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Effect of electron beam irradiation on chemically synthesized nanoflake-like CdS electrodes for photoelectrochemical applications

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ABSTRACT

In this paper, we chemically synthesized interconnected nanoflake-like CdS thin films for photoelectrochemical solar cell applications and subsequently irradiated them with electron beam irradiation at various doses of irradiation. The as-synthesized and irradiated samples were characterized by means of X-ray diffraction (XRD), field emission scanning electron microscopy (FE-SEM), high-resolution transmission electron microscopy (HR-TEM), and electrochemical measurements. XRD and XPS results confirmed the formation of CdS with a hexagonal crystal structure. FE-SEM and HR-TEM studies confirmed the photoelectrochemical performance, which was dependent on the surface morphology. The calculated values for efficiency demonstrated an outstanding photoelectrochemical performance with a fill factor of 0.38 and efficiency of 3.06% at 30 kGy. The high photoelectrochemical performance may be due to the interconnected nanoflake-like nanostructure and higher active surface area of the CdS samples. These results show that the electron beam irradiation is capable as an electrode for photoelectrochemical solar cells.

1. Introduction

In recent year, the availability of different options for energy conversion in solar cells has become a very important concept in the energy conversion and energy storage field due to it's the source of sun lights are available on the earth [1–6]. Solar energy is very important for combating environmental pollution because it is low cost, easily available, and does not contribute to environmental pollution [1–9]. Various semiconductor materials are used for solar cell applications. Among these, CdS is a promising semiconductor material for solar cells [1,2] because it is a direct band gap semiconductor material with high absorption compared to other metal chalcogenide semiconductors, in addition to its ease of preparation, and high stability [3].

CdS is binary materials in II–VI compounds and have been studied extensively for solar cell applications. CdS has been prepared using several techniques such as successive ionic layer adsorption and reaction [7], pulsed laser deposition [8], hydrothermal [9], gas/liquid interface [10], electrodeposition [11], sonication-assisted sequential chemical bath deposition (S-CBD) [12], thermal evaporation [13], and chemical bath deposition [14]. Among these different techniques available for the preparation of CdS thin films, chemical bath deposition has gained significance recently, as it is a simple and economically practical technique and is a technique in which deposition takes place under standard conditions such as room temperature [12,14,15].

To the best of the author's knowledge, there are no any reports on the effect of electron beam irradiation of CdS thin films for solar cell applications. A literature survey showed that various concepts have been used to improve solar cell performance, such as doping [16], annealing [17], molar ratio [18], CdS/rGO [19], composition [20], composites [21], and decoration [22]. Electron beam irradiation is superior to the other techniques due to the low irradiation time, and no need for different instruments for the experiments. Ghosh et al. [17] synthesized In:CdS thin films by vacuum evaporation and studied the effects of different temperatures in atmospheric air. The authors reported that no noticeable

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shift was observed after annealing. Shinde and his coworkers [23] prepared CdS thin sheets by electrodeposition for solar cell applications and irradiation. The sheets exhibited an efficiency of 1.8% at 25 kGy of irradiation. Dhaygude et al. [24] studied the relationship between the crystal structure and the photoluminescence properties of ZnS thin films with respect to electron beam irradiation.

In this paper, we report the effect of electron beam irradiation on chemical synthesized nanoflake-like CdS nanomaterials for photoelectrochemical cell applications. Briefly, we studied the effect of different doses of irradiation on the physical and chemical properties of pristine and electron beam irradiated CdS samples. Afterward, the photoelectrochemical cell properties of the pristine and irradiated CdS electrodes were examined to determine their J–V characteristics. After irradiation, the CdS electrodes improved the fill factor and efficiency of the solar cells.

2. Experimental section

2.1. Materials

Cadmium sulfate and thiourea were dissolved in 50 mL of DI water and Ammonia (NH_3).

2.2. Synthesis method for the CdS thin films

CdS thin films were deposited using CBD as reported elsewhere [25]. We used a similar methodology to obtain thicker films of pristine CdS.

2.3. Characterization

The structures and morphologies of the CdS thin films were characterized using X-ray diffraction (XRD; with CuK_α radiation, $\lambda = 0.154$ nm), X-ray photoelectron spectroscopy (ULVAC-PHI Quantera SXM), field emission scanning electron microscopy (FESEM; QUANTA 400F), and high resolution transmission electron microscopy, (TEM; FEI, Titan G2 Chemi STEM Cs Probe) with an energy-dispersive X-ray spectroscopy (EDS) detector.

2.4. Photoelectrochemical studies

The CdS on the FTO-coated glass substrate deep in the electrolyte was controlled at around the unit area. Photoelectrochemical tests were conducted with a CHI 660E electrochemical workstation in an aqueous 1 M polysulphide (NaOH:Na_2S:S) electrolyte solution with a three-electrode cell using a platinum electrode as the counter electrode, the CdS electrode as the working electrode, and a standard calomel electrode (SCE) as the reference electrode.

2.5. Experimental processes for high energy electron irradiation (10 MeV)

Electron beam irradiation experiments were carried out in the Bhabha Atomic Research Center using an electron beam accelerator LINAC at ILU-6, BRIT Campus, Vashi, Navi Mumbai. This accelerator was operated with the following parameters: electron energy 10 MeV, dose per pass 1 kGy, convey speed 1 m/min, current 33 mA, and pulse width 10 μs [23–26]. The irradiation process was carried out under atmospheric conditions [26]. The samples were kept normal to the beam. To avoid an excess increase in the sample temperature, an irradiation dose of 10 kGy was applied at every pass and the total irradiation applied to each sample was controlled by the total number of passes [26]. In the present case, a dose of 10 kGy was applied in a single pass [23–26]. Fig. 1 shows the growth mechanism of the CdS thin films synthesized using the chemical bath deposition method after and before electron beam irradiation [27].

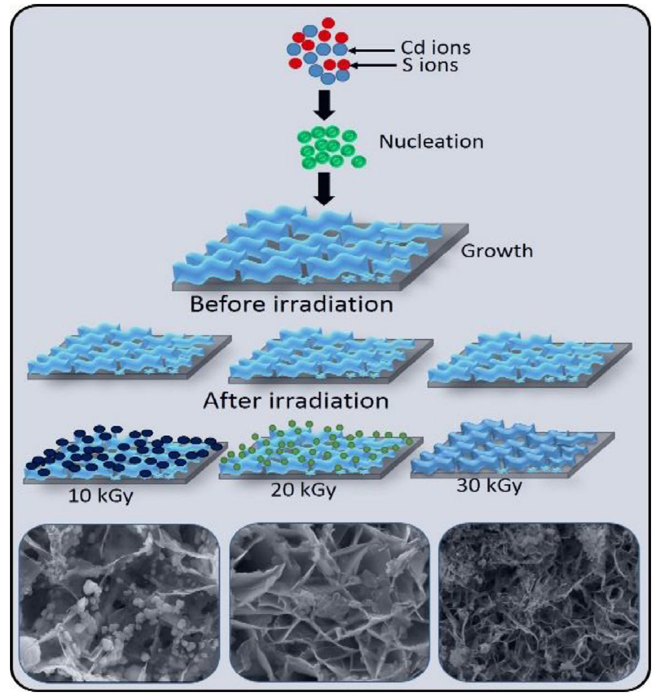

Fig. 1. Schematic experimental setup of electron beam irradiations for CdS sample.

3. Results and discussion

3.1. X-ray diffraction studies

X-ray diffraction was used for determination of the phase and identification of the cubic crystal structure of the as-synthesized and irradiated samples. Three irradiation doses were used: 10 kGy, 20 kGy, and 30 kGy in an air atmosphere. Fig. 2 shows the XRD patterns of the as-synthesized and irradiated CdS samples with different doses of irradiation. XRD results confirmed the formation of the pure phase of the CdS materials with a hexagonal phase [28]. All peaks found at 26.79°, 29.38°, 44.42°, 52.07°, and 55.59° corresponded to the (111), (200), (220), (311) and (222) planes of the CdS material, respectively. All peaks of the sample were well matched with the standard JCPDS result. All samples of the as-synthesized

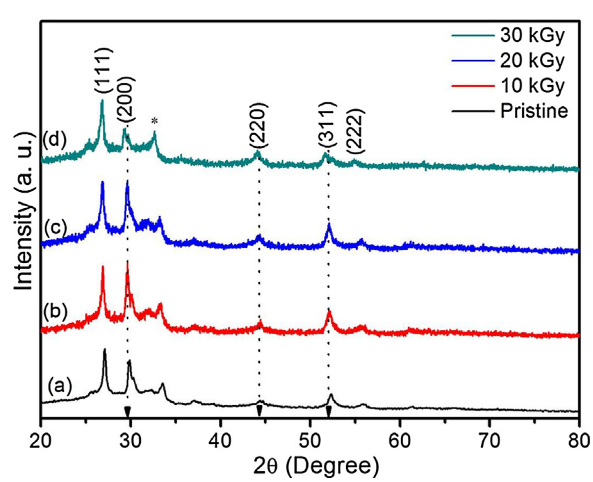

Fig. 2. XRD patterns of the pristine and irradiated CdS samples with different doses.