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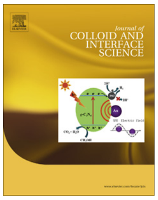

Regular Article

Enhanced photovoltaic performance of dye-sensitized solar cells based on nickel oxide supported on nitrogen-doped graphene nanocomposite as a photoanode

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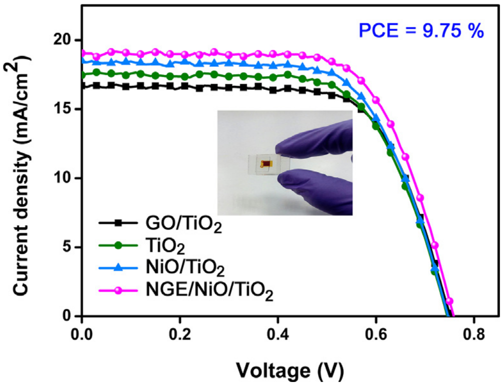
GRAPHICAL ABSTRACT



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ABSTRACT

We applied the nitrogen-doped graphene@nickel oxide (NGE/NiO) nanocomposite doped TiO_2 as a photo-anode for dye-sensitized solar cells (DSSCs) on fluorine-doped tin oxide (FTO) substrates by screen printing method. Power conversion efficiency (PCE) of 9.75% was achieved for this DSSCs device, which is greater than that of DSSCs devices using GO/TiO_2, and NiO/TiO_2 based photo-anodes (PCE = 8.55, and 9.11%). Also, the fill factor (FF) of the DSSCs devices using the NGE/NiO/TiO_2 nanocomposite photo-anode was better than that of other photo-anodes. The NGE/NiO/TiO_2 short-circuit photocurrent density (J_{sc}) of 19.04 mA cm^{-2}, open circuit voltage (V_{oc}) of 0.76 V, fill factor (FF) of 0.67 and dye absorption rate 0.21×10^{-6} mol cm^{-2}. The obtained results suggest that as-prepared NGE/NiO/TiO_2 nanocomposite is suitable photo-anode for DSSCs application.

1. Introduction

The dye-sensitized solar cells (DSSCs) or photovoltaic cell is utilized photons to covert the solar energy to electrical energy [1]. The excellent characteristics of DSSCs are their easy developed methods (low toxic, good performance in diverse light conditions, lightweight, and flexible), and low-cost. A DSSCs typically contain some

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major components like a sensitizer (i.e., dye (some organic dyes by monolayer adsorption, or inorganic dyes like N719, N3)), an electrolyte (Co^{2+}/Co^{3+} redox couples, and I_3^-/I^-) which is injected between counter electrode, and sensitizer, a counter electrode (Pt or carbon materials) deposited on another conductive substrate and finally semiconductor (SnO_2, ZnO and TiO_2) film play as a photo-anode that is coated on a conductive substrate [2,3]. Among these components, photo-anode is an one of the major components in DSSCs, the power conversion efficiency (PCE) is mainly depends on many other factors including the recombination of photo-generated charge carriers, and carrier mobility etc., By changing the physical characters of these materials, the PCE of the DSSCs can be improved. Many research has been proposed to improve the PCE of a photo-anode material, like as doping [4,5], surface modification, [6] and use of mixed semiconducting materials [7]. New composite systems are also being explored. We have chosen for DSSCs performance of a nitrogen doped graphene decorated with nickel oxide (NGE/NiO), as a photo-anode, by using different analytical tools.

Graphene (GE) has excellent research property owing to its extraordinary properties. These great features offer promise for many potential applications such as biosensors, energy storage, electronics, and catalysis due to its high specific surface area, and superior electrical conductivity. In most cases, GE is prepared from the reduction process of graphene oxide (GO), and during the oxidation-reduction process, the graphitic structure of GE is destroyed [8–10], which would decrease the electrochemical property of GE. Additionally, the introduction of nitrogen (N) into GE during the reduction process it may increase the electrical conductivity of GE [11–13], owing to the introduction of additional *n*-type carriers in carbon systems by *N*-doping. A large number of transition metal oxides such as CuO, NiO, Co_3O_4, and RuO_2 have been discovered as the photo-electrodes in DSSCs. Among these metal oxides, NiO has good electro-catalytic properties, low toxicity, and low cost are particular interest, which makes them suitable for photo-anode in DSSCs. In current years, lots of NiO-based non-enzymatic glucose sensors have been reported, in which the electrode surface treatment of NiO is the initiate to be vital for effective and fast glucose oxidation, and such as, nanostructured NiO resources with a high surface area are superior. Recent improvements in electrochemical sensor methods have also revealed that the electro-catalytic movement can be considerably improved by moving from bulk materials to nano-sized structures [14–18].

To improvement of the electron conductivity, we doped the nitrogen into graphene and decorated nickel oxide nanoparticles during this process the urea is employed to reduce the graphene oxide into N-doped graphene and here as a photo-anode, which may have an excellent electron conductivity due to the combination of N into GE. Additionally, each N atom has π electron, which is only responsible for enhancing the electron conductivity. In our current study, nitrogen doped graphene decorated with nickel oxide (NGE/NiO) nanocomposite prepared and characterized by various analytical and spectroscopy technique. In addition, the as-prepared nanocomposite useful as a photo-anode in the DSSCs, where the NGE were used as the track for electrical conduction, controlling the loading and enlarging space in the NiO. The nanocomposite to be a capable photo-anode for enhancing the PCE of DSSCs.

2. Experimental

2.1. Chemicals

Graphite flakes (~105 mm flakes), sodium nitrate ($NaNO_3$), sulphuric acid (H_2SO_4), potassium permanganate ($KMnO_4$), hydrogen peroxide (H_2O_2), hydrochloric acid (10% HCl), nickel oxide (NiO), urea, ethanol (C_2H_5OH) were obtained from Shanghai Chemical Reagent Co. α-Terpinol (>95%) were purchased from Kanto Chemical. All the solvents, chemicals and reagents used were of analytical grade. Double distilled water was used whole experiments.

2.2. Characterization

The crystalline structure of the NGE/NiO nanocomposite was characterized by X-ray diffraction (XRD) by XPERT-PRO (PANalytical B.V., The Netherlands) diffractometer (Cu Kα radiation, $\lambda = 1.54$ Å). Fourier-transform infrared (FT-IR) spectrum was recorded using a Bruker IFS28 spectrometer with a spectral resolution of 2 cm^{-1} using dry KBr pellet at ambient temperature. The Raman spectrum was documented at room temperature using a WITech CRM200 confocal microscopy Raman system with a 488 NM laser. Thermogravimetric analysis (TGA) measurements were performed using a Netzsch TG-209 series apparatus at a heating rate of 10 °C min^{-1} under a constant flow of nitrogen. The morphology and elemental mapping of the as-prepared composite was studied by scanning electron microscopy (SEM Hitachi S-3000 H) attached with energy-dispersive X-ray analyzer, respectively. The chemical compositions and orientations of the grains were studied by Transmission electron microscope (TEM) using a JEOL 2000 operating at 200 kV. Electrochemical performance was studied by using cyclic voltammetry (CHI 400) techniques. An EIM6ex Zahner (Kronach, Germany) was used for electrochemical impedance spectroscopy (EIS) studies.

2.3. DSSC measurements

The TiO_2 film thickness was accurately measured by α- surface profiler (EZ Step, Force). Photocurrent density-voltage (IV) curves of the DSSCs were recorded using a Keithley 2400 source meter with 300 W xenon lamp under global AM 1.5 G. IPCE spectra were studied by Oriel QE/IPCE measurement Kit (equipped with 150–300 W full spectrum solar simulators). The absorption, reflection, and transmittance of the DSSCs were studied by Jasco V-770 UV–Vis spectrophotometer.

2.4. Preparation of NGE/NiO nanocomposite

GO was prepared by the modified Hummers method [19]. 1.6 mmol of nickel oxide (NiO) were further into GO solution (90 mg of GO were dispersed in 60 mL of distilled water) and kept under energetic stirring for 30 min at ambient temperature. Consequently, 10 mmol of urea dissolved in 10 mL water was additional into the above solution drop by drop and placed on magnetic stirring for 30 min. The resulted mixture was detached into a Teflon-lined autoclave with a stainless-steel shell, sustained at 180 °C for 2 h. Subsequently, the precipitate was separated and washed with distilled water, and ethanol. Then, it was dried at 60 °C under vacuum overnight. The precursor obtained was further calcinated in flowing argon by heating at a rate of 10 °C min^{-1} from room temperature to 400 °C and maintained for 2 h to obtain the final nanocomposite [20].

2.5. Preparation of DSSCs

For the preparation of DSSCs, 0.5 g of TiO_2, 3 mL of ethanol, 1 g acetic acid, 10 cp ethyl cellulose, and 1.5 g α-terpineol undergo stirring for 5 days after that they kept in a hydrothermal process for 1 day to get a sticky paste. The obtained TiO_2 paste was screen printed on the cleaned fluorine-doped tin oxide (FTO, Solaronix, 8 Ω/sq) glass by screen printing technique for getting optimum thick $TiO_2 \sim 12–15$ μm. After each step of screen printing, the films were