Influence of Concentration of Precursor Solution on the Performance of Nanocrystalline CdTe Thin Films Used as Photoelectrode in Photoelectrochemical Solar Cell

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Abstract

Among various techniques for preparation of nanometer size materials, chemical methods offers better orientation, which are least expensive, non-polluting and easy to incorporate suitable doping materials for altering the film properties. These processes are the variable-concentration processes which enable formation of thin films onto glass substrates in addition to the conducting films (substrates) which can potentially lead to a new generation of photovoltaic devices that are light in weight, foldable, flexible and moldable. The inorganic thin films of cadmium telluride is focused in this work by direct chemical deposition method and annealed at 200°C for 2 hrs for crystallinity improvement.

In this Paper the preparation of photoelectrode with different concentrations of precursor solution are discussed. The thin film of CdTe on glass substrate were examined for their structural, surface morphological and optical properties by means of X-ray diffraction (XRD), and atomic force microscopy (AFM) respectively. The photovoltaic response of nanocrystalline CdTe thin film photoelectrodes in PEC cell has been investigated.

Keywords

Cadmium Telluride Thin Films; Chemical Bath Deposition (CBD) Photoelectrochemical Cells; XRD; Surface Morphology, Atomic Force Microscopy (AFM) Photovoltaic Effect

I. Introduction

A major prerequisite for the modern style of life is existence of sustainable and inexpensive energy sources. Without affordable electricity, oil, and gas resources, we simply would not be able to exploit most of the advantages provided to us by new technologies.

The majority of world economies rely on oil and other fossil fuels as the primary energy sources. However, global population growth along with rapid development of underdeveloped countries has significantly increased the energy demand in the last two decades. Therefore, from the economic point of view, it is necessary to replace fossils with alternative energy sources. The hope for a "solar revolution" has been floating around for decades -- the idea that one day we'll all use free electricity fro¬m the sun. A solar cell (also called photovoltaic cell or photoelectric cell) is a solid state electrical device that converts the energy of light directly into electricity by the photovoltaic effect. Nowadays, nanocrystalline thin film became a very useful material in the thin film solar cell industry, because in this less material use and less energy intensive processing leads to lower cost.

A reduction in manufacturing costs can be achieved by utilizing nanocrystalline thin film technology. In the today's modern era of nanoscale devices, thin film growth has emerged as a leading technique. Growth of thin films is responsible for the wide range of structures and devices, which has made a significant impact on the development of both science and technology. From the early days of photovoltaics thin-film solar cells have always competed with technologies based on single-crystal materials. Owing to their amorphous or polycrystalline nature, solar cells always suffered from power conversion efficiencies lower than those of the bulk technologies. This drawback was and still is counter balanced by several inherent advantages of thin-film nanotechnologies.

Cadmium Telluride is well-known p-type semiconductors having potential applications in solar cells. Cadmium telluride is studied with great interest during the past decades because of its potential application in the fabrication of photovoltaic devices.

Present paper describes preparation of nanocrystalline films of CdTe on ITO coated glass substrate their characterization and study of their performance in PEC cell. The effect of concentration of precursor solution has especially been investigated.

II. Experimental

The nanocrystalline thin film of cadmium telluride were grown on glass and indium tin Oxide (ITO) substrates using chemical bath deposition method .

A. Photoelectrode Preparation

A reaction vessel containing glass and indium doped tin oxide (ITO) coated substrates were used in the experiment connected to auto-thermostat to maintain and control the accurate temperature of reaction solution. The reaction vessel was filled with the composition of solution: [0.1 M 20 ml ($CdCl_2$) + 0.1M (K_2Te)] buffer solution is used to maintain 11.2 pH.

Chemical Reaction

$CdCl_2 + K_2Te = CdTe + 2KCl$

The reaction was carried out by the refluxing the mixture of starting materials at 90°C for 5 hrs. Water bath with reflux assembly was used for this purpose. The CdTe nanocrystallite was formed at this stage, by the addition of 2- propanol to the solution named as A. The glass slides were cleaned with a suitable cleanser, scrubbed with soft cotton, washed thoroughly with de-ionized water followed by rinsing and drying in air. These glass and ITO coated glass plates were used as substrates for deposition, fixed to the circular holder with ITO side facing towards the solution A and allowed to rotate with a speed of 25 rpm. The thermostat was set to a temperature of 45°C and the reaction was carried out for different concentration of precursor solution and for 120 Min, with constant stirring of the solution throughout the experiment. Good transparent films were deposited onto both glass and ITO substrates. The CdTe film are deposited from different concentration of precursor solution normal concentration, half concentration, double concentration at controlled temperature 45°C and for 120 min deposition time. The transparent CdTe thin films were annealed at 200ºC for 2hrs in Oven.

Table 1: Different Concentration of Precursor Solution of Deposited CdTe Thin Film

Chemicals	Half concentration A	Normal concentration B	Double concentration C
$CdCl_2$	.05 Mole (20 ml)	.1Mole (20 ml)	.2 Mole (20 ml)
K_2Te	.05 Mole (20 ml	.1Mole (20 ml)	.2 Mole (20 ml)

The temperature, concentration of precursor solution and pH used for deposition are tabulated in Table 2.

Table 2: Parameter Used for Deposition of Nanocrystalline CdTe Thin Films

Deposition parameter	Optimum value / item
Deposition time	120min
pH	11.2
Concentration of precursor	half A Normal B, double C concentration
Deposition temperature	45°C
Solvent	Deionised water

B. Characterization

The samples of CdTe thin film deposited onto glass substrates from different concentration of precursor solution were examined by means of X-ray diffraction (XRD) and (AFM) micrographs for their structural and morphological properties.

C. Photoeletrochemical Cell Studies

The configuration of PEC cell is a single glass vessel painted by black paint, using CdTe nanocrystalline film on ITO substrate as photo electrode, graphite as counter electrode and polysulphide solution as electrolyte. Photo-electrochemical (PEC) performance of cadmium telluride formed onto ITO was investigated.

The distance between working electrode and counter electrode was 2 centimetres. Photocurrent–voltage (I–V) characteristics of cadmium telluride photoelectrodes were measured with change in resistance using potentiometer in circuit, with 315 Lux light illumination intensity.

III. Results and Discussions

The thickness of the CdTe film was measured by weight difference method or gravimetric method, employing sensitive electronic microbalance taking bulk density of CdTe (6.02gm/cm^3).

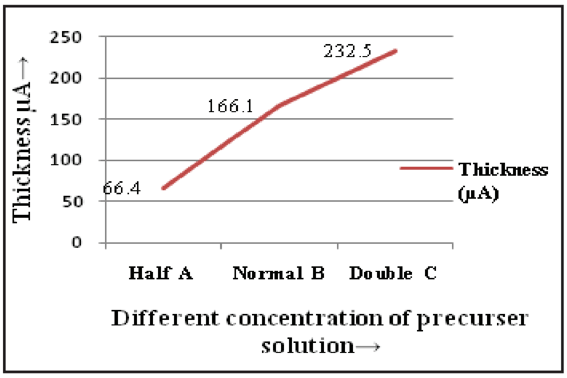


Fig. 1: Thickness of the Films as a Function of Concentration of Precursor Solution

The thickness of the deposited Cadmium Telluride thin film increases with concentration of precursor solution as shown in fig. 1. The increase in thickness with concentration of precursor solution could be due to the change in crystallite size and grain size accompanied with deposition time.

1. XRD Studies

In order to determine the size and to study the structural properties of the synthesized CdTe thin films, the XRD analysis was performed. The phenomenon of X-ray diffraction can be pictured as a reflection of the incident beam from the lattice plane. The X-ray diffraction patterns of nanocrystalline CdTe thin film was performed by using X-ray diffractometer ((XRD-SMART lab) - Rikagu, NIKON, Japan) using CuKα radiation with a wavelength, λ = 1•542 A°. At Centre for nanoscience and Nanotechnology Sathyabama University Chennai.

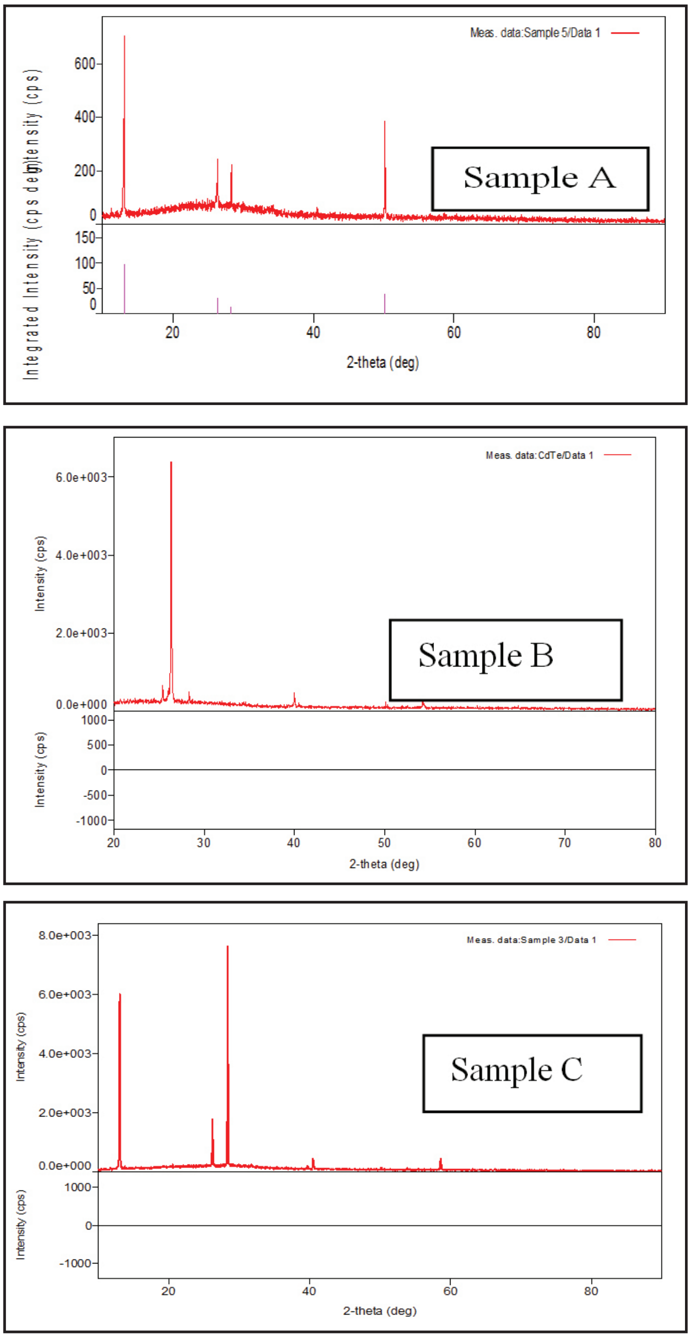


Fig. 2: [A][B] [C] X-ray Diffraction Pattern of Deposited CdTe thin film for half concentration A,normal concentration B, double concentration C of precursor solution respectively.

 ISSN : 2230-7109 (Online) | ISSN : 2230-9543 (Print)

The structural identification of CdTe films was carried out with X-ray diffraction in the range of angle 2θ between 10ºto 80º. Fig. 2 shows the XRD patterns for CdTe thin films. The structure of CdTe deposited is predominantly tetragonal and reasonably crystalline. PDF card number 9007154 is used for comparing the standard values with the experimental data. The well defined **(110), (101), (111), (200), (210) (220), (311)** and **(222)** peaks were observed in the XRD patterns due to CdTe crystals. The strong and sharp diffraction peaks indicate the formation of well crystallized sample. It can be seen that the major peak (111) at 2θ is strongly dominating the other peaks. The average crystal size of CdTe samples were calculated by using the Scherer's formula

$D = 0•9\lambda / \beta cos\theta$ (1)

Where:

D = Average crystallite size

λ = X-ray wavelength (1•542 Å)

β = FWHM of the peak

θ = Bragg angle.

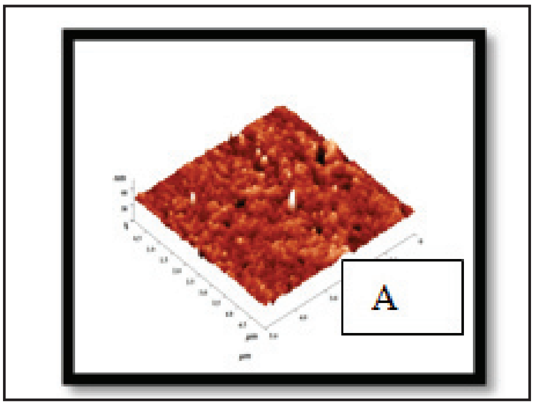
From the full-width at half-maximum of the diffraction peaks, the average sizes of the nanocrystallites have been calculated for various Concentration of precursor solution and given in table 3.

Table 3: Effect of Concentration of Precursor Solution on Particle Size

S.No.	Concentration of precursor solution	Particle Size
1	Half Concentration A	17.24 nm
2	Normal Concentration B	25.32 nm
3	Double Concentration C	30.30 nm

B. AFM Studies

Surface morphologies of films were measured using AFM. The microstructure and element composition of the films were analyzed using Atomic Force microscope (NTEGRA PRIMA NTMDT Ireland). At Centre for nanoscience and Nanotechnology Sathyabama University Chennai.



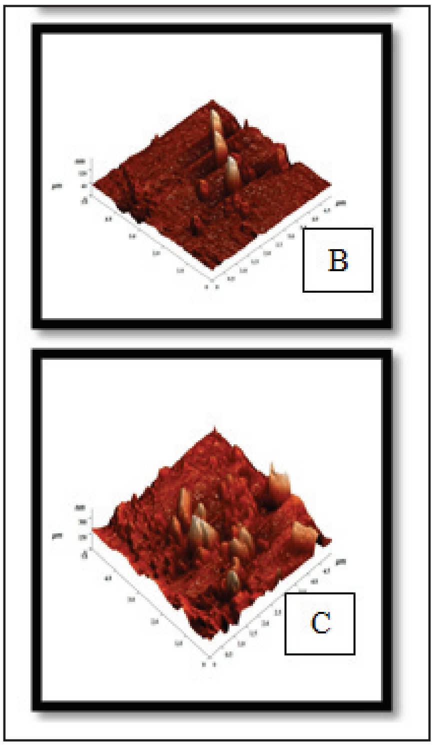


Fig. 3: [A], [B], [C] shows AFM 3D image confirming surface morphology of CdTe thin film for half A, normal B and Double C Concentration of Precursor Solution Respectively.

There appears agglomeration of particles in most of the cases as evident from the 3D Image (Fig. 3). The surface roughness is found to be 2.67867 nm 8.14745 nm 31.8745 nm. The surface roughness of the film is unavoidable because particles are spherical in shape. This observation reveals that the films are crystalline in nature. It is found that roughness of surface of electrode increases with concentration of precursor solution and is maximum with CdTe thin film photo electrode prepared with Double concentration C of precursor solution. It may be due to the formation of new bigger domed spherical grains.

3. Photovoltaic Studies

Photovoltaic response of the CdTe thin films was studies. The I-V characteristics are plotted for all the three CdTe film electrodes, prepared from different concentration of precursor solution. The light illumination used is 315 Lux and polysulphide solution serves as a redox to maintain the stability of the Cadmium telluride photo electrodes. Fig. 4 shows the I–V characteristics of solar cell for different CdTe thin films. The different behavior of I-V curve is obtained because the thickness as well as roughness of electrode surfaces increases with concentration of precursor solution. It is observed that the performance improves by increasing the concentration of precursor solution.

Table 4: Solar Cell Parameter

Sample	Temp(ºC)	Deposition Time	Short circuit Current Isc (mA)	Open circuit Voltage Voc(mV)	Fill Factor ff (%)	Efficiency η (%)
Half Concentration	45	2hrs	.032	75	.2466667	.855
normal Concentration	45	2hrs	0.034	110	.3379679	1.8275
Double Concentration	45	2hrs	0.038	126	.35554	2.46

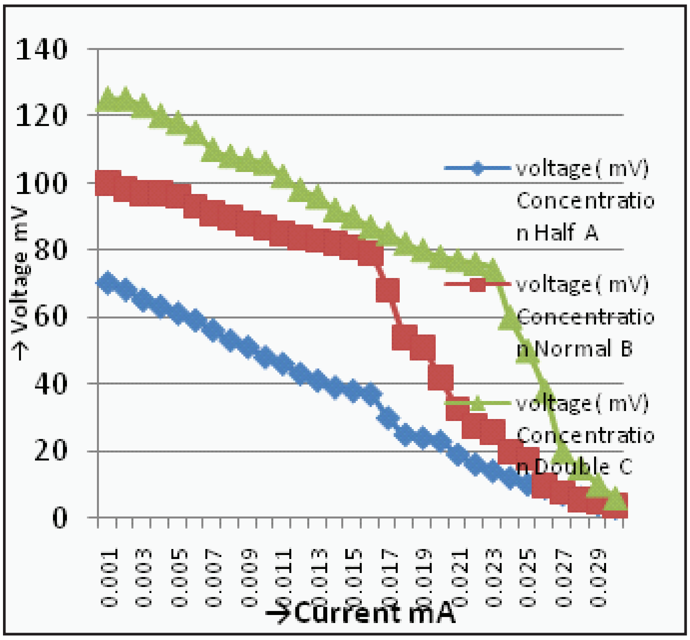


Fig. 4: I-V Characteristics of PEC Solar Cells for Photo Electrodes Prepared for Different Concentration of Precursor Solution

Observation shows that cadmium telluride electrode in solar cell is P -type. The solar cell parameters short circuit current (Isc), open circuit voltage (Voc). fill factor (FF) and efficiency (η%) are influenced by concentration of precursor solution (i.e. thickness) used for preparation of photoelectrodes.

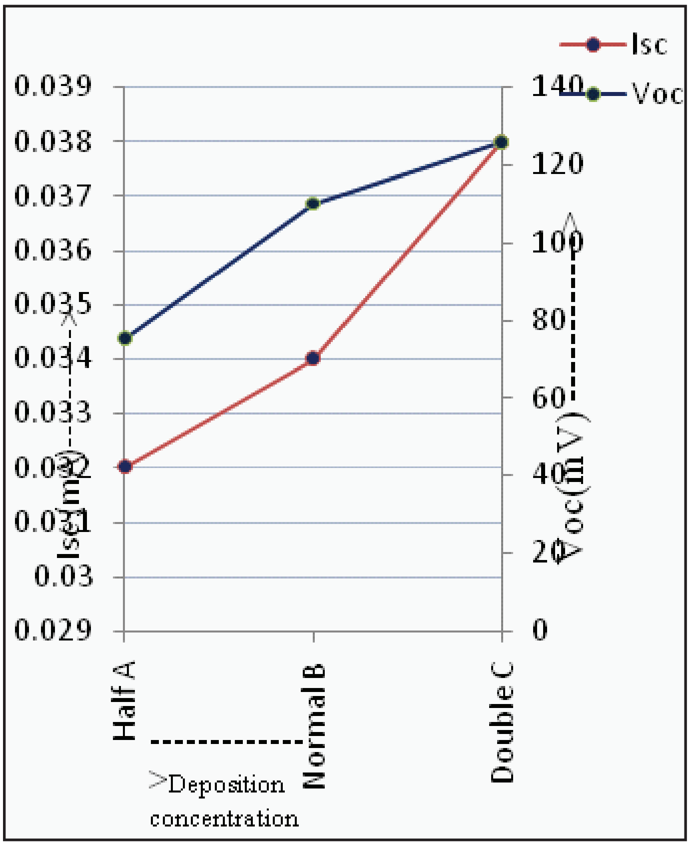


Fig. 5: Variation of Voc and Isc With Different Deposition Time of Photo Electrodes

Fig. 5 shows variation of solar cells parameters Voc and Isc for different concentration of precursor solution of photo electrodes. From the results it may be observed that Isc as well as Voc increases by increasing concentration of precursor solution.

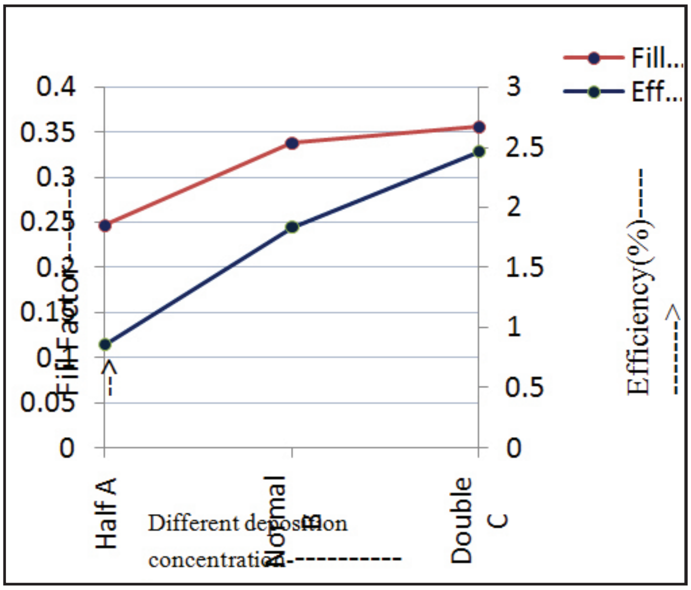


Fig. 6: Variation of Fill Factor and Efficiency With Different Concentration of Precursor Solution of Photo Electrodes

Fig. 6 shows variation of solar cell parameters fill factor and efficiency for different concentration of precursor solution of CdTe photo electrodes. The value of fill factor and efficiency increases with the concentration of precursor solution (i.e. half A, normal B, and double C) because the amount of deposited CdTe (i.e. thickness) increases. From these results we also see that solar cell efficiency as well as fill factor is maximum when electrodes are prepared with double concentration C of precursor solution.

IV. Conclusion

The chemically synthesized cadmium telluride thin film photo electrodes have been investigated for photovoltaic response in PEC cell.

The thickness of the Cadmium Telluride thin film increases with increase in concentration of precursor solution. The XRD shows the structure of CdTe is predominantly tetragonal and reasonably crystalline. PDF card number 9007154 is used for comparing the standard values with the experimental data. It is concluded from AFM that roughness of surface of CdTe thin film photoelectrode increases with concentration of precursor solution. A photoelectrochemical study confirms p-type conductivity. By increasing the concentration of precursor solution, Isc, Voc,fill factor and efficiency of solar cell increases. Hence it is suggested that the CdTe thin film on ITO substrate should be prepared from concentrated precursor solution for photoelectrodes in PEC cell .Further increase in concentration may be beneficial but there is some difficulty in obtaining proper solution.

V. Acknowledgement

The authors are thankful to the University Grants Commission, (U.G.C) for financial support through project no. (FN MS-209/106045/10-11/CRO) and Centre for nanoscience and Nanotechnology Sathyabama university Chennai (Tamilnadu) for characterization of samples.

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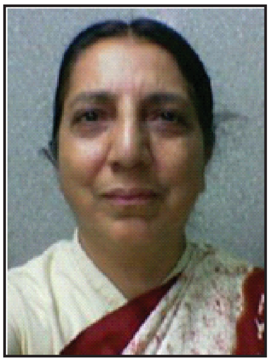

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