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Influence of Silicon Nanoparticle on the Electrical Properties of Heterostructured CdTe/CdS thin films based Photovoltaic Device

A. A. Faremi[a,*], S. S. Oluyamo[b], K. D. Adedayo[b], Y. A. Odusote[b], O. I. Olusola[b]

[a]*Department of Physics, Federal University, Oye-Ekiti, Nigeria*
[b]*Federal University of Technology, Akure, Nigeria*

Abstract

This paper presents the influence of silicon nanoparticles at the interface of heterostructured Cadmium telluride and cadmium sulfide thin films based photovoltaic device with improved electrical parameters leading to tremendous improvement in CdS/CdTe thin film based solar cells performance. The films of CdTe, CdS and Si were electrodeposited using electrodeposition technique to form a heterostructured CdTe/Si/CdS/FTO. The films respective structural properties were also examined using X-ray Diffractometer (XRD) before forming a heterostructured material. The heterostructured CdTe/Si/CdS/FTO and the structure without the inclusion of silicon nanoparticle were examined using electrometer for the extraction of electrical parameters such open circuit voltage (V_{OC}), short circuit current density (J_{SC}), and fill factor (FF). Although a large body of experimental results are available to date on the optoelectronics properties of the materials. However, there is relatively low research studies or works on the electrical properties of the materials. Therefore, we formed heterostructured based photovoltaic device and characterized the structure to determine useful electrical properties. The value obtained for V_{OC}, J_{SC} and FF are 418 mV, 25 mA/cm^2 and 0.72 which are indicative of pin holes free semiconductor materials and no leakage path emerging from high-grade materials used in the deposition of heterostructured CdTe/Si/CdS.

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Keywords: Silicon nanoparticles, Electrodeposition technique, Heterostructured based photovoltaic, Electrical properties

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1. Introduction

The use of p-type CdTe, n-type CdS and transparent conducting substrates such as fluorine doped tin oxide and indium doped tin oxide for the formation of heterostructured CdTe/CdS based solar cells have received considerable attention because of their notable performance in energy conversion devices [1-3]. The suitability of CdS thin film as a good window layer material capable of providing excellent receptive surface to absorber layer materials such as p-type cadmium telluride (CdTe), p-type copper indium selenide (CuInSe2), etc is owned to its high electron affinity [3]. Despite the potential of CdS in the formation of heterojunction based solar cells, there is need to treat its surface for better receptive surface which offer better improvement on the electrical parameters of the photovoltaic solar cells [4-6]. CdTe thin film as one of the primary candidates in the field of photovoltaic technology has gained worldwide prominence owning to its near ideal bandgap energy of 1.45 eV for the absorption of photons [6]. Interdiffusion of tel-

*Corresponding author tel. no: +2347033712587
Email address: abass.faremi@fuoye.edu.ng (A. A. Faremi)

lurium as a dopant in CdTe has been reported as a hindrance to the performance of CdTe based devices [7]. However, a lot of improvement have been made to prevent such as an inter-diffusion such as post-heat treatment of the films surface in the presence of cadmium chloride or oxygen [6], [8], [9]. Silicon thin film as a leading and the most building block for electronics has been report being a useful material to set an enabling environment for CdTe/CdS based solar cells [7]. We therefore use silicon nanoparticles as a preventive measure to inter-diffusion of tellurium since we aimed at forming heterojunction of CdTe/CdS. The films of CdTe, CdS and Si have been prepared by various techniques, including sputtering, spray-pyrolysis, chemical bath deposition, Sol-gel, close space sublimation, ion implantation and electrodeposition [1], [2], [10-12]. Among the various techniques available for the synthesis of these materials, electrodeposition and sol-gel techniques have been reported as viable techniques over other processes because of their simplicity in term of material growth [13-15]. However, in a typical sol-gel technique, the chosen reagents for a thin film need to undergo series of hydrolysis and polymerization reactions to form a solution bath [16]. The series of process require in the formation of solution bath make the technique to be more less cost-effective than electrodeposition technique. The technique has also gained research attention due to its possibility of scaling down bulk Silicon to either thin film or nanoparticles [17], [18]. In our study, we employed electrodeposition in the synthesis of the heterostructured CdTe/Si/CdS because of its relatively simple, easy, robust, easily scalable, bath self-purification and economically viable for large area production of photovoltaic devices [4], [19], [20].

2. Materials and Method

The film of CdS sourced from the solution of high-grade Cadmium Sulphate ($3CdSO_4.8H_2O$, 99%) and thiourea ($(CS(NH_3)_2$, 99%) without further purification was electrodeposited at a cathodic potential of 1400 mV on a thoroughly degreased conducting FTO/substrate of 3.2 by 3 cm^2 in dimension. After deposition, the material was subjected to curing at substrate temperature of 400^o C in 20 minutes and further purified in deionized water so that the surface could provide a perfect receptive surface for the other materials since we aimed at forming a heterostructured device. Silicon powder of 2 grams by weight was dispensed in 500 ml beaker containing 400 ml of deionized water and magnetically stirred for 2hrs. The electrolytic bath of silicon powder was electrodeposited potentiostatically at cathodic potential of 1000 mV on the deposited CdS. The structure of Si/CdS/FTO was also further cured at the same substrate temperature and washed thoroughly to remove possible undissolved particles on the surface to enable proper adherent of CdTe film sourced from the solution of high-grade Cadmium Sulphate ($3CdSO_4.8H_2O$, 99%) and tellurium dioxide (TeO_2, 99%). The electrolytic bath of CdTe, CdS and Si was adjusted and controlled using ammonium solution and pH probe. The pH value of the bath was 2.0 since the employed technique is favourable in acidic medium. Deposition took place at bath temperature of 80 ^{o}C in 60 minutes using working electrode with carbon as counter electrode. The films of CdTe, CdS, Si, the heterostructure of CdTe/Si/CdS/FTO and structure without the inclusion of silicon was also fabricated. The structure was examining for their structural and electrical properties using XRD and Electrometer probe. The particle crystallite size and the electrical parameters of the electrodeposited structure were extracted using equation 1-5

$$D = \frac{K\lambda}{\beta cos\theta} \tag{1}$$

where λ is x-ray wavelength in A°, K is a Scherrer constant (K=0.9), β is measured at half-maximum of the diffraction peak and θ is the Bragg's angle and D is the particle size or crystalline size.

$$\eta = \frac{P_{max}}{P_{in}} = \frac{V_m I_m}{P_{in}} \tag{2}$$

Where P_{max} is the maximum power out, P_{in} is the maximum power input (A solar simulator made from a 25 W incandescent light bulb was employed for this. The distance between the bulb and the surface of the cells was approximately 9.2 cm, which good enough for maximum radiance without significant heat transfer. The radiance intensity of the simulator used, considering sample distance from source as 9.2 cm was estimated at 220 W/m^2.), V_m is the maximum voltage power and I_m is the maximum current power

$$FF = \frac{P_{max}}{V_{oc} I_{sc}} = \frac{V_m I_m}{V_{oc} I_{sc}} \tag{3}$$

Where FF is the fill factor, V_{OC} is the open circuit voltage and I_{SC} is the short circuit current

The conversion efficiency can also be estimated by combining equation 1 and 2 to form equation 3

$$\eta = \frac{FF \times V_{oc} \times I_{sc}}{P_{in}} \tag{4}$$

It is important to note the relationship between J_{sc} and I_{sc} as the two parameters are often used.

$$J_{sc} = \frac{I_{sc}}{A} \tag{5}$$

Where A is the surface area of the heterostructured CdTe/Si/CdS which is estimated as 0.000096 m^2.

3. Result and Discussion

3.1. Structural characterization of CdTe, CdS thin films and Si nanoparticle

Figure 1 reveals eight basic peaks (111), (210), (211), (220), (222), (321), (411) and (420) with their corresponding diffraction angles 22.71^o, 28.01^o, 30.00^o, 37.00^o, 48.80^o, 50.00^o, 57.88^o and 60.24^o. The different peaks as observed in the XRD pattern of CdTe, CdS and Si indicated structural transformation from single phase to polycrystalline. There is no noticeable broad hump in the structures of polycrystalline CdTe, CdS and Si. Figure 2 reveals similar structural transformation with six basic

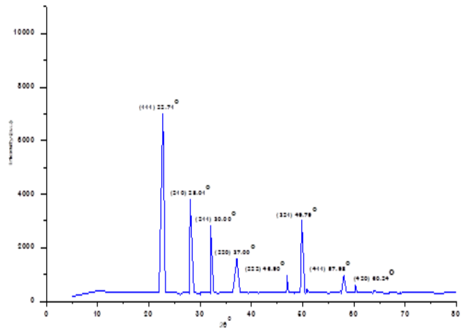

Figure 1. XRD plot for cadmium telluride thin film prepared using 1400 mV cathodic deposition technique, with peaks characteristics of polycrystalline cadmium telluride

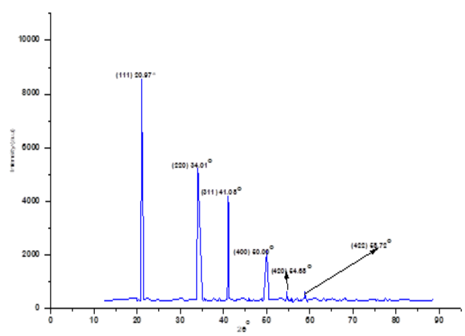

Figure 2. XRD plot for cadmium sulfide thin film prepared using 1400 mV cathodic deposition technique, with peaks characteristics of polycrystalline cadmium telluride

peaks (111), (220), (311), (400), (420) and (422), as a function of diffraction angles 20.97^o, 34.01^o, 41.08^o, 50.00^o, 54.68^o and 58.72^o. In Figure 2 and 3, three prominent peaks that's (111), (220) and (311) are observed which holds potentiality to polycrystalline cadmium sulfide (CdS) thin films and Silicon (Si) nanoparticles [21], [22]. Peak 111 as a dominant peak in both Figures 1, 2 and 3, revealed the preferred orientation of the structures being the most intense peak which is also an indication of particles crystallization (highly and randomly oriented) and zinc blende structure. The full width at half maximum of CdTe CdS and Si were obtained by broadening most intense peak through a gaussian fitting which was used to determine the particle crystallite size using Sherer's equation. The estimated particle crystallite size of CdTe, CdS and Si are 11.98, 14.08 and 89 nm respectively. The estimated particle crystallite sizes of both CdTe, CdS and Si agreed with the previous work [21], [22], [24], [25].

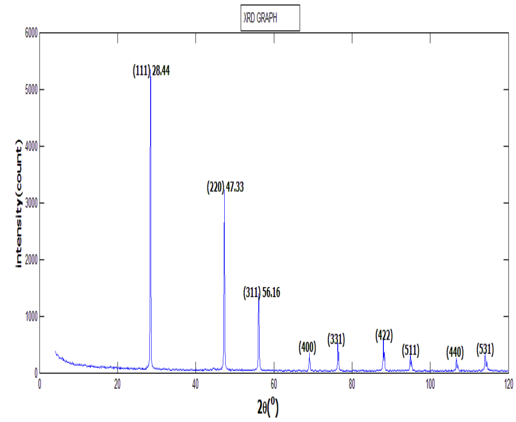

Figure 3. XRD plot for electrodeposited silicon nanoparticles prepared using 1000 mV cathodic potential, with peaks characteristics of polycrystalline silicon

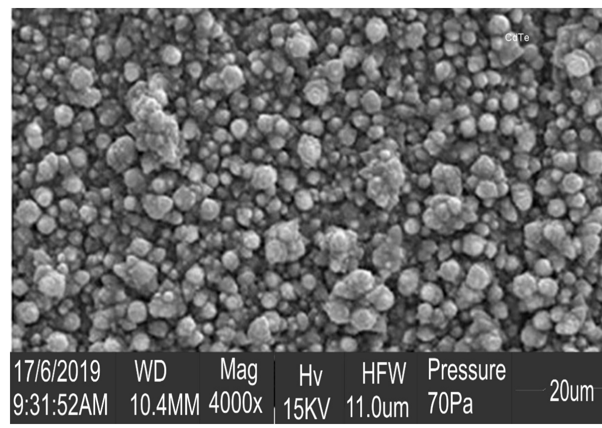

Figure 4. SEM micrograph of electrodeposited CdTe thin film

3.2. Morphological characterization of CdTe, CdS thin films and Si nanoparticle

The electrodeposited materials are uniformly distributed on the substrate and the grains as depicted in figure 4-6 have spherical shape with faceted edges. The uniformity of materials reveals the significance of cathodic deposition technique over anodic technique [26]. However, the nucleation CdTe, CdS and Si on the well degreased FTO/substrate show uniform distribution of grains and relatively little agglomeration. Such a uniformity in the grains distribution could reducing electron trapping in the lattice site resulting to improved electrical parameters [22], [23]. The little agglomeration in the SEM micrographs of the materials agrees with previous works [3], [4], [26], [27].

3.3. Electrical characterization of heterostructured CdTe/Si/CdS and CdTe/CdS

In order to characterize the electrical behaviour at the interface of the heterostructured devices, it is necessary to carry out I-V characterization under illumination and dark conditions which helps to harness the potentials of heterostructured photovoltaic devices [28], [29]. Figure 7 revealed the electrical parameters

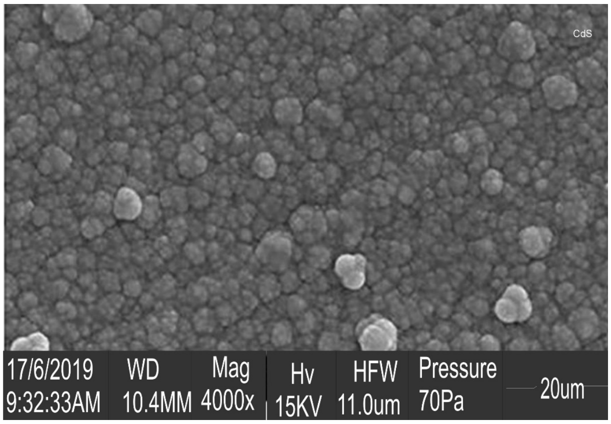

Figure 5. SEM micrograph of electrodeposited CdS thin film

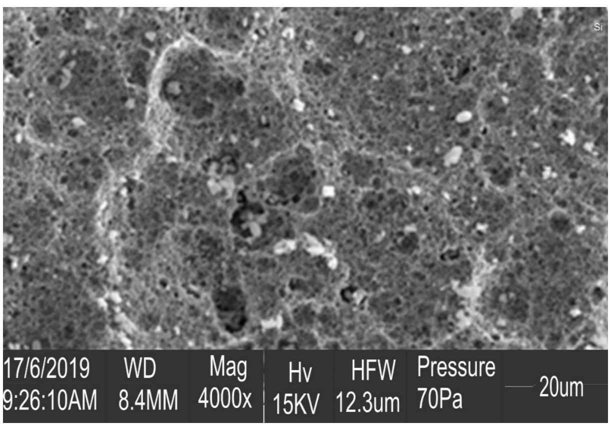

Figure 6. SEM micrograph of electrodeposited Si thin film

of CdTe/Si/CdS/FTO based photovoltaic measured under illumination condition using electrometer. The fill factor as an important photovoltaic parameter which characterized the grade and the curve fitness of the device revealed the potential of the structures. The slight change in the electrical parameters as depicted in figure 8 was as result of measurement condition, dark. Despite the variation in the parameters, there is tremendous improvement in the electrical conductivity of the device. Such improvement could be attributed to overcoming the barrier potential or potential hill using forward bias voltage. Figure 9 and 10 revealed the electrical parameters of the device without the inclusion of the silicon nanoparticle. The injection of silicon nanoparticles in the structure also aided the device electrical parameters such as open circuit voltage (Voc), short circuit current density (Jsc), and ll factor (FF) of the heterostructure devices as shown in Table 1. The structure exhibits PIN-diode like characteristic due to the injection of silicon nanoparticles which serve as an intrinsic material between the p-type CdTe and n-type CdS. Such a structure could act as a good photodetector, high voltage rectifier and radio frequency switches. The high values of the extracted open circuit voltage (Voc), short circuit current density (Jsc) and ll factor (FF) showed that pinhole free semiconductor materials have been successfully fabricated and their suitability have been confirmed in the electrical properties

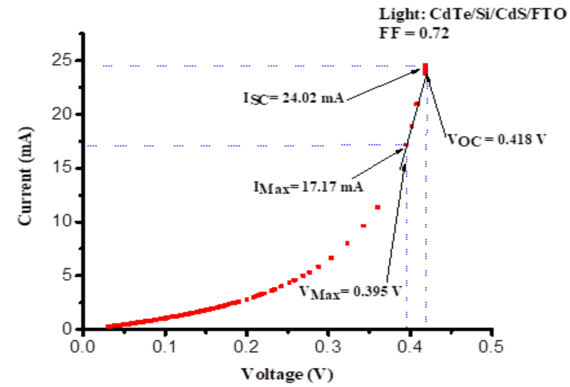

Figure 7. Electrical properties of CdTe/Si/CdS/FTO based photovoltaic structure measured under illumination condition using electrometer

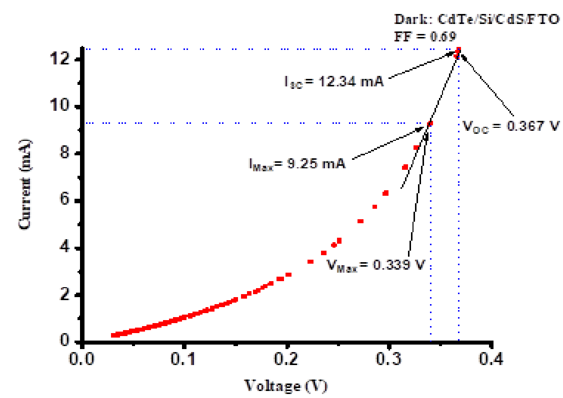

Figure 8. Electrical properties of CdTe/Si/CdS/FTO based photovoltaic structure measured under dark condition using electrometer

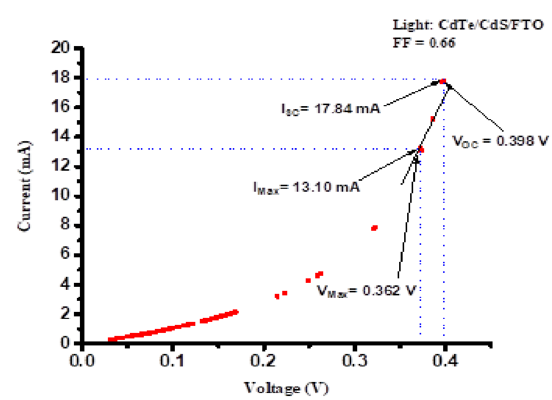

Figure 9. Electrical properties of CdTe/CdS/FTO based photovoltaic structure measured under illumination condition using electrometer

of the heterostructured CdTe/CdS based photovoltaic.

Table 1. Quantitative electrical parameters of heterostructured based Photovoltaic device

Heterostructured CdTe/Si/CdS									
Light					Dark				
V_{OC} (mV)	J_{SC} (mA/cm^2)	V_{Max} (mV)	I_{Max} (mA)	FF	V_{OC} (mV)	J_{SC} (mA/cm^2)	V_{Max} (mV)	I_{Max} (mA)	FF
418	25.02	395	17.17	0.72	367	12.85	0.339	9.25	0.69
Heterostructured CdTe/CdS									
Light					Dark				
V_{OC} (mV)	J_{SC} (mA/cm^2)	V_{Max} (mV)	I_{Max} (mA)	FF	V_{OC} (mV)	J_{SC} (mA/cm^2)	V_{Max} (V)	I_{Max} (mA)	FF
398	18.58	362	13.10	0.66	338	9.55	0.297	6.33	0.61

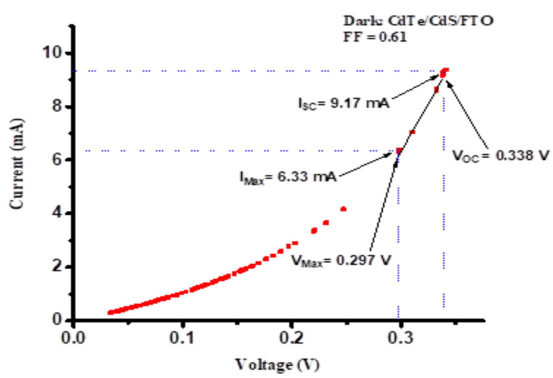

Figure 10. Electrical parameters of the fabricated CdTe/Si/CdS and CdTe/CdS under illumination and dark conditions

4. Conclusion

The potential of electrodeposition technique in the fabrication of heterostructure based photovoltaic has made a significant improvement in the electrical properties of the CdTe/Si/CdS and CdTe/CdS configurations. The probe into electrical behaviour at the interface of the heterostructured based device has revealed the successive development of photovoltaic devices. The injection of silicon into the structure also offer better and improved photovoltaic parameters leading to high value in both open circuit voltage and short circuit current density. Such increase in the photovoltaic parameters are indicative of high-grade reagents used which have also resulted to no leakage path and pinhole free compound semiconducting materials. The structural analysis of the films revealed structural transformation from single phase to polycrystalline which is an evidence that we have successfully fabricated polycrystalline CdTe, CdS and Si

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