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Electrochemical Studies of Chemically Deposited $Cd_{1-x}Hg_xTe$ (CMT) Thin Films

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Abstract: ***Cd-rich Cadmium-mercury telluride (CMT) thin films have potential application as photovoltaic material especially at room temperature, owing to their high photosensitivity and better stability. The CMT ($Cd_{1-x}Hg_xTe$, $0 \le x \le 0.5$) thin films were therefore synthesized for diverse concentration of Hg^{2+}ions on conducting stainless steel substrates by a simple solution growth technique. The preparation parameters were finalized in the initial stages of the work and are used to prepare the CMT electrodes employed in these investigations. The photovoltaic cells were then fabricated in H-shaped cuvette using sulphide/ polysulphide electrolyte and a treated carbon counter electrode. The cells were characterized via the current-voltage and capacitance –voltage characteristics, photo, and spectral responses. The data were analyzed to determine various performance parameters viz. V_{ph}, I_{ph}, ff, η, n_d, n_L, V_{fb}, R_s, R_{sh} etc. A maximum short circuit photocurrent (I_{ph}) of 157 µA/cm^2 and open circuit photo potential (V_{ph}) of 495 mV have been observed for a CMT photoelectrode of x value equal to 0.1. The solar to electrical conversion efficiency and fill factor have also been found improved for this x value. The improvement in performance has been attributed to the modified properties of the photosensitive CMT electrodes.***

Keywords: CMT, electrochemical photovoltaic cell, photosensitivity, spectral responsivity

1. Introduction

The properties of mercury and cadmium telluride and their solid solutions are worth desirable for investigations because these materials have promising applications in a variety of electronic devices [1-5]. HgTe is widely investigated and best-known representative of mercury chalcogenides, which has a negative bandgap and has a number of properties different from those generally found for II-VI compounds. In particular, mean square displacements of vibrating mercury atoms are greater than the telluride atoms though Hg is heavier than Te. The reverse is true for CdTe and other II-VI compounds. The HgTe is therefore said to exhibit inverted band structure and can be grown as intrinsic and n or p- doped material [5]. It is therefore finding a lot of applications particularly as a constituent of various mixed crystals and quantum structures for optoelectronic devices. Another important II-VI material is CdTe. It is an ideal bandgap photovoltaic material with high absorption coefficient and band to band type of electronic transitions. It also can be grown as either n or p type material and hence has extreme importance in a variety of high performance electro-optic and optoelectronic device applications. It alloys well with the mercury telluride and therefore $Cd_{1-x}Hg_xTe$ is the most widely used material in mid infrared semiconductor optoelectronic devices and optical communications (at 1.3 and 1.55 µm) [5]. It has also been recommended as high performance solar cell material when it is cadmium rich [1]. A device consisting of thin cadmium mercury telluride on CdS may approach a solar to electrical conversion efficiency close to 11 % [1, 3] whereas a single crystal CMT of x value equal to 0.92 and 0.7, devised as a regenerative photoelectrochemical cell yielded an efficiency of 6 % [1, 3, 4]. We therefore, believe to be the first to fabricate this important class of material by a simple chemical route (apart from the cost involving, tedious, time consuming and requiring high process instrumentation techniques) developed in our laboratory and to employ it in the electrochemical photovoltaic detector applications.

2. Experimental Techniques

2.1 Method for Materials Synthesis

The chemical synthesis of the Cadmium Mercury Telluride (CMT) was carried out using a simple chemical bath technique [8, 9]. The method uses a beaker-bath consisting equimolar solutions of cadmium chloride, mercury chloride and sodium-tellurosulphite (obtained by a reflux action [9]). The bath was made using 10 ml (1M) cadmium chloride, varying quantity of mercury chloride (1M), and 33 ml (0.33M) sodium-tellurosulphite[8, 10]. First, 10 ml cadmium chloride was taken in a beaker and complexes with a sufficient quantity of 17N aqueous ammonia. 33 ml sodium tellurosulphite was added into the bath and then calculated amount of mercury chloride was mixed into the bath with a continuous stirring. The resulting reaction solution was than diluted to 200 ml by volume. Thoroughly cleaned glass and polished stainless steel substrates were assembled on a substrate holder and were fixed to a constant speed DC motor. The temperature of the bath was then raised to 80^{0}C using an oil bath whose temperature was maintained within ±0.2 ^{0}C. The motor was then positioned properly and substrates were rotated with 72 rpm in the bath. The reaction was allowed for 90 minutes and then samples were taken off the bath and washed several times with double distilled water and preserved in a dark desicator.

2.2 Fabrication and Characterization of the Electrochemical Cell

The H-shaped glass cell was designed in our laboratory and an electrochemical cell was fabricated using the above CMT films on stainless-still as the active photoelectodes, sensitized carbon as the counter electrode and various electrolyte systems as the conducting medium. Various cells were devised for different x values of the electrode and characterized through the current- voltage and capacitance-voltage characteristics, power output curves and photo and spectral responses. Voltages and currents were measured with the sensitive 6 ½ digit HP make multimeter and 4 ½ digit nanoammeter. Three electrodes system was employed to measure the junction capacitance under reverse bias. The capacitance measurements were performed with a 4 ½ digit Aplab LCR-Q meter for the range of reverse bias from 0 to 1 V. The photo response was examined under a variable input intensity of 5 mW/ cm^2 to 50mW/ cm^2. Input intensities were noted with a Lutron-LX-101 (Taiwan) Lux meter. Spectral studies were undertaken for the range of wavelengths from 700 nm to 1300 nm with a photo spectrometer.

3. Results and Discussion

Electrochemical photoactive properties of $Cd_{1-x}Hg_xTe$ thin film electrodes are presented in this paper. The as-grown films were synthesized using an universal chemical bath deposition process and are crystalline in nature, tightly adherent to the substrate support, rough in appearance and diffusely reflecting [6, 7]. The color of the samples changed from grayish-white to gray-black as Hg-concentration in the film was increased. This has indicated that Hg can be easily incorporated in the lattice of CdTe. The compositional analysis was therefore carried out on these films, which strengthens the above observations. Thus the terminal layer thicknesses of these layers were measured by an interferomatric technique. It has been seen that the layer thickness decreased with addition of Hg-concentration in CdTe. This is shown in Fig.1. The details pertaining to the growth mechanism and kinetics have already formulated as a research article [6, 7].

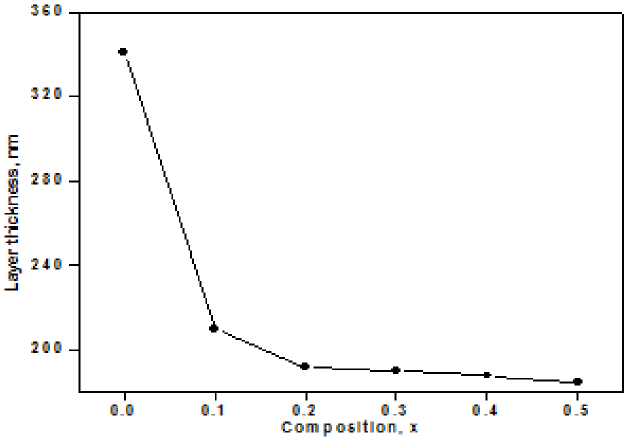

Figure 1: Variation of the terminal layer thickness with composition, x

First, the electrochemical cells were fabricated using these thin films as the photosensitive electrodes and different electrolyte systems and were illuminated by a white light source of 20 mW/cm^2. The short circuit photocurrents (I_{ph}) and open circuit photo potentials (V_{ph}) were then measured. It is found that the polysulphide electrolyte is a better choice for $Cd_{1-x}Hg_xTe$ and rest of the studies was then carried using polysulphide electrolyte as an optimum choice. Figure 2 represents this optimum choice of an electrolyte. The junction quality factors under illumination were then determined from the slopes of V_{ph} versus ln F_L were therefore constructed and these variations. The various values of n_L are listed in table-1.

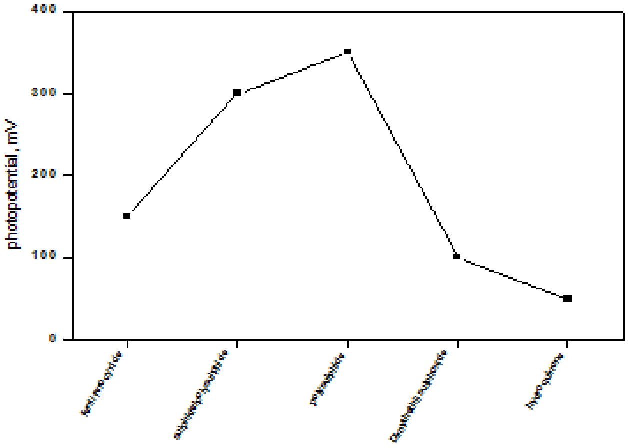

Figure 2: Choice of redox electrolyte for Cd1-xHgxTe by the measurement of Vph

An important characteristic of a photoelectrochemical cell is its power output curve. These curves were obtained for all the cell configurations and their diagrammatic representation is shown in Figure 3.

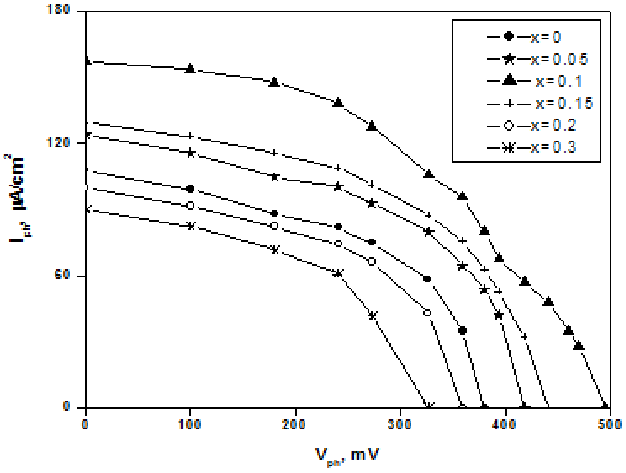

Figure 3: Power output characteristics of few of the typical cells

The curves deviated from their rectangular shape and rounded off due to the series resistance effect. The different performance parameters such as $V_{ph,}$ I_{ph}, η%, ff%,, R_s, and R_{sh} were then determined and are cited in table-1. It appears that the conversion efficiency, η and form factor, ff improved significantly by the addition of Hg (0.1%) in to CdTe. Obviously, for this cell, I_{ph} and V_{ph} are larger that enhanced and ff. Compared to the solid-solid junction, performance of these cells is poor. The reasons are many: the materials resistance that forms series resistance of a cell, dark color of the electrolyte and absence of the post preparative treatments are some of the adverse. The enhancement in I_{ph} and V_{ph} can be understood from the increase in crystallite size and solar photon absorption volume and decrease in materials resistance due to Hg incorporation in CdTe [8, 9]. Table-1 shows composition dependence of the crystallite size and materials resistance (R_s) which is self explanatory of the performance. As regards the solar absorbance, it has been found that the photon absorbance coefficient (α) is highest of all for a cell with the electrode composition x= 0.1. The spectral response studies were also carried out for these cells. I_{ph} was noted for different incident wavelengths. It has been seen that the absorption edge shifted towards higher wavelength. The enhancement in the short circuit photocurrent, I_{ph} can be correlated directly to the decreased series resistance R_s, of a cell and increased absorption by the electrode material. In this case R_s decreased by approximately an order and can be explained as usual [6, 7]. The room temperature electrical conductivities of these materials were therefore measured. The electrical conductivity (σ) vs composition (x) spectra are shown in Figure 4.

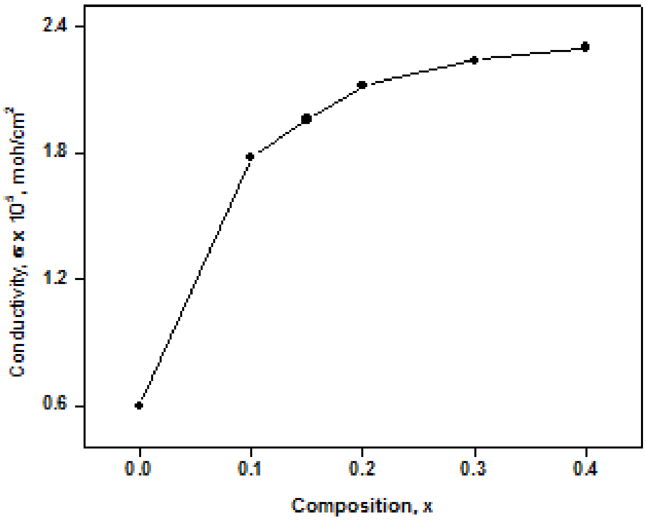

Figure 4: Electrical conductivity vs composition

It is seen that the bulk conductivity (which contributes mainly to R_s of a cell) increased with x up to x= 0.1 and then it becomes insensitive to further increase in x [11]. The conductivity modulation can also be correlated with the decreased bandgap of $Cd_{1-x}Hg_xTe$ films and the enhanced crystallite size. The crystallite sizes were therefore determined for all the compositions by an X-ray diffraction technique.

4. Conclusions

The electrochemical photovoltaic cells were formed and the behavior of these cells was examined with a special emphasis given to the photoelectrode composition, x. The dark I-V and C-V characteristics showed presence of the recombination centers surface states at the electrode / electrolyte interface. The PEC cell performance under light excitation is found to be optimum for a cell formed with electrode composition, x = 0.1 and is solely due to the increased flat band potential, increased photoelectrode absorption, improved crystalline structure of the photoelectrode material and decreased series resistance of a cell.

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References

[1] M. Neumann-spallart and G. Tamizhmzni, C.Levy-Clement and N.Boutry-forveille, “Physical properties of electrochemically deposited cadmium mercury telluride films” Thin Solid Films, **169** (1989) 315

[2] M.A.Herman and. Pessa, “$Hg_{1-x}Cd_xTe$-$Hg_{1-y}Cd_yTe$ ($0 \le x$, $y \le 1$) heterostructures: properties, epitaxy, and applications”, J.Appl. Phys., **57** (1985) 2671

[3] W.E. Spicer, D.J.Friedman and G.P.Carey, “The electrical properties of metallic contacts on $Hg_{1-x}Cd_xTe$”, J.Vac. Sci. Technol. (1988) 2746

[4] C.Levy-Clement, R. Triboulet and R.Tenne, “Photoelectrochemical properties of the Cdrich $Cd_xHg_{1-x}Te$ alloy”, Sol. Ener. Mat. 17 (1988) 201. A 6(4)

[5] M.H. Rais, C. A. Musca, J. Antoszewski, J. M. Dell, B.D. Nener and L.Faraone, “Characterization of dark current in novel Hg1~xCdxTe mid-wavelength infrared photovoltaic detectors based on n-on-p junctions formed by plasma-induced type conversion ”, J. Cry, Growth, 214/215 (2000) 1106

[6] S. H. Mane, V.S. Karande, V.B. Pujari, J.S. Dargad and L.P.Deshmukh, “A study of cadmium mercury telluride (CMT) thin films structures: Some physical observations and Characteristics”, J. Mat. Sci: Mat. In Elect., 16 (2005) 733

[7] S. H. Mane, V.S. Karande, V.B. Pujari, J.S. Dargad and L.P.Deshmukh, “Studies on Nanocrystalline (Cd, Hg) Te Detector Thin Films” National Seminar on Science and Technology of Thin Films (NSSTTF), 16-17 Oct.2004, R.S. College, Latur, M.S. India

[8] P.D.More and L.P.Deshmukh, “Photoelectrochemical investigations of n-$CdSe_{1-x}Te_x$ thin film electrodes”, Mat. Chem and Phys.80 (2003)586

[9] V.B. Pujari, S. H. Mane, V.S. Karande and L.P.Deshmukh, “Mercury-CdmiumSelenide thin film layers: structural, microscopic and spectral response studies, ” Mat. Chem. Phys. 83 (2004) 10

[10] S. Chandra Photoelectrochemical Solar Cells, : (ed.) D.S. Campbell, Gordon and Breach Science publishers, New York, 1985

[11] V.B. Pujari, V.B. Gaikwad, E.U. Masumdar, P.D.More and L.P.Deshmukh, “An electrochemical visible radiation detector with pseudo-binary Hg_xCd_{1-x} Se thin films”, Turk. J. Phys.” 26 (2002) 407

Table 1: The performance parameters of the various n-$Cd_{1-x}Hg_xTe$ ($0 \le x \le 0.5$) electrolyte cells

x	**n_L**	**V_{ph} [mV]**	**I_{ph}[µA/cm^2]**	**η**	**ff%**	**R_s [Ω]**	**R_{sh} [KΩ]**	**$V_{\Phi B}$ [V]**
0	1.85	375	108	0.07	38	1625	7.03	0.54
0.005	1.69	390	115	0.09	39	1470	7.14	0.60
0.01	1.56	405	118	0.1	39.7	1250	7.50	0.67
0.05	1.45	415	124	0.12	40	1041	7.81	0.78
0.075	1.35	470	147	0.14	42	751	8.68	0.88
0.1	1.27	495	157	0.17	43	650	9.38	0.96
0.15	1.31	420	132	0.11	40	873	8.13	0.82
0.2	1.4	355	100	0.06	39	1654	6.72	0.74
0.3	1.5	325	90	0.05	38	1700	6.52	0.64
0.5	1.63	310	82	0.04	37	1815	6.20	0.51

Author Profile

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