Deposited Nanostructure Cds Thin Film by Using Pulse Laser Deposition Technique for Fabrication of Heterojunction Solar Cell

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ABSTRACT

In the present study, nanostructure Cadmium sulfide (CdS) thin films on Si P-type substrates heterojunction solar cell has been made by using a pulsed 532 nm Nd:YAG laser. Deposition of films is achieved at 200 °C substrate temperatures and oxygen pressure 10^{-1} Torr. X-ray diffraction (XRD), Scanning electron microscopy (SEM), atomic force microscope (AFM) and UV-VIS transmittance analyses were employed to characterize thin films. XRD measurements approved that CdS film is a hexagonal Wurtzite structure. The morphology of deposited films were characterized by scanning electron microscope (SEM) and atomic force microscope (AFM), the grain size value (18) nm and rms roughness values are (12.6 nm) for thin films deposited at 200°C. UV-VIS transmittance measurements have shown that our films are highly transparent in the visible wavelength region, with an average transmittance of ~90% . The direct optical band gap of the film has been found to be 2.2 eV.The photovoltaic characteristics included short circuit current (Jsc), open circuit voltage (Voc), where the maximum (Jsc) and (Voc)obtained at AM1 were 29.3 (mA cm^{-2}) and 635(mV), respectively. The fill factor (FF) was (0.44). The fabricated cell exhibits good performance with 7.8 % conversion efficiency.

Keywords: Nanostructure CdS /Si Heterojunction, Solar Cell, Conversion Efficiency

ترسيب اغشية كادميوم سلفايد الرقيقة النانوية باستخدام تقنية الليزر النبضي لتصنيع خلية شمسية هجينة

الخلاصة

في هذا البحث , تم ترسيب اغشية رقيقة نانوية من الكادميوم سلفايد على قواعد من السليكون الاحادي البلورة من النوع القابل لتصنيع خلايا شمسية هجينة باستخدام ليزر النيودميوم-ياك النبضي ذو الطول الموجي 532 نانو متر.تم ترسيب الاغشية عند درجة حرارة قاعدة 200 درجة مئوي. اظهرت قياسات الاشعة السينية ان الاغشية المحضرة ذات طور الفرتزايت السداسي .حددت خصائص طبوغرافية السطح من خلال قياس المجهر الالكتروني الماسح و مجهر القوى الذرية , حيث بلغت قيمة الحجم الحبيبي (18) نانو متر وقيمة خشونة السطح (12.6)نانومتر للأغشية المحضرة بدرجة حرارة قاعدة (200) مئوي.اوضحت نتائج مطياف الاشعة المرئية والفوق البنفسجية امتلاك غشاء الكادميوم سلفايد نفاذية بلغت بحدود 90% و بلغت قيمة فجوة الطاقة المباشرة (2.2 الكترون.فولط) درست الخواص الفولطائية المتمثلة بتيار الدائرة القصيرة (J_{sc}) وفولتية الدائرة المفتوحة (V_{oc}) بالاضافة لعامل الملئ (FF) ووجد ان اعظم قيمة لكل من (J_{sc}) و (V_{oc}) لحالة AM1 هي (29.3 (mA cm^{-2}

و ,635(mV) على التوالي وان قيمة عامل الملئ هي (0.44) .الخلية المصنعة اظهرت قيمة كفاءة جيدة بلغت 7.8%.

INTRODUCTION

Cadmium sulfide is a wide band gap semiconductor extensively studied under various configurations: bulk material [1], thin films [2], nanostructures as nanowires [3] and tetrapod nanocrystals [4], etc. Pure and doped CdS have considerable interest due to their applications in electronic and optoelectronic devices [5] like solar cell [6], field effect transistor [7], low dimensional semiconductor structures [8] .The resort to CdS doping is useful to adjust these properties. For instance, doping with group III elements has been used to decrease the dark resistivity of CdS thin films [9]. As recently observed for another II–VI semiconductor, carbon doping of ZnO allows observing room temperature ferromagnetism [10]. According to Pan et al. [11], C-doped CdS is a possible way to produce magnetic semiconductor (used in spintronic applications). Pulsed laser deposition (PLD) is an efficient process to deposit high quality CdS films at low substrate temperature using nanosecond [12] and femtosecond pulsed lasers [13]. In this work the structural, optical and electrical properties of CdS thin films deposited by ns-PLD was studied.

There has been considerable interest in recent years directed towards the development of heterojunction solar cells [11]. Such interest is based on the fact that these heterojunctions have a number of advantages over diffused p-n junction solar cells include: (i) a lower junction-formation temperature, (ii) higher spectral response at short wavelengths, and (iii) many of deposited layers have the right indices of refraction to act as antireflection coating [6]. In the last three decades, CdS/Si heterojunction solar cells have been reported to have power conversion efficiencies of 4% and greater [13]. These cells were considered as low–cost and high efficient photovoltaic devices. In this work we reported the preliminary results of the fabrication of CdS/Si heterojunction solar cells of high efficiency made by pulsed Nd:YAG [λ(wavelength) = 532 nm, pulse width 7ns repetition rate 10Hz] laser ablation and investigated their structural and optical characteristics.

EXPERIMENTAL PROCEDURE

Film preparation

Single-crystal silicon wafers of p-type conductivity with (111) orientation are used as substrates. They have a resistivity in the range of 1-5 Ω-cm and one face of the wafer is polished to the mirror-like surface. Prior to deposition of CdS, these wafers were chemically etched in dilute hydrofluoric acid to remove native oxides. Subsequently, after oxide removing, the wafers were scribed into individual pieces of 0.5 cm^2 sizes, then they were sent to vacuum chamber to fabricate the CdS /Si heterojunction. Crystalline CdS films were deposited on cleaned Single-crystal silicon substrates using 10 Hz, 7 ns, Nd:YAG laser at 532 nm. The laser beam was focused on high purity CdS target using 5 cm positive lens. Laser fluence of 1.5 J/cm^2 used for in the ablation. The substrates were placed at 4 cm distance from CdS target. The chamber was kept at vacuum pressure of 10^{-6} mbar. The CdS target was ablated from 10 to 100 pulses (10–20 min) to get single layer thin films. During the deposition, the substrate temperatures (Ts) were kept at 200 $^{\circ}$C as shown in Figure (1). The deposited film had a thickness of approximately 150 nm. The thickness of the film was estimated from cross-sectional scanning electron microscopy (SEM_JEOL 7000) measurement. After the deposition of CdS , frontal and back metal electrodes were formed by depositing 200 nm of Al. The effective area was about 0.25 cm^2.

J-V measurements were done under illuminated conditions. The illumination was achieved by halogen lamp type "PHILIPS", 120W, which connected to a Variac and calibrated at AM1 illumination power density by a silicon power meter as shown in Figure (2).

Film characterization

The structure of the grown films was determined by X-Ray diffraction (XRD) measurements (Philips PW 1050, λ = 0.1542 nm) using Cu-ka source. Film transmission measurement is performed at a spectral range 400–900 nm using UV–VIS-PV-8800 (Perkin Elemer Company) spectrophotometer. The surface morphology was examined by scanning electron microscopy (SEM–JEOL Germany 7000) and atomic force microscopy (AFM-Digital Instruments NanoScope Italy) working in tapping mode.

RESULTS AND DISCUSSION

The XRD result pattern of CdS /Si heterostructure for as-deposited sample is shown in Figure 3. The film is polycrystalline in nature. Reflection peaks from (100) plane, (002) plane, and (101) plane were observed. This orientation corresponds to the hexagonal phase (according to ASTM card No. 6-0314). Accordingly, evaporated CdS film shows Wurtzite structure. The lattice parameter of (002)-oriented CdS film from ASTM-Card is 6.75 Å, while that obtained from XRD pattern is 6.74 Å.

The SEM images of the CdS/p-Si thin films prepared at a substrate temperature of 200 $^{\circ}$C shows that the CdS/p-Si nanoparticle were obtained in an agglomerated state and also the voids take place between the grains (see Figure 4). It can be seen from Figures that the CdS grain size of thin film is about (18) nm .

In Figure (5) the AFM images of the CdS /p-Si thin films prepared at a substrate temperature of 200 $^{\circ}$C show a uniform granular surface morphology. The average grain diameter was evaluated from the plane view image at about 30 nm. The tilted image reveals grain heights of a few tens of nanometers. It is observed that the surface of the film is very smooth. The root mean square roughness (Rrms) of the films is 12.6 nm.

The transmittance spectra of the CdS film grown at the substrate temperature of 200 ^{0}C are shown in Figure (6). The average transmittance of CdS films is over 90 %. In order to determine the value of energy gap as well as the dominant absorption processes in such material, the relation of $(\alpha h\nu)^2$ with the incident photon energy (hν) is explained in Figure (7). The obtained value of energy gap is about 2.2 eV and it is very close to the value obtained from the literature [9,10]. The relation was linear, which indicates that the CdS of this work has direct energy gap. And the direct allowed absorption processes are the dominant the energy gap increases with increases substrate temperature and approximately remains constant at T_s=500°C. The energy gap reached at 3.3eV. The absorption coefficient (α) of such processes is given by[11,12]:

$$\alpha = A\,(h.\nu \_Eg)^{n/2}$$

Where ν is the frequency of the incident radiation, h is the Planck's constant, A is the constant, and the exponent n is equal to 1 for direct band gap materials such as CdS [9]. The direct band-gap values are calculated by extrapolating the straight-line portion over the (h.ν) axis from the evolution of $(\alpha.h.\nu)^2$ versus h.ν reported in Figure (7).

The photovoltaic performance is shown in Figure(8) in which the power can be extract from the cell form this curve we obtained the open circuit voltage (Voc) is 635 mV while shot circuit current density (Jsc) is 29.3 mA/cm^2 and fill factor (FF=0.44). The higher short circuit current density may be because the photons are due to carriers that are generated deep in the bulk of the silicon.

Figure (9) demonstrates the variation of the output power (the power generated by the cell under simulated (AM1) versus voltage across the load resistance. This figure reveals that deposited nanoparticle of CdS/p-Si heterojunction is a suitable device to produce a high efficient solar cell with conversion efficient of 7.8 %.

CONCLUSIONS

CdS/p-Si nanostructure heterojunction solar cell formed by using a pulsed 532 nm Nd:YAG laser. Results of these cell showed that this technique is an appropriate to fabricate highly efficient solar cells with conversion efficiency about (7.8 %) and fill factors about (0.44). This is because of the window effect taken place between these combinations, which reduces the role of the surface recombination effects. The variation of J_{sc} with illumination intensity showed the exponantly behavior in AMl, lumintion that explained to the saturate in carriers. The concept of a CdS heterojunction solar cell comprised a transparent conducting window material on an active semiconductor substrate, offers the possibility of manufacturing low cost solar cells suitable for large scale terrestrial applications.

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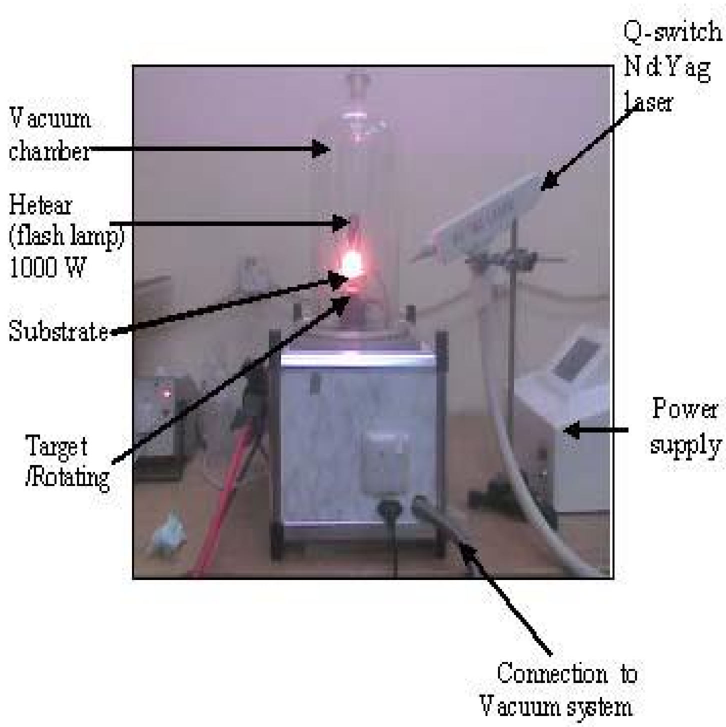

Figure (l) Experimental setup.

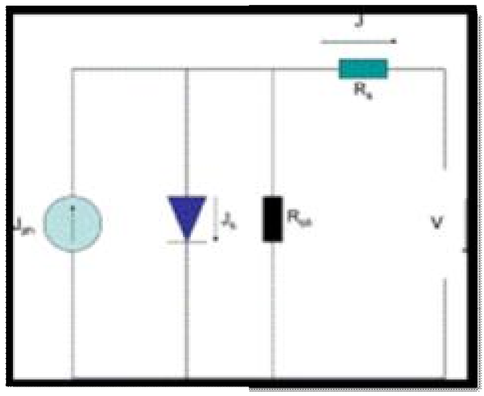

Figure (2) Photo-induced open-circuit voltage Measuring circuit.

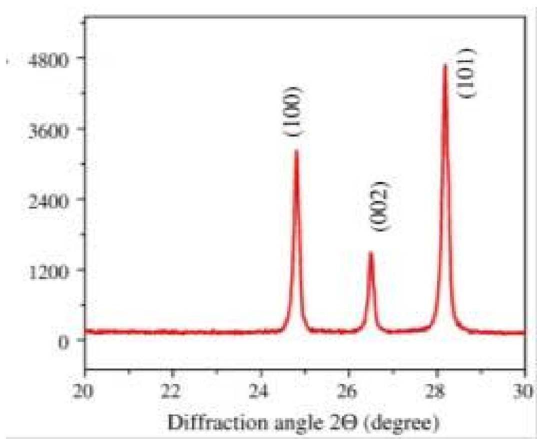

Figure (3) XRD Pattern of CdS film.

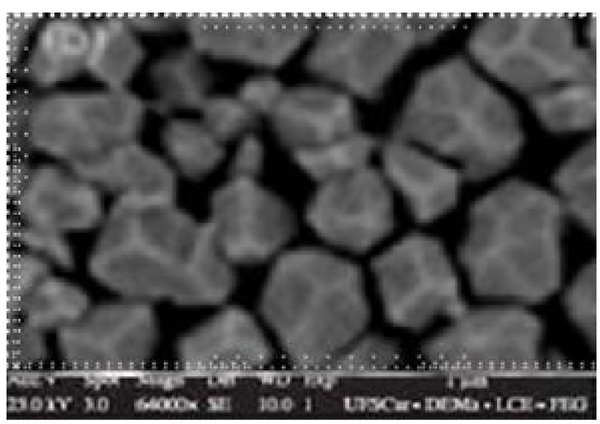

Figure (4) SEM image of the products.

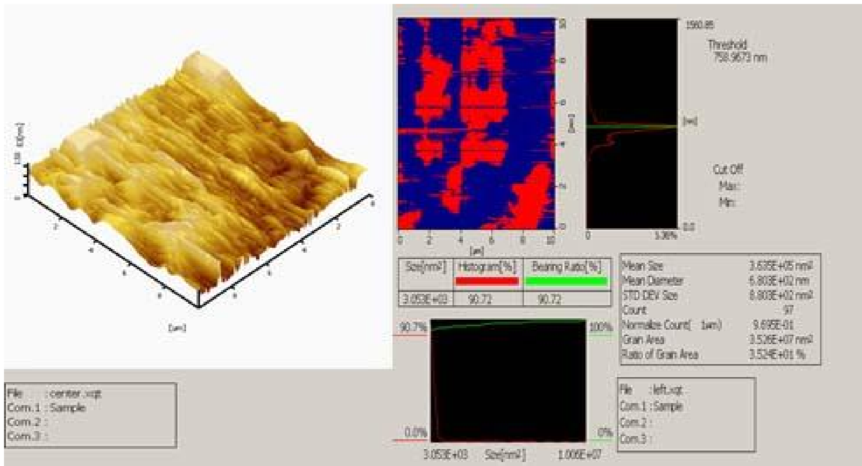

Figure (5) AFM image of the products.

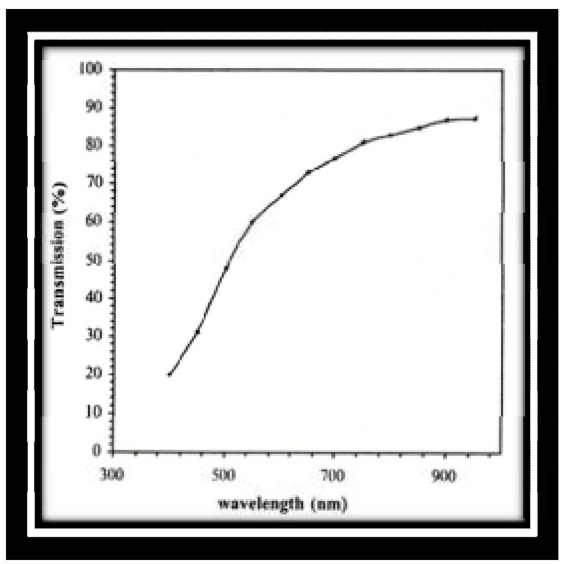

Figure (6) show the transmission spectrum of the CdS film as a function of the incident wavelength.

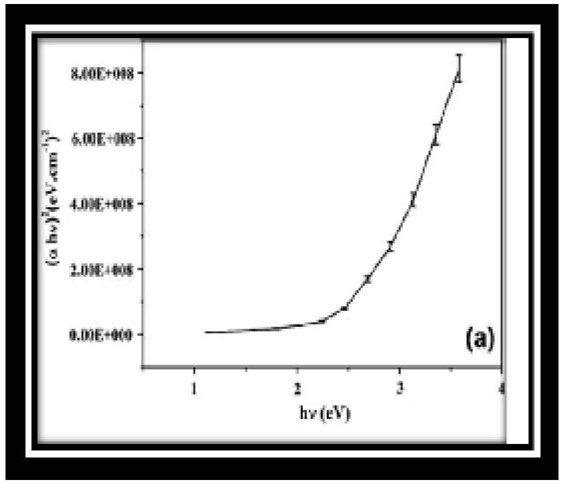

Figure (7) show the relation of $(\alpha h\nu)^2$ with the incident photon energy (hν).

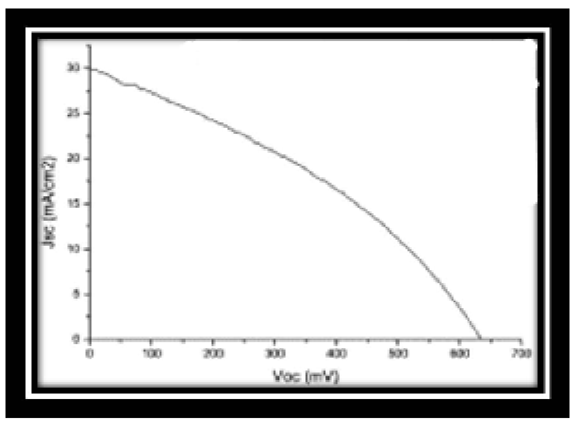

Figure (8) The Photovoltaic Performance of the Cell.

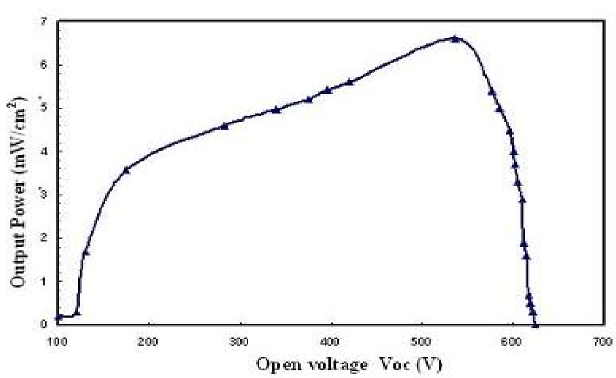

Figure (9) The Output power generated by the Cell.