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Cadmium sulfide coated zinc oxide photoelectrode: Preparation and characterization

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ABSTRACT

Cadmium sulfide (CdS) coated zinc oxide photoanode is prepared using two step deposition processes at relatively low temperature. The zinc oxide (ZnO) were deposited on the conducting glass substrates using doctor blade technique followed by the coating of CdS over ZnO at room temperature using chemical bath deposition method. In the present article, we are using three different types of CdS (bulk and nano forms) prepared by using chemical route. The size of the CdS was controlled using different concentration of capping agent during preparation. The samples were characterized by optical absorption, X-ray diffraction, scanning electron microscopy techniques. Further, the photoelectrochemical (PEC) performance of ZnO with CdS was tested in polysulfide electrolyte. When the CdS nanoparticles were coated on the ZnO, the optical absorption is enhanced and band edge is shifted towards visible region (from 470 to 525 nm) as compared with zinc oxide (375 nm). The device with CdS nanoparticles (type-b) shows higher photoelectrochemical (PEC) performance showing maximum short circuit current density (J_{sc}) of 1.51 mA/cm^2 along with maximum electron life time (25.2 ms).

1. Introduction

Quantum dot sensitized solar cell (QDSSC) is one of the most promising low cost and highly efficient 3rd generation solar cells [1–3]. Various semiconductor metal chalcogenides such as PbS [4], Bi_2S_3 [5], CdSe [6], and CdS [7,8] have been typically explore now a day as sensitizers for solar cell applications. These semiconductors have been prepared by using a range of methods. CdS is having bulk band gap of ~2.4 eV and showing high conduction band edge to that of ZnO with absorption in visible part of solar spectrum makes it a appropriate candidate as a sensitizer in solar cell application [9,10]. In view of the above, we report the study on optical, structural and electrical properties of the chemically deposited ZnO sensitized with three different types of CdS nanoforms prepared by using simple chemical method at room temperature with change in concentration of capping agent.

In this article, we have synthesized ZnO photoelectrode by a simple doctor blade technique and coated them with CdS nanoparticles using chemical bath deposition (CBD) method. The deposition conditions have been optimized with their photoelectrochemical performance. The CBD method facilitates a room temperature and cost effective method and has the potential for large-scale production of QDs. This method is suitable for preparing high quality sensitizers at room temperature.

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2. Experimental and characterization

2.1. Experimental

All the chemicals used in the experiment were purchased from SRL chemicals. Fluorine doped tin oxide (FTO) coated glasses were used as substrates having resistance of~15 Ω/cm^2 (Sigma-Aldrich, India).

2.2. Preparation of ZnO paste

Here we have used commercial ZnO nanopowder with the average particle size of ~30 nm. Ethyl cellulose, Terpineol, Acetyl acetone is used to prepare the Zinc oxide paste. The preparation of ZnO slurry is describe in brief as; take 0.5 g of Zinc oxide powder in 7 ml ethanol, mix the same for 20–25 min with help of mortar and pestle. Grinding of suspension results in breaking of the microscopic aggregation of powder then sonicate the mixture for 1 h. After that take 0.3 g of ethyl cellulose in ethanol (7 ml) was grinded separately for 10 min and add the same in ZnO suspension followed by addition of 1.36 g of terpineol drop wise in above suspension and sonicate for 3 h. Finally, add 4–5 drops of acetyl acetone, ultrasonicate the suspension for another 1 h. The above suspension is kept in an incubator for removing extra amount of ethanol up to required viscosity.

2.3. Preparation of ZnO photoelectrodes

On FTO substrate; prepared paste of commercial ZnO is coated by using doctor blade technique. In brief, take a drop of ZnO paste on glass slide. Slide is moved over the FTO substrate leaving behind a layer of wet ZnO film. Scotch tape is used for controlling geometrical thickness of the film. Wet films of ZnO were dried in incubator for 2-3 h followed by air annealing at 450 °C for 1 h to removing the binder and any other organic impurity, annealing also provides good crystallographic arrangement of ZnO particles.

2.4. Preparation of CdS bath (Bulk and Nano)

The chemical bath for the synthesis of bulk CdS was prepared by cadmium sulfate dissolved in diluted ammonia then this mixture (M) was added into thiourea. Stoichiometry of cadmium sulphate and thiourea was kept as 1:1. Whereas the nano CdS were synthesized by adding the different molarities of capping agent [1-thioglycerol (1-TG) in an organic solvent NN-dimethyl formamide (NN-DMF)] in the mixture (M) prepared for bulk CdS and then added into thiourea at room temperature. The morality of the capping agent was increased and accordingly the samples were named as type-a CdS for bulk (without capping agent), type-b CdS nano (1 mM 1-TG with 1 M DMF) and type-c CdS nano (15 mM 1-TG with 1 M DMF).

2.5. Coating of CdS over ZnO

The bulk and nanoparticles CdS were coated on ZnO photoelectrodes using chemical bath containing 0.05 M cadmium sulfate, 0.05 M thiourea, and 80% diluted ammonium hydroxide at room temperature for 20 min without capping agent for bulk form and with capping agent of different concentration for nano form as listed above. The pH of the chemical bath used for the coating of CdS was maintained ~11 by adding the excess of aqueous ammonia (NH_4OH) into the growth. After deposition, the films were taken out from the bath and washed in distilled water.

2.6. Characterization

The structural characterization was carried out by using X-ray diffractometer (Bruker D8-Advanced) operated at 25 kV, 20 mA with Cu-K_α radiation ($\lambda = 1.54$ Å). The UV–Vis. absorbance spectra of the samples are recorded using a spectrophotometer (JASCO V-670). The surface morphology was studied using scanning electron microscopy (JOEL JSM 6360). The photoelectrochemical (PEC) performance is studied with semiconductor characterization system (Keithley 2420 source meter) using two electrode configuration under illumination in simulated sun light (80 mW/cm^2) supplied from solar simulator. The following cell configurations were used to record J-V characteristics: FTO/ZnO/CdS/Electrolyte/Counter electrode. The electrochemical impedance spectroscopy (EIS) measurements for fabricated device were carried out using potentiostat/galvanostat (IVIUM:Vertex) under dark.

The ZnO/CdS films (average area 1×1 cm^2) and Carbon coated FTO (average area 1 cm^2) were employed as the working and counter electrodes, respectively. The photoanode and counter electrode was separated by spacer of ~3 μm thickness. A non-aqueous polysulphide redox electrolyte was composed of 0.98 g of sodium sulfide flakes in 22.5 ml methanol and 0.08 g sulfur powder in 5 ml methanol solution was used. Measurements of the photovoltaic output characteristics (J-V) were made at fixed intervals after waiting a sufficient amount of time for the system to reach equilibrium (both in the dark and under illumination).