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Bismuth oxide nanoplates-based efficient DSSCs: Influence of ZnO surface passivation layer

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ABSTRACT

For the first time, bismuth oxide (Bi_2O_3) nanoplates synthesized by single-step chemical method were envisaged as photoanodes in dye-sensitized solar cells. The structural elucidation demonstrated tetragonal structure with a predominant β-Bi_2O_3. The power conversion efficiency (1%) of Bi_2O_3 nanoplates-based dye-sensitized solar cells was enhanced up to 50% when decorated with zinc oxide thin layer (ZnO). The best performing electrode showed 24% incident photon-to-current conversion efficiency. This high DSSC performance of Bi_2O_3–ZnO photoanode is attributed to the increased electron transportation due to the suppression of recombination centers by ZnO passivation layer.

1. Introduction

Dye-sensitized solar cells (DSSCs) have attracted great scientific attention for sunlight to electricity conversion due to its low cost and high light-harvesting efficiency [1]. DSSCs are composed of a dye-modified semiconductor photoanode, a liquid iodide electrolyte as redox couples, and a counter electrode [2]. Among these, photoanodes of various structures and electronic properties have prime importance due to their different tendency toward dye loading as well as charge transfer characteristics. Along with TiO_2 (one of the highest preferred metal oxides so far), ZnO, Nb_2O_5, WO_3, SnO_2, etc., are also employed as photoanodes in DSSC [3–6]. Each metal oxide has several advantages and disadvantages. For example, ZnO exhibits poor stability in acidic condition. When ZnO was dipped in dye solution such as N3 and N719 (being acidic in nature), it dissolves slowly and aggregates on the surface of electrode. Such aggregation is reported to reduce the electron injection efficiency [7]. In case of SnO_2, its low V_{oc} due to a more positive conduction band position is critical to achieve high performance, though the charge carrier mobility of SnO_2 (240 $cm^2\,V^{-1}\,s^{-1}$) is 100 times more than that of TiO_2 [8]. Hence, the design and development of efficient and cost effective photoanode materials are necessary to improve the overall performance of DSSCs.

Many groups have focused their research on improving the efficiency of DSSCs and a maximum of 12.3% efficiency is reported [9]. However, this value is far below the theoretical efficiency of DSSCs which is 30% [10]. One of the factors that limit the efficiency of DSSC is attributed to the presence of trapping states at the interfaces within the photoanode. These surface states act as recombination centers where the photo-injected electrons recombine with redox electrolyte, thereby decreasing the photocurrent as well as cell efficiency. One of the effective ways to suppress the charge recombination is to coat the surface of photoanode with wide band gap materials such as ZnO, Al_2O_3, ZrO_2, MgO, and Nb_2O_5 [11–15]. Such a coating acts as a barrier between the injected electrons and electrolyte thus decreasing the rate of charge recombination.

In this study, we have explored bismuth oxide (Bi_2O_3) as a photoanode for DSSCs applications. This material has several advantages due to its unique electrical, optical and mechanical properties. It exists in four crystal phases i.e., monoclinic α-Bi_2O_3, tetragonal β-Bi_2O_3, cubic γ-Bi_2O_3, and cubic δ-Bi_2O_3. The α-phase is most stable at relatively low temperatures, while δ-phase is stable when the temperature is above 1000 K. The β and γ phases are high temperature metastable phases [16]. Bi_2O_3 also exhibits a high refractive index, dielectric permittivity, high oxygen ion conductivity, remarkable photoconductivity and photoluminescence [17–19]. Its band gap energy is commonly observed in the range of 2.5–3.1 eV; mostly depends on the crystal phase type [20]. The narrow band gap of Bi_2O_3 makes it suitable for a large range of applications including optical coatings, photovoltaics and microwave integrated circuits superconductor [21–23].

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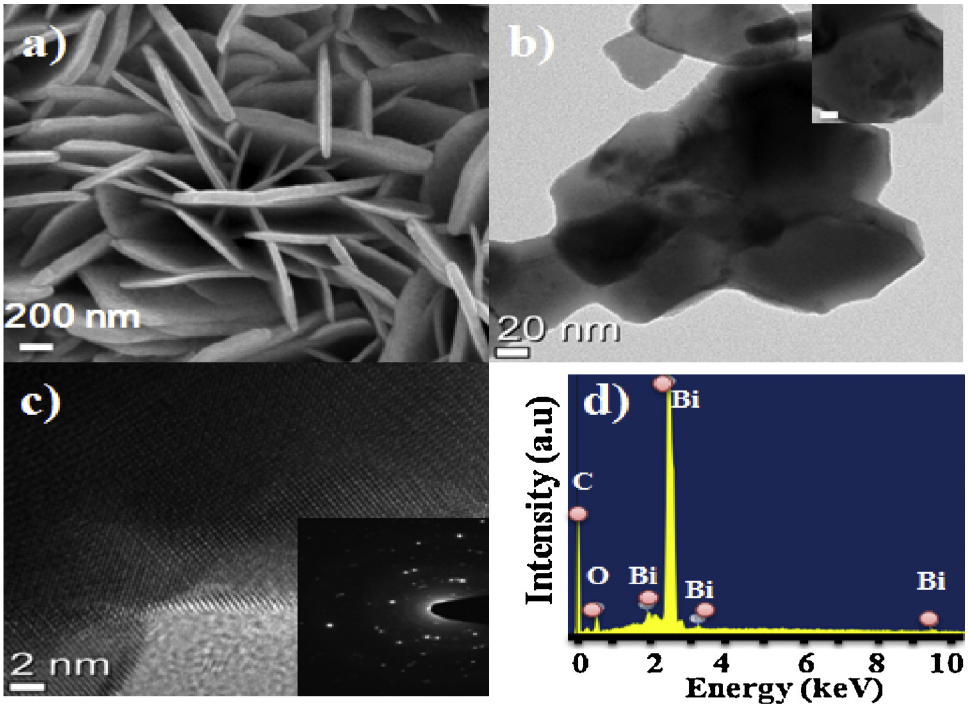

Fig. 1. (a) FE-SEM images, (b) HR-TEM image of the photoanode at low magnification (20 nm) and inset (10 nm), (c) high magnification image (inset SAED pattern), and (d) EDX spectra of Bi_2O_3 NPLs.

Furthermore, Bi_2O_3 can be grown in numerous forms such as nanoporous, nanoplates, nanoparticles, nanorods, nanotubes, nanolines, etc., depending upon the type of morphology required for a particular application [24–28].

To the best of our knowledge, there is no report in literature regarding Bi_2O_3 as photoanode material in DSSCs. We report for the first time the use of Bi_2O_3 nanoplates (NPLs) as a photoanode in DSSCs which was synthesized by a facile one-step chemical bath deposition method. We demonstrate that the Bi_2O_3 NPLs architecture photoanode supports for dye loading, efficient light harvesting and simultaneously affords a direct conduction pathway for photo-excited electrons. We also investigate the effect of ZnO surface passivation layer on performance of Bi_2O_3 NPLs-based DSSCs and the difference in results is corroborated with other electrochemical measurements.

2. Experimental details

Bismuth (III) nitrate pentahydrate (98%), tri-ethanolamine (98%) were purchased from Sigma Aldrich. Sodium hydroxide (97%) was purchased from Junsei. Zinc acetate di-hydrate was purchased from Kanto Chemicals Co. Inc. Ammonia solution (28–30%) was purchased from Samchun Chemicals. The sensitizer dye N719 was obtained from Solaronix SA (Switzerland). All reagents were of analytical grade and used without further purification. Fluorine-tin-oxide (FTO) glass substrates were ultrasonically cleaned sequentially in detergent-added distilled water, acetone and isopropyl alcohol. The Bi_2O_3 films were deposited from the solution containing 0.1 M bismuth (III) nitrate pentahydrate, *tri*-ethanolamine and sodium hydroxide [20]. Three clean FTO glass slides were vertically immersed in 100 ml beaker capacity maintained at 50–80 °C for 2 h. At higher deposition temperatures loosely bonded Bi_2O_3 film was grown on FTO substrate. The deposition of $Bi(OH)_3$ on the surface of FTO substrate occurred via heterogeneous reaction. The as-deposited films were annealed in air at 350 °C for 1 h at 5 °C per min heating rate to obtain Bi_2O_3. The thickness of film was about 2.8 μm.

Field-emission scanning electron microscopy (FE-SEM) images and energy-dispersive spectrometry (EDS) spectrums were

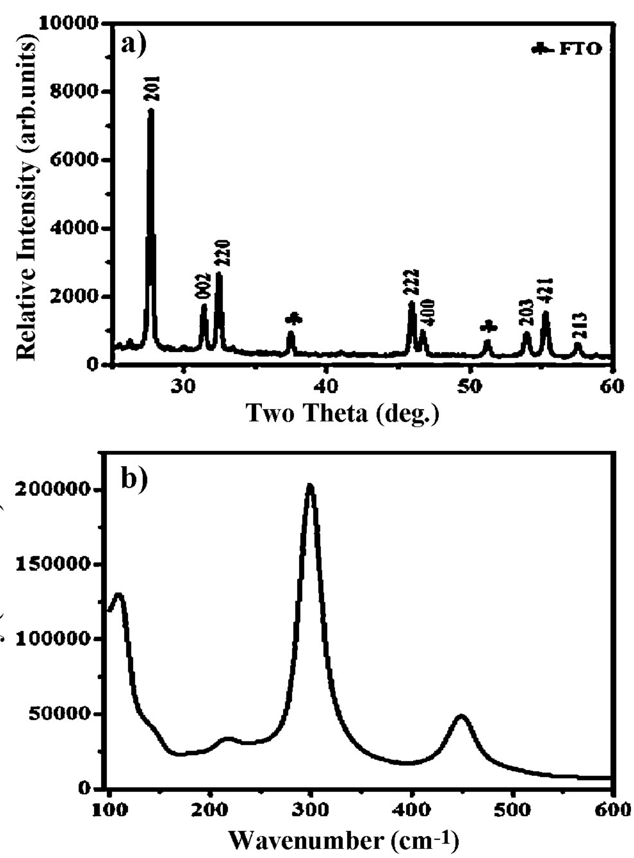

Fig. 2. (a) X-ray diffraction pattern and (b) Raman shift of Bi_2O_3 NPLs.