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Synthesis and characterization studies of NiO nanorods for enhancing solar cell efficiency using photon upconversion materials

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ABSTRACT

We report the effect of calcination on the structural and optical properties of nanocrystalline NiO nanoparticles were successfully synthesized by virtue of a single source precursor method at mild reaction conditions between nickel nitrate and sodium hydroxide. Composition, structure and morphology of the products were analyzed and characterized by X-ray powder diffraction (XRD). The ultra-violet visible (UV–vis) absorption peaks of NiO exhibited a large blue shift and the luminescent spectra had a strong and broad emission band centered at 328 nm. The intense band gap was also observed, with some spectral tuning, to give a range of absorption energies from 2.60 to 3.41 eV. The various functional groups present in the NiO nanorods were identified by FTIR analysis. High resolution transmission electron microscopy (HRTEM) and the chemical composition of the samples the valence states of elements were determined by X-ray photoelectron spectroscopy (XPS) in detail. The electrochemical response of NiO proved that the nano-nickel has a high level of functionality due to its small size and higher electrochemical activity without any modifications. The above studies demonstrate the potential for the utilization of NiO nanoparticles as a promising material for opto-electronics applications.

1. Introduction

Nanomaterials exhibit significantly enhanced mechanical, electronic, magnetic, thermal, catalytic, and optical properties in comparison with their bulk counterparts, and have attracted significant interests [1–12]. NiO nanoparticles have the prospective for use in applications such as in the fabricate of magnetic materials, gas sensors, p-type transparent conducting films, catalyst, electrochromic, films, alkaline batteries cathode, and solid oxide fuel cells anode [13–17]. Typically, preparation of nickel involves the solution phase chemistry route, which in theory should present multiple, easy ways to manage the morphology, particle size and attractive crystalline phase [18–20]. Nickel oxide nanoparticles have been synthesized through the reduction of metal salts using reducing agents such as NaOH. These processes can produce sphere-shaped, stable nanoparticles without agglomeration; the synthesized particle surfaces are frequently found to be forceful and exhibit spiky surface morphology [21–24]. Therefore, it is very important to enlarge methods for the mixture of nickel oxide nanoparticles in which the particle size and the crystal structure of the yield can be illicit at room temperature (RT). The main center of attention of significance in the field of nanocomposites is the creation of materials that have a soaring yield, are low cost and have high conflict to scratch [25]. Nanostructured

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approaches have recently been confirmed to be highly effective in greatly improving the electrochemical performance of electrode materials. For illustration, nanostructured materials can enlarge the surface, as well as crossing point storage, owing to the sky-scraping contact between electrode material and electrolyte provision periodically [26–28]. Furthermore, nanostructured materials can defense the stresses caused by the amount difference taking place during the charge/discharge method, alleviating the crisis of aptitude lighten and the reduced rate potential connected with the material infringement absent into the electrolyte. However, nanostructured materials, particularly single-phased nanostructured materials, are not a critical clarification to assemble the necessities of the potential. One of the principal reasons is the inherent substance properties of the bulk phase, such as low conductivities and small energy densities at towering charge/discharge rates [29,30]. At present, profitable batteries are frequently based on nanometer-size electrode materials, which are inadequate by their kinetics, lithium-ion intercalation capacities, and structural firmness. Moreover, lacking a number of facade protections, nanostructured materials may expand the protection issues due to a soaring surface reactivity and may exaggerate capacity weaken due to aggregation. A synergistic consequence exists as a product of the interplay connecting the particle shape, properties, and achievable relationship of the entity components, which can be synchronized to investigate the occupied potential of the materials in requisites of the performance (e.g. high energy density, high power density, longer cycle life, and improved safety). For instance, they have been reported to reveal a very high reversible capacity, outstanding cycling, and security characteristics, which are ascribed to the synergic possessions of the nanorods mechanism [31]. One such novel nanomaterial constructed from SnO_2 nanoparticles and poly (ethylene glycol) chains has been reported. The synergic properties and functionalities of together materials facilitate this composite material to reveal unexpectedly towering lithium storage greater than the theoretical capacity of SnO_2 [32,33]. Graphene bedecked with ZnO and Co_3O_4 nanoparticles have been synthesized and utilized as anode materials, exhibiting a great reversible capacity, brilliant cyclic performance, high columbic efficiency, and superior rate capability owing to a physically powerful synergic effect between Co_3O_4 nanoparticles and graphene nanosheet [34–39]. Therefore, developing heterogeneous nanostructured electrode materials is measured to be the most promise avenue towards future electrode performance with high energy density, high power density, longer cycle life, and enhanced safety. However, it is first required to make out how heterogeneous nanostructured materials collision the concert of the synergic affects these materials exhibit [40]. In this report, we focus on the recent trends and developments of heterogeneous nanostructured electrode materials for uses in optoelectronic devices. We provide a summary of the synthesis, synergic apparatus of heterogeneous nanostructured components, and an investigation of promising candidates based on heterogeneous nanostructured materials for energy applications.

2. Experimental procedure

2.1. Synthesis procedure of NiO nanorods

In the present work nanoparticles of NiO nanorods are synthesized by a sol–gel method. This process involves the formation of a colloidal suspension (sol) and gelation of the sol to form a network in a continuous liquid phase (gel). The starting materials are processed to form a sol in water or dilute acid. Removal of the liquid from the sol yields the gel. Nanoparticles of NiO are prepared by thermal decomposition of freshly prepared $Ni(OH)_2$ as described elsewhere. The $Ni(OH)_2$ is prepared by reacting aqueous solutions of 0.1 M% nickel nitrate and 0.5 M% sodium hydroxide. For this NaOH solution is added drop wise with constant stirring until the pH of the system reaches. The chemical reaction between nickel nitrate and sodium hydroxide solutions is as follows:

$$Ni(NO_3)_2 + 2NaOH \rightarrow Ni(OH)_2 + 2NaNO_3$$

The resulting green gel is washed several times with distilled water. Finally the gel is dried by heating at 100 °C for 10 h. Nickel hydroxide decomposes into nickel oxide on heating as follows:

$$Ni(OH)_2 \rightarrow NiO + H_2O$$

In this work the nanocrystalline NiO sample is prepared by heating the nickel hydroxide in air for 3 h at 450 °C.

2.2. Characterization studies

Structural characterization was carried with an X-ray diffraction pattern (XRD) were recorded on a RigaKu D/max-RB diffractometer with Ni-filtered graphite monochromatized with CuK_α ($\lambda = 1.5418$ Å) with the range of the diffraction angle 2θ values are recorded between the ranges 20–80°. Optical absorption was measured by means of Varien Cary 5E spectrophotometer with an excitation wavelength ranges from 350 to 700 nm. The functional groups in NiO nanorods were graphed by Fourier transform infrared spectroscopy (FTIR) the spectra were recorded with a (Brukker IFS – 66 V) spectrometer. The thermo gravimetric analysis (TGA) and differential thermal analysis (DTA) were carried out using NETZSCH STA-409 thermal analyzer at a heating rate of 200 °C/min in the nitrogen atmosphere to determine the thermal stability of the compound between room temperature and 375 °C. All AFM images were acquired under tapping mode on a Digital Instrument Nanoscope IIIA at ambient conditions. A sharp TESP tip (Veeco) with a radius of end of 8 nm was used. Typical values for the force constant and resonance frequency were 42 N/m and 320 kHz, respectively. The morphology and microstructure were examined using field emission scanning electron microscopy (FESEM) performed on a (Philips CM12) with an acceleration voltage of 20 kV. The energy dispersive spectroscopy (EDS) (IH-300X) analysis was performed at several points in the FESEM arrangement. High-resolution transmission electron microscopy (HRTEM) measurements were made on a HITACHI H-8100 electron microscopy (Hitachi, Tokyo, Japan) with an accelerating voltage of 200 kV. The sample for HRTEM characterization was prepared by placing a drop of colloidal solution on carbon-coated copper grid and dried at room temperature. The elemental composition was determined using the selected area electron diffraction (SAED) (IH-300X) analysis was performed at several points in the HRTEM system respectively. Current-voltage characteristics studies of the synthesized nanomaterials were measured using the instrument Keithley 2640 source meter. The samples were pelletized and pellets of uniform dimensions were placed between the two copper electrodes and silver paint was coated on the surface of the samples in order to make firm electrical contact. The XPS spectrum was recorded on a ESCALAB 250 photoelectron spectrometer (Thermo-VG Scientific, USA) with AlKα (1486.6 eV) as the X-ray source.

3. Results and discussion

3.1. XRD analysis and Williamson–Hall plot

Structural characterization of the prepared sample is done using a X-ray diffractometer and CuK_α radiation ($\lambda = 1.5418$ Å) at room temperature. Intensity of the diffracted X-ray beam is

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