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High Efficiency and cost effective Cu_2S/CdS thin-film solar cell

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Abstract: *Cu_2S and CdS nanoparticles due to their unique band character, high extinction coefficients and impact ionization effects are the most promising light absorbers for solar cells. Here Cu_2S and CdS nanoparticles are prepared by wet chemical method and are characterized using UV-Vis Absorption Spectroscopy and X-ray Diffraction. The thin film of Cu_2S/CdS is prepared using Spin Coating technique. Cu_2S/CdS solar cells form a p-n heterojunction solar cells with CdS having energy gap of 4.4eV and Cu_2S having an energy gap of 2.65 eV. The results are quite appreciable and 10.9% efficiency is obtained from Cu_2S/CdS thin-film solar cell. The photovoltaic properties including I–V characteristics, short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), fill factor (ff), efficiency (η) of Cu_2S/CdS heterojunction cells have been examined.*

Keywords: *Cu_2S/CdS solar cell, Illumination, I-V Characteristics, Open circuit voltage, Short circuit current*

I. Introduction

The demand for clean energy technologies has spurred academic interest in new and efficient ways to capture and store sunlight. Concerted efforts are now being directed toward both the design of light harvesting assemblies, construction of economically viable solar cells, and the development of efficient energy storage devices. Even in the age of nanotechnology, century-old liquid junction electrochemical cells play a pivotal role in our daily lives by delivering portable energy to everything from mobile phones to automobiles. In recent years, the concept of utilizing nanomaterial-based architectures in light energy conversion devices has emerged as an alternative to single-crystalline based photovoltaic devices. It was found that Cu_2S/CdS photovoltaic cell have solar energy conversion efficiency 9.1% but they are difficult to prepare and have high cost. In this paper, Cu_2S and CdS nanoparticles have been synthesized using wet chemical method and thin film of Cu_2S/CdS has been used as solar cell. The results clearly show the high efficiency of thin film Cu_2S/CdS cell around 10.9% and is easily prepared and have low cost.

1. Introduction

The synthesis and characterization of nanoparticles of semiconducting metal sulfide has been an intense field of research due to the interesting optical properties and potential applications of this compound [2-7]. Their unique band character, high extinction coefficients and impact ionization effects suggest that these materials are promising light absorbers for solar cells. Semiconductor nanostructures are promising building blocks for future-generation photovoltaic devices, such as dye sensitized solar cells [8-10], all-inorganic nanoparticle solar cells [11-13], and hybrid nanocrystal-polymer composite solar cells [14-17]. Such materials are promising candidates in electronics, data storage, energy storage, catalysis and sensors. All of these could offer processing, scale, and cost advantages when compared with conventional single crystal and thin film solar cells. One of the most challenging aspects in this area is to find a semiconductor material with a suitable band gap, near 1 eV for a conventional, single-gap device, which can be made in nanostructured form. Here, we explore a candidate material satisfying these requirements: copper (I) sulfide, Cu_2S. Cu_2S is an indirect gap semiconductor with a bulk bandgap of 1.21 eV [18]. Its use in combination with cadmium sulfide, CdS as a solar cell material.

In thin film studies, Cu_2S/CdS solar cells did show significant promise, but copper diffusion into and doping of the CdS layer led to long-term performance degradation and ultimately abandonment of this system. Copper sulfide, a p-type semiconductor in which copper atom vacancies act as acceptors and Cadmium sulphide, a n-type semiconductor in which cadmium atom vacancies act as donors. They have been frequently investigated due to their attractive optical and electronic properties. In recent years, efforts on the development of thin film solar cells have been more and more concentrated on Cu_2S/CdS cells with a p-n heterojunction. It was found that the thin film photovoltaic cell of Cu_2S/CdS have high solar energy conversion efficiency more than 9.1% and have low cost [1]. Cu_2S/CdS solar cells form a p-n heterojunction solar cells with CdS having energy gap of 4.4eV and Cu_2S having an energy gap of 2.65 eV.

Different methods with different chemical reagents have already been used for the preparation of Cu_2S and CdS nanoparticles like chemical route, co-precipitation method, physical methods etc. Chemical route is the most easily available and cost favourable method. This method is also easily accessible and also conventional to

general labs in comparison to other methods. In the present paper, Cu_2S and CdS Nanoparticles have been synthesized using wet chemical method. Nanoparticles have been characterized using UV-Visible absorption spectroscopy and X-ray Diffraction. The thin film of Cu_2S/CdS has been prepared using Spin Coater. Thin film of Cu_2S/CdS has been investigated as solar cells.

II. Experimental procedure

2.1 Preparation of Cu_2S and CdS Nanoparticles

For the synthesis of Cu_2S Nanoparticles, prepare 0.2M solution of Cuprous chloride [CuCl] in 100 ml distilled water by stirring it for 15 min and add 0.5 ml of Thioglycerol as a capping agent in this solution and stir the whole solution for 2 hrs. Then add 0.2M solution of Sodium sulphide in 100 ml distilled water dropwise to the above solution. The resultant solution is stirred for 3-4 hrs. Capping agent is used to avoid the agglomeration of nanoparticles and helps in maintaining the sized specific nanoparticles.

For the synthesis of CdS Nanoparticles, add 0.5 ml of Thioglycerol to 0.2M solution of Cadmium acetate dihydrate $[(CH_3COO)_2Cd.2H_2O]$ in 100 ml distilled water and stir it for 2 hrs. Now add 0.2M solution of Sodium sulphide in 100 ml distilled water dropwise to the prepared solution and stir the whole solution for 3-4 hrs.

2.2 Preparation of Cu_2S/CdS thin film

The preparation of colloidal suspensions of semiconductor nanocrystals allows for the control of parameters such as particle size, particle concentration, and method of deposition. With this ability to control the properties of the film on the particulate level, the colloidal synthesis of many different types of nanoparticles has become popular. A small aliquot of CdS sample is diluted into distilled water in one beaker and Cu_2S sample in another beaker. A thin film of CdS nanoparticle approximately 100 nm in thickness is created using spin-coating technique on top of a glass substrate and then a thin film of Cu_2S nanoparticle approximately 10 μm in thickness is created on CdS thin film using the same technique. The back electrode is obtained by deposition of silver layer of 150 nm thick on glass substrate under vacuum of 10-3 Pa. The silver layer acts an ohmic back contact with the deposited CdS layer.

III. Results and Discussion

3.1 UV-Visible Characterization of CdS and Cu_2S nanoparticles

UV-Vis spectroscopy is a powerful tool for characterization and examination of aqueous suspension containing nanoparticles which have their excitation energy in UV-Visible range. UV-Vis spectroscopy is well known to investigate shape and size controlled nanoparticles. Fig.1 shows the UV-Vis Spectroscopy of CdS Nanoparticles which gives a clear absorption peak at the wavelength of 270 nm. Fig.2 shows the UV-Vis Spectroscopy of Cu_2S Nanoparticles which gives a clear absorption peak at the wavelength of 480 nm. For the determination of Energy Bandgap, we have Tauc relation which is given as :

$$\alpha h\nu = A(h\nu - E_g)^n \qquad (1)$$

where α = Absorption coefficient , $h\nu$ = Photon energy , E_g =Energy bandgap , A = constant and n = ½ the allowed transition between the extrema of the conduction and valence bands for direct transition and n = 2 provides the allowed transition for indirect transition.

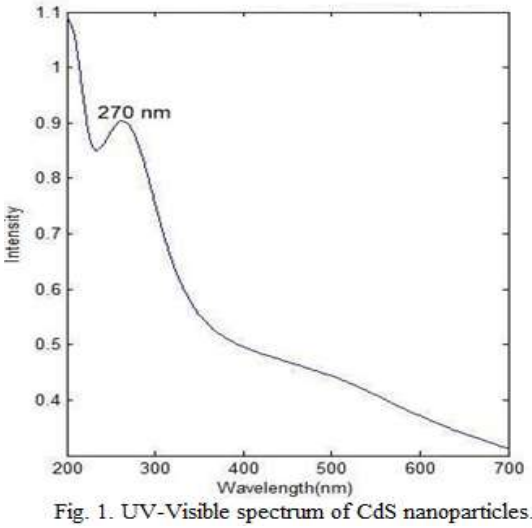

Fig. 1. UV-Visible spectrum of CdS nanoparticles.

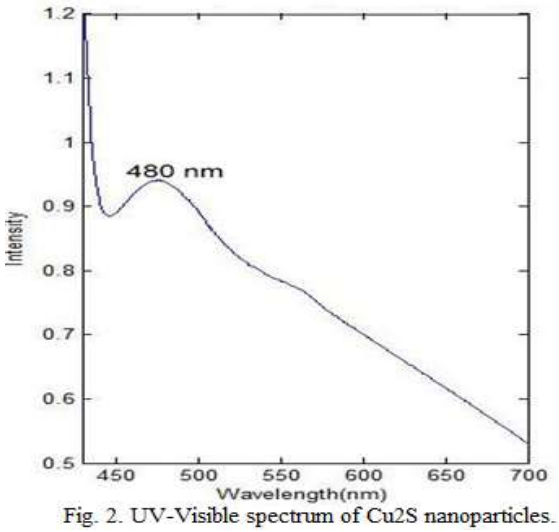

Fig. 2. UV-Visible spectrum of Cu2S nanoparticles.

In case of CdS nanoparticles, a plot of $(\alpha h\nu)^2$ vs photon energy ($h\nu$), when extrapolated to zero absorption provides the value of energy gap (E_g). Fig.3 shows the plot $(\alpha h\nu)^2$ vs $h\nu$ which gives the energy gap, E_g = 4.4 eV. In case of Cu_2S nanoparticles, a plot of $(\alpha h\nu)^{1/2}$ vs photon energy ($h\nu$), when extrapolated to zero absorption provides the value of energy gap (E_g). Fig.4 shows the plot $(\alpha h\nu)^{1/2}$ vs $h\nu$ which gives the energy gap, E_g = 2.65 eV.

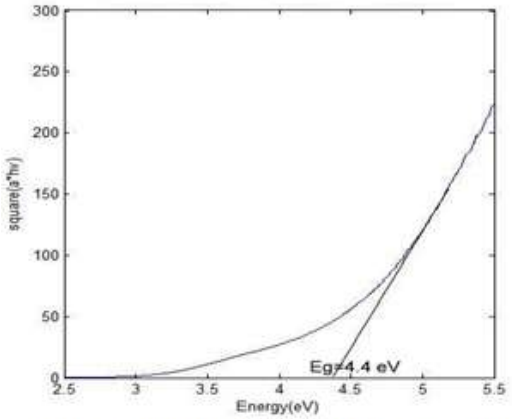

Fig. 3. Bandgap estimation of CdS nanoparticles.

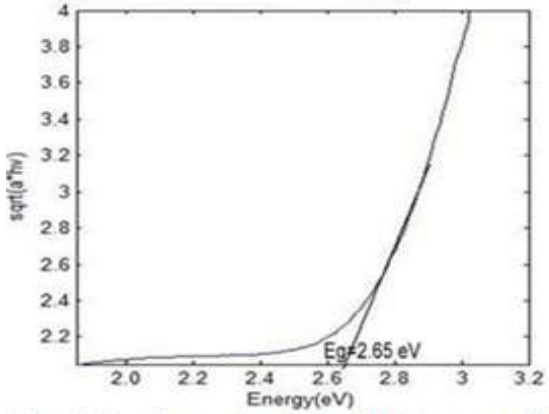

Fig. 4. Bandgap estimation of Cu2S nanoparticles.

3.2 XRD patterns of CdS and Cu_2S nanoparticles

Fig.5and Fig.6 demonstrates the XRD patterns of the synthesized CdS and Cu_2S nanoparticles respectively. The X-ray diffraction data are recorded by using Cu Kα radiation (1.5406 Angstrom). The average grain size of the samples is estimated with the help of the Scherrer equation, using the diffraction high intensity peak. The broadened peaks are indicating that the sizes of the particles are in nanorange. X-ray diffraction studies confirmed that almost all the diffraction peaks agreed with the reported JCPDS data. The mean grain size (D) of the particles is determined from the XRD line broadening measurement using the Scherrer Equation :

$$D = 0.89\lambda/(\beta Cos\theta) \quad (2)$$

Where λ is the wavelength (Cu Kα), β is the full width at the half- maximum (FWHM) of the peak and θ is the diffraction angle.

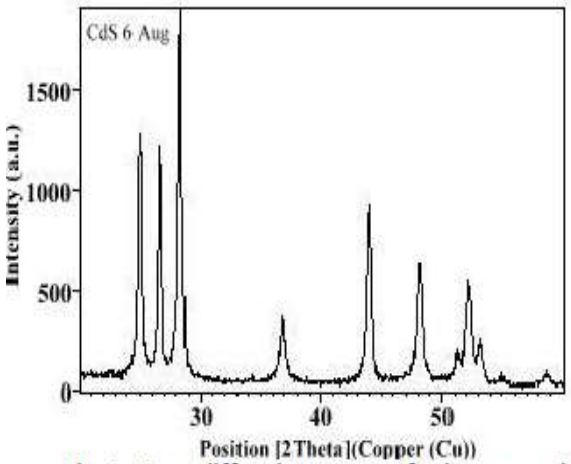

Fig. 5. X-ray diffraction pattern of CdS nanoparticles

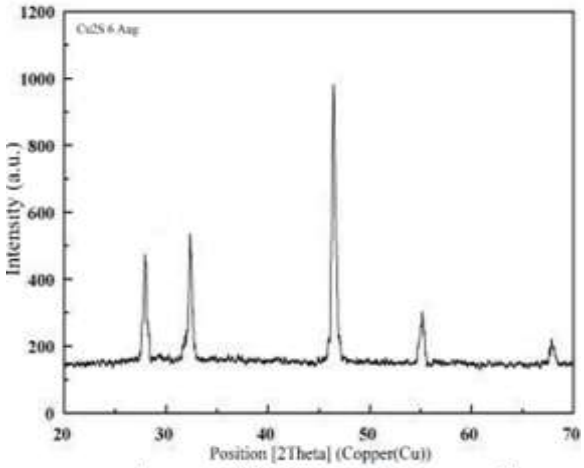

Fig. 6. X-ray diffraction pattern of Cu2S nanoparticles.

The average crystallite size D calculated for Cu_2S and CdS nanoparticles by Debye-sherrer formula are about 84 nm and 67 nm respectively.

3.3 I-V characteristics of Cu_2S/CdS thin film

I-V characteristics curve measures the values of current produced under various applied potentials for Cu_2S/CdS thin film. This single characterization provides all the quantitative information necessary to integrate a solar cell, in series or parallel with others, into a circuit which can then fulfill specified power needs. There exist several points along the I-V curve which are of practical importance and from which relevant cell parameters can be determined. The I-V characteristics in dark and under 100 mW cm^{-2} illumination by using a halogen lamp on Cu_2S side. The I-V characteristic without illumination (in dark), the forward current of the cell increases slowly with increasing voltage as shown in Fig.7.

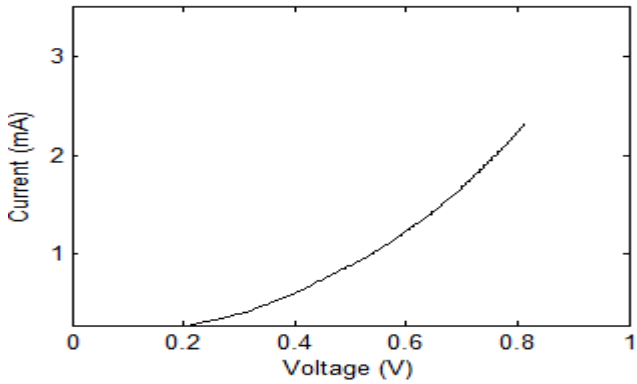

Fig. 7. I–V characteristics of Cu_2S/CdS heterojunction in dark condition at room temperature.

Since the dark I–V plots are similar to the diode characteristics. The value of the series resistance (R_S) in dark condition for the cell can be determined from the forward I–V characteristics of Fig.7 at higher voltage. The result given is R_S about 360 Ω at room temperature. The higher resistance may be responsible for decreasing the quality of the cell [19]. The current – voltage relation in heterojunction can be generally described by any of the diffusion model, the emission model or the recombination model from which the relation is represented by the standard diode equation [20, 21]:

$$I_d = I_o \{ \exp (eV/nkT) -1\} \quad (3)$$

where e is the electronic charge, n is the diode quality factor, k is Boltzmann's constant, T is the absolute temperature and I_o is the reverse saturation current.

The I-V characteristic under illumination of the cell is shown in Fig.8. The open circuit voltage (V_{oc}), represents the maximum voltage obtainable from the cell, which occurs at zero current and short circuit current (I_{sc}) is the current obtained from the cell at zero voltage. The total current through the solar cell is:

$$I = -I_{ph} + I_o \{ \exp (eV/nkT) -1\} \quad (4)$$

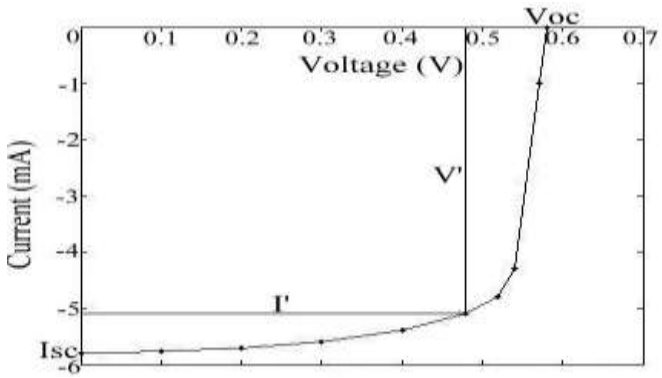

Fig. 8. I–V characteristics of Cu_2S/CdS solar cell under illumination at room temperature.

The short circuit current of the cell is substantially lower than the best cells in the literature. The cell exhibits the short circuit current (I_{sc}, 5.8 mA), but the open circuit voltage (V_{oc}, 0.58V).

In general, the heterojunction solar cells have a tendency towards multiple recombination centres located in the vicinity of the pn−junction. This leads to increase in the photocurrent in a non-linear manner as the light intensity is increased. This is the fact that with higher light intensities (if $h\nu \geq E_g$) there is an increased concentration of photo-generated charge carriers and they succeed in saturating the recombination centres. The point along the I-V curve, which maximizes power is labeled P_m. Approximate points for V_{oc}, I_{sc}, and P_m are labeled in Fig.8.

From Fig.8, V_{oc} = 0.58 V, I_{sc} = 5.8 mA, I' = 5.1 mA, V'=0.48 V, P_m = 2,45. Power conversion efficiency is given as-

$$\eta = P_m*100/(I*A) \% \quad (5)$$

where η ranges from 0 to 100%, A is the area of experimental irradiance, I.

Efficiency in the fabricated cell measured about 10.9%. Fill factor [24], ff, is a computed value, ranging from 0 to 1, which reports on a cell's performance relative to its V_{oc} and I_{sc}.

$$ff = P_m/(I_{sc}*V_{oc}) \quad (6)$$

The fill factor is about 73%. Obviously the weak value of this cell is the low value of the fill factor and the efficiency. This is may be due to the higher series resistance [22,23].

IV. Conclusion

The study included the synthesis of Cu_2S and CdS nanoparticles by wet chemical method and their application in solar cells. The Cu_2S and CdS nanoparticles are characterized using UV-Visible Spectroscopy and X-ray Diffraction. The determined energy band gap of Cu_2S and CdS nanoparticles are 2.65 eV and 4.4 eV respectively. A thin film of CdS nanoparticle is created on top of a glass substrate and then a thin film of Cu_2S nanoparticle is created on CdS thin film using the spin-coating technique. The current-voltage under dark, illumination conditions are described. Efficiency of thin film Cu_2S/CdS cell approached around 10.9% and fill factor around 73%. The results clearly show the high efficiency of thin film Cu_2S/CdS cell and is of low cost.

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