IOP Conf. Series: Journal of Physics: Conf. Series **853** (2017) 012044 doi:10.1088/1742-6596/853/1/012044

Study on conventional carbon characteristics as counter electrode for dye sensitized solar cells

Muhammad Noer Fajar and Endarko*

Physics Department, Institut Teknologi Sepuluh Nopember, Kampus ITS, Sukolilo, Surabaya, 60111, East Java, Indonesia

*Corresponding email address : endarko@physics.its.ac.id

Abstract. Activated carbon (AC), black carbon (BC), and graphite were deposited onto ITO (Indium Tin Oxide) glass for counter electrode application in Dye-Sensitized Solar Cells. SEM-EDX was used to observe and analyse the morphology and composition of electrodes. The results showed that the particle distribution of the graphite electrode observed was approximately 34% with a size of 1 to 2 µm and BC electrode about 20% have a size of 0.5 to 1 µm, while AC electrode has a size of 0 – 0.5 µm observed around 20%. AC electrode has a more porous and uniform particle aggregates compared to BC and graphite electrodes. The efficiency of the counter electrode was measured using the solar simulator. The highest efficiency was at 0.011516% for the counter electrode that was fabricated by AC. Meanwhile, black carbon and graphite electrodes were achieved at 0.008744% and 0.010561%, respectively. The results proved that the porosity and the uniform aggregate of the particles were the most significant factors to improve the performance of DSSC.

1. Introduction

Recently, DSSC has gained extensive attention due to their environment-friendliness, simple fabricating procedure, and low-cost compared to conventional Si solar cells [1-2]. A typical DSSC is composed of a nanoporous TiO_2 photoanode and a Pt counter electrode separated by an iodide/triiodide electrolyte [3]. The photoanode is usually prepared from TiO_2 nanoparticles on a transparent conducting oxide (TCO), while the counter electrode is a thin layer of Pt deposited on another TCO substrate [2].

As one of the most important components, counter electrode should possess mesoporous [4], high catalytic activity [5] and chemical stability against the corrosive electrolyte in the DSSCs [6]. Pt counter electrode has been extensively used as an efficient catalyst for reduction of I^{3-} ions in DSSC. Pt exhibits high electrochemical catalytic activity for triiodide reduction. However, Pt is scarce, expensive metal and has poor stability in corrosive I^-/I^{3-} redox system [2][7].

Recently, a various carbon-based material including graphene [5], graphite [8], and carbon nanotubes [9] have been studied as a low-cost replacement for Pt counter electrode. Carbon materials attracted much attention due to their high porosity, high electrochemical catalytic activity, low cost, and excellent corrosion resistance against the redox couple [10-12]. In this present study, we reviewed some carbonaceous material including graphite, activated carbon, and black carbon used as counter electrode and compared their performance in DSSC system.

2. Experimental design

2.1. Preparation of carbon counter electrodes

The carbon powders that were used in this research are graphite, black carbon, and activated carbon. Each carbon paste was prepared by mixing carbon powder with ethanol and was then stirred for 1 hour. The carbon pastes were deposited onto a conductive glass substrates-ITO glass using doctor blade method with a *thickness* around $\sim 10\ \mu m$. The electrode was heated at 250°C for 30 minutes to remove the organic residue and stabilize the material.

2.2. DSSC's fabrication

TiO_2 photoanode was prepared according to the procedure previously reported by Lee *et.al*[12]. 0.7 g of TiO_2 powder is finely ground in a mortar, then 1.4 mL of distilled water were added. After10 minutes, 0.3 g of PEG, 0.7 mL of acetic acid, along with 1 mL and 0.7 mL Acetylacetone triton X-100were added. The TiO_2 paste was coated on 2.5 cm^2 area of ITO by a doctor blade technique with a thickness around10 µm, and was then sintered at 450°C for 30 minutes. The electrode was immersed overnight in a 0.05 mM ethanol solution of the N749 dye at room temperature. A sandwich-type DSC was fabricated with the dye-sensitized TiO_2 photoanode, electrolyte gel, and carbon as the counter electrode. **Figure 1** shows the structure of the DSSC's cell. The electrolyte consisted of 7 g PEG 1000, 25 mL chloroform and a liquid electrolyte homogeneously mixed and stirred with a magnetic stirrer while heated at80°C for 1 hour.

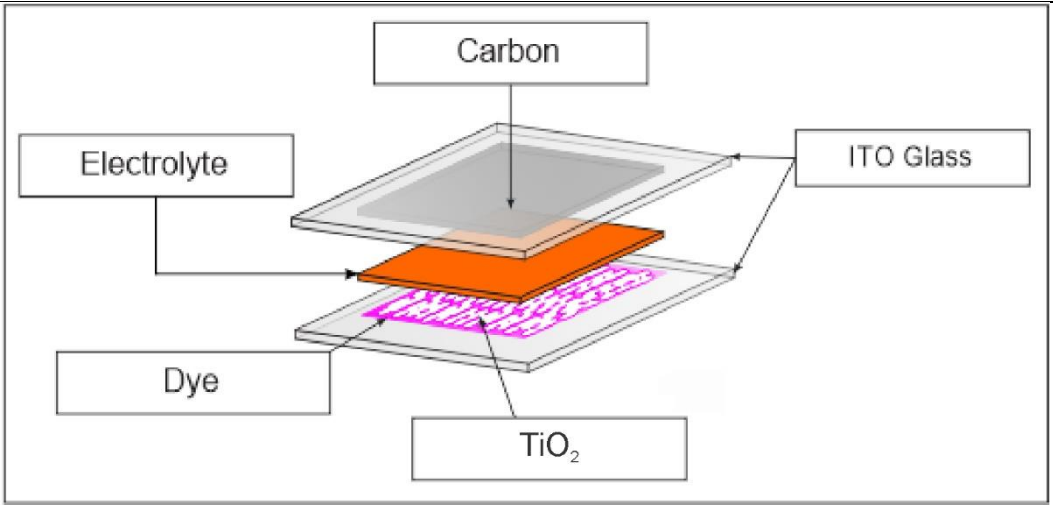


Figure 1. DSSC's formation

The surface morphologies and compositions of the counter electrodes were observed and analyzed using SEM-EDX whilst the current density-voltage (*J-V*) characteristics of assembly DSSC were measured using an I-V Keithley meter, under illumination at 100 mW/cm^2

3. Results and discussion

Figure 2 shows the top view SEM images of activated carbon (AC), black carbon (BC), and graphite electrode. These images confirmed that particle shape of all samples is spherical irregular particles. It also can be seen that porous structure was observed in activated carbon. The morphology of BC and graphite electrodes showed somewhat large intensity inhomogeneous agglomerations. These agglomerations were decreased by electrical contact, making the resistance of charge transfer increase[13].

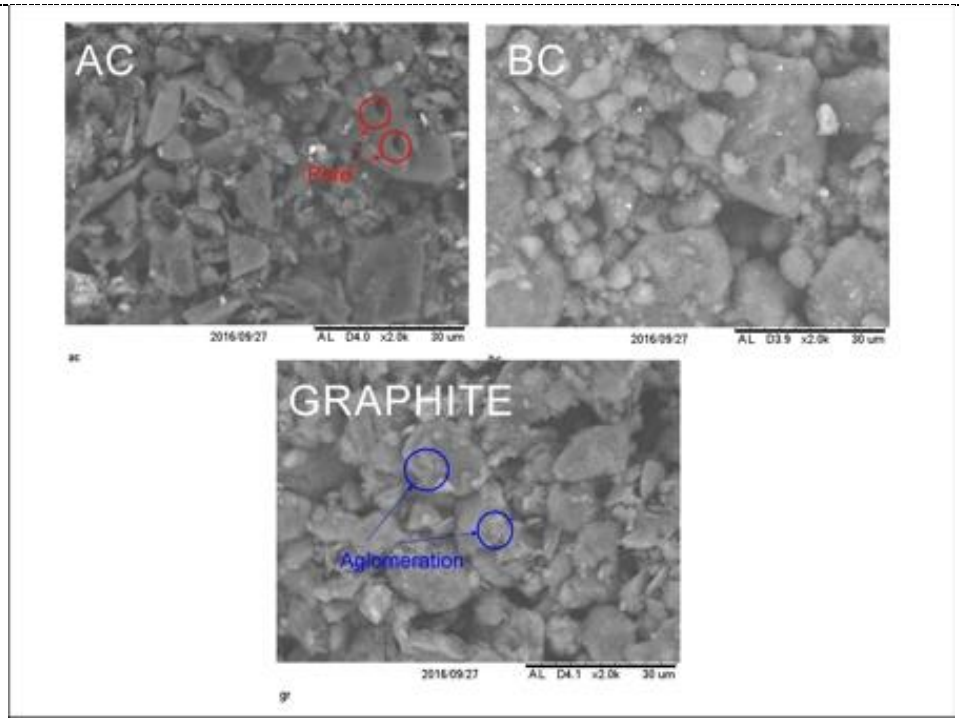
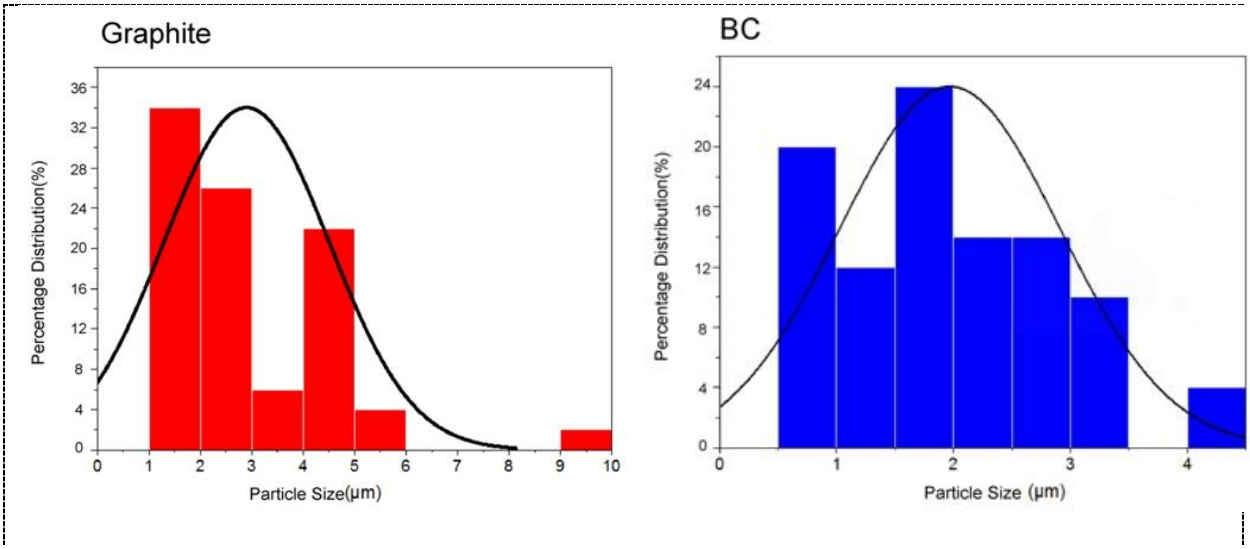


Figure 2. SEM images of AC, BC, and Graphite counter electrode

Figure 3 shows the particle size distribution observed in any carbon materials used in the present study. The distribution of particles with a size between 1 to 2 μm around 34% observed in graphite electrode and the size of 0.5 to 1 μm for 20% occurred in BC electrode, whilst a size of 0 to 0.5 μm for 20% was observed in AC. The distribution of particle gave large surface area so that the surface contact between carbon materials and electrolyte will increase the transport of electrons to the dye contained in photoanode [10]. The large particles resulted in limited transport of electron process from the outside toward the inner circuit and affect the performance of DSSC.



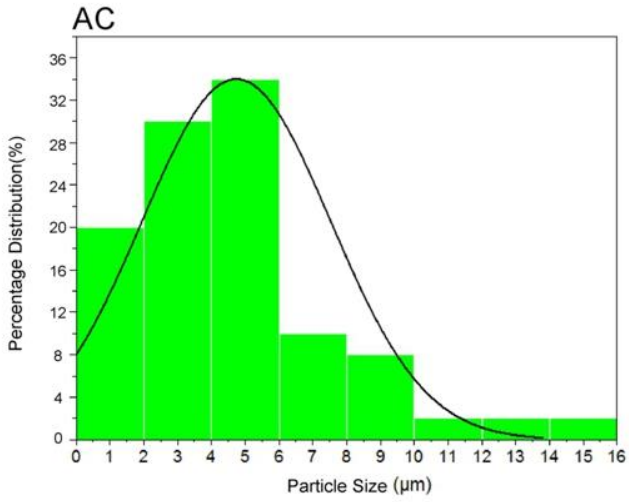


Figure 3. Distribution particle size of Graphite, BC, and AC counter electrodes

From Table 1, it can be deduced that AC electrode gave the highest efficiency compared to BC and graphite electrodes. This result agrees with the result that obtained by [14-15]. The best values for fill factor was shown by AC electrode. Fill factor is the performance values from DSSC obtained from short circuit current density and open circuit voltage. The fact proved that the performance of AC electrode is better than other carbons used in this study. This is because large particles would slow the rate of I3 reduction due to the high charge transfer resistance (RCT). The high RCT has a negative influence on the fill factor (FF) and shows poor energy conversion efficiency (η)[16].

Table 1. Photovoltaic parameters using conventional carbon of CE for dye-sensitized solar cell

CE	Voc/mV	Jsc/mA cm_2	FF (%)	Ƞ(%)
AC	0.581132	0.198157	0.897788	0.011516
BC	0.901621	0.220368	0.440098	0.008744
Graphite	0.701047	0.287001	0.524888	0.010561

[a]Jsc: short circuit current density, Voc: open circuit voltage, FF: fill factor, Ƞ: energy conversion efficiency

4. Conclusion

The study successfully demonstrated the counter electrode that was fabricated from activated carbon, black carbon, and graphite for DSSC applications. The activated carbon has the best performance compared to the black carbon and graphite electrodes due to the efficiency of dye-sensitized solar cells (DSSCs). The results showed that the activated carbon has more porous structure, smallest particle size, and highest fill factor compared to the other two. Due to this fact, we were able to deduce that the morphology of the surface on the counter electrode provides an effect on the performance of DSSCs.

References

[1] M Wu, X Lin, T Wang, J Qiu, and T Ma, *Low-cost dye-sensitized solar cell based on nine kinds of carbon counter electrodes Energy Env Sci* 2011.

[2] S Suhaimi, M M Shahimin, Z A Alamed, J Chysky, and A H Reshak, Material for Enhanced Dye-sensitized Solar Cell Performance: Electrochemical Application *electrochemsci* **vol. 10**, pp 2859–2871 2015.

[3] Z Huang *et al* Application of carbon materials as counter electrodes of dye-sensitized solar cells

elecom **vol. 9** pp 596–598 2007.
[4] E Ramasamy and J Lee Large-pore sized mesoporous carbon electrocatalyst for efficient dye-sensitized solar cells *ChemComm* **vol 46** pp 2136–2138 2010.
[5] J D Roy-Mayhew D J Bozym C Punckt and Ii A Aksay Fuctionalized Graphene as a Catalytic Counter Electrode in Dye-Sensitized Solar Cells *acsnano* **vol 4** pp 6203–6211 2010.
[6] Z Shi, K Deng, and L Li, Pt-free and efficient counter electrode with nanostructured $CoNi_2S_4$ for dye-sensitized solar cells **vol 5** p 9317 2015.
[7] Y-C. Wang *et al* FeS2 Nanocrystal Ink as a Catalytic Electrode for Dye-Sensitized Solar Cells *angewandte* **vol 52** pp 1–6 2013.
[8] G Veerappan, K Bojan, and S-W Rhee, Sub-micrometer-sized Graphite As a Conduvting and Catalytic Counter Electrode for Dye-sensitized Solar Cells **vol 3** pp 857–862 2011.
[9] F M Al-Marzouki, S Abdalla, and S Al-Ameer, Dye Sensitized Solar Cells with Low Cost Carbon Nanotubes Electrodes 2013.
[10] I Y Y Bu and J Zheng, A new type of counter electrode for dye sensitized solar cells based on solution processed SnO_2 and activated carbon *mssp* **vol. 39** pp 223–228 2015.
[11] Q MIAO, M Wu, W GUO, and T Ma, Studies of high-efficient and low-cost dye-sensitized solar cells **vol 4** pp 103–107 2011.
[12] J-K Lee *et al* Preparations of TiO_2 pastes and its application to light-scattering layer for dye-sensitized solar cells *J Ind Eng Chem* **vol 15** no 5 pp 724–729 2009.
[13] K Basu, D Benetti, H Zhao, L Jin, A Vetrone, and F Rosei, "Enhanced photovoltaic properties in dye sensitized solar cells by surface treatment of SnO_2 photoanodes.," *Sci Rep* **vol 6** 2016.
[14] C Sampath Kumara Ranasinghe, E Nirmada Jayaweera, G Rajanya Ashoka Kumara, R Mudiyanselange Gamini Rajapakse, H Mudiyanselage Navarathna Bandara, and M Yoshimura, "Low-Cost Dye-Sensitized Solar Cells Based on Interconnected FTO-Activated Carbon Nanoparticulate Counter Electrode Showing High Efficiency" **vol 5** pp 361–368 2015.
[15] S-H Park, H-R Jung, and W-J Lee, "Hollow activated carbon nanofibers prepared by electrospinning as counter electrodes for dye-sensitized solar cells," *Electrochimica Acta* **vol** 102 pp 423–428 2013.
[16] G Veerappan, K Bojan, and S-W Rhee, "Sub-micrometer-sized graphite as a conducting and catalytic counter electrode for dye-sensitized solar cells" *ACS Appl Mater Interfaces* **vol 3** no 3 pp 857–862 2011.