Sensing and Bio-Sensing Research 13 (2017) 40–48

Contents lists available at ScienceDirect

Sensing and Bio-Sensing Research

journal homepage: www.elsevier.com/locate/sbsr

High performance supercapacitor and non-enzymatic hydrogen peroxide sensor based on tellurium nanoparticles

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ARTICLE INFO

Article history:
Received 21 September 2016
Received in revised form 23 January 2017
Accepted 2 February 2017

Keywords:
Tellurium nanoparticles
Supercapacitor
Biosensor
Hydrogen peroxide

ABSTRACT

Tellurium nanoparticles (Te Nps) were synthesized by wet chemical method and characterized by XRD, Raman, FESEM, TEM, XPS, UV–Vis and FL. The Nps were coated on graphite foil and Glassy carbon electrode to prepare the electrodes for supercapacitor and biosensor applications. The supercapacitor performance is evaluated in 2 M KOH electrolyte by both Cyclic Voltammetry (CV) and galvanostatic charge-discharge method. From charge-discharge method, Te Nps show a specific capacitance of 586 F/g at 2 mA/cm^2 and 100 F/g at 30 mA/cm^2 as well as an excellent cycle life (100% after 1000 cycles). In addition, the H_2O_2 sensor performance of Te Nps modified glassy carbon electrode is checked by CV and Chronoamperometry (CA) in phosphate buffer solution (PBS). In the linear range of 0.67 to 8.04 μM of hydrogen peroxide (H_2O_2), Te NPs show a high sensitivity of 0.83 mA mM^{-1} cm^{-2} with a correlation coefficient of 0.995. The detection limit is 0.3 μM with a response time less than 5 s.

1. Introduction

Recently, tellurium (Te) and Te based compounds have attracted great interest due to their outstanding physical and chemical properties. Elemental Te has been widely studied owing to its thermoelectric, nonlinear optical, gas sensing and electrochemical properties. Trigonal Te is a p-type semiconductor of bandgap 0.35 eV with a unique helical-chain conformation in its crystal structure. Thermoelectric properties of Te nanowires hybridized with carbon nanotubes show excellent mechanical stability and an electrical conductivity of 50 Sm^{-1} [1]. Nonlinear optical transmission of Te nanowires at 532 nm exhibits excited state absorption (β 3.8 × 10^{-11} m/W) [2]. NH_3 sensing of Te nanowires by hydrazine hydrate assisted hydrothermal route displays high sensitivity, excellent selectivity, short response (5 s) and recovery (720 s) times at room temperature [3]. Similarly, electrochemistry of Te has been investigated both in acidic and alkaline media. The electrochemical behavior of Te on stainless steel substrate in alkaline solution exhibits two cathodic and an anodic peak assigned to the four electron reduction process of Te (IV) to Te (0), Te (0) to (Te-II) and the oxidation of bulk Te [4]. In the cyclic voltammetric (CV) study in HNO_3 solution (pH 2.0 and 2.5), an oxidation potential of 0.48 V is found in the forward scan. Also, with normal hydrogen electrode (NHE), the reduction potential is −0.8 V [5]. The systematic study of current-voltage measurements leads to the fabrication of electrochemical capacitors, also referred to as supercapacitors. Due to its higher charge storage and charge delivery response in comparison with other energy storage devices, supercapacitors achieved importance in modern science and technology.

The electrochemical capacitors have a large specific capacitance associated with fast charge-discharge characteristics, capable of delivering high power and exhibit a longer life cycle compared to batteries. They are mainly used in mobile phone, computer, digital camera and solar cell. In general, supercapacitor electrode materials are divided into carbon based materials, metal oxides/hydroxides and conducting polymers. Among these, carbon based materials such as activated carbon and carbon nanotubes have been used as an electrode in electric double layer capacitor (EDLC). Transition metal oxides exhibit pseudo capacitance behavior and RuO_2 has the most promising performance (953 F/g) [6]. However, the high cost, rareness and toxicity of RuO_2 have limited its commercial attractiveness. Metal tellurides also find applications in energy conversion and thermoelectric materials. Liu et al. [7] have synthesized Te/C nanocomposite in lithium–tellurium batteries with 87% storage capacity. Te/Au/MnO_2 core shell on carbon fiber as super capacitor electrode is reported with maximum specific capacitance of 930 F/g with an excellent rate capability and long cycle life

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http://dx.doi.org/10.1016/j.sbsr.2017.02.001

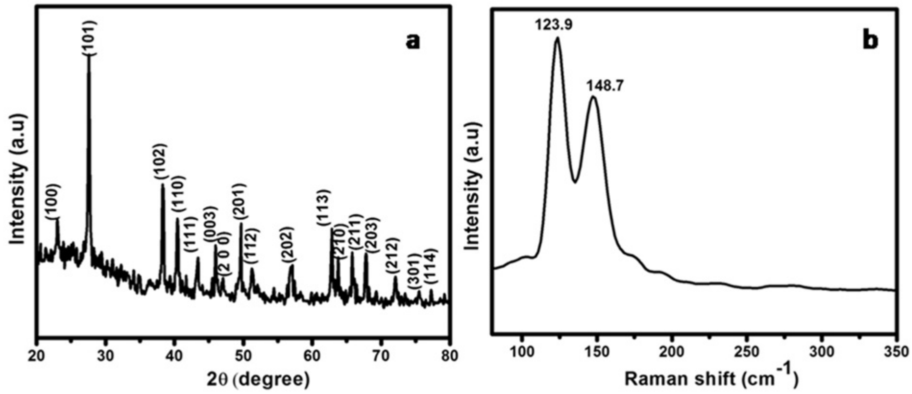

Fig. 1. (a) Powder XRD pattern of Te Nps, (b) micro-Raman spectrum of Te Nps.

(97%) [8]. Electrochemical synthesis of tellurium nanowires with a specific capacitance of 25 F/g with 46% of retention has been investigated by Tsai et al. [9].

Hydrogen peroxide (H_2O_2) finds various industrial applications such as pharmaceutical, clinical and environmental. It is a byproduct of almost all oxidases in mitochondria and separates out freely through membranes and reaches various cellular compartments. It takes part in biological functions as it is a highly reactive ion and reacts with other molecules to achieve stability. The deficiency of H_2O_2 leads to the diseases like Alzheimer's and Atherosclerosis diseases [10,11]. Many analytical tools such as spectrophotometric, fluorometric, chemiluminescent electrochemical and volumetric have been employed for the detection of H_2O_2. It is reported that the electrochemical method owing to a low cost, highly selective, sensitive with limit of detection, wide linear range, fast response and repetitive ability plays a crucial role in the amperometric determination [12,13]. In the last decade, the response to H_2O_2 by electrochemical biosensor modified with several metal nanomaterials has been studied [14]. Detection of H_2O_2 has been reported for Pt-TeO_2 nanowires and Pt-Te microtubes with a sensitivity of 130.6 μA mM^{-1} cm^{-2} and 2 mA mM^{-1} cm^{-2} [15,16]. Pt-Te microtubes have also been tested against glucose and the proposed electrode shows very strong and sensitive amperometric response [17]. An electrochemical detection system based on tellurium nanowire coated glassy carbon electrodes (GCE) has been proposed by Tsai et al. to sense dopamine at nanomolar concentrations [18]. Pt nanowires core with carbon shell using Te nanowires as template has prepared by Fang et al. shows a high sensitive, wide linear range and low detection limit [10].

Tellurium nanostructures have been synthesized by different methods like hydrothermal [19], microwave assisted [20], chemical vapor deposition [8] and biomolecule assisted method [21]. Additionally, Te can react with other transition elements to generate many functional compounds such as CdTe, ZnTe, Sb_2Te_3, and PbTe. Single crystalline ZnTe nanorods have been fabricated by Hou et al. with a high blue fluorescence [22]. The effect of size and doping concentration on the power factor of n-PbTe nanocrystal for thermoelectric energy

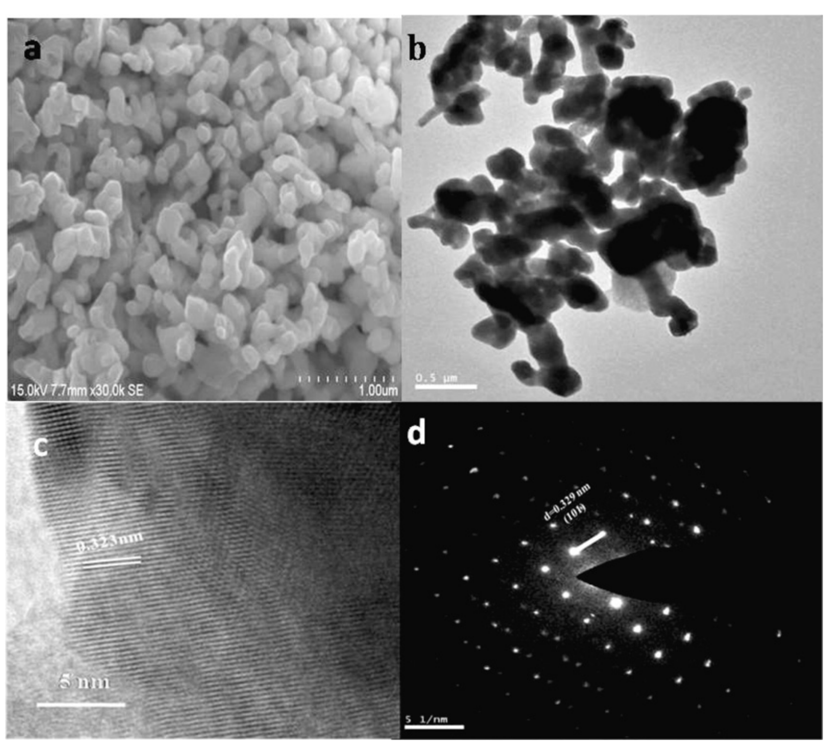

Fig. 2. (a) FESEM (b) TEM (c) lattice-resolved TEM (d) SAED pattern of TEM image (e) EDX spectrum for Te Nps.