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Featured Letter

Photovoltaic performance of Pb-doped CdS quantum dots for solar cell application

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ABSTRACT

The successive ionic layer adsorption and reaction (SILAR) method was employed to deposit the un-doped CdS and Pb-doped CdS quantum dots (QDs) with different doping concentrations over the TiO_2 nanostructures. The systematic investigations of photoanode were carried out and the observed results reveal that the deposited sensitized layer has spherical morphology. Polycrystalline nature of the deposited film was observed, but the characteristic peaks for Pb or PbS are not observed. However, the presence of lead was confirmed through energy dispersive X-ray spectrum (EDX) and elemental mapping study. The superior optical absorption and photovoltaic performance were observed in the 2% Pb-doped CdS QDs sensitized cell. The corresponding cell parameter values such as η, J_{sc}, V_{oc} and FF were 1.19%, 3.76 mA/cm^2, 0.61 V and 51.5% respectively.

1. Introduction

The development of photovoltaic devices has a great opportunity for utilizing the solar energy [1]. In recent years, quantum dot sensitized solar cells (QDSSCs) are the promising materials for low-cost next-generation photovoltaic devices due to the tunable band gap, high absorption coefficient and multiple exciton generation (MEG) [2]. In QDSSCs, the mesoporous TiO_2 nanostructures were coated on fluorine doped tin oxide (FTO) conducting glass substrate and then the TiO_2 was sensitized with the quantum dot. The nanostructured TiO_2 is one of the best semiconductor electrode materials for solar cell application due to its high photostability, wide band gap (3.42 eV) and excellent photocatalytic performance [3]. Additionally, the porous nature of TiO_2 nanostructures allows the proper anchoring of QDs and penetration of electrolyte.

Several materials in the form of QDs have been used as sensitizers, because of their particular properties for photosensitization. Among them, cadmium sulfide (CdS) is an excellent sensitizer for QDSSCs application. The research groups are working to improve the photovoltaic performance of CdS QDs through the addition of host atom. The added host atom in the CdS QDs plays an important role to increase the lifetime of charge carriers by creating the mid-gap region between the TiO_2 and CdS QDs. By controlling the doping concentration, it is possible to alter the electronic and optical properties of the CdS QDs. The reported dopants are Mn [4], Cu [5], Co [6], Ag [7], La [8] and Hg [9]. In the present work, the effect of Pb doping in CdS QDs is studied to understand the effect of higher ionic radius element substitution in the CdS lattice. The Pb^{2+} ionic radius is 1.20 Å which is slightly higher than that of Cd^{2+} (0.97 Å) [10]. Also, lead is one of the post-transition metal used for quantum dot solar cell application and it can control the light absorption in the 600–3000 nm range [11].

2. Experimental procedure

To prepare the titanium oxide (TiO_2) paste, a small amount of ethanol added in the TiO_2 powder (Degussa-P25, Solaronix SA) and grained in a mortar. Then the ethylcellulose and α-terpineol were mixed followed by one hour grinding. Then the prepared paste was spin coated on the FTO substrate using the Spektronspin-spin coating instrument. The coated films were allowed to dry in air for 10 min and then kept at 325C, 425C and 500 ℃ for 5 min, 15 min and 20 min respectively.

The SILAR method was used for the deposition of un-doped CdS and Pb-doped CdS QDs on the TiO_2 coated FTO substrate. The aqueous 0.1 M of cadmium nitrate ($Cd(NO_3)_2{\cdot}4H_2O$) solution was used as a cationic solution. To deposit the Pb doped CdS QDs the lead nitrate ($Pb(NO_3)_2$) was added to the cationic solution. The Pb concentration was varied from 0.001 M to 0.004 M in steps of 0.001 M. The aqueous anionic solution consists of 0.1 M of sodium sulfide

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flakes nonahydrate (Na_2S). The deposition cycle was kept as 15 cycles. Dipping time was fixed as 2 min, 2 min and 1 min in the cationic, anionic and rinsing solution respectively.

3. Characterization and photovoltaic measurements

The crystalline phase and structure were confirmed by using X'pert Pro XRD instrument. The Cu kα_1 was used as an X-ray source during the analysis and the wavelength is λ = 1.5406 Å. The surface morphology, elemental analysis, and elemental mapping were investigated by using an FE-SEM SUPRA 55-CARL Zeiss. The UV-Visible (UV-Vis) absorbance spectroscopy was obtained from a UV-2550 spectrophotometer.

The current-voltage (J-V) characteristics were recorded using a Keithley 2400 solar simulator (AM 1.5G, 100 mW/cm^2). The platinum (Pt) was used as counter electrode (CE) and the photoanode consists of FTO/TiO_2/QDs in a sandwich configuration. Before performing the photovoltaic measurements, Iodide/Triiodide (I^-/I_3^-) electrolyte was injected into the assembled solar cell. The active area of the solar cell device was defined as 0.5 cm $\times$ 0.5 cm.

4. Results and discussions

4.1. Morphological and elemental analysis

Fig. 1(a), (b) and (c) shows the surface morphology of TiO_2, TiO_2/CdS and TiO_2/2% Pb-doped CdS thin films respectively. Spherical shape TiO_2 nanoparticles can be clearly seen from the Fig. 1(a). There are clusters like small particles. Fig. 1(b) and (c) shows the un-doped CdS and 2% Pb-doped CdS thin film over the TiO_2 coated FTO substrate. The uniformly distributed spherical shaped particles morphology was observed. While comparing the un-doped and 2% Pb-doped CdS thin films, the change in the morphology was not observed. It reveals that the effect of dopant does not change the morphology under the selective preparation condition. The TiO_2/2% Pb-doped CdS sample was studied through high-resolution transmission electron microscopy (HR-TEM) and the results are given in Supplementary Material-1. The observed nanoparticle's sizes were 20 nm and 10 nm for TiO_2 and 2% Pb-doped CdS QDs respectively.

Fig. 2(a), (b) and (c) shows the EDX spectrum of bare TiO_2, TiO_2/un-doped CdS and TiO_2/2% Pb-doped CdS QDs. The detected elements through the analysis were Ti and O elements in TiO_2 nanostructures, Ti, O, Cd and S elements in TiO_2/un-doped CdS QDs sample and Pb, Ti, O, Cd and S elements in TiO_2/Pb-doped CdS sample. The corresponding weight and atomic percentage are given in the table (inset of Fig. 2(a), (b) and (c)). The distribution of elements in the TiO_2/2% Pb-doped CdS QDs sample was studied through elemental mapping and the results are given in the Supplementary Material-2.

4.2. Structural analysis

Powder X-ray diffraction (PXRD) pattern of photoanodes are shown in Fig. 3. The obtained peaks are well matched with the ICDD card no.: 77-0448, 21-1272 and 10-0454 which correspond to bulk tetragonal structured SnO_2, body-centered tetragonal

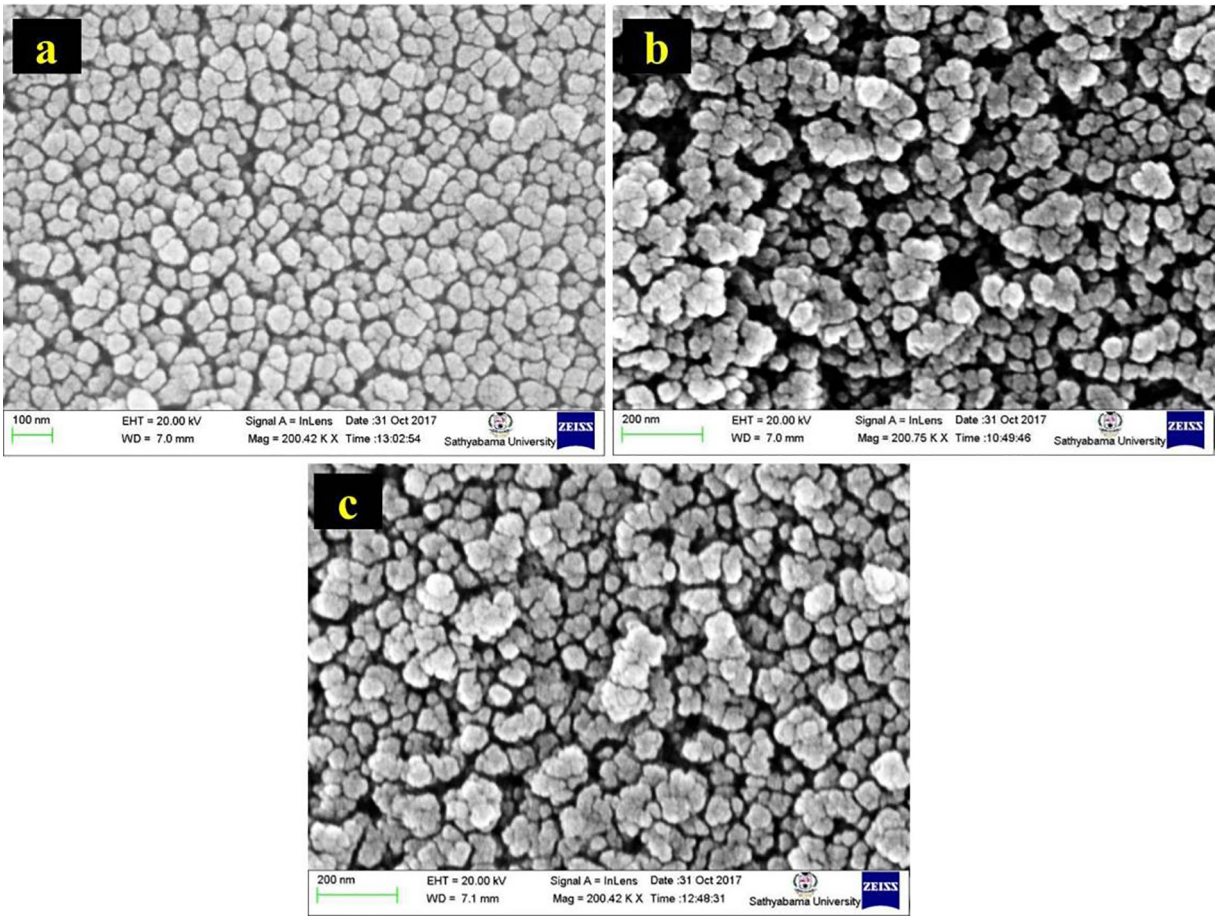

Fig. 1. FE-SEM images of (a) TiO_2, (b) TiO_2/un-doped CdS (c) TiO_2/2% Pb-doped CdS QDs.