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The effect of metal Ag nanoparticles on CdS/ZnTe heterojunction solar cells

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Recent research on organic and inorganic solar cells has demonstrated that adding metal nanoparticles to the active layer can dramatically boost the performance of thin-film cells. In this research, Silver (Ag) nanoparticles have been added in CdS/ZnTe thin films that were prepared using the pulsed laser deposition (PLD) technique with laser energy ranging from (200-300 mJ). X-ray diffraction (XRD) analysis was used to examine the thin films of CdS and ZnTe for structural details. Atomic force microscopy (AFM) and scanning electron microscopy (SEM) were also employed to examine the morphology of the films. The typical rectifier behavior was seen using the current-voltage (I-V) characteristic curves. Furthermore, by studying the effect of adding silver (Ag) nanoparticles on the capacitance-voltage (C-V) characteristics.

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1. Introduction

In recent years, group II–VI chalcogenide compound semiconductors, including cadmium sulfide (CdS) and zinc telluride (ZnTe) become very interesting due to they have numerous potential uses in optoelectronics, where they exhibit exceptional electrical and optical properties. ZnTe usually possesses a cubic (sphalerite or zinc blende) crystal structure there are four zinc ions and fourtellurium ions per unit cell [1] but can be also prepared as hexagonal crystals (wurtzite structure) [2]. Its lattice constant is 6.1034 Å with a wide energy band gap of 2.26 eV at room temperature [3,4]. Furthermore, is a material with a high absorption coefficient. On the other hand, CdS has a small 3.5% lattice misfit with ZnTe and a direct optical band gap (2.4 eV), making it a suitable cubic n-type material for p-ZnTe.[5]. Therefore, it can be possible to form a thin layer p-n junction more suitable for photovoltaic solar energy conversion. The main growth techniques to fabricate ZnTe/CdS heterojunction are thermal evaporation [6 ,7], PLD [8], Bridgman–Stockbarger [9]and Electrodeposited method [10,11]. Despite the variety of deposition techniques, PLD allows for the use of many targets simultaneously without opening the chamber between deposits, improving the interfaces between layers and lowering contamination, In addition to producing soft films. Also, we can control the thickness of the film [8].

When the PN junction has doped the concentration of holes and electrons will be more in p and n- type areas respectively. So when the doping concentration is high the excess holes on the (p) side and electrons on the(n) side again recombine with the junction ions to neutralize the charge hence the depletion width decreases [12]. In the present study, silver nanoparticles were added to the possibility of improving ZnTe/CdS cell efficiency and reducing production costs.

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2. Experimental

In this work, cadmium sulfide (CdS) and zinc telluride (ZnTe) targets were deposited on a base of the glass with dimensions of (2.5cm*7cm) at room temperature using a pulsed laser deposition (PLD) technique. using Nd:YAG pulsed laser with wavelength (1.06 μm) . Silver nanoparticles were added to the cadmium sulfide layer with different laser energies from (200 – 300) mJ in increments of 50 mJ per step and a pulse (10 ns), Made by company Diamond.288 (pattern EPLS). The evaporation system included an evaporation chamber that includes a (bell jar) made of Pyrex glass with a thickness of 1 mm, a diameter of 320 mm, and a height of 45 cm and a branching system that consisted of a rotating mechanical pump type Edward, Where the lowest pressure obtained from this pump is 10^{-3} torr.

Nine samples have been prepared. The first two samples are CdS and ZnTe, respectively, to study their structure by x-ray diffraction (XRD) (XRD-6000, Shimadzu, made in Japan) are done using Cu-Kα (l=1.54) for provides data related to the film. Three samples have been deposited with CdS and Ag only using the laser with different energies (200 – 300 mJ) to observe silver nanoparticles using an SEM type Tescan, are Czech origin and AFM (Scanning probe Microscope type (AA3000), supplied by Angstrom Advanced Inc to analyze the size and distribution of the silver particles on the film surface. Three samples have been deposited with CdS/Ag/ZnTe, and treated with $CdCl_2$ at 500 C^o for 15 minutes to improve solar cell efficiency [11]. Finally, the last sample has been deposited with CdS/ZnTe. to see the effect of silver nanoparticles on the solar cell. I-V was measured with a Philips Multimeter with a 10-14 resolution, a 1540D.C. 40-300A power supply, and a Keithley 616 digital electrometer. Halogen lamp type Philips (120W) with intensity 100 mW/cm^2 has been used to illuminate the junction. The capacitance of CdS/Ag/ZnTe heterojunctions was measured using an HP-R2C unit model 4274A and 4275A multi-frequency LRC meter as a function of an applied reverse bias voltage between -3.5 and 3.5 Volt with frequency 100KHz.

3. Result and discussion

3.1. x-ray diffraction (XRD)

The x-ray diffraction (XRD) patterns for the Crystalline Structure of CdS and Films are shown in Fig. 1, revealing that both films were polycrystalline. The crystal structure of ZnTe film was a zincblende phase with a cubic crystalline structure according to (JCPDS) card no. 15-0746. Also, it has observed a preferred strong orientation along (111) direction at 25.15. while XRD analysis of CdS thin film indicated the hexagonal polycrystalline structure with peaks at 2θ = 27·1◦,28·05◦,37·15◦,44·01◦,48·1◦and 52·2◦ with the orientations (0 02), (1 0 1),(102),(110),(103) and (1 1 2), respectively.

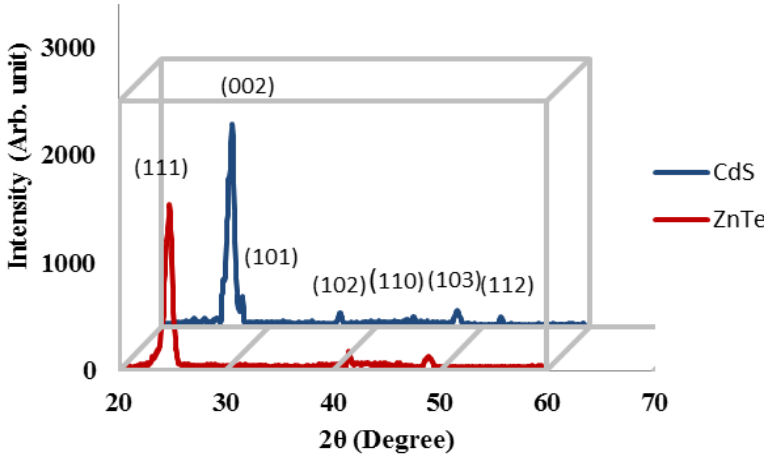

Fig. 1. XRD patterns for and CdS and ZnTe thin films.

3.2. SEM analysis

Scanning electron microscope (SEM) techniques are well suited for analyzing the surface's composition and topography. By using electrons rather than light to form an image. It is clear from the SEM images for samples with only CdS/Ag layers (Fig. 2) that the size of the silver particles decreases with increasing laser energies while the density of these particles increases.

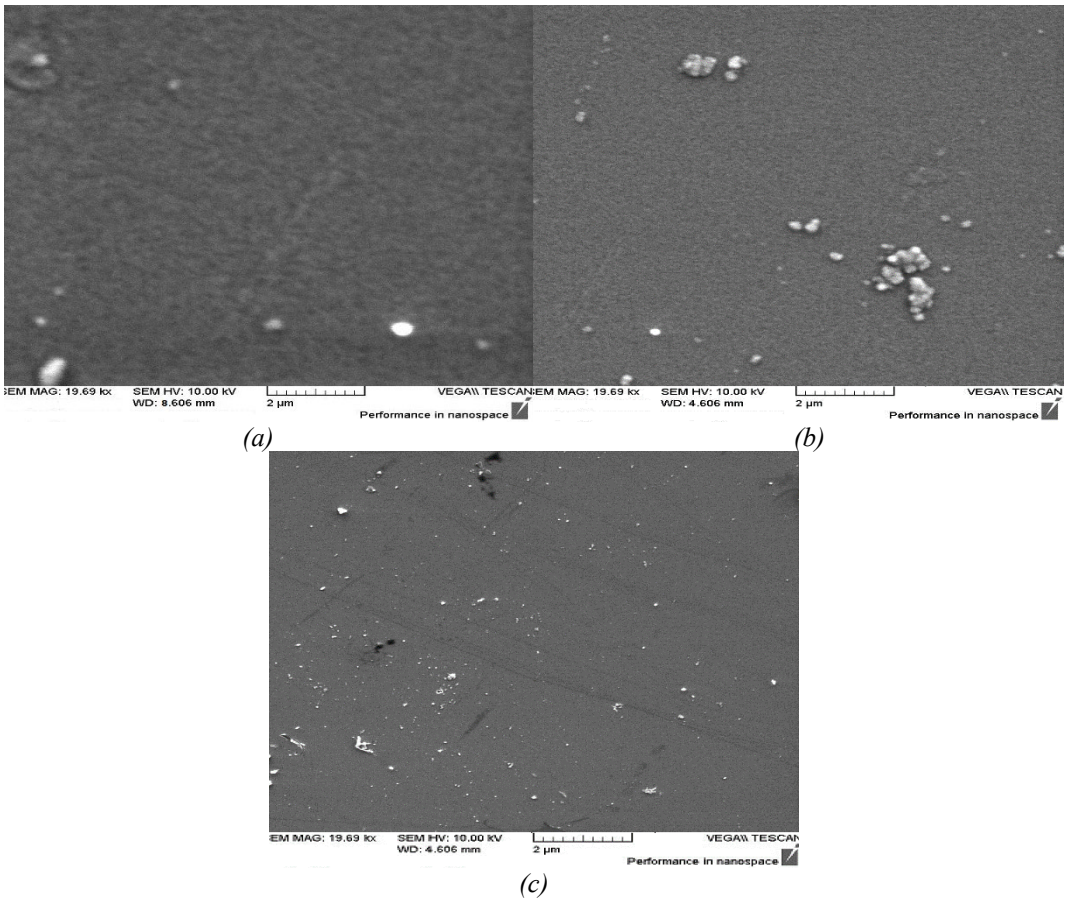

Fig. 2. SEM images for CdS/Ag layers with different laser energies (a) 200 mJ (b)250 mJ (c) 300 mJ.

3.3. AFM analysis

Fig. 3 shows Atomic Force Microscopy (AFM) for samples with only CdS/Ag layers deposited by (PLD) technique with different laser energies at glass substrate. These AFM images demonstrated that the surface of films is compact and homogeneous, and that the particles have gotten more spherical as the laser energy has increased. The results for average particle size and surface roughness as a function of laser energy are shown in (Table 1).

Table 1. AFM analysis of CdS/Ag layers under different laser energies.

laser energies	Average particle (nm)	Average Roughness (nm)
200 mJ	63.09	1.54
250 mJ	69.43	1.33
300 mJ	82.47	1.73

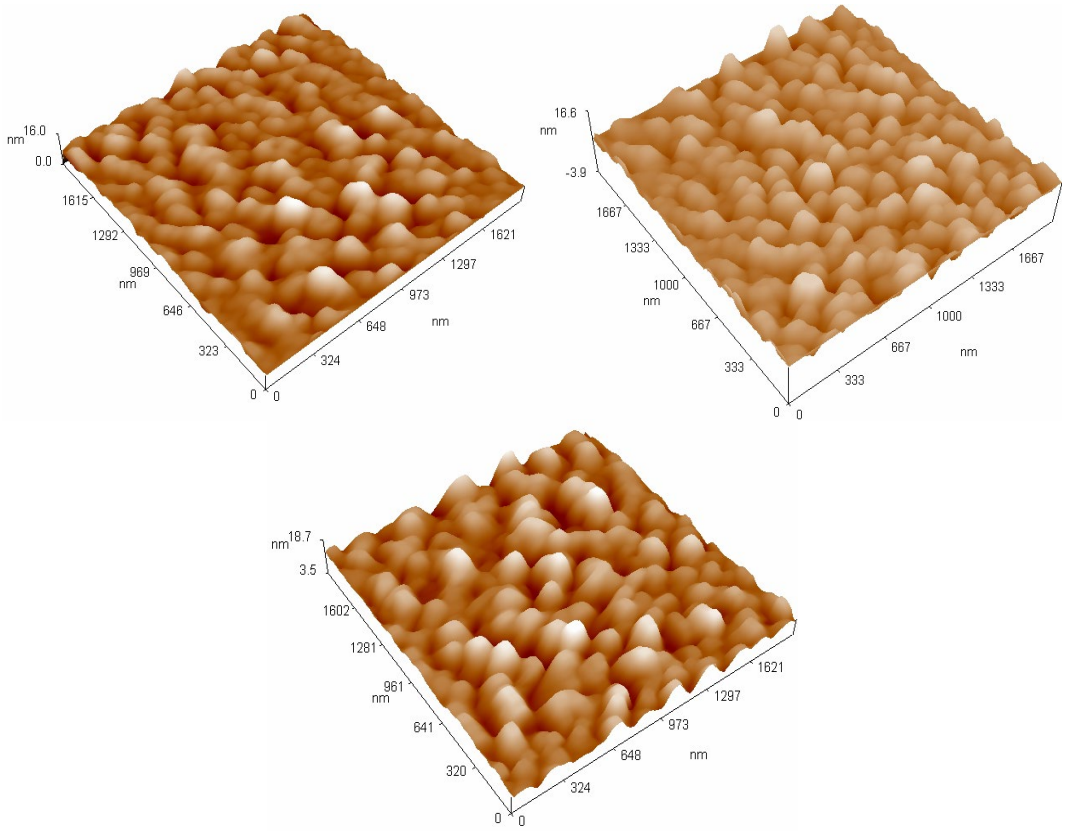

Fig. 3. AFM images for CdS/Ag layers with different laser energies (a) 200 mJ (b)250 mJ (c) 300 mJ.

3.4. Electrical and photovoltaic properties

Fig. 4 shows the current–voltage characteristics of CdS/Ag/ZnTe heterojunction solar cell Measured at under 100 W/m^2 measured irradiance and total device area: 0.408 cm^2 with different laser energies. (200, 250, and 300) mJ, In addition, the sample was deposited with no silver nanoparticles.

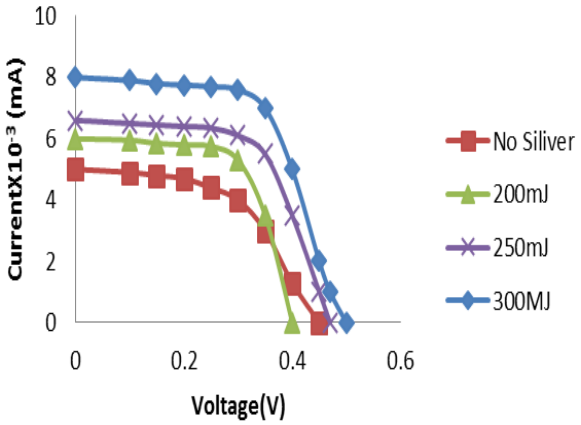

Fig. 4. I-V Characteristics under illumination for CdS/Ag/ZnTe Solar Cell at different laser energies.

It is observed that the CdS/Ag/ZnTe heterojunction solar cell device displays a great photovoltaic effect and rectifying behavior where increased deposition laser energies of silver.

Table (2) shows the open–circuit voltage(Voc), short-circuit current(Isc), fill factor (FF), and conversion efficiency (η %) for different laser energies. We can observe from this table that metal nanoparticles can improve the performance of the solar cell and also by comparison between samples, we can find that the photovoltaic effect of CdS/Ag/ZnTe heterojunction increases with increased deposition laser energies. The optical absorption of thin-film photo-active layers was enhanced by scattering and trapping due to the addition of silver nanoparticles, which can greatly increase the performance of thin-film cells.[13]. The best conversion efficiencies obtained for the three samples that differed in the energies of the laser used in a silver deposition is 6.438% for the sample deposited with an energy of 300mJ. A number of characteristics, including a high defect density, low doping concentration, the presence of an interfacial layer, and the presence of series resistance, can be linked to the high voltages and fill factors of all the cells.

Table 2. Solar cell parameters for CdS/Ag/ZnTe under different laser energies.

laser energies	V_{oc} (Volt)	J_{sc} (mA/cm^2)	FF	η %	
No Silver	0.45	12.25	0.44	2.425	
200 mJ	0.4	14.7	0.72	4.233	
250 mJ	0.47	16.17	0.66	5.015	
300 mJ	0.45	19.60	0.73	6.438	

C-V characteristics of heterojunctions are crucial in explaining junction features. The type of heterojunction, carrier concentration, built-in voltage (V_{bi}), and finally the width of the depletion layer, were all determined using these characteristics.

For a CdS/Ag/ZnTe heterojunction, the relationship between ($1/C^2$) and a reverse bias voltage is shown in Fig. (5) for various laser energies. The built-in potential is represented by the ($1/C^2$) voltage curve extended to ($1/C^2 = 0$).

Plotting ($1/C^2$) vs applied voltage (V) showed a straight line, indicating an abrupt junction type. You can write as the equation for junction capacitance per unit area[14].

$$\frac{C}{A} = \left\lfloor \frac{qN_D N_A \varepsilon_1 \varepsilon_2}{2(N_A \varepsilon_1 + N_D \varepsilon_2)} \right\rfloor^{\frac{1}{2}} / (V_{bi} - V)^{\frac{1}{2}} \quad (1)$$

where, N_D and N_A are the donor and acceptor concentrations, ε_1 and ε_2 are the dielectric constants of n –CdS and p- ZnTe , respectively.
where the width of the depletion region (w) can be determined using relation (2):

$$W = \varepsilon_s / C_o \quad (2)$$

where, ε_s is the permittivity of a semiconductor and Co is the capacitance at zero biasing voltage.

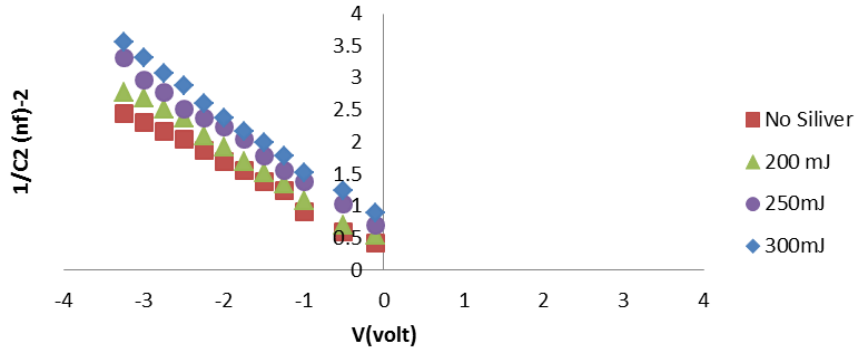

Fig. 5. The variation of $1/C^2$ as a function of reverse bias voltage for CdS/Ag/ZnTe Solar Cells at different laser energies.

It can be seen from Table (3) that the increase in deposited laser energies for Ag will increase built–in the potential for all prepared junctions, due to the decrease in the carrier concentration(ND) which leads to a decrease of the capacitance value. This leads to an increase in depletion layer width, which yields an increase in the value of built-in potential.

Table 3. Values of depletion layer width and built-in potential for CdS/Ag/ZnTe hetero-junction with different laser energies.

laser energies	W (nm)	built-in potential V_{bi} (Volt)	ND(cm^{-3})
No Silver	145	0.50	8.9×10^{14}
200 mJ	168	0.79	8.3×10^{14}
250 mJ	197	0.82	8.0×10^{14}
300 mJ	205	0.92	7.5×10^{14}

4. Conclusion

We have fabricated CdS/ ZnTe solar cells with the addition of Ag nanoparticles between these layers by pulsed laser deposition (PLD) technique with different laser energies from (200 – 300) mJ. The X-ray revealed that both films CdS and ZnTe were polycrystalline. According to SEM images, the density of the silver particles rises while their size decreases with increasing laser intensities. It was revealed from AFM images, the surface of films is compact and uniform, also the particles have become more spherical when increasing laser energies. Analysis of the current–voltage curves CdS/Ag/ ZnTe solar cells shows the performance can be improved further by increasing deposition laser energies of silver. The best conversion efficiencies obtained with energy 300 mJ (6.438%). while the C-V measurement showed that the constructed devices are abrupt in nature.

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