase forming a thin film of Cu_2O on the top of the p-CuSCN forming a n-p junction providing an efficient charge separation process for the photogenerated charge carriers. However it was observed that the QD sensitized photocurrent is higher than that of produced by the n-p junction.

When the boiling time increases the crystal size of n-Cu_2O increase then it creates a p-n junction.

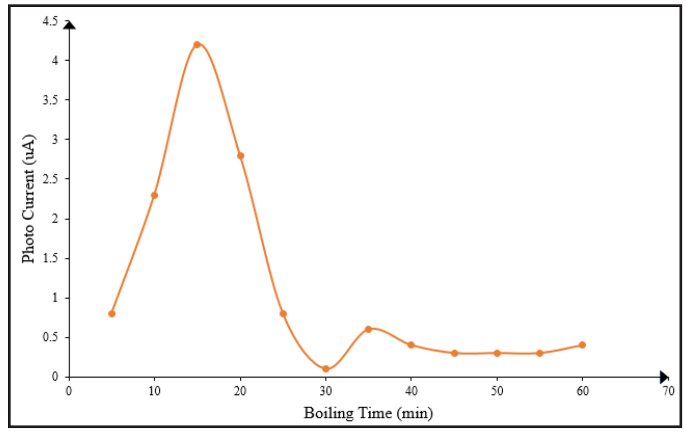

Fig. 2. Photocurrent vs boiling time of the Cu/p-CuSCN Photoelectrode in 1 M $CuSO_4$

Fig. 3 shows the variation of photocurrent for the device Cu/p-CuSCN/n-Cu_2O(QD) / CAC solid state photovoltaic cell with the CAC amount deposited on n-Cu_2O QDs prepared from 15 min boiling period by immersing Cu/p-CuSCN photo-electrode in the $CuSO_4$ solution. Initially photocurrent found to increase with increase of the thickness of CAC layer and maximized at $3mgcm^{-2}$ as shown in the Fig. 3. Further increase of CAC on n-Cu_2O QDs, continuously photocurrent found to decrease may be due light cut off preventing to incident the light on n-Cu_2O to operate the photocurrent generation. Further the pore sizes in the CAC may be good enough to accommodate n-Cu_2O QDs inside the CAC pore facilitating to extract the photogenerated electrons accumulated on QDs readily to enhance the photo-current suppressing the recombination process. Fig. 4 shows the particle size distribution of CAC at pH=7. Average size obtained is ≈ 3μm.

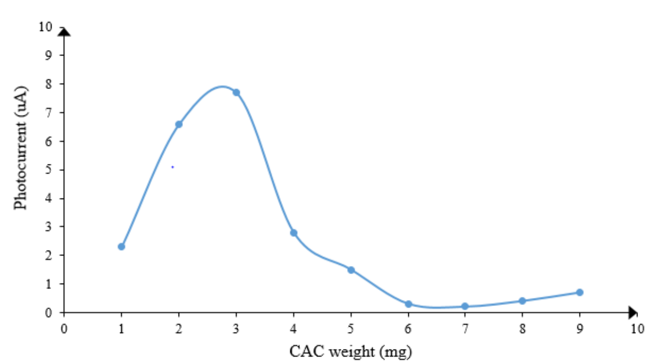

Fig. 3. Photocurrent vs CAC weight of Cu/p-CuSCN/n-Cu_2O /CAC photo electrode

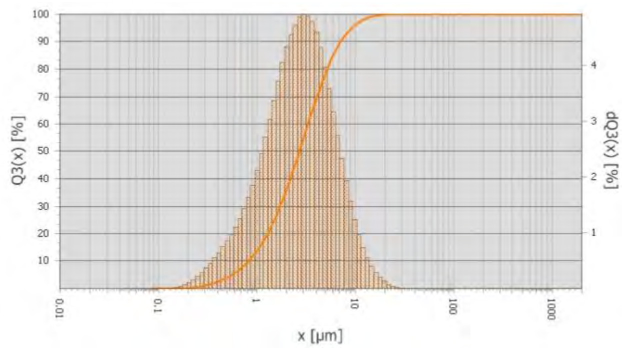

Fig. 4. Particle size distribution of the CAC powder

Fig. 5 shows the defuse reflectance spectra of Cu/p-CuSCN (curve a), Cu/p-CuSCN/n-Cu2O (curve b) and Cu/p-CuSCN/n-Cu_2O / CAC (curve c). Distinct absorption edges for p-CuSCN, Cu_2O can be observed confirming the configuration presented schematically as shown in Fig. 1. It should be mentioned that the absorption properties in the visible region of p-CuSCN/n-Cu_2O were much improved after fabricating QDs on p-CuSCN with compare to that of bare p-CuSCN.

A broader spectrum can be observed for the device Cu/p-CuSCN/n-Cu_2O extending the spectral response of p-CuSCN wide band gap semiconductor into visible region. The shape of the curve b and curve c were resembled with each other because there is no any phase changes occurred by introducing CAC on Cu/p-CuSCN/n-Cu_2O layer. Therefore CAC can be served as an upper electrode to collect photo-generated charge carriers and most light at the Cu/p-CuSCN/n-Cu_2O / CAC solid state photovoltaic cell is absorbed by Cu_2O.

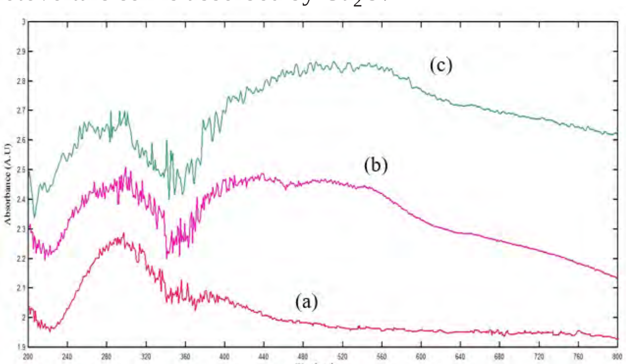

Fig. 5. Defuse reflectance spectra for (a) Cu/p-CuSCN, (b) Cu/p-CuSCN/n-Cu_2O and (c) Cu/p-CuSCN/n-Cu_2O / CAC

IV. Conclusions

Cu/p-CuSCN/n-Cu_2O quantum dots (QDs) novel solid state photovoltaic cell with coconut shell activated carbon (CAC) as the upper electrode was fabricated for the first time as a low cost device. Photocurrents obtained were extremely stable and possibilities to make high efficiency solar cells from these combination are higher. CAC supported to collect photogenerated electrons readily from the QDs to enhance the charge separation mechanism effectively.

V. Acknowledgements

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. Mr. B.M.G Dharmasiri and Mr. S.A.D. Wijayasinghe Nano Technology Research Laboratory, Wayamba University of Sri Lanka is appreciated for providing technical assistance.

References

[1] M. S. Dresselhaus and I. L. Thomas, "Alternative enery technology," *Nature International Weekly Journal of Science*, vol. 414, pp. 332-337, 2001.

[2] N. Singh, A. Kapoor, and R. M. Mehra, *Invertis Journal of Renewable Energy*, vol. 3 no. 133, 2013.

[3] B. Oregan, and M. Gratzel, "A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO_2 films," *Nature*, vol. 353, pp. 737-740, 1991.

[4] P. B. Ahirrao, S. R. Gosavi, S. S. Sonawane, and R. S. Patil, *Archives of Physics Research*, vol. 2, pp. 29-33 2011.

[5] W. Ji, G-Q. Yue, F-S. Ke, S. Wu, H-B. Zhao, L-Y. Chen, and S-Y. Wang, *Journal of the Korean Physical Society*, vol. 60, pp. 1253-1257, 2012.

[6] P. G. D. C. K. Karunarathna, and C. A. N. Fernando, *Invertis Journal of Renewable Energy*, vol. 5, pp. 1-5, 2015.

[7] C. A. N. Fernando, and S. K. Wetthasinghe, *Solar Energy Materials and Solar Cells*, vol. 63, pp. 299-308, 2000.

[8] R. P. Wijesundera, M. Hidaka, K. Koga, M. Sakai, and W. Siripala, *Thin Solid Films*, vol. 500, pp. 241-246 2006.

[9] E. Frackowiak, and F. Beguin, "Carbon materials for the electrochemical storage of energy in capacitors," *Carbon*, vol. 39, pp. 937-950, 2001.

[10] S. Gang-wei, W. Can, Z. Liang, Q. Wen-ming, L. Xiao-yi, and L. Li-cheng, "Influence of high temperature treatment of activated carbon on performance of supercapacitors," *Journal of Materials Science and Engineering*, vol. 2, no. 12, p. 41, 2008.

[11] A. Kay, and M. Grätzel, "Low cost photovoltaic modules based on dye sensitized nano crystalline titanium dioxide and carbon powder," *Solar Energy Materials and Solar Cells*, vol. 44 pp. 99-117, 1996.

[12] K. A. S. K. Hemachandra, and C. A. N. Fernando, *Invertis Journal of Renewable Energy*, vol. 3, pp. 230-235, 2013.

[13] K Tennakone**,** C. A. N. Fernando, A. H. Jayatissa, S. Wickramanayake, and S. Punchihewa, " Semiconducting and photoelectrochemical properties of n- and p-Type β-CuCNS," *Physica Status Solidi (A)*, vol. 103, no. 2, pp. 491-497, 1987.