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Passivation layer–dependent catalysis of zinc oxide nanostructures

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ABSTRACT

Electrochemical and photoelectrochemical catalysis of surface-passivated zinc oxide (ZnO) nanostructures with three different metal oxides were investigated. Initially, vertically aligned ZnO nanorods structures were developed over conductive substrates by a two-step approach and then passivated with an ultrathin zinc hydroxide, that is, $Zn(OH)_2$, cobalt oxide, that is, CoO, and $Zn(OH)_2$/CoO as bilayer, by electrochemical deposition. Compared with the pristine ZnO structures, the surface-passivated nanostructures possess slightly rough surfaces, whereas their crystal structure remains unchanged. From electrochemical catalysis studies under dark and illumination, it is noticed that vertically aligned ZnO nanostructures passivated with narrow band-gap CoO layers have a predominant water oxidation performance than that of the structures passivated with other oxide materials. It is mainly attributed to the eradication of surface states present on ZnO nanorods. Interestingly, the structures passivated with bilayers, that is, $Zn(OH)_2$/CoO, showed significant stability and durability (~103% retention in current density@60th min) with a continuous oxygen evolution reaction process for long durations.

1. Introduction

In recent years, the development of electrode materials, that is, as anodes as well as cathodes, for sustainable and efficient water-splitting process and thereby the production of eco-fuels has received great attention because of the threatening signals of global warming and climate changes [1]. After the invention of photocatalysis in titanium oxide by Fujishima and Honda [2], various oxides and non-oxides metallic compounds came into the limelight due to their suitable physical and chemical properties along with rich surface morphologies [3]. In particular, various metal oxide materials, including Cu_2O, TaON, $BiVO_4$, WO_3, Fe_2O_3, etc. [4], have been evolved as a special class of materials because of their easy processability and scalability along with excellent chemical stability and favorable band alignment toward the redox potential of water [5,6]. Among these metal oxide semiconductor materials, zinc oxide (ZnO) has received great attention as a suitable, efficient, and cost-effective anode material for not only the water-splitting process by oxygen evolution reaction (OER) for O_2/H_2 production [7–10] but also two-electron water oxidation reaction process to generate H_2O_2 [11]. This is mainly due to the low-temperature synthesis, non-toxicity, and abundancy of ZnO along with finely aligned conduction and valance band positions around the redox potential of water. However, photodegradation of OER electrodes greatly hinders their usage in real-time applications. In this view, enhancement of the performance along with chemical sustainability of electrocatalytic electrodes has appeared to be one of the challenging issues.

To overcome the above bottlenecks, the researchers have been implemented various approaches, including the development of nanostructures, loading of co-catalysts, growth of core/shell heterostructures, surface passivation, etc [12,13]. As a result, enriched chemical active surface area, amplification of chemical kinetics, increase of light absorption cum protection from chemical corrosion, and reduction of surface states and thereby a decrease of recombination losses have been observed [4]. For instance, different types of ZnO nanostructures, including nanorods, nanowires, nanoparticles, nanoflakes, etc., have been developed and explored their electrocatalytic as well as photoelectrochemical

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Impact of shock waves on the physical and chemical properties of aligned zinc oxide structures grown over metal-sheets

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ABSTRACT

Zinc oxide (ZnO) nanorods were developed on stainless steel (SS) sheets as well as glass substrates in two steps by adopting well-established two different chemical methods namely, spray pyrolysis and chemical bath deposition techniques. Then, the structures were exposed to dynamically generated shock waves in a home-built shock tunnel. All the as-grown and shock waves exposed structures were characterized with advanced analytical techniques. Surface morphology and structural studies reveal that the as-grown nanostructured films over the both SS and glass substrates possess nanorods-like surface morphology; however, they exhibited (101) and (001) orientations as predominant orientations, respectively. From micro Raman analysis, it is noticed that the nanorod structures grown on both surfaces have good phase purity and crystalline quality. On the other hand, the cathodoluminescence studies show that these hydrothermally grown ZnO nanorods possess a large number of native defects. Finally, the ZnO nanorods exposed to shock waves generated with a temperature and pressure of ca. ~20,000 K and ~6 MPa for a short duration of 2–3 ms exhibited superb sustainability in terms of surface morphology as well as crystalline quality, which is mainly attributed to the slantly overlapped morphology as well as the high melting temperature of ZnO nanorods.

1. Introduction

Materials science is one of the crucial branches in space engineering technology where the materials have been synthesized, processed, and tested for different applications [1,2]. The reduction of weight and cost of the materials along with the enhancement of specific device functionalities are a few key issues that have received great focus today [3–5]. State-of-the-art in space engineering reports suggests that most of these bottleneck problems can be handled by developing new class materials [6]. Noticeably, the primary selection of materials is determined by their mechanical and physical properties along with chemical characteristics [7–9]. In this direction, the combination of various kinds of materials has been adapted for different space engineering applications including electrical and electronics, sensors, controllers, detectors, protection, and energy conversion and storage devices since it is impossible to achieve all these applications by using a single material [10]. Though there are plenty of high-temperature materials with melting temperatures higher than 2000 °C including carbides, refractory metals, oxides, nitrides, and borides, the ceramic materials have received considerable attention due to their multifunctional characteristics along with considerable sustainability even under extreme temperatures or harsh operating conditions [11]. At the same time, these compound materials possess significant mechanical strength along with suitable optical and electrical properties. As a result, different kinds of devices have been developed and tested for various space applications including leak detection, temperature monitoring, emissions monitoring, and fluctuations in the surrounding environment.

In recent years, the development of materials with nanoscale dimensions by adopting advanced processing methodologies allows scientists to realize efficient and eco-friendly devices not only for day-to-day applications but also for space engineering and medical applications [12]. As a result, various semiconductor

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