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Photovoltaic application of ZnS loaded silicon dioxide rich composites

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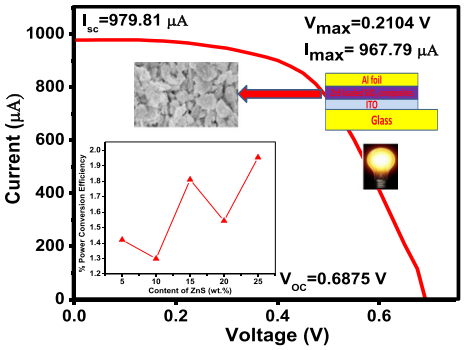
HIGHLIGHTS

- ZnS loaded SiO_2 rich composites were prepared by solid state diffusion route.
- ZnS content in composites have influenced to optical band gap.
- Power conversion efficiency shows good dependence on ZnS content in composites.
- The composites have considerable efficiency against low incident power 0.0104 W/m^2.

GRAPHICAL ABSTRACT



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ABSTRACT

In the present work, the composites between ZnS nanoparticles and silicon dioxide were prepared by solid state diffusion method. The oxidation of silicic acid to silicon dioxide and simultaneously formation of composites between ZnS and silicic acid were carried out during solid state diffusion process. As-prepared samples were characterized by using X-ray diffractions (XRD), field emission-scanning electron microscopy (FE-SEM), Ultraviolet–visible spectrophotometers (UV–vis), Raman spectroscopy, Photoluminescence (PL) spectroscopy, thermal analysis (TG-DTA) and photovoltaic response measurements respectively. The influence of increasing ZnS concentration in composites was reflected from photovoltaic characteristics. The highest power conversion efficiency was found to be 1.954% associated with 25 wt.% ZnS loaded SiO_2 composite, whereas the highest value of fill factor for 10 wt.% ZnS loaded SiO_2 composite in presence of light source of power 0.0104 W/m^2. These composites may be practically useful in a region where the light intensity is very weak like polar region (South and North pole).

1. Introduction

Zinc sulfide (ZnS) is the most versatile semiconductor, which has range of potential application. In addition to this nanotechnology exploring a large number of novel applications for ZnS based materials systems. In forthcoming discussion, we studied some recent reports based on ZnS nanoparticles for various applications. The literature survey mainly focused on the photovoltaic application of ZnS nanoparticles.

Ahmed et al. [1] have analyzed the role of luminescent down-shifting effect to enhance the performance of photovoltaic cell. They have obtained up to 22% (relative) increase in efficiency. Their main accomplishment was to enhance the performance of solar cells which have poor optical response, below 500 nm. Khomyak et al. [2] have been comparatively studied the electrical characteristics of Cd-free photovoltaic cell with CdS with photovoltaic heterostructures. In their

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Fig. 1. Schematic of the fabricated final solar cell.

study, $ZnO_{1-x}S_x$ films are prepared by RF magnetron sputtering which used as a buffer layer. Mizuhata et al. [3] have studied the correlation between photoluminescence intensity and current density for ZnS porous silicon composites. In this study, ZnS thin film is deposited on the nanopores of porous silicon by electro deposition method. The concluding remarks of this study show that, the photoluminescence intensity decreases with increasing the current density due to segregation of ZnS on nanopores of porous silicon. Pawar et al. [4] have reported the boosting role of inner buffer layer of CdS in cascade structure of TiO_2/CdS/CdSe/ZnS quantum dot sensitized solar cell. The chemical bath deposition techniques are employed to prepare CdS, CdSe and ZnS thin film over TiO_2 nanorods assembly. Sanchez et al. [5] have prepared the Cu_2ZnSnS_4 thin films by using technique of sequential thermal evaporation of metal binary sulfides. This study identifies the elemental ratio for good solar cell. The optimized compositions show the good optical and electrical properties for the photovoltaic application. Rajabi et al. [6] studied the photocatalytic properties of ZnS quantum dots synthesized by chemical precipitation method. The optical study ZnS quantum dots shows that it is appropriate for photovoltaic application. Chen et al. [7] carried out the research for synthesis Cu_2ZnSnS_4 thin films. This material is found excellent absorber and suitable for photovoltaic application. The main issue associated with Cu_2ZnSnS_4 is the high-density voids. The results of this study indicate that the issue of high-density voids is resolved by the selection of appropriate buffer materials. In this work, SnS buffer layer work excellently. Photoluminescence properties of materials played key role in increasing power conversion efficiency of materials. Venkatasubbian et al. [8] reported pretty study on ZnS nanocrystals doped with Ni^{2+} and Mn^{2+}. The result of such study shows that the photoluminescence intensity increase by three fold for optimized concentration of dopant. Li et al. [9] have prepared TiO_2 nanowires/nanotubes by using a two-step anodization method. TiO_2 nanowires/nanotubes based solar cells have found higher efficiency when co-sensitized with CdS/CdSe QDs. The prepared composite has maximum power conversion efficiency of the order of 2.41%. Jrad et al. [10] studied the optical properties of Ga-doped ZnS thin films prepared by chemical bath deposition technique. The optical band gap study of thin films shows that the films are suitable for optical window or buffer layer application photovoltaic cell. The effect of Cu doping on the ZnS thin film is analyzed by Chalana et al. [11]. In this work, ZnS thin film is prepared by RF magnetron sputtering technique. The result of the present study shows that Cu incorporation responsible for band gap renormalization, which is crucial aspect of photovoltaic application. Zhao et al. [12] prepared the ternary alloyed $CdSe_xS_{1-x}$ and $CdSe_xS_{1-x}$/ZnS core/shell quantum dots by simple chemical routes. The prepared ternary alloy is exhibited the good nonlinear optical properties which enhanced as compared to their core semiconductor counterparts. The optical properties of material are found suitable for photovoltaic application. Deng et al. [13] have studied the solar cell properties of titanium dioxide based quantum dot-sensitized solar cells. The insertion of ZnS in the layers between CdS/CdSe increases power conversion efficiency by 79%. Patel et al. [14] have prepared Cu_2ZnSnS_4 thin-films as light harvesting layer in thin film solar cells. In this study, effect of annealing on optical properties of CZTS films is analyzed at 623 K, 723 K and 823 K. The direct band gap study of materials shows that the as-prepared Cu_2ZnSnS_4 thin-films have direct band-gap of 1.42 eV, which is the excellent value for absorber in solar-cells. Nam et al. [15] prepared different Cu_2ZnSnS_4 solar cells by sputtered precursor multilayers at different temperatures. In optimized solar cell, ZnS secondary phase accumulates in the vicinity of the interface between CZTS. The highest conversion efficiency in this study is 7.5% for the CZTS prepared at 570 °C, in which no ZnS is detected in the MoS_2 layer. The photovoltaic properties of Cd doped ZnS nanoparticles analyzed by Jabeen et al [16]. The wet chemical method is adopted for the synthesis of Cd doped ZnS nanoparticles. The prepared nanoparticle in combination with P3HT is used for solar cell application. In combination state, materials show 2.33 times higher efficiency than reference device. The comprehensive review by Ummartyotin et al. [17] on the topic ZnS based solar cell indicates that ZnS can be synthesized by different straight forward route for solar cell application. This material has outstanding ability to use for solar cell application due to its good optical characteristics.

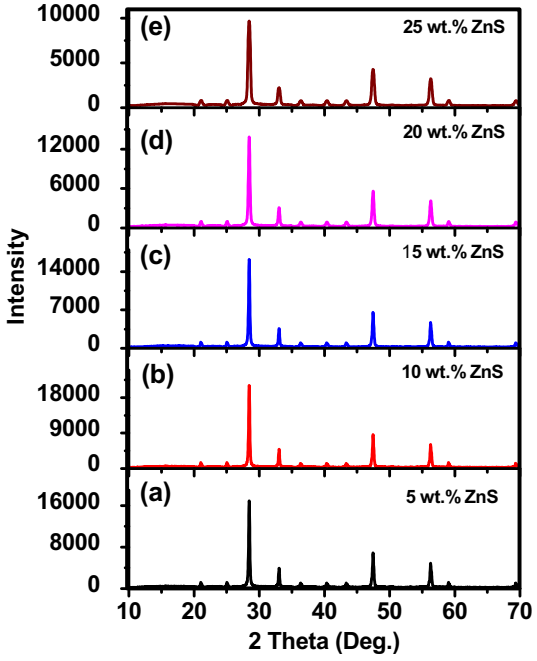

Fig. 2. XRD patterns of ZnS loaded (a) 5 wt.%, (b) 10 wt.%, (c) 15 wt.%, (d) 20 wt.% and (e) 25 wt.% SiO_2 rich composites. XRD pattern recorded between 10 and 70 °C with scan rate 0.02°.

Briscoe et al. [18] reported that the fabrication of dye-sensitized solar cell with expensive platinum has solution of Earth abundant elements. In this report, metal sulfides, oxides, carbides, and nitrides and carbon-based materials such as carbon nanotubes, graphene, and conductive polymers are suggested as an alternative counter electrode. The comprehensive review made by Wang et al. on perovskite materials suggest that photocatalysis and photovoltaics are two of the most important applications, which enable to utilize maximum solar energy. This work noted that perovskite-based solar cells are good for electricity generation, due to their easy band gap engineering [19].

In the present study, we are synthesized SiO_2 rich ZnS composites for photovoltaic application. The composites are prepared by altering the incorporation concentration of ZnS in composites. In this work, ZnS nanoparticles are synthesized by chemical route. For incorporation of ZnS in SiO_2, solid state diffusion route is adopted. The as-obtained composites further investigated for photovoltaic application. The significant power conversion efficiency is extracted from the prepared materials systems.

2. Experimental

For the preparation of ZnS loaded silicon oxide rich composites, AR grade (SD fine, India) chemicals were used without any further