Results in Physics 14 (2019) 102390

Contents lists available at ScienceDirect

Results in Physics

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

Experimental studies of TiO_2 nanoparticles synthesized by sol-gel and solvothermal routes for DSSCs application

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ARTICLE INFO

Keywords:
TiO_2 nanoparticles
Sol-gel method
Solvothermal method
Dye-sensitized solar cells
Cell efficiency

ABSTRACT

This paper presents the synthesis and characterization of TiO_2 nanoparticles prepared by the sol–gel (SG) and solvothermal (ST) methods. The crystallinity and phase identification examined by the X-ray diffraction (XRD) evidenced the pure-anatase TiO_2 nanocrystals without any impurities. The scanning electron microscopy (SEM) analysis showed the preparation of spherical-shape TiO_2 nanoparticles while energy-dispersive X-ray spectroscopy (EDS) study endorsed the elemental compositions of Ti and O. Transmission electron microscopy (TEM) investigation evidenced the mesoporous microspheres of TiO_2 nanoparticles with their average size 119 nm. By UV–vis spectroscopy study, the optical band gaps were estimated to be 2.9 and 3.2 eV corresponding to the samples SG and ST. Furthermore, both SG and ST samples were employed as the photoanode materials for the dye-sensitized solar cells (DSSCs) however, ST based DSSC endorsed the enhanced photovoltaic performance.

Introduction

Titanium dioxide (TiO_2) is the most demanded photoanode material in dye-sensitized solar cells (DSSCs) including its potential applications in water treatment, pigments, self-cleaning surfaces, biosensors, chemical sensors, biodiesel production and so on [1–7]. The main attraction of TiO_2 is its non-toxicity, easy handling, and inexpensive production. In spite of several synthesis methods, the sol-gel and solvothermal processes are the easiest ways to synthesize TiO_2 nanoparticles with their tailor-ability to attain the required optical and physical properties. The solvothermal synthesis method is ideal for the preparation of nanomaterials and has the controllability to prepare the various forms of the nanostructures i.e. nanoparticles/nanorods/nanotubes etc. The process parameters to attain these kinds of nanostructures are the reaction temperature, reaction time, autoclave pressure and the solvent type. Further, the particles morphology and crystallinity can also be tailored with the chemical composition, solution pH and the aging time. This method produces the fine particles with their unique physical properties as compared to other chemical routes. An analogy to solvothermal synthesis, the sol-gel method is easy due to its low-temperature and pressure process. Depending upon the chemistry of the precursor and synthesis conditions, this method provides the flexibility to tune the compositional and microstructural properties of the nanoparticles. As the precipitates derived by the sol-gel process is amorphous in nature therefore, calcination at adequate temperature is required in order to attain the crystallinity of the sample. Furthermore, calcination at a higher temperature may promote the phase transformation due to agglomeration of the particles and the growth on the grain boundaries.

The anatase and rutile crystalline phases of TiO_2 are mainly demanded for the industrial applications as compared to other phases such as brookite and the TiO_2 (B) monoclinic. The energy band gap values of the anatase and rutile crystalline phases are 3.2 and 3.0 eV respectively. As the anatase-TiO_2 has its high electrons mobility therefore, it is employed as the photoanode material in dye-sensitized solar cells (DSSCs). The choice of the anatase-TiO_2 evidenced the reasonable enhancement in the cell efficiency [8]. Furthermore, the mixed phases of the anatase-rutile have also been employed in the DSSCs [9]. The rutile phase nanoparticles can be prepared by the thermal treatment at higher temperature beyond 400 °C [10]. Ahn et al. investigated the photovoltaic performance of the dye-sensitized solar cells by employing the photoanodes based on multiwalled carbon nanotubes embedded with TiO_2 nanowires prepared via electrospinning and the calcination process. The composition of 5 wt% of the multiwalled carbon nanotubes with TiO_2 nanowires was reported the enhanced cell efficiency due to the enhanced electron-transfer mechanism with the

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https://doi.org/10.1016/j.rinp.2019.102390
Received 20 April 2019; Received in revised form 26 May 2019; Accepted 26 May 2019
Available online 31 May 2019