ACTIVATED CARBON-TiO_2 NANOPARTICLES COMPOSITE ELECTRODE FROM ORGANIC WASTE MATERIAL FOR SOLAR CELL AS ELECTROCHEMICAL APPLICATION

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ABSTRACT: *A composite of palm kernel activated carbon (PKC AC)/Titanium Dioxide nanoparticles (TIO_2) was prepared for photoanode (working electrode) of dye-sensitized solar cell (DSSC). PKC-AC by-product was obtained from the residue of carbonization (Pyrolysis – Nitrogen Environment). PKC-AC-TIO_2 composite was used in DSSC photoanode for promoting low cost energy generation. The PKC-AC-TIO_2 as photovoltaic active layer provide a medium for electron transport system for DSSC. Photoanode with a natural sensitizer as composite catalyst in electrode (platinum replacement) was made for electrochemical devices. Composite of carbon electrodes from PKC-AC and Iron (III) Oxide black – Fe_2O_3 (FEO) were characterized. Synthesized composites were made into thin pallet (200nm) with hydraulic press (100 kPa) to enhance stacking of porous composite structure to obtain improved electron hoping permeability mechanism. A peel-able Polyurethane-Silicone (PU) was prepared and encapsulation of DSSC was made with Cu adhesive conductor. EIS test was carried out to investigate electrical conductivity from the frequency response analyses. The electrical conductivity was higher for the PKC-AC/TIO_2 in comparison with FEO carbon with a conductivity of (2.9x10-5) S.cm^{-2}. Uv-Vis result shown TIO_2 photo-absorbance was best for Titanium compare to other metal oxides. The efficiency of DSSC using PKC-AC as photosensitiser was 3.2% and comparable to N-719 sensitized DSSC system (3.5%) with fill factor of 40% and 53% respectively. It is expected that the electrode system has the potential application in photoelectrochemical devices especially solar cells electrodes..*

Keywords: Activated carbon, Composites (organic-inorganic), Palm kernel cake (PKC), Electrical impedance; Electrochemical electrode, Dye Sensitized Solar Cells (DSSC)

1. INTRODUCTION

Activated Carbon from palm kernel cake (PKC AC) was made into electrode for dye-sensitized solar cell (DSSC). The electrode thin film was formed (solution casting) by incorporating onto Polyurethane (PU) substrate. PU as flexible substrate has become a protective layer was incorporated with PKC AC as the electro-catalyst in DSSC circuit. PKC AC made into electrode elements is now seen as potential in solar cell and electrical application. In this work, PKC AC carbon electrodes for solar cell using metal oxide and carbon residues were viewed as DSSC application. It is one of the more studied fields in DSSC currently for their simple and low cost methodology which is more environmental friendly.

Electrical impedance and Incident to photon conversion efficiency (IPCE) with photoluminescence study were characterized. The study evaluations were conducted for conductivity and other scientific evaluations. The heterojunction incorporated thin film device when exposed to photon could result a conductivity and photoelectron conversion factors. The electrical conductivity of composite material and hybrid DSSC success depends on conducting polymer development principally by nanotechnological development. To other view, disconnect contacts due to physical degradation of structures of the electrodes affect the IPCE performance of DSSC. PKC AC is now made for alternative electrode that is cheaper and non-corrosive [1-5].

Photoanode combine with PKC AC made from among great fact as TIO2 best photon-absorptive material combine with porous carbon structures have resulted organic type composites as active layer material and electrode system and photo-advanced (light scattering) photocatalyst properties [6-7]. The primary factors affecting electrode stability is greatly influenced by the physical morphological environment of the elements along with the electro-chemical in composite of carbon components [8-10]. Therefore, a proper electrode of carbon-TIO_2 composite gives critical stability on optoelectronic properties as sensitizer and catalyst DSSC system. The electrode conducting properties and photocatalytic ability of polymer structure have shown more substrate-mobilize and essentially more electron effective catalyst and material physic of electrochemical properties.

DSSC technology was first developed by O-Regan and Gratzel in 1991 and there are three main components which are the working electrode (photoanode), the Electrolyte system (I3-/I-) and the counter electrode (CE) [11-12]. The photoanode is normally comprised of Titanium Dioxide attached with sensitizer dye (Ruthenium N719) coated on a transparent conductive substrate. In this study, a substrate made of Polyurethane-Silicon or PU was prepared to replace the glass of the transparent conductive structure with incorporation of metal conductor Polyethylene Terepthalate (Cu-PET). Polymers hybrid DSSC was incorporated with conductive polymer of polyethylene oxide. The redox system was placed in between as figured in Figure 1 and encapsulation of the liquid take place where PU is highly adhesive when prepared with solvent to visualize the encapsulation method.

The TP-N719 counter electrode was made with platinum (Platisol, Solaronix SA) with platinum film cured at room temperature. For comparative study, the thin film of PKC AC was characterized. Alternatively a material is proposed apart from using Platinum for most used catalyst now being adopted. Fabrication of DSSC with the solution-cast method and flexible substrate technique provide applicable conductive polymer hybridized with activated carbon used in the study.

To fabricate the inexpensive solar cells, substrate of peel-able Polyurethane (PU) was chosen as it is a desirable substitute of glass. PU with material that is more resistance of heat i.e. Silicone, was prepared as advanced substrate due to its properties of high resistance of heat. The PU thin film was to become substitute of glass of which the material has becoming more solution driven type of DSSC fabrication.

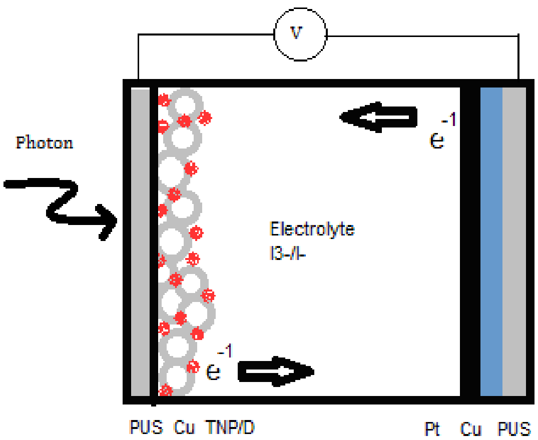

Figure 1 : The Structure of cell of DSSCs

Flexible substrate like Silicon-Polyurethane (PU) has a great transparency advantage as well as the material has a flexible application type of which, coating material is now applicable in any type of surface where the solar cell technology is being envisioned [13-14]. This is proposed as a solution in supporting building type material and enriching homes as being more renewable and sustainable. Other aspect of power is now generated for new appropriate building design using solar energy generation and other views of material application design.

2. EXPERIMENTAL DETAILS

Photoanode preparation

Photoanode material was selected based on the photoluminous study or UV-Vis. Material as such titanium dioxide, zinc oxide and zirconium oxide were undergone UV Vis as a study of photo adsorption as shown in Figure 3. TIO_2 was selected as optimum material with highest photo adsorption. PKC and Base carbon-TIO_2 composite were synthesized using magnetic stirrer overnight of composition with Acetonitrile (0.1M) and carbon-TIO_2 (1:1) until precipitations were dried followed by ball milling of planetary method (1000rpm) with mill diameter of 8mm and placed in cylindrical container with weight compositions ratio of 10:1 of ball to powder weight ratio. The samples prepared were tested against its respective EIS properties to determine conductivity of the electrode system. Carbon-TIO_2 composite electrode was formed as pallet conductive carbon-TIO_2 composite (EIS). PKC Carbon where obtained from a pyrolysis process was prepared. The mixture of PKC Carbon-TIO_2 composite was mixed using ethanol/acetone (1:1) and ball milled for 18 hr. The sample of specimen was further stirred at low-speed stirring at 120 ^oC until dried precipitation was obtained. Once ready as compactable item, the sample of electrodes was then palletized at 100kPa using hydraulic press and the composite electrode system was stored in a dry dark room. Effect on PKC carbon-TIO_2 or hybrid (organic-inorganic) composites on electrical conductivity characteristics was viewed. The properties of the conductivity of Rb from the EIS determined the resistivity of the PKC carbon/TIO_2 and determined the performance produced for each type of electrodes.

Preparation of counter electrode carbon PKC AC

Palm kernel cake organic waste was obtained from local supplier and placed in a vacuum oven to dry the sample at 60 ^oC. The PKC samples were pyrolized at fix-bed reactor with Nitrogen inlet for 1 hr at 500 ^oC and quenched at room temperature to obtain an activated carbon of PKC-AC. The PKC AC was then further synthesized to become a composite of PKC AC-TIO_2. The PKC AC-TIO_2 electrodes film was screen printed on the PU film prepared with conducting Cu-Pet polymer and dried in vacuum oven.

Preparation of electrolyte solution

The electrolyte solution was prepared using conducting Polyurethane diol with a mixture of (1:1) NaI solution of 0.3M [3] with Acetonitrile of 0.1M in distilled water solution. Additionally 0.05 M Iodide (I_2) in NaI solution then mixed as prepared in detailed of various researchers. The redox system of free-ion-transport (I^{3-}/I^-) functionality is proportionate with more iodide ion present in the electrolyte where the bigger diffusion of electron migration could be achieved in the oxidation and reduction process of electron regenerations.

DSSC Assembly

The DSSC cell fabrication was assembled using carbon-TIO_2 pallet-PU ready set as the working electrode. For the counter electrode, Pt-conducting polymer and PKC AC film as the counter electrode as illustrated in Figure 1. The Photoanode electrode was ready for fabrication. When the assembled PU pre-seal, a few drops of electrolyte of redox system was added before sealing with exposed electrode of both terminal made an open circuit output voltage.

The cell prepared output voltage was known as voltage-open circuit, Voc and Jsc as the short circuit current voltage. The embed-TIO_2 film of carbon-TIO_2 pallet was inserted in the PU capsule design with an area of 1 cm^2 along with an opening for the injected electrolyte for the solar cell fabrication. All DSSC components were connected as one system of solar cell and sealed with solvent and ready as one cell. The unit cell was kept at dark dry cabinet to prevent surging current due to photoexcitation.

UV-VIS Spectroscopy

Titanium Dioxide Nanoparticle from Sigma Aldrich with 99.9% purity was undergone Uv-Vis characterization to investigate the photo-absorption properties and to compare the performance with the relationship of zinc oxide (ZnO) and Zirconium Oxide (ZrO) adsorption band. The wider adsorption of visible light or photon adsorption determined the light spectrum functionalized for solar photoanode. The porosity of the mesoporous TIO_2 formed the light interaction between solid-solid interfaces. The absorption spectra values were measured to determine the band of wavelength spectrum used in the study. The results obtained were explored as the basis for photocatalytic for the regeneration of electron transfer [7] and other view in conductivity of PKC carbon-TIO_2 composites. The mean values of specific adsorption for the nanomaterials used in the study were correlated with the performance of electrical evaluation.

Electrical Impedance Spectroscopy

Electrical impedance spectroscopy (EIS) samples were prepared in palletized PKC carbon-TIO_2 composite and were placed in a Teflon sample holder with conductor fitting for undergoing the frequency response analysis of frequency range of 10Hz to 10 KHz. The frequency response was to evaluate the bulk resistance to represent electron transferability process. The accelerated response of EIS containing PKC carbon and Base carbon were studied at room temperature (27^{o}C) using Hioki Electrical Impedance Spectroscopy.

Film characterization

Film morphology was characterized using field emission scanning electron microscopy (FESEM). The view of FESEM showed nano-morphological aspects of composite material used in the electrodes where the structure of composites was analyzed. Other view also relates to the porous nature of electrode which explain how electron-hop was achieved when more porous nature structure was obtained as it provide more efficient electron tunneling system.

Incident-Photon-current conversion efficiency (IPCE)

The cell performance was measured using a solar simulator system (INET/FKE-UiTM-Japan) system with a light intensity of 100 mW.cm-2 The device under short circuit condition with fitted monochromatic light source and a silicone photodiode (Newport 818-UV, USA) was used for power density calibration with Pico ammeter (Keithley 6485, USA) for current density measurement.

3. RESULTS AND DISCUSSION

3.1 Uv-Vis characterization

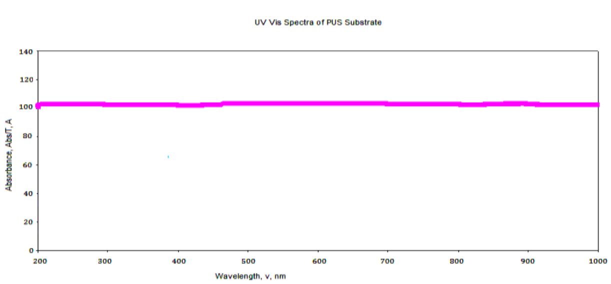

Figure 2: UV Vis Spectra of PU Substrate

Figure 2 shows that the PU photoluminescence test showed that the PU substrate was a transparent substrate which is highly needed for photo luminous environment. The PU from figure has resulted about 100% transparency of material when prepared (solvent-cured) and comparable to glass as transparent material needed for solar cell fabrications. The indicated organic-inorganic composite contributed the electrode conductivity and stabilization from porous structure provided mechanisms for polymer/TIO_2 matrix for electrocatalytic was pinpointed in Figure 3. The adsorption of TIO_2 material from Uv-Vis band spectrum analysis indicated the significance of TIO_2 properties for as the optimum light absorbance material has been indicated in Fig. 3. The figure depicts that TIO_2 post the best light adsorption material with mean values measurement differentiation was found within 1.5% for photoanode material.

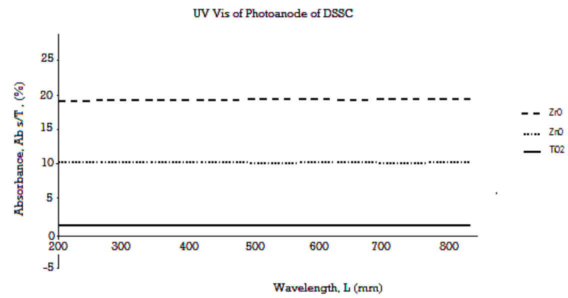

Figure 3: Adsorption band of Uv-Vis

The properties for TIO_2 material was further explored by morphological view of Field Emission Scanning Electron Microscopy (FESEM). The result showed that electrode porous nanoparticles structure has enable an efficient electron transfer of electrodes onto the carbon-TIO_2 matrices of composite as shown in the morphological evaluation in Figure 4.

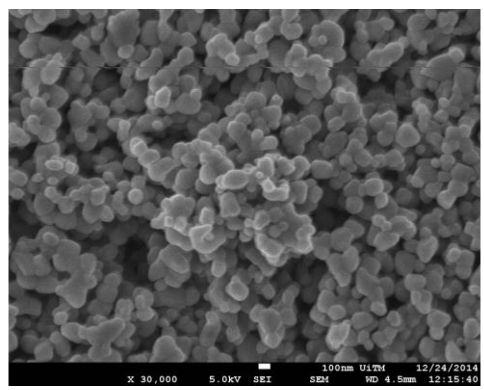

Figure 4: FESEM porosity and nano-characterization

FESEM images showed a large area of porous surface area transport structure with nano-roughen surface. The efficiency of the PKC-AC sensitized composited in TIO_2 through press-preparation and encapsulation method for DSSC fabrication was successful. The PKC-AC IPCE was 3.2% and comparable to the N719 sensitized cell (IPCE 3.5%) of which the same DSSC system was used. It provides a great potential application in solar cell or photo electrochemical. The applications of natural dyes derived from palm kernel cake as organic waste to become a DSSC sensitizer promise high performance DSSC from natural with low cost environmental preparation method in making photovoltaic cells. Organic waste to energy derivation material (Pyrolysis) indicated sustainable waste recycling development of renewable energy.

The EIS test has resulted electrode conductivity observed as the best mechanisms of electron transport evaluation system. The addition of carbon in TIO_2 composite electrode has shown improved conductivity according to figure. The characteristics presented in Figure 4 showed a frequency response analysis showing the quality of the conductivity. The composite material resulted a bulk resistance value was obtained. The differential (dE) in electron conductivity was shown according to types of carbon used in figure 5. The respected Rb of the analysis was obtained from the inverse space coordinate (Nyquist plot) and total electron conductivity (σ) and was calculated according to equation:

$\sigma = 1.t/ (A.Rb)$

Where t and A are the thickness and Area as constant with Rb as the bulk resistance obtained from the Admittance plot or the inverse of impedance plot analyzed in Figure 5.

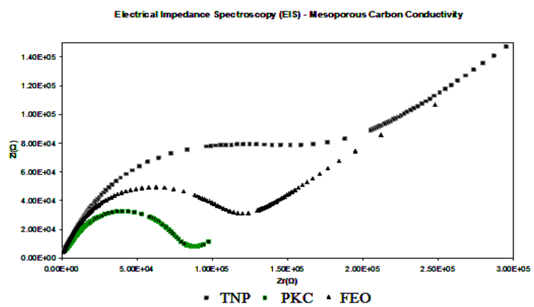

Figure 5: Impedance Plot of PKC/Base-Carbon/TIO_2

PKC and Base carbon/TIO_2 conductivity as electrode was obtained with good conductivity result where the calculated resistance value was obtained from the plot. The semicircle fluctuation is moving towards the same trend which corresponds to the same circuit system with consistency value. The composition of carbon/TIO_2 have been identified as good electro-chemical processes initiated for electron hole transport system suggesting that an electron was easily move from Cu/PU to front surface of the film (in contact with electrolyte).

The short circuit current density- open circuit voltage (Jsc-Voc) characteristic of carbon-TIO_2/EE/carbon/PU was illustrated in Figure 7. The photovoltaic performances of the DSSCs was comparative where PKC-AC resulted Voc of 0.6 V, Jsc of 0.78 mA.cm-2 and IPCE resulted for 3.2% with a fill factor (FF) of 40%. Meanwhile, the P_N719 had Voc of 0.5 V, Jsc 0.87 mA.cm-2 and IPCE of 3.5% with a fill factor (FF) of 53%. The trend of plots showed about similar polarity with comparable IV measurement and maximum power output was obtained. The performance of cell was calculated according to the following

IPCE = Jsc.Voc.FF/Io; FF = Pout / Pin

Where Pout is the maximum power output of the DSSC cell and Pin is defined as te power output of the total power at photon flux of 100 mW.cm^{-2} (Io) and the efficiency of the sensitizer valued the DSSC performance where commercial P_N719 sensitizer used showed similar trend as PKC_AC shown in Figure 7 and comparison of IPCE performance between cells was analyzed.

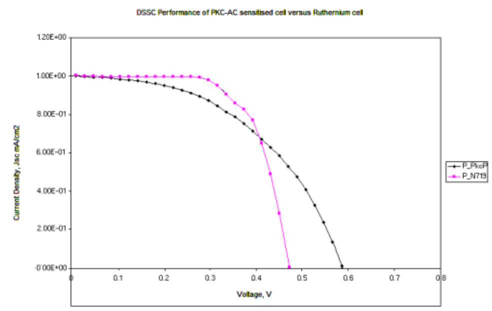

Figure 7: IPCE performance for DSSCs of TIO_2/PKC_AC and Ruthenium N719 sensitizer.

4. CONCLUSIONS

The indicated work reported the preparation of electrode and photovoltaic performance of a natural-organic-based DSSC using PKC-AC. Electrodes of pyrolysis residue and the commercial N719 sensitizer were compared for conversion efficiency. The PKC-AC and carbon TIO_2-electrodes produced were prepared for conductivity study. PKC-AC and FEO studied and PKC_AC was selected as the type of carbon in the electrode composition. The resulted conductivity of PKC was chosen from its best conductivity. Electro-photo conductivity and other properties have played roles in obtaining good sensitizer-conductivity enhanced and as conductive electrode. The effect of different carbon as conductivity mechanism of electrodes was produced, and flexible DSSC composite was able to performed functional material as electro-photo electrode. The photocatalytic/luminous properties of the PU and TIO_2-composite electrodes were acceptable and superior in photoconductive and flexible substrate.

Carbon/TIO_2 composite using PKC and FEO carbon composite electrode showed good conductivity of (2.9 x10^{-5}) S.cm^{-2} with PKC activated carbon. The other composite material of electrodes tested was with FEO and obtained second best performance. The Nyquist plot of EIS analysis and the electrode system resulted superior electron transportation of sensitizer-photoanode. The efficient sealant-flexible substrate and catalytic material of the DSSC composite electrodes was found as one hybrid material of DSSC cell fabrication. Efficient nanostructures of the morphological aspects were a nanosize ranged in material and enabled electron tunneling for an electrical conductivity material. The incidence photon conversion efficiency (IPCE) analysis as DSSC performance obtained conversion efficiency of 3.7% with a fill factor of 0.64. DSSC materials of flexible substrates and carbon composite has been combined and obtained photovoltaic performance with acceptable conductivity and IPCE.

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