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Electrodeposited heterojunctions based on cadmium chalcogenide, CdX (X = S, Se, Te) and polyaniline

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Abstract We have fabricated heterojunctions based on all-electrodeposited cadmium chalcogenides CdX (X = S, Se, Te) and polyaniline thin film. Cadmium chalcogenide films were deposited onto low cost stainless steel substrate using potentiostatic mode. Over Cd chalcogenide film, polyaniline was deposited potentiodynamically. The junctions were heated at 353 K for 20 min and junction current–voltge (*I–V*) and capacitance–voltage (*C–V*) plots were studied. From *I–V* plots, junction ideality factors for heterojunction based on CdS, CdSe and CdTe were calculated to be 1.55, 1.60 and 1.89, respectively. Studies on C-V plots revealed flat band potentials for heterojunction based on CdS, CdSe and CdTe to be + 0.4, + 0.45, and + 0.64 *V*, respectively.

Introduction

Literature survey on heterojunction devices fabricated so far, highlights mostly the fabrication of junction using various methods in combination such as, vacuum evaporation, chemical vapour deposition, molecular beam epitaxy, liquid phase epitaxy, vapour phase transport, flash evaporation, sputtering etc. These methods are highly expensive, time consuming and complicated. The n–p and p–n anisotype inorganic semiconductor heterojunctions eg., Ge/Si, Ge/GaAs, Ge/PbS, Si/GaP, Si/PbS, GaP/GaAs, CdS/CdTe, CdS/PbS, CdSe/ZnSe, ZnSe/ZnTe, etc. studied so far, are the minority carrier devices [1]. Most studied n-CdS/p-CdTe junction has ideality factor of about 1.50 at 324 K [2]. Also SiC/ Si heterodiodes have been fabricated by Yih et al. [3]. The CdS/Au diode, constructed by Patel et al. [4] has two ideality factors, one in low and other in high forward bias regions. Being low cost and having flexible electronic applications, recently in junction device area, much work is going on the devices fabricated by organic polymers with the replacement of metal and inorganic semiconductors [5]. Some attempts have been made, to fabricate the photovoltaic organic/inorganic semiconductors based heterojunction. These include $CuInSe_2$/ polypyrrole or polyaniline heterojunctions [6], GaAS/ polythiophene [7], and CdS/ poly(3-methylthiophene) [8]. The polyaniline/silicon heterojunctions reported by Laranjeira et al. [9] was fabricated by spin coating of polyaniline onto single crystalline silicon substrate. The electrical properties of various metals (Al/In/Sb/Sn)/polymer (N-methylaniline) structures were studied by Syed and Saraswathi [10]. The junctions were fabricated over electrodeposited polymer film by vacuum evaporated Al, In Sb and Sn. The values of ideality factors were in the range 1.30–9.65. The quality of the junction formed between two semiconductors is a consequence of the methods used to fabricate it. Among all the physical and chemical methods used to deposit semiconductor thin films, electrodeposition has some advantages: It is easy, economical, low temperature process and particularly suited to fabricate heterojunction solar cell [11]. The growth rate of the film can be controlled by depositing film in potentiostatic, galvanostatic or potentiodynamic modes. The potentiodynamic mode has advantages over potentiostatic or galvanostatic methods that the direction of potential is reversed at the end of each scan. Also deposition of polyaniline by

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Table 1 Preparative conditions of cadmium chalcogenide films

Sr. No	Thin film	Bath composition	pH of bath	Deposition voltage V/SCE	Deposition time (min)
1	CdS	0.05 M (1 cc) $CdSO_4$ + 0.5 M (9 cc) $Na_2S_2O_3$ + 0.1 M (10 cc) EDTA (tetrasodium salt)	9.5	–1.29	20
2	CdSe	1 M (10 cc) $CdSO_4$ + 0.05 (10 cc) SeO_2	3.0	–0.8	20
3	CdTe	0.05 M (10 cc) $CdSO_4$ + 0.01 M (10 cc) Na_2TeO_3 + 0.1 N (10 cc) $HClO_4$	2.0	–0.75	20

potentiodynamic method has the advantage of short exposure time at anodic potential and the reduction of unreacted oxidized species during cathodic scan [12]. The essence of present work lies in a simple deposition method employed, as well as the ideality factors are comparable with those obtained so far with other deposition methods.

In this paper, we report on fabrication of cadmium chalcogenide/polyaniline heterojunction based on all-electrodeposition method. Cadmium chalcogenide films were deposited on stainless steel substrate using potentiostatic mode of deposition. Over cadmium chalcogenide films, polyaniline was deposited using potentiodynamic mode.

Experimental

Electrodeposition of CdX (X = S, Se, Te) on stainless steel substrate has been carried out from aqueous electrolyte solution bath from potentiostatic mode, using convensional three electrode cell with graphite as a counter electrode and saturated calomel electrode (SCE) as a reference electrode. Depositions were carried out at room temperature using potentiostat EG & G Princeton Applied Research Model 263-A. The preparative conditions for cadmium chalcogenide films are shown in Table 1.

On the cadmium chalcogenide films, polyaniline thin film was deposited from monomer solution consisting of 4cc of aniline in 10% H_2SO_4 solution. The deposition of polyaniline was carried out from potentiodynamic mode at room temperature. Deposition conditions for polyaniline thin film on various chalcogenide are given in Table 2.

The so formed junctions were heated at 353 K for 20 min to improve the junction performance. The 1 × 1 cm^2 junction area of polyaniline was defined and using aluminium front contacts, the junction current–voltage (*I–V*) plots were obtained. The nature of contacts between aluminum and polyaniline was found to be ohmic in the voltage range ± 1.5 V.

Table 2 Deposition conditions of polyaniline thin film on cadmium chalcogenide

Sr. No	Substrate	Scanning voltage range (versus SCE)	Voltage scan rate (mV/s)
1	CdS	–0.2 to + 1.8	20
2	CdSe	–0.2 to + 2.0	100
3	CdTe	–0.2 to + 2.0	50

Results and discussion

The X-ray diffraction patterns of cadmium chalcogenide films, CdX (X = S, Se, Te) are shown in Fig. 1(a–c). The X-ray diffraction studies revealed that all the three chalcogens are polycrystalline with hexagonal phase. Fig. 1d shows the XRD pattern of polyaniline film. Polyaniline exhibited amorphous nature. Similar type of results for polyaniline is reported by Murugesen and Subramanian [13].

Fig. 2(a–c) shows the scanning electron micrographs of CdS/polyaniline, CdSe/polyaniline and CdTe/polyaniline junction, respectively. Morphology of Cd chalcogenides are different from polyaniline morphology. The SEM showed the information of diffusion free junction.

The *I–V* characteristics of cadmium chalcogenide/polyaniline junction are shown in Fig. 3(a–c). The dependence of current on voltage is exponential which is given by the diode equation, $I = I_0\ (\exp^{qV/nKT}–1)$ where I_0 is the reverse saturation current and n is the junction ideality factor. The characteristics exhibited expected asymmetry and showed that Cd chalcogenide/polyaniline heterojunctions can function as a diode.

Fig. 4(a–c) shows ln (*I*) versus *V* plots for junctions in the forward bias region. Linear nature of plot was used for the estimation of junction ideality factors. From the *I-V* characteristics various electrical junction parameters of cadmium chal./polyaniline junction were obtained and shown in Table 3.

Fig. 5(a–c) shows the plots of $1/C^2$ versus voltage V, for cadmium chalcogenide/polyaniline junctions. Heterojunction have shown linear variation of C^{-2} with V indicating the formation of an abrupt heterojunction [1]. Intercepts of plots on voltage axis determine the flat band potential value of junctions as mentioned in Table 3.

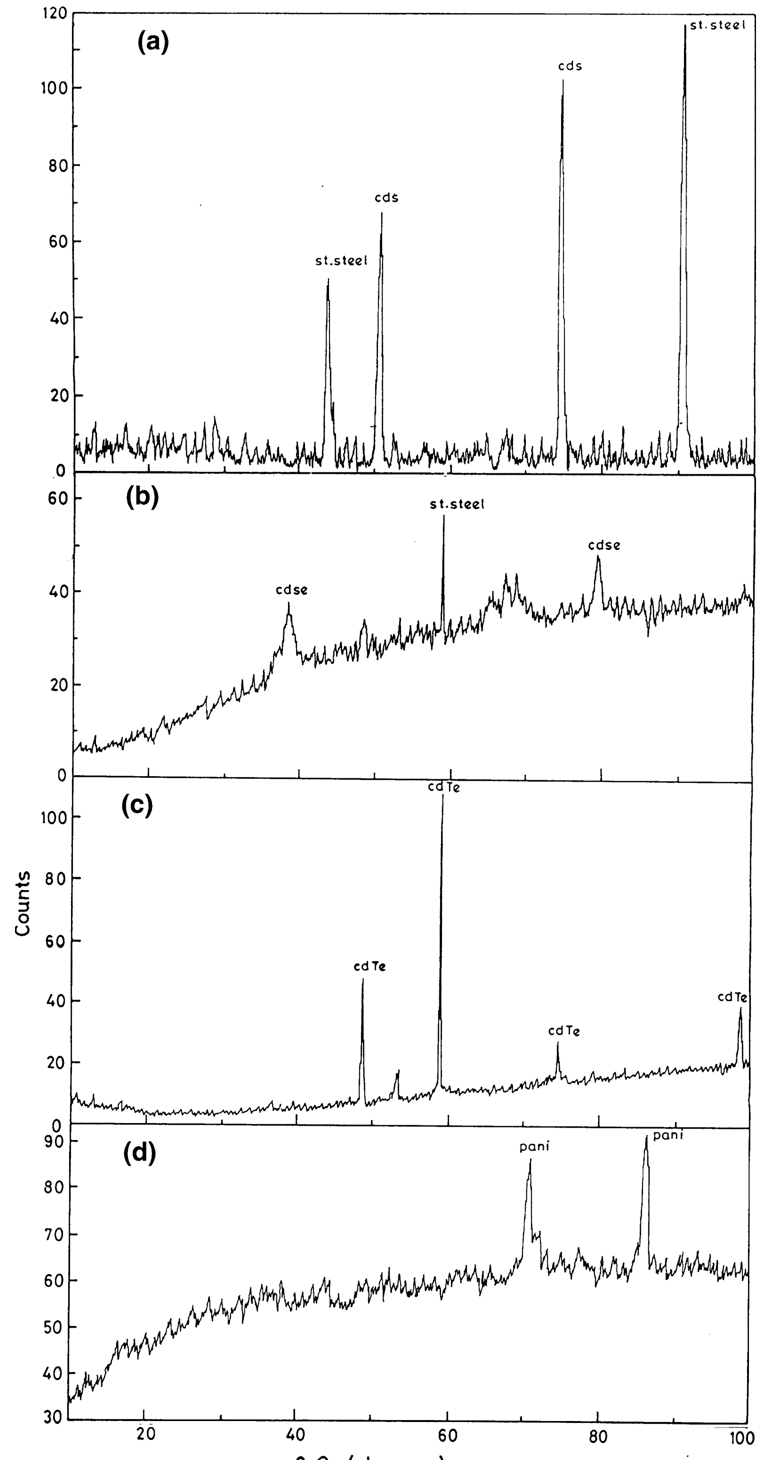

Fig. 1 The X-ray diffraction patterns of electrodeposited (**a**) CdS, (**b**) CdSe, (**c**) CdTe and (**d**) polyaniline (pani) thin films on stainless steel substrate. The St. Steel substrate peaks are also shown in figure

Conclusions

The cadmium chalcogenide/polyaniline junctions are formed using all-electrodeposition method. The CdX (X = S, Se, Te) showed rectifying behaviour. Junction ideality factors for were found in the range of 1.5–1.9. These ideality factors are comparable with those reported earlier for inorganic–organic based semiconductor junctions. The flat band potentials were found in between + 0.40 and + 0.64 *V*.

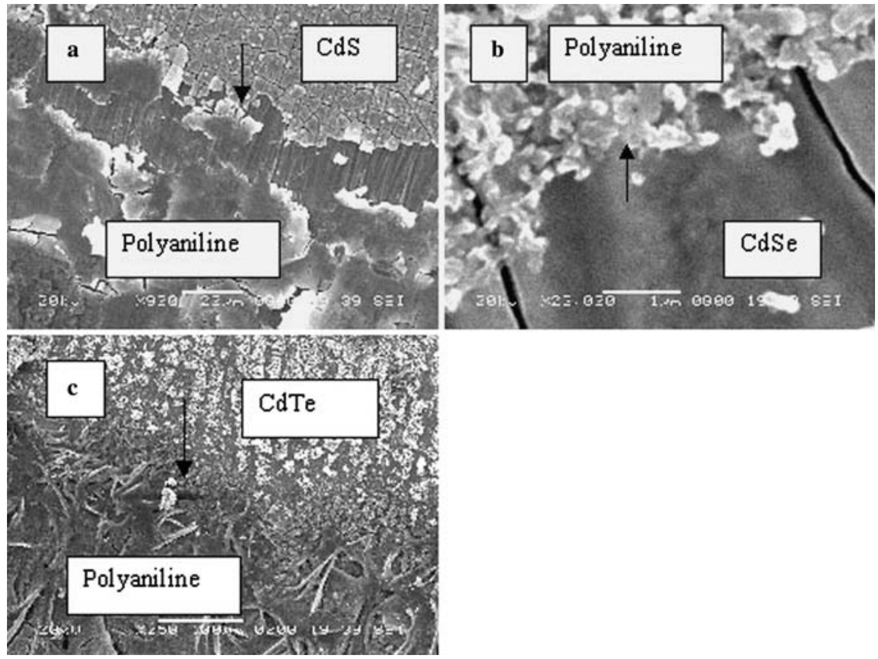

Fig. 2 Scanning electron micrographs of, (**a**) CdS/polyaniline, (**b**) CdSe/polyaniline, and (**c**) CdTe/polyaniline heterojunctions. The arrow shows interface

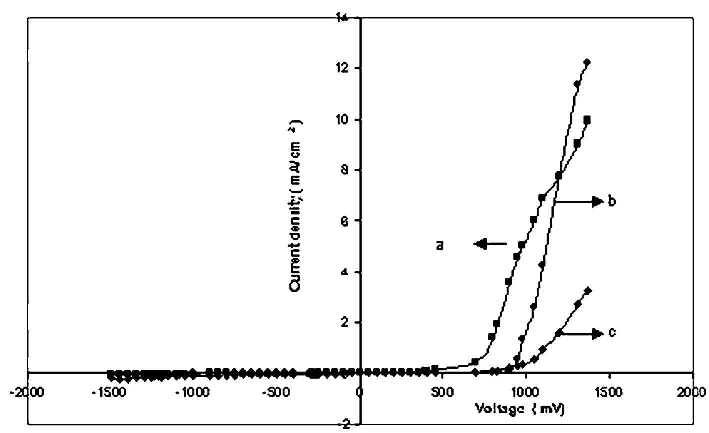

Fig. 3 The current versus voltage plots of cadmium chalcogenide/polyaniline junctions: (**a**) CdS/polyaniline, (**b**) CdSe/polyaniline, and (**c**) CdTe/polyaniline

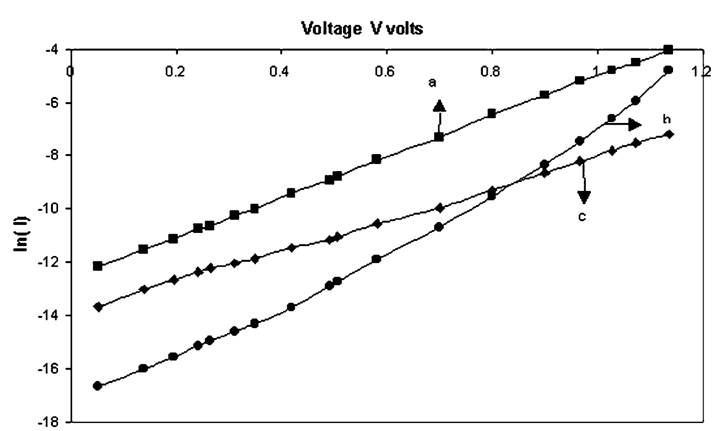

Fig. 4 The ln(I) versus V plots of cadmium chalcogenide/polyaniline junctions: (**a**) CdS/polyaniline, (**b**) CdSe/polyaniline, and (**c**) CdTe/polyaniline

Table 3 Various electrical-junction parameters of cadmium chalcogenide/polyaniline heterojunctions

Sr. No	Junction	Knee voltage, (V)	Static resistance (()	Dynamic resistance (()	Junction ideality factor	Flat band potential (V)
1	CdS/polyaniline	0.2	30	220	1.56	0.40
2	CdSe/polyaniline	0.5	37	288	1.60	0.45
3	CdTe/polyaniline	0.7	185	1576	1.89	0.64

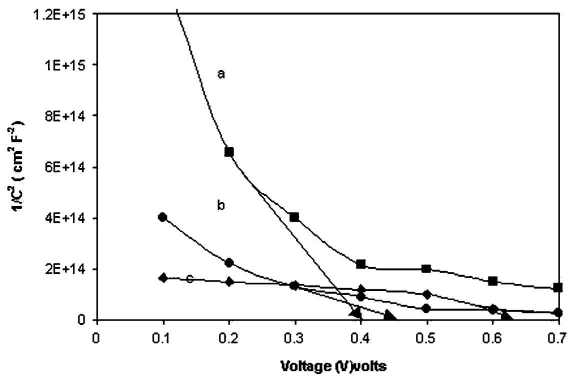

Fig. 5 The $1/C^2$ versus V plots of cadmium chalcogenide/polyaniline junctions: (**a**) CdS/polyaniline, (**b**) CdSe/polyaniline, and (**c**) CdTe/polyaniline

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