Synthesis of Cadmium Sulphide and its investigation for solar cell applications

Sushant kotwal[1], Lakhvinder kaur[2],
[1]M.tech (ECE), Adesh Institute of Technology, Gharuan, Distt. Mohali
[2]A.P , ECE, Adesh Institute of Technology, Gharuan, Distt. Mohali
(E-mail: sushantkotwal93@gmail.com)

Abstract- In this work, cadmium sulphide (CdS) nanoparticles were synthesized via sol-gel method and then successfully characterized and implemented for fabrication of solar cell. The synthesized CdS nanoparticles were studied for their morphological, optical and electrical characterization. X-ray diffraction (XRD), Scanning Electron Microscopy (SEM), Energy Dispersive spectroscopy (EDS), UV- visible spectroscopy and photoluminance (PL) studies confirmed their successful synthesis with desired optical properties. Moreover, a solar cell is fabricated using the synthesized nanoparticles. The results confirmed that the synthesized CdS nanoparticles can be integrated into the device to develop a solar cell with 1.28% efficiency.

Keywords- *CdS nanoparticles, sol-gel, solar cell.*

I. INTRODUCTION

During recent times, several nanomaterials demonstrate potential characteristics to develop photovoltaic assemblies. Genuine efforts were being made to engineer the structures of elements that show promising features toward light energy conversion [1]. However, only few of them had been reported which are fabricated with low-cost, low-temperature, atmospheric-pressure along excellent efficiencies [2]. Still, exhaustive studies are required under such areas to develop a photovoltaic (PV) module with economical and reliable features [3]. Several researchers are inspecting some efficient nano-materials that may the potential to convert light energy into power. Among all of them, cadmium sulfide (CdS) is one of the materials that undergo into intense scientific study due to its ample potential applications varying from photovoltaic to radiant devices [4-7]. Researchers proved that it is an important with semiconductor properties showing *n*-type conductivity that exhibits due to sulphur vacancies owing to excess cadmium atoms. The bandgap of such material depends on the size of nanoparticles [8]. Thus, CdS nanoparticles show quantum size effect. In other words, the bandgap of CdS nanoparticles varies in accordance to their particle size and the size of nanoparticles are dependent on the absorption wavelength [9]. CdS also exhibit stupendous visible light detecting properties as compared to other semiconductor materials. Hence it plays an important role in determining their electronic properties [10]. CdS nanoparticles can be obtained in different shapes and structures depending upon the technique used for synthesization. Accordingly, the properties can be optimized by controlling the physical properties, such as environmental conditions, temperature, solvents used, etc [11].

In this work, the CdS nanoparticles are synthesised via sol gel technique. The prepared nanoparticles were then characterized for their elemental composition and morphology. Also, the band gap was determined using optical characterization. The prepared material in then investigated for its use to form solar cell. A complete structure of solar cell is fabricated on ITO glass. CdS nanoparticles were deposited by spin coater followed by depositing the aluminum (Al) electrode via vacuum thermal evaporation deposition system.

II. EXPERIMENT

A whole experiment is divided into two parts- (A) Synthesis of CdS nanoparticles, and (B) device formation using synthesized CdS nanoparticles.

A. Synthesis of CdS nanoparticles

In this part of experiment, CdS nanoparticles were synthesized by sol-gel method. All the chemicals and reagents used in this experiment were of analytical grade (>99%). Cadmium nitrate ($Cd(NO3)_2$) and sodium sulphide (Na_2S) were used to prepare the CdS naoaprticles. 0.5 M solution of $Cd(NO_3)_2$ was prepared by dissolving 7.712 g of $Cd(NO_3)_2$ in a beaker containing 50 ml of distilled water. In another beaker, Na_2S solution of the same morality (0.5 M) is obtained by dissolving 1.951 g of Na_2S in 50 ml distilled water. Cadmium nitrate solution was kept for stirring on a magnetic stirrer at 450 rpm. Thereafter, the prepared Na_2S solution was added dropwise into it. The resultant solution was aged for 24 hrs. The particles were settled at the bottom in a beaker. It is then centrifuged and washed sequentially with both ethanol and distilled water to remove the impurities. The overall experiment was performed at room temperature. The obtained pellets were then dried. After adequate drying, the precipitate was crushed to fine powder. Thus, CdS nanoparticles were synthesized and then characterized for further studies. Finally, the as-synthesized nanoparticles were further used to fabricate the solar cell device.

B. Device Formation

For device fabrication, ITO coated glasses, with a sheet resistance of 20 Ωsq-1 were used. It is then cleaned with soap, DI water and acetone for 2h. The as-prepared CdS nanoparticles was dissolved in C_4H_8O solvent to form a colloidal solution. It is then spin-coated on a clean ITO coated glass substrate at 2000 rpm for 1 min. The CdS coated thin film was then annealed at 120 ^{0}C for 15 min to evaporate residual solvent. The thickness of films was estimated as ~50 nm. Further, the ITO were coated using the shadow mask by thermal evaporation of 100 nm Al electrodes as anode. Thus a thin film based glass/ITO/CdS/Al device is fabricated. Finally, the fabricated device with pixel area 0.05 cm^2 is tested to obtain the electrical characteristics.

Results and Discussions

The synthesized nanoparticles were characterized through XRD, EDS, SEM, and UV-Vis spectrometry. Further, the fabricated solar cell device by involving the synthesized CdS nanoparticles is studied for their *I-V* characteristics. In this section, the obtained measured results are discussed as follows.

C. XRD Characterization

Figure 1 shows the X-ray diffraction pattern of the synthesized CdS nanoparticles scanned in 2θ range from 20^0 - 80^0. The diffractogram shows some major peaks at 2θ values of 24.7º, 26.4º, 27.5˚, 36.5˚, 43.7º, 47.5º, and 51.6º which could be indexed to diffracting from the (100), (002), (101), (102), (110), (103), and (112) planes, respectively, of the CdS crystal lattice. The peaks obtained were in very good agreement with the international centre for diffraction data (JCPDS card file no. 41-1049). Almost every observed XRD reflections are highly intense which confirmed that the as-synthesized nanoparticles are well crystalline. The particle size was also calculated using the Scherrer's formula [12], i.e.

$$D = \frac{k\lambda}{\beta \cos\theta} \qquad \text{………………(i)}$$

where D is the average particle size perpendicular to the reflecting planes, λ is the X-ray wavelength, k is constant and is equal to 0.9, β is the full width at (FWHM) half maximum , and θ is the diffraction angle. The average particle size was found to be 11 nm respectively.

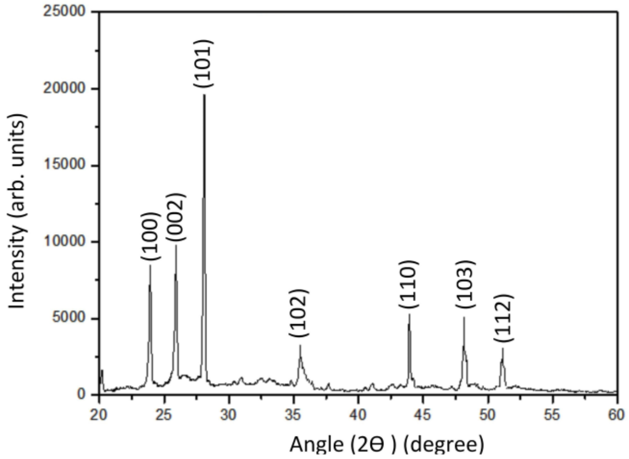

Fig. 1. XRD pattern of synthesized CdS nanoparticles.

D. EDS Characterization

The elemental compositions of the synthesized CdS nanoparticles is observed by EDS and results are shown in Fig. 2. This is an automated generated graph by built-in software and shows the highest counts of Sulphur. As can be seen from the observed EDS spectrum that the dominated peaks belong to Cadmium and Sulphur which reveal that the synthesized products is made of these two elements.

Percentage (%) composition of these elements present in sample of CdS nanoparticles are shown below in Table 1. No other dominated peak is observed in the spectrum which clearly revealed that the synthesized material is in pure form.

Table 1**.** Elemental composition observed by EDS

Sample	Cu	S
CdS nanoparticles (%)	48.10	51.90

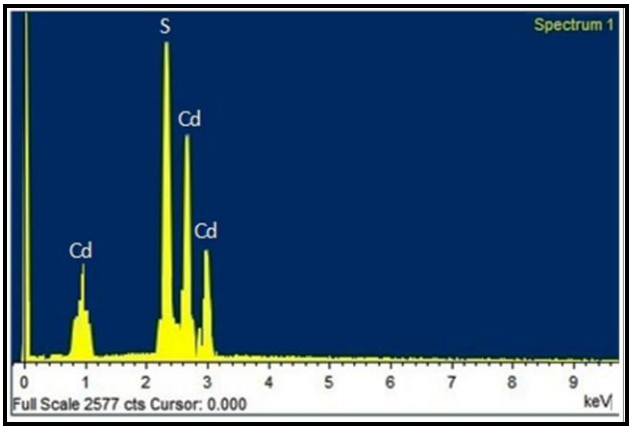

Fig. 2. The elemental compositions of the synthesized CdS nanoparticles observed by EDS

E. SEM Characterization

Fig. 3 shows the surface morphology of the synthesized CdS nanoparticles that were analyzed by using scanning electron microscopy (SEM). The SEM image shows that the particles are spherical in shape and are homogenously distributed. Also, the particles appeared in uniform and consistent shape.

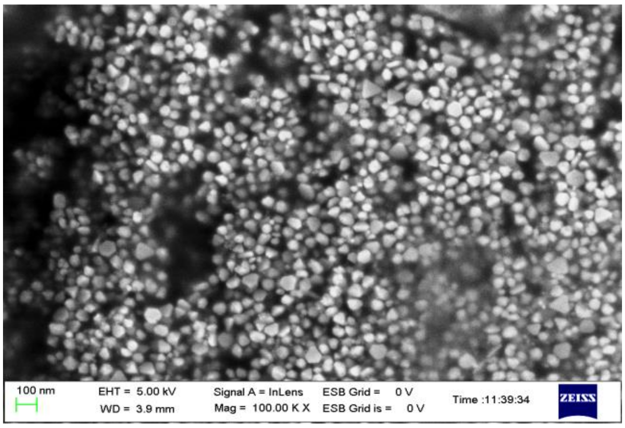

Fig. 3. SEM of synthesized CdS nanoparticles with X = 100 K.

F. UV-Vis Characterization

The optical property of the synthesized CdS nanoparticles is examined by UV-vis. spectroscopy at room-temperature and is shown in Fig. 4. The observed graph showed a single absorption peak at 330 nm.

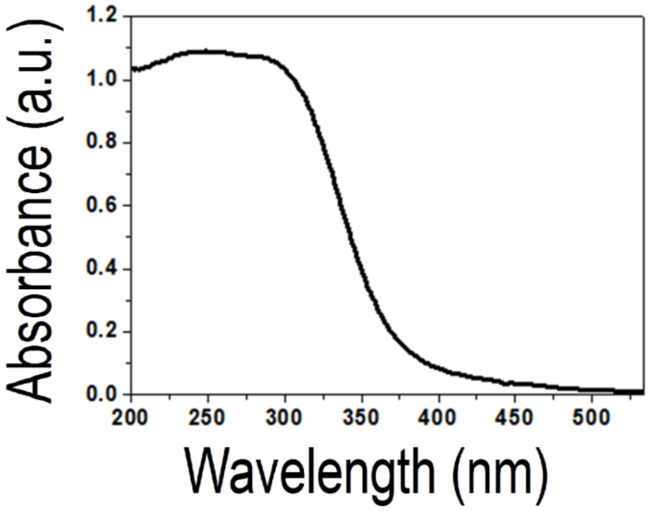

Fig. 4. UV–vis absorption spectra of CdS nanoparticles.

This graph indicates that the prepared CdS nanoparticles behave as a direct band-gap semiconductor and shows absorption due to the electronic transitions from the valence band to the conduction band. The energy band gap (E_g) is also determined from the optical absorption spectra using Tauc relation [13],

$$\alpha h\nu = A\left(h\nu - E_g\right)^n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(ii)}$$

where α is the absorption coefficient, $h\nu$, is the photon energy, E_g is the band gap and $_n$ is a constant that determines the type of optical transitions (n=1/2 and 3/2 for direct allowed and forbidden transition, respectively, n=2 and 3 for indirect allowed and forbidden transition, respectively). The bandgap is determined by extrapolating the straight line to zero absorbance, i.e., $(\alpha h\nu)^{\frac{1}{2}} = 0$ and the plot is shown in Fig. 5. Thus, the band gap energy of the synthesized CdS nanoparticles is 1.63 eV. This value is shifted as compared to the bulk value. This shift is may be due to size quantization effect.

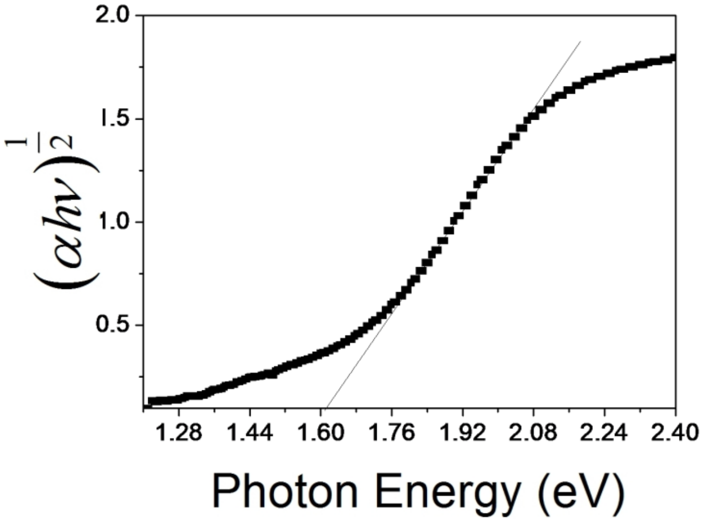

Fig. 5. Tauc's plot obtained fron UV-vis spectrometry showing $(\alpha h\nu)^{\frac{1}{2}}$ vs $h\nu$ graph.

G. Solar cell Characterization

The *J-V* characteristics of the proposed device are shown in Fig. 6. The voltage is applied from -1V to +1V and the graph is plotted for current densities measured for dark and under illumination at AM 1.5 (100mW/cm^2). The white light of solar simulator is the source for illuminated light. These characteristics were measured at room temperature and 70% relative humidity environmental condition.

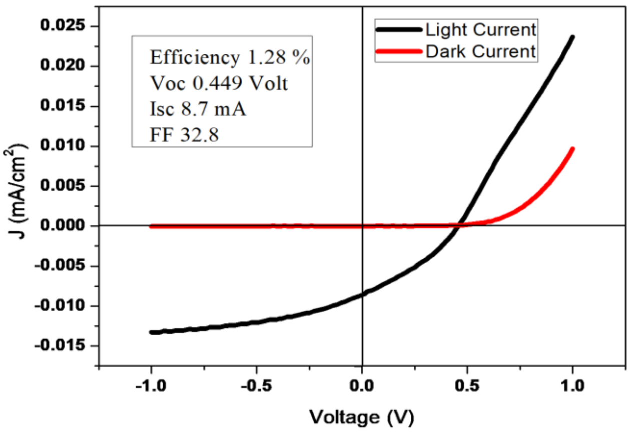

Fig. 6. J-*V* characteristics of fabricated glass/ITO/CdS/Al solar cell device measured under dark and illumination.

Conclusion

In summary, Cu-doped CdS nanoparticles are synthesized via sol gel method. By using the synthesized nanoparticles, a thin film based glass/ITO/CdS/Al device has been proposed and demonstrated experimentally as a solar cell. A proposed device shows satisfactory results particularly for small bias voltage (-1V to +1V) with efficiency (1.28%), V_{OC} (0.449 V), I_{SC} (8.7 mA) and fill factor (32.8). Thus, the proposed thin film grown on ITO substrate showed that the device under study can be explored for photovoltaic applications.

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