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Fabrication and study of (p-Si/CdTe/V_2O_5/SnO_2) solar cell

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Abstract

This article discusses a simple vacuum evaporation technique for deposition of CdTe thin films with different thicknesses (100, 200, 300, 400, and 500) nm on P-type silicon substrates. Then, V_2O_5 and SnO_2 thin films were deposited as a buffer layer and window layer with a thickness of 100 nm respectively, using the same technique. In addition, other samples of these films have been deposited on a glass substrate for the purpose of studying optical transmission and their optical properties. X-ray diffraction (HR-XRD) was used to characterize the films crystalline structures. The aim of this work is to investigate the effects of different thicknesses of CdTe thin films on the optical, Structural and electrical potential of CdTe/V_2O_5/SnO_2 films and their potential applications in solar cells. The results show that using different thicknesses of CdTe-deposited thin films can enhance the performance. The efficiency improved by increasing the thickness of the CdTe films, and at 500 nm it reached (3.3%), and with a Voc (0.382 Volt).

Keywords: Cadmium telluride; CdTe; Solar cells; Thin films; Electrical properties; Optical properties; Structural properties

1. Introduction

In order to solve the serious difficulties associated with the reduction of fossil fuel resources, weather pollution, global warming and critical energy shortages, solar cells are emerging as one of the best encouraging prospects for the use of renewable energy. Semiconductor materials with energy bandgaps suitable for absorbing sunlight, such as silicon, gallium arsenide (GaAs), cadmium telluride (CdTe), copper zinc tin (CZTS) and copper indium gallium selenide (CIGS) have been used to make thin film solar cells. Among them, CdTe has many advantages: ideal energy gap amount (1.5 eV), relatively high efficiency, and low production cost [1].

A range of deposition techniques can be used to produce efficient CdTe solar cells as this material proves to be flexible with respect to production technology, distinguishing it from other thin films. Vacuum thermal deposition is one of several methods with potential for development and efficient use of materials. In addition, CdTe is one of the best materials competing with silicon for solar cell applications due to its low cost, high efficiency, and long-term stability [2]. It has a direct type energy gap of (1.5 eV) which is close to the ideal value in solar PV conversion [3,4]. It has an absorption coefficient ($5 \times 10^5\ cm^{-1}$) [5,6]. Vanadium pentoxide (V_2O_5) is an n-type semiconductor material with an energy gap of (2.4-2.8 eV) [7,8]. This material can be used as a buffer layer between the absorbing layer and the transmitting layer because of its suitable energy gap. Tin oxide (SnO_2) is an n-type semiconductor with an energy gap of about (3.6 eV) [9,10]. It is considered one of the best materials used as a window for the incident solar rays [11]. Silicon is a semiconductor material with an energy gap of (1.1 eV) of the indirect type [12], there are two types of silicon, n-type and p-type, which are the best materials for solar energy conversion [13,14].

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This paper discusses the effect of CdTe thickness modulus on the structural and electrical properties of the films and determines the best thickness important for achieving high efficiency. The membranes were investigated using high-resolution X-ray diffraction (HXRD), a UV-visible spectrophotometer, and some solar cell parameters.

2. Experimental part

2.1. Thin films preparation and solar cell fabrication

P-type silicon wafers were cut into dimensions (1cmx1cm) with orientation (100), then cleaned with alcohol and dried. CdTe films were deposited by thermal evaporation under the vacuum method and a pressure of (10^{-5} mbar) on silicon slides and other glass slides, then heat treatment was carried out at (250 ˚C) in an oven for (1 hour) to increase the adhesion of the films to the slides [15], (This grade was chosen to avoid oxidation of the film and improve the pattern of the films), and in this way CdTe films with a thickness of (100, 200, 300, 400, 500) nm were deposited. Then, V_2O_5 films were deposited with a thickness of (100 nm) in the same manner as a Buffer layer on all previously produced samples, as well as obtaining film on glass slides, and heat treatment was carried out at (300 ˚C) in an oven to improve the crystallinity and stability of the film [7]. Then, by the same method of deposition, pure tin with a thickness of about (100 nm) was deposited on the previously prepared samples and on additional glass slides. The films were oxidized in an oven for half an hour at a temperature of (400 °C) [16,17], tin dioxide (SnO_2) as a top layer that transmits light. Cell electrodes were deposited from pure aluminum wires using the same deposition method. The front electrodes were deposited after placing metal masks on the upper surface of the cells, while the back electrodes were left without masks. Finally, the metal wires were soldered to the electrodes using silver paste, as in Figure (1).

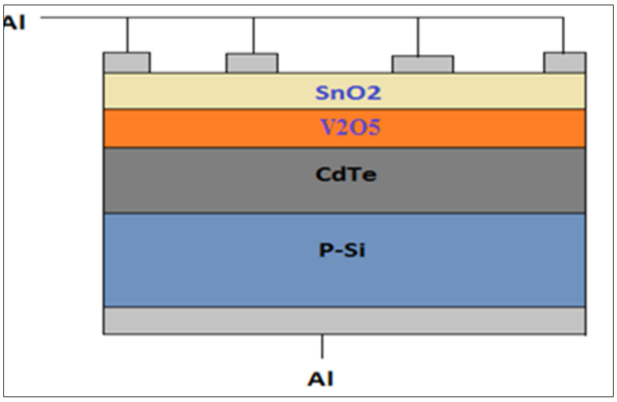

Figure 1 Schematic of the p-Si/CdTe/V_2O_5/SnO_2 solar cells structure

2.2. Characterizations

The optical properties of the prepared films were studied by (UV-1800 SHIMADZU UV-SPECTROPHOTOMETER), The X-ray diffraction of the films was also studied by (XRD 600 SHIMADZU Japan), with Cu Kα/40kV/30mA, radiation source (λ=1.5406A°), The optical interferometry method for thin films was used to measure their thickness using a helium-neon laser with a wavelength of (632.8 nm). The current-voltage (I-V) characteristics of the manufactured solar cells were studied under illumination using a galvanometer and a voltmeter.

3. Results and discussion

3.1. X-ray diffraction

X-ray diffraction examination proved that the deposited films are the same as the crystalline films to be deposited. The X-ray interference pattern showed diffraction peaks at 2θ ≈ (23.8, 39.5)° which correspond to the orientation (111, 220) at the films with thicknesses of (100 and 200) nm, and this indicates the diagnosis of crystallization of the CdTe film, and another peak appeared in the thicker films at 2θ ≈ (51.5)°, which is slightly offset from the orientation (311), and this is consistent with studies [3,4,18], and as in the figure (2).

As for the X-ray examination of (V_2O_5) film, two peaks were detected at 2θ ≈ (15.35, 20.3, 41)° which correspond to the orientation (200, 001,002) respectively [8,19], and as in the figure (3). For the SnO_2 film, the X-ray examination showed a single peak at 2θ ≈ (26.7) which is consistent with the orientation (110) [10,11], and as in the figure (4).

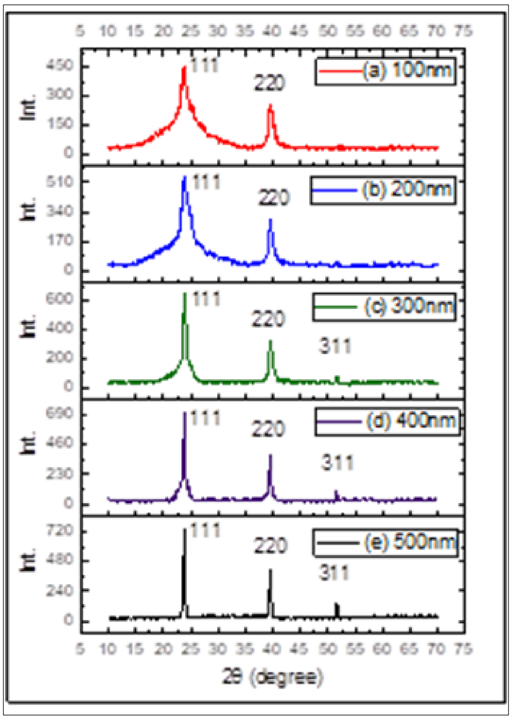

Figure 2 XRD examination for the diagnosis of the prepared films of CdTe: (a) 100nm, (b) 200nm, (c) 300nm, (d) 400nm, (e) 500nm

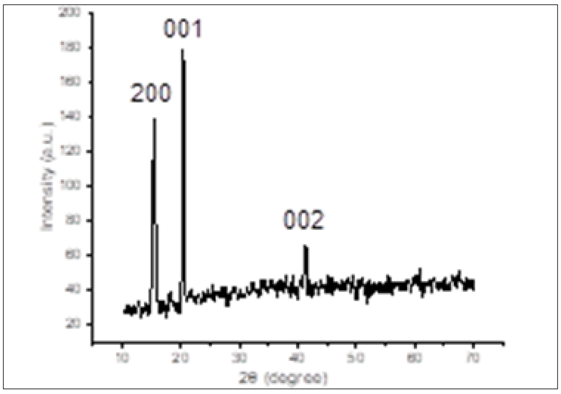

Figure 3 XRD examination for characterization of V_2O_5 film prepared with a thickness of 100 nm

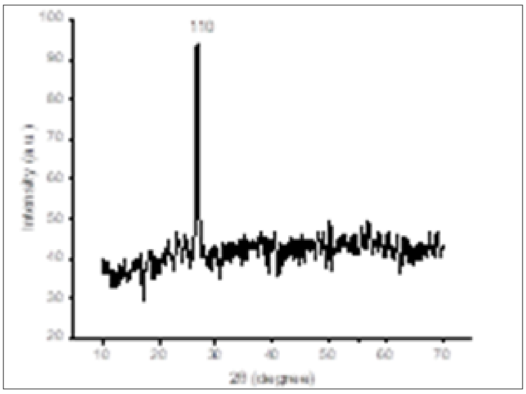

Figure 4 XRD examination for characterization of SnO_2 film prepared with a thickness of 100 nm

3.2. UV-Visible spectroscopy analysis

The optical properties of the films deposited on glass slides were studied by UV-visible spectrophotometer, where the transmittance spectra for wavelengths (300-900) nm were taken in the figure (5). The transmittance spectrum of the CdTe film shows a decrease in the transmittance ratio with a decrease in the visible and ultraviolet region wavelengths [20], the same thing happened with the transmittance spectrum of vanadium pentoxide (V_2O_5) [21], the transmittance spectrum of SnO2 film shows very high in the visible region, which makes it one of the best windows in solar cells [17].

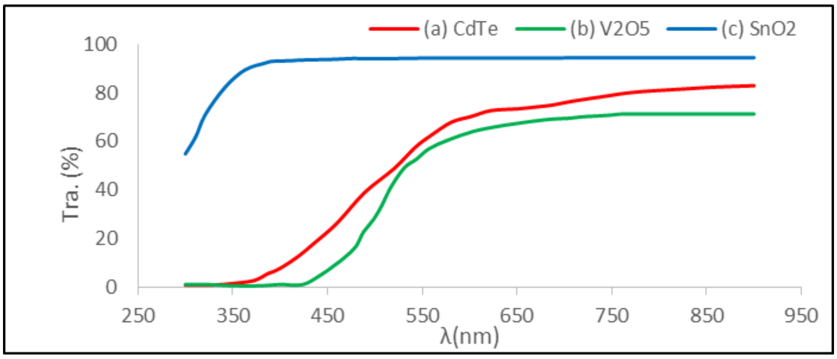

Figure 5 Transmittance spectrum of the prepared films of thickness 100 nm on glass slides: (a) CdTe, (b) V_2O_5, (c) SnO_2

The energy gap values for the films were also calculated and they were (1.55, 2.8, 3.5) eV, for CdTe, V_2O_5 and SnO_2 respectively, as in the figure (6).

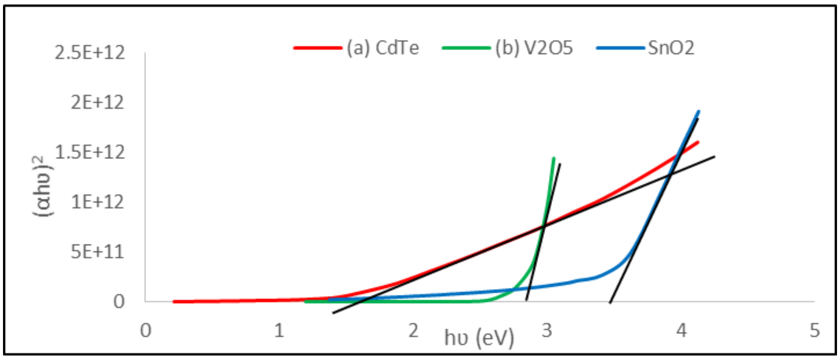

Figure 6 Energy gap of the prepared films of thickness 100 nm on glass slides: (a) CdTe, (b) V_2O_5, (c) SnO_2

3.3. Electrical properties

The electrical properties (voltage-current) of the manufactured solar cells were studied under the illumination with an optical power of (100 mW/cm^2) as in Figure (7).

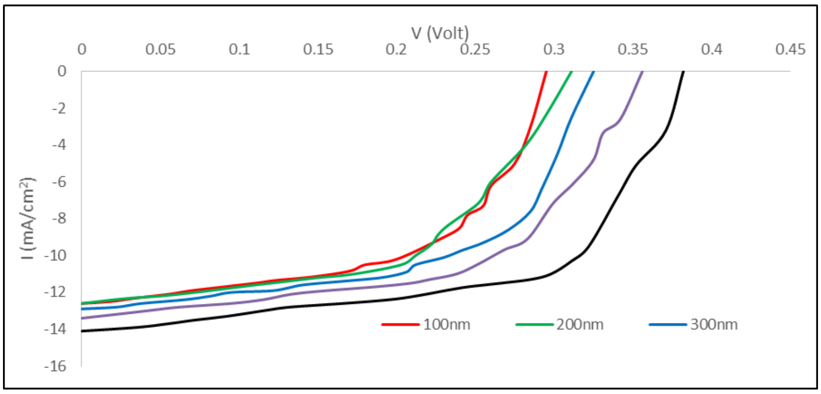

Figure 7 I-V relationship for CdTe layer solar cells with a thickness of (100, 200, 300, 400, 500) nm.

Table 1 includes the obtained results.

Fill factor (F.F) was calculated through the formula [22].

$$FF = \frac{I_{mp} \cdot V_{mp}}{I_{SC} \cdot V_{OC}} \quad \text{.......................................}(1)$$

I_{mp}, V_{mp}: The maximum current density and voltage that the solar cell can generate, I_{SC}: short circuit current, V_{OC}: open circuit voltage.

The results showed that the filling factor is not uniform with the increase in the thickness of the CdTe layer, as shown in Figure (8).

As for the efficiency η of the manufactured solar cells, it was calculated through the equation:

$$\eta = \frac{I_{SC} \cdot V_{OC} \cdot FF}{P_{in}} \quad \text{...}(2)$$

P_{in}: The incident radiation power, and because the average energy of solar radiation falling on the ground is (100 mW/cm^2), it is a basis for measuring the efficiency of solar cells [23].

The increase in the CdTe layer showed a significant increase in the efficiency of the solar cells, as the increase in the thickness of the absorbing layer increased the amount of light absorbed [24,25,26], as shown in the figure (9).

Table 1 Performance data for solar cells ($Si/CdTe/V_2O_5/SnO_2$) having contacts with Al, they were prepared by Vacuum thermal evaporation

CdTe thickness (nm)	Isc (mA/cm²)	Voc (Volt)	Imp (mA/cm2)	Vmp (Volt)	F.F %	η %
100	12.6	0.295	9.5	0.222	56.73931	2.109
200	12.6	0.311	9.4	0.225	53.97336	2.115
300	12.9	0.325	9.7	0.242	55.99046	2.3474
400	13.4	0.356	10	0.264	55.34127	2.64
500	14.1	0.382	11	0.3	61.26768	3.3

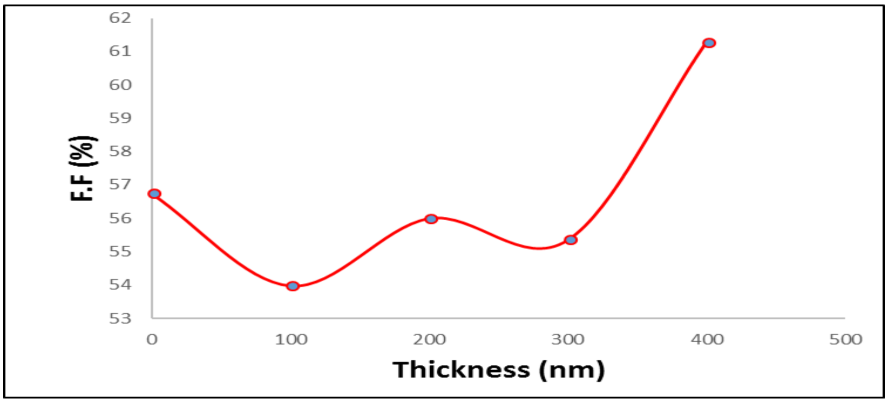

Figure 8 The effect of changing the thickness of the CdTe films in solar cells on the fill factor.

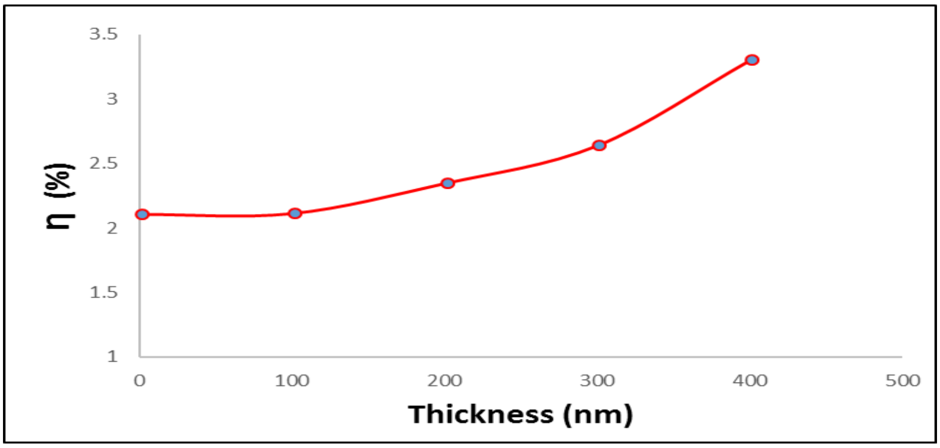

Figure 9 The effect of changing the thickness of the CdTe films in solar cells on the efficiency.

4. Conclusion

In this study, we used vacuum thermal evaporation in an experiment for CdTe films and photovoltaic cells made using V_2O_5 and SnO_2 were deposited as buffer layer and window layer, respectively. The deposited CdTe films show crystallization of the film with the formation of different phases. The optical bandgap values calculated from the absorption spectra were (1.55 eV) for CdTe, (2.8 eV) for V_2O_5, and (3.5 eV) for SnO_2 films. The highest values were at the thickness of the absorption layer (500 nm), where the efficiency was (3.3%), F.F was (61.26%), with V_{oc} = 0.382 V, J_{sc} = 14.1 mA/cm^2.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

There is no conflict of interest.

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