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ELECTROLESS DEPOSITION OF NANOSCALE TIN OXIDE ON COCONUT ACTIVATED CARNON FOR SUPERCAPACITOR ELECTRODE

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Abstract

Supercapacitors, whose evolution dated back to about fifty years, are widely considered as energy storage devices that have great potential of filling the power-energy gap that exist between the batteries and the dielectric capacitors owing to their extended cycle life and tremendous power density. Nanostructured tin oxide (SnO2)–activated carbon (AC) was successfully synthesized via zinc ions and dispersion catalyzed coconut activated carbon from Malaysia in aqueous solution using electroless plating method. The crystallinity of the composites was studied by X-ray diffraction analysis (XRD) while the structure of the composites was examined by field-emission scanning microscopy (FESEM) and energy dispersive spectroscopy (EDX). Using a three-electrode cell configuration, the electrochemical performance of the composite was studied by cyclic voltammetry (CV). The specific capacitance of the SnO_2-AC composite measured at a scan rate of 20 mV s^{-1} was found to be 281 F g^{-1}.

Keywords: Tin oxide (SnO_2); Activated carbon (AC); Electroless plating; Nanomaterials; Supercapacitor

1.0 INTRODUCTION

Supercapacitors, whose evolution dated back to about fifty years, are widely considered as energy storage devices that have great potential. Therefore, more research attention are currently being paid to the development and improvement of the supercapacitors as efficient alternative energy storage devices owing to their extended cycle life and tremendous power density [1]. As such, supercapacitors are seen as energy storage devices capable of filling the power-energy gap that exist between the batteries and the dielectric capacitors. Supercapacitors are grouped into two categories – electrochemical double-layer capacitor (EDLC) and pseudocapacitor – on the basis of the electrode materials utilized for their fabrication. The electrochemical double-layer capacitors utilize high surfsce area carbon materials like activated carbon, carbon glass, carbon aerogel, etc as electrode materials while pseudocapacitors utilize transition

metal oxides (Ru, Co, Mn, Ni, Zn, etc.) and conducting polymers as electrode materials.

Then again, investigation on the utilization of metal oxide/carbom composites as electrode materials for supercapacitors' applications have been carried out by various researchers with the aim of mitigating the disadvantages and exploiting the advantages of the individual component [2]-[5]. Ruthenium oxides have been found to exhibit conspicuous electrochemical characteristics and high specific capacitance, as such, have been commonly utilized as electrode in electrochemical supercapacitors [6], [7]. Nonetheless, the high cost of ruthenium has been a major factor militating against its commercial acceptability. Therefore, other metal oxides with comparable capacitive characteristics and are relatively cheap are being investigated. Metal oxides such as nickel oxide [8]-[10], manganese oxide [11], [12], cobalt oxide [11], [13] and cerium oxide [14], due to their inexpensiveness, good conductivity and pseudocapacitive behavior, have been utilized as electrodes and found to exhibit high capacitive performance comparable to that of ruthenium oxide. For example, SnO2 having high surface area, has been organized using sol-gel technique and used as an electrode in a organic solution because it is highly conductive and chemically stable [15], [16].

Fabrication of composite materials has been carried out by researchers using various techniques including electrodeposition, wet impregnation, chemical deposition and mechanical mixing, some of which require additional electricity and electrodes, and expensive equipment. In addition, it is difficult to control the morphology and the particle size of the composites [17]. In recent time, the use of electroless deposition technique to organize metal oxide/carbon composite has continue to gain more ground because of its effectiveness in depositing metal nanoparticles on substrate with different shapes. Also, it is a simple process that require only basic equipment, hence, the low cost of production [17]. Be as it may, the impact of electroless plated tin oxide on the surface of coconut-based activated carbon and its influence on the electrochemical performance of the supercapacitor has not been reported to our knowledge.

This paper describes the synthesis of SnO2–AC nanocomposites via a simple electroless deposition technique. The SnO_2-AC nanocomposite was applied as supercapacitor electrode. Cyclic voltammetry (CV) was utilized to study the electrochemical performance of the prepared supercapacitor cell.

2.0 EXPERIMENTAL

Preparation of Materials

The fabrication of tin oxide-carbon nanocomposites was done by depositing nano tin particles on coconut-based activated carbons via electroless plating. The reagents used for this study were bought from Aldrich Chemicals. All the reagents are of analytical grade (AR grade) and were utilized in their original state without further refinement. The cocnut-based activated carbon used as substrate was supplied by Laju Group of Companies, Malaysia, and has surface area of 980 $m^2\ g^{-1}$. Before the commencement of the electroless tin deposition, dispersion of the carbon sustrate particles in distilled water was done using ultrasonic cleaner for 30 min and after that dried at 60 oC in air overnight. In order to further clean the activated carbon structures and increase the surface area, a pretreatment procedure was incorporated. Electroless deposition of the tin coatings on the carbon particles was carried out using immersion procedure. The amount of AC utilized for the electroless tin plating was kept at 1 gm [6]. The bath composition was respectively: 0.02 M stannous chloride, 0.6 M thiourea (TU), 0.3 M hydrochloric acid. The plating time was 30 min. The bath temperature was maintained at 70 °C throughout the deposition process [18]. After the deposition, the product obtained was washed thoroughly with distilled water and then dried at 70 °C in a vacuum oven overnight, thus completing the electroless deposition process.

Characterization and electrochemical test

X-ray diffraction (XRD) of the SnO_2-AC composite was done on a diffractometer system (PANalyticalX'Pert PRO MRD PW3040) with Cu Ka radiation (λ = 1.5418Å) at 40 kV, 60 mA. Morphology of the SnO_2–AC composite was studied with field-emission scanning microscopy (FESEM, LEO SUPRA 55VP) that come with an energy dispersive X-ray (EDX) spectrometer (Oxford INCA 400). A classic three-electrode test cell containing electrolyte at room temperature was utilized for the electrochemical test conducted on an Autolab electrochemical framework (ECOChemieBV, The Netherlands). The electrochemical test was carried out in a 1 M H_2SO_4 electrolyte. For the three-electrode cell configuration, SnO_2/AC composite electrode, saturated calomel electrode (SCE), and platinum foil were utilized as the working electrode, reference electrode and counter electrode, respectively. The CV test was recorded at a potential window of −0.2 to 0.8V scanned at rate of 20 mVs^{-1}.

3.0 RESULTS AND DISCUSSION

Surface analysis

FESEM image of the SnO_2–AC sample showing its morphology and structure is presented in Fig. 1. It is clearly seen from the FESEM image that the SnO_2–AC particles have spherical shape and the diameter of the particles range from 20 to 60 nm. The particles are in cluster form with visible open channels. The presence of these open channels is an indication that the electroless coating of the carbon substrate does not resulted to the blockade of the porous structure of the carbon substrate. Thus, suggesting the effectiveness of electroless plating in the coating of intricate shapes. The XRD patterns of SnO_2–AC composite are depicted in Fig. 2. It can be observed from the figure that the patterns consist of diffraction peaks that are well-defined and very sharp, thus signifying that the crystalline are of high quality. The observed diffraction peaks of 2θ which correspond to (110), (101), (200), (111), (211), (220), (002), (310), (112), (301), (202) and (321), respectively are consistent with the standard JCPDS values and are assigned to the tetragonal structure of SnO_2 (JCPDS Card No. 41-1445). Fig. 3 presents a typical EDX spectra for SnO_2. Fig. 3 clearly shows that the SnO_2-AC nanocomposite consists mainly of Sn and O elements, thus signifying the high purity of SnO_2[19].

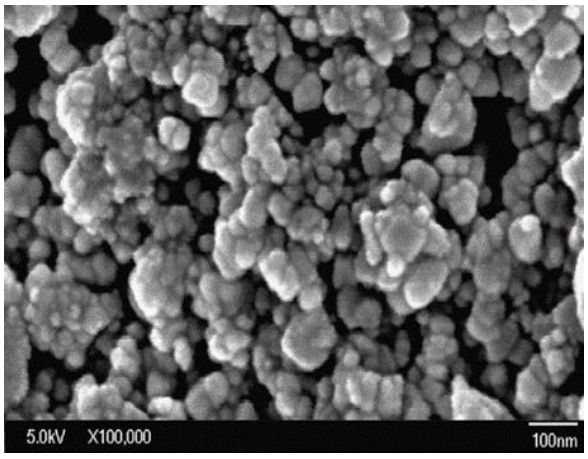

Fig. 1. FESEM photograph of nano SnO_2–AC composite

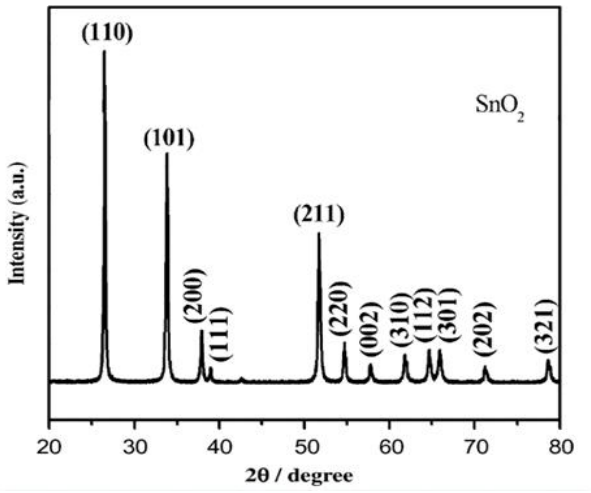

Fig. 2. XRD pattern of SnO_2–AC nanocomposite

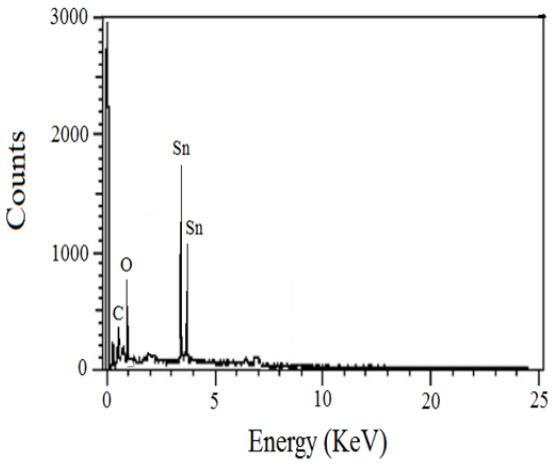

Fig. 3. EDX spectrum of SnO_2–AC nanocomposite

Electrochemical testing

Fig. 4 presents the CV curves of the carbon substrate and SnO_2–AC composite electrode scanned at a rate of 20 mV s^{-1}. Voltammetry test was conducted at potential window of -0.2 to 0.8 V in 1 M H_2SO_4 aqueous electrolyte solution. It can be obsreved that the shape of the CV curve of SnO_2–AC composite is pod-like with no redox peaks within the measured potential window. Ideally, for a three-electrode cell configuration, cyclic voltammetry (CV) test is adaquate to study the capacitive performance of any electrode material [20]. The working electrode's specific capacitance (C_S) was obtained from the CV curves by means of the following equation:

$$C_S = \frac{2 \times I \times t}{m \times \Delta V} \qquad (1)$$

where I (A), t (s), m (g) and ΔV (V) stand for discharge current, discharge time, mass of the active material, and potential window, respectively. The calculated specific capacitances of SnO_2–AC and AC are 92 and 281 F g^{-1}, respectively. These results show that there is over 200% performance improvement as a result of the electroless coating of the AC. These results are similar to those reported by other researchers [17], [21]. The observed improvement in the capacitive performance of the composite electrode could be attributed to a number of factors such as the synthesis technique, type and weight percent of the deposited metal oxide, nature and structure of the carbon substrate and the cell configuration.

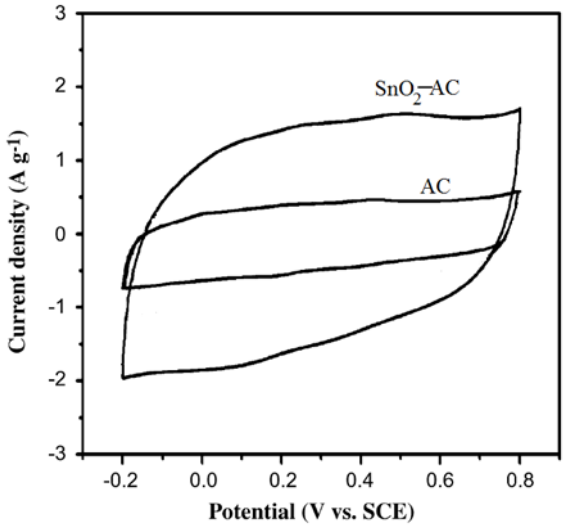

Fig. 4. CV for SnO_2–AC nanocomposite and AC scanned at mV s^{-1} in 1 M H_2SO_4

4.0 CONCLUSION

In summary, SnO_2-AC nanocomposite has been fabricated via electroless tin deposition strategy and its elemental composition, morphological structure and capacitive behavior were studied. The SnO_2-AC nanocomposite electrode displayed an improved capacitive performance in comparison to the activated carbon electrode. SnO_2-AC nanocomposite attains a capacitance value of 281 F g^{-1} at 20 mV s^{-1} in the potential window of -0.5 to 0.5 V compared to the activated carbon electrode of 92 F g^{-1} within the same potential window. The increament in the supercapacitance of SnO_2-AC nanocomposites compared to AC is due to the combined electric double layer capacitance contribution of the AC and the pseudocapacitance contribution of the SnO_2 phase. Additionally, the results demonstrate a high pseudocapacitive contribution from SnO_2, thus signifying that an evenly dispersed metal oxide is essential for an enhanced supercapacitive performance of the composite electrode.

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