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OVERVIEW ON WORKING PRINCIPLE OF TIO2CDTE SEMICONDUCTOR SENSITIZED SOLAR CELLS

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Abstract:

In this paper we describe the preparation of TiO2/CdTe semiconductor sensitized solar cells (SSSCs). TiO2 nanoparticles were deposited on FTO glass substrates with array-like nanostructure. Further the CdTe sensitizer nanoparticles electrodeposited on TiO2 nanorod using three electrode electrodeposition technique. The crystal structure of TiO2 was found to be tetragonal with rutile phase where as the crystal structure of CdTe nanoparticles was zinc blend cubic structure. The morphological characterizations demonstrate nanoarrays of TiO2 covered with nanoparticles of CdTe. The working principle of this heterostructure was elaborated systematically. This configuration is expected to show higher efficiency and more durability compare to Dye Sensitized Solar Cells (DSSCs).

Keywords:

Semiconductor Sensitized Solar Cells, TiO2 nanorods, CdTe nanoparticles, XRD, SEM

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Introduction:

Since the introduction of low-cost photovoltaic dye-sensitized solar cells (DSSCs) by Gratzel and O'Regan in 1991 (O'Regan, B. and Gratzel, M. 1991), considerable research has been done by various groups to increase the efficiency of these solar cells. Semiconductor Sensitized Solar Cells (SSSCs) are new emerging solar energy devices known for their distinct qualities such as the ability to harvest sunlight that generates multiple electron–hole pairs, simplicity in fabrication, and cost effectiveness. Although the power conversion efficiency of many of SSSCs is lower than those of DSSCs, but they have better absorption and more stability and durability compare to dye molecules. Therefore modification of sensitizers are necessary to be developed to further increase the efficiency of SSSCs. Semiconductor nanoparticles are the most applicable material for photosensitization because of their high absorption and the obtained emission spectra that can be manipulated by varying particle sizes. This paper presents a comparison between SSSCs and DSSCs and provides suggestions to improve efficiency of SSSCs. Particular focus is directed on the behavior of CdTe nanoparticles as the sensitizers which is electrodeposited on the surface of wide band gap nanoarrays of TiO2. These materials are developed and modified to enhance the electron transfer efficiency of SSSCs. Understanding the working principle of this novel solar cell device can provide design guidelines for future successful applications.

A typical SSC consists of four major components: photoanode, semiconductor sensitizer, hole transporting material or electrolyte with redox couples and counter electrode. The photoanode in SSC is typically constructed with a wide bandgap metal oxide semiconductor such as TiO2, SnO2, or ZnO scaffold coated with a layer of semiconductor sensitizer in thin film or quantum dot formats. The metal oxide scaffolds also act as electron acceptor and transporter. Upon photo irradiation, electron-hole pairs (excitons) are generated in the sensitizer. The excited electrons are then injected into the conduction band of metal oxide, leaving the sensitizer in its oxidized state. The Injected electrons in metal oxide are collected by the transparent conducting oxide (TCO) substrate and transported through the external load to the counter electrode. The oxidized nanoparticle sensitizers are restored to their ground state through hole scavenging by reduced species (e.g. S^(2-)) in the redox couples of S^(2-)/(S_n^(2-)) in the electrolyte. The oxidized species (S_n^(2-)) diffuse to the counter electrode where they are reduced by electrons from the external circuit, resulting in electrolyte regeneration (Xu, J. and Chen, Z. 2014). However figure 1 schematically represents the charge transfer processes occur in the present study.

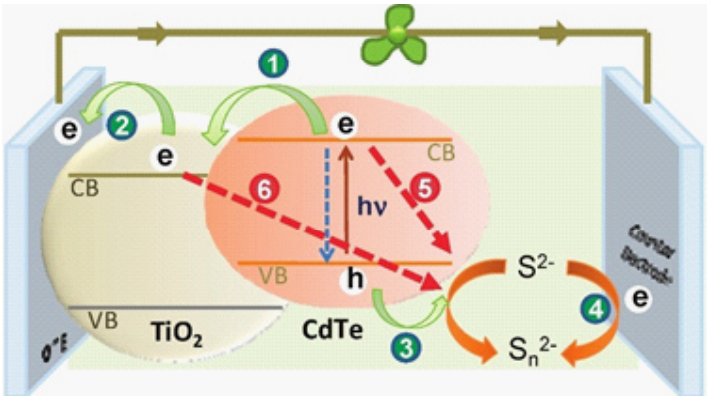

Figure 1: *Schematic diagram of the working mechanism of SSSCs [3].*

These include (1) electron injection from CdTe semiconductor sensitizer into TiO2 metal oxide nanoparticle, (2) electron transport to the FTO collecting electrode surface, (3) hole transfer to the redox couple, and (4) regeneration of the redox couple at the counter electrode. A major force that counteracts these favorable processes 1-4 is the charge recombination of electrons at the electrolyte interface which are shown by arrays 5 and 6 in Figure 1. (P. V. Kamat 2012). These include (1) electron injection from CdTe semiconductor sensitizer into TiO2 metal oxide nanoparticle, (2) electron transport to the FTO collecting electrode surface, (3) hole transfer to the redox couple, and (4) regeneration of the redox couple at the counter electrode. A major force that counteracts these favorable processes 1-4 is the charge recombination of electrons at the electrolyte interface which are shown by arrays 5 and 6 in Figure 1. (P. V. Kamat 2012).

Material and Methods:

To construct the mesoporous TiO2 nanostructure, briefly 5 ml of TiCl3 (aqueous, 15%) was added to 20 ml of double distilled water. The pH of the solution was increased from 0.5 to 1.5±0.1 by drop wise addition of dilute NH4OH with constant stirring. A precipitate rapidly formed without film formation at pH>2.5. By contrast, at pH<1.0, no precipitate or film formed. The solution was light violet in color and this changed to blackish violet with increasing pH. After 30 min of vigorous stirring at room temperature, a dark violet clear solution was obtained. FTO glass substrates were washed with acetone in an ultrasonic bath for 15 min and were then immersed vertically in the chemical bath. After 35 hours, the FTO glass substrates were removed from the solution, rinsed with double-distilled water to remove any residue and dried at room temperature without any further treatment.

To fabricate the photoanodes of SSSC device, TiO2 electrodes were sensitized by CdTe sensitizer's nanoparticles using electrochemical route. The electrodeposition of CdTe was performed in a three-electrode electrochemical cell with TiO2 thin film as the working electrodes, a graphite plate as the counter electrode and a saturated Ag/AgCl electrode as the reference electrode. The prepared electrochemical bath contains 0.7 M Tartaric acid, 10 mM CdSO4 and 6 mM Na2TeO3 with the solution pH of 2. The electrochemical synthesis was carried out at ambient condition for the applied potential of -0.45V and deposition time of 20 minutes. After synthesis, samples were rinsed extensively with double distilled water in order to remove the excess reactants from the substrate. These prepared samples were further used for structural and morphological characterization.

Low angle x-ray diffraction patterns were obtained by X-ray diffractometer (Bruker D8 Advance, Germany) using CuKα line (λ = 1.54 Å) at a grazing angle of 10. The field emission scanning electron microscopy (FE-SEM) images were recorded using a Hitachi, S-4800, Japan microscope with operating voltage 5 kV to study the surface morphology of the films.

Results and Discussion:

To know about structural, morphological and compositional characteristics of the synthesis material X-Ray Diffraction analysis, Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray spectroscopy (EDX) have been carried out.

X-Ray Diffraction (XRD) Analysis:

Figure 2 shows the XRD patterns of the FTO/TiO2/CdTe nanocomposite. FTO glass substrate is rutile structure (JCPDS no. 41-1445), and are marked by stars.

Regardless the peaks of SnO2, the diffraction peaks located at 2θ~ 27.4°, 36.2°, 41.2°, 44.05°, 54.3° and 56.6° are corresponding to (110), (101), (111), (210), (211) and (220) diffraction plane of tetragonal rutile-TiO2 (JCPDS Data Card No. 21-1276).

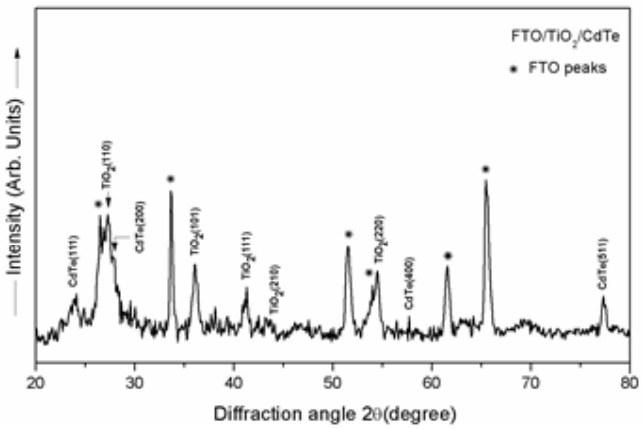

Figure 2: *XRD pattern of FTO/TiO2/CdTe nanocomposite (peaks of FTO glass substrate are marked by stars)*

FTO/TiO2/CdTe was formed by the controllable deposition of CdTe onto the surfaces of TiO2 nanoarrays. The optimized conditions are that the applied potential is -0.45 V and the time interval for the electrodeposition of CdTe nanoparticles on TiO2 nanoarrays is 20 minutes. The additional peaks located at 2θ~ 24.02°, 27.8°, 57.4° and 77.2° corresponding to (111), (200), (400) and (511) can be attributed to CdTe phase with a cubic zinc blende structure (JCPDS no. 75-2086).

Scanning Electron Microscopy (SEM) Analysis :

The morphology and microstructure of FTO/ TiO2 and FTO/ TiO2/CdTe are shown in Figure 3. Figure 3(a) shows the highly ordered TiO2 nanoarrays which are chemically grown on the FTO glass substrate. The TiO2 nanoarrays are almost perpendicular on the substrate with the length of about 100 nm. The diameters of TiO2 nanorods are almost 10 nm. The SEM image of the FTO/ TiO2/CdTe is shown in Figure 3(b) representing the well coverage of TiO2 nanoarrays with CdTe grains. The diameters of the TiO2/CdTe nanoarrays increase to 250–300 nm.

Therefore the present work is a direct approach to construction of core-shell TiO2/CdTe nano-structure. This nanoarray composite avoid the partial coverage of TiO2 surface which is one of main energy loss pathway in quantum dot solar cell devices.

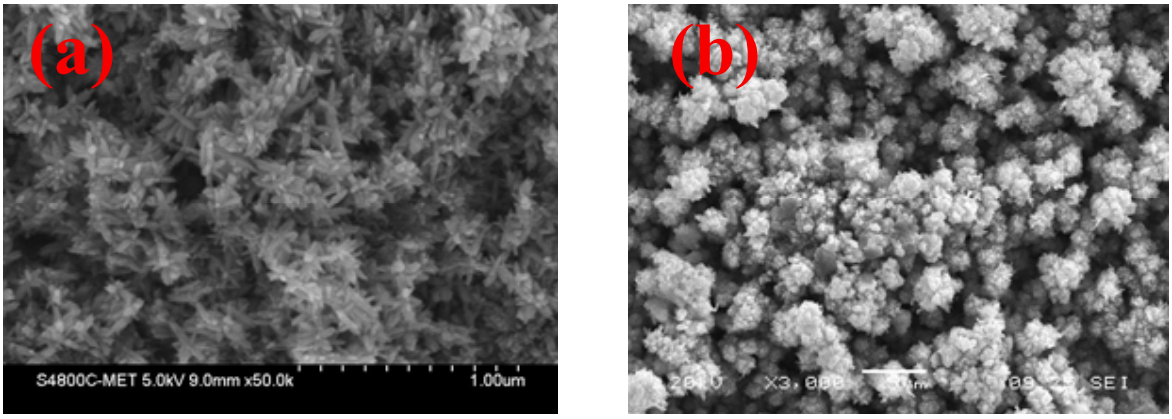

Figure 3: *Scanning Electron Microscopy (SEM) images of (a) FTO/TiO2 and (b) FTO/TiO2/CdTe nanoarray thin films.*

Energy-Dispersive X-ray (EDX) Spectroscopy:

The compositional analysis of the TiO2/CdTe nanocomposite thin films was carried out using Energy Dispersive X-ray Analysis (EDX) technique. A typical EDX spectrum recorded in the binding energy region of 0-10 keV is shown in figure 4. The EDX data is given in Table 1. It shows the presence of elemental Ti, O, Cd, Te and Sn (from the substrate) indicating the purity of the synthesis material (Luo, B. and Deng, Y. 2012).

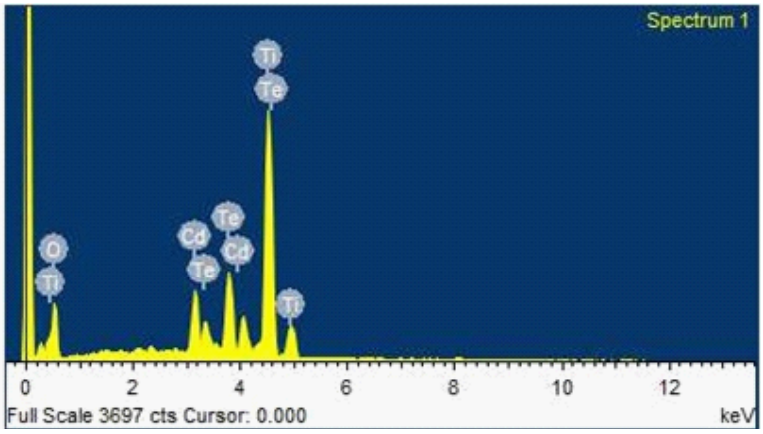

Figure 4: *Typical EDX spectrum of FTO/TiO2/CdTe nanoarray thin films.*

Conclusions:

In summary, a heterogeneous rod-like TiO2/ CdTe nanostructure has been prepared using a two-step chemical synthesis route on the FTO substrate. The TiO2 nanorods were coated with CdTe nanograins on the surface forming core–shell heterostructure. This special nanostructure effectively broadens the absorption spectra, enhances the charge extraction efficiency by the electron and hole separation and provides a fast transfer channel for charge carriers. Therefore, the coating of CdTe grains on the surface of TiO2 nanorod arrays broadens the spectra absorption range and increases the photo induced current significantly which suggests it a promising material to absorb and convert sunlight into electricity for SSSCs.

Acknowledgement:

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