Structural and Optoelectronic Characterization of CdO/Si Solar Cell Prepared by DC Magnetron Sputtering

Ghuson H. Mohammed1, Ahmed K. Al-Zubeidi2, Haider Kadhim Joudah3

1Department of Physics, College of Science, University of Baghdad, Iraq
2, 3Department of Physics, College of Science, University of Wasit, Iraq

Abstract: Cadmium oxide thin films were prepared by DC magnetron sputtering in argon gas mixed with 20% oxygen gas with different sputtering voltages (700-1200) V at 0.3 mbar pressure. The prepared films annealed in oxygen atmosphere at 523 K. The structural and optical properties of the produced films were examined by X-ray diffraction and UV-Visible absorbance, respectively. The results show a polycrystalline structure and the crystallinity of the films were enhanced. Also, the results revealed that the crystalline size and the lattice parameter increase with increasing of the sputtering voltage. UV-Visible measurements show that the absorbance thin films increases while the optical energy gap decreases with increasing the sputtering voltage. I-V Characteristics show a low efficiency for all samples, but the efficiency decreases with increasing of the sputtering voltage from 900 to 1200 V.

Keywords: DC sputtering, CdO thin films, optical properties, I-V characteristic

1. Introduction

Cadmium oxide (CdO) is n-type semiconductor with direct energy gap (2.2 -2.5) eV[1]. CdO thin films deposited by different techniques such as spray pyrolysis[2], DC sputtering [3], Sol-Gel[4] and Chemical bath methods [5] etc.

CdO thin films used in many fields such as used in photodiodes, phototransistors, photovoltaic cells, transparent electrodes, IR detectors, and anti-reflection coating[6].

Sputtering deposition is one of the most important methods that give us a high quality thin films, such as high homogeneity and adhesion, which are useful in many applications[7].

Deposition parameters play major method to tune various properties, such as electrical, structure and optical properties, of CdO thin films[8]. Study these properties for thin films very important to fabricated solar cells or any photo-electric devices[9].

2. Experimental

2.1 The Films Preparation

DC discharge plasma system consists of glass chamber of 18 cm diameter and 35 cm height, vacuumed by double stage rotary pump type Edward and Pirani gauge type Edward, with two disc electrodes of 7 cm radius, the anode made of aluminum while the cathode from cadmium target withting magnet above it to enhance the sputtering, DC-power supply, high voltage voltmeter and ammeter. The gases were delivered into the chamber using needle valve by two flow controller and mixer to control Oxygen: Argon ratio (20%) and gas pressure (0.3 mbar). The electrode was polished before every run. The CdO thin films were prepared on glass and p-type Si wafer substrates at different voltages from 700 to 1200 V at constant electrodes separation of 6 cm. The produced thin films annealed in oxygen atmosphere pressure inside closed vessel at 523 K to enhance films crystallinity.

2.2 Measurements

2.2.1 X. Ray Diffraction Spectra

The prepared films on glass substrates were examined by X-ray diffractions using (BRUKER D2 PHSER model) of \( \lambda = 1.54 \text{ Å} \) from Cu - Kα. The main law in studying the structural properties is the Bragg's law in X-ray diffraction[10]

\[ n \lambda = 2d_{hkl} \sin \Theta \]  

where \( d_{hkl} \) is the distance between the adjacent atomic layers, \( \Theta \) is the angle of diffraction and \( \lambda \) the XRD wavelength.

While the crystalline size (G S5) calculated by Scherrer equation depending on the full width at half maximum (FWHM)[11]

\[ G.S = \frac{0.9 \lambda}{FWHM \cos(\Theta)} \]  

2.2.2 Optical Properties

UV-VIS, Metertech type Sp-8001 device was used to record the optical properties for CdO thin films in the range (300 – 1100) nm.

The intensity reduced with its path in material according to the absorption coefficient \( \alpha \) as shown by Beer-Lambert equation [12].

\[ I = I_0 e^{-\alpha t} \]  

Where \( I_0 \) is the incident light intensity and \( I \) is the transmitted one. In Tauc equation \( r = 1/2 \) for the allowed direct transition [13]:

\[ \alpha h\nu = B (h\nu - E_g) \]  

where \( \alpha \) is the absorption coefficient (cm)\(^{-1}\), \( h\nu \) is the photon energy (eV), \( B \) constant depended on the type of material and preoperational inversely with the amorphosity, \( E_g \) is
the energy gap and parameter give the type of the transition..

2.2.3 The Electrical Properties
The DC electrical properties of CdO thin films deposited on glass substrate at different sputtering voltage were measured through the change of resistance with temperature. This was done by putting the samples inside the (electrical blast dry box, model WG 20) and using (Keithley 616 Multiter) to measure the film temperature, the resistivity (ρ) was determined by equation [13]:

\[ \rho = \frac{R A}{L} \]  

(5)

where R is the film resistance, A is the cross section area of the film and L is the distance between the electrode.

The conductivity (σ) from the following:

\[ \sigma = \frac{1}{\rho} \]  

(6)

The films deposited on Si substrates used to fabricated solar cell by doing Ohmic contact on top of CdO as mesh and cover all the back of Si wafer. Then examined the I-V characteristics for solar cell.

3. Results and discussions

Fig. (1) illustrates the XRD patterns for CdO films deposited with different voltages by DC sputtering in Argon: Oxygen gas mixture and annealed at 523 K in oxygen. The XRD patterns shows polycrystalline structure with four peaks, enhanced to five peaks with increasing voltage, located at 2θ = 32.9094°, 38.3425°, 55.2836°, 65.8423° and 69.2941° matching with (111), (200), (202), (311) and (222) directions in standard card No. 96-900-8610. The preferred orientation along (111) direction. The peaks intensities increase with increasing the used voltage which indicate to enhance the crystallinity. TheFull width at half maximum (FWHM) decrease, i.e. increase the crystalline size, with increase voltage from 700 to 1200 V as shown in Table (1).

![Figure 1: X-ray diffraction curves CdO films deposited by different voltages](image)

### Table 1: XRD peaks, standard and experimental dhkl for CdO films deposited by different voltages

| V (volt) | 2θ (Deg.) | FWHM (Deg.) | dhkl Exp.(Å) | G.S (nm) | hkl | dhkl Std.(Å) | card No. |
|---------|-----------|-------------|--------------|----------|-----|--------------|---------|
| 700     | 32.9094   | 0.3888      | 2.7194       | 21.3     | (111)| 2.7108       | 96-900-8610 |
|         | 38.3425   | 0.3239      | 2.3457       | 26.0     | (200)| 2.3477       | 96-900-8610 |
|         | 55.2836   | 0.3564      | 1.6603       | 25.2     | (202)| 1.6600       | 96-900-8610 |
|         | 69.2941   | 0.6479      | 1.3549       | 14.9     | (222)| 1.3554       | 96-900-8610 |
| 800     | 32.8994   | 0.2916      | 2.7203       | 28.4     | (111)| 2.7108       | 96-900-8610 |
|         | 38.3397   | 0.4211      | 2.3458       | 20.0     | (200)| 2.3477       | 96-900-8610 |
|         | 55.2484   | 0.4860      | 1.6613       | 18.4     | (202)| 1.6600       | 96-900-8610 |
|         | 69.2765   | 0.4535      | 1.3552       | 21.3     | (222)| 1.3554       | 96-900-8610 |
| 900     | 32.8914   | 0.3887      | 2.7209       | 21.3     | (111)| 2.7108       | 96-900-8610 |
|         | 38.2873   | 0.3563      | 2.3489       | 23.6     | (200)| 2.3477       | 96-900-8610 |
|         | 55.2160   | 0.3888      | 1.6622       | 23.1     | (202)| 1.6600       | 96-900-8610 |
|         | 65.8423   | 0.4536      | 1.4173       | 20.9     | (311)| 1.4157       | 96-900-8610 |
|         | 69.2613   | 0.7127      | 1.3555       | 13.5     | (222)| 1.3554       | 96-900-8610 |
Fig. (2) shows the variation of average crystalline size with used voltage. The crystalline size increase with increasing voltage from 700 to 1200 V as a result of increasing the rate of deposition. Fig. (3) shows the variation of lattice constant (a) with used voltage, which calculated using the preferred peak. This figure shows that the lattice constant increase with increasing used voltage as a result of increase the average crystalline size, where decreasing the particle size to nano range cause a strain in lattice.

Fig. (4) shows the variation of absorbance for cadmium oxide as a function of wave length, within the range (300 – 1100) nm deposited at different sputtering voltage (700 to 1200) V. It can be noticed that all films have high absorbance at small wave length and low values in the visible and near infrared region due to that the incident photons...
with small energy do not interact with atoms, the photon will transmitted, while high energy photon, greater than the energy gap, interact with valance electrons create hole-electron pairs and then the absorbance will increase [14].

The absorbance for all type of films increase with increasing sputtering voltage as a result of increasing film thickness and decreasing the energy gap.

Figure 4: The absorbance curves for CdO thin films deposited by different voltages

The optical energy gap values have been determined by using Tauc equation by plotting the relation \((\alpha h\nu)^2\) versus photon energy \((h\nu)\). The energy gap \((E_{\text{opt}})\) was determined from the intersection of tangential line with \(h\nu\) axis as shown in Fig. (5) for samples with different sputtering voltage. The energy gap decrease from 2.9 eV to 2.4 eV with increasing the sputtering voltage as a result of increasing the particle size due to increasing the ion collided energy with target [15].

Figure 5: variation of \((\alpha h\nu)^2\) with \(h\nu\) for CdO thin films prepared with different applied voltages

The incremental in CdO energy gap sample compare with bulk CdO due to the quantum size effect [16].

Fig. (6) shows the variation of natural logarithm of conductivity with the inverse of temperature for all film deposited with different applied voltage. This figure shows linearly relation with two activation energies ranges from 303-393K and 393-473 K. The conductivity enhanced with increasing the sputtering voltage from 700 to 1200 V. While the activation energies decrease with it. All activation energy values have been listed in Table (2).
Figure 6: variation of \( \ln(\sigma) \) with \( 1000/T \) for CdO thin films prepared with different applied voltages

Table 2: Activation energies and their ranges and electrical conductivity at RT

| V (V) | \( E_{a1} \) (eV) | Range (K) | \( E_{a2} \) (eV) | Range (K) | \( \sigma_{RT} \) (\( \Omega^{-1}.\text{cm}^{-1} \)) |
|-------|------------------|-----------|------------------|-----------|-----------------|
| 700   | 0.065            | 303-393   | 0.197            | 393-473   | 11.58           |
| 800   | 0.059            | 303-393   | 0.169            | 393-473   | 18.73           |
| 900   | 0.050            | 303-393   | 0.136            | 393-473   | 22.02           |
| 1000  | 0.040            | 303-393   | 0.105            | 393-473   | 31.63           |
| 1100  | 0.029            | 303-393   | 0.082            | 393-473   | 41.65           |
| 1200  | 0.010            | 303-393   | 0.048            | 393-473   | 58.63           |

Fig. (7-a,b,c,d) shows the I-V characteristics for n-CdO/p-Si heterojunction for films deposited with different sputtering voltage. This figure shows that the efficiency (\( \eta \)) decreases with increasing the voltage as a result of increasing the film absorption as shown in Table (3).
Figure 7: a,b,c,d: I-V Characteristics and the Ideality Factor calculation for n-CdO/p-Si heterojunction prepared with different voltage

| V(V) | I_L(mA) | V_m(V) | I_m(mA) | V_oc(V) | F.F | η%  | β   |
|------|---------|--------|---------|---------|-----|-----|-----|
| 900  | 20.0    | 0.320  | 13.00   | 0.170   | 0.345| 2.210| 1.4 |
| 1000 | 7.0     | 0.480  | 4.000   | 0.300   | 0.357| 1.200| 1.7 |
| 1100 | 6.0     | 0.430  | 3.400   | 0.250   | 0.329| 0.850| 2.9 |
| 1200 | 0.8     | 0.440  | 0.600   | 0.220   | 0.375| 0.132| 1.7 |

Table 3: Solar cells parameters for CdO/Si deposited with different voltage
4. Conclusions

CdO thin films synthesized by DC magnetron sputtering show a variety in its properties with deposition voltage. XRD results show that the crystallinity enhanced and the crystalline size increase with increasing used voltage. From Optical properties, it is found that the optical energy gap decreased with increasing sputtering voltage as a result of increasing particle size. Also, increasing the used voltage enhance the electrical conductivity and reduce the activation energies.

Solar cell measurements show a low efficiency for all samples, but the efficiency increased with increasing the sputtering voltage to from 900 to 1200 V.

References

[1] T. Krishnakumar et al., “CdO-based nanostructures as novel CO₂ gas sensors,” Nanotechnology, vol. 22, no. 32, p. 325501, 2011.
[2] R. H. Bari and S. B. Patil, “Nanostructured CdO thin films for LPG and CO2 gas sensor prepared by spray pyrolysis technique,” Int. Lett. Chem. Phys. Astron., vol. 37, pp. 31–46, 2013.
[3] A. I. H. Khaled H Mahmoud, Zeinhom M El-Bahy, “Photoluminescence analysis of Er nanoparticles in cadmium- phosphate glasses,” J. Non. Cryst. Solids, vol. 363, pp. 116–120, 2013.
[4] S. Sakhthivel and D. Mangalraj, “Cadmium Oxide Nano Particles by Sol-Gel and Vapour- Liquid-Solid Methods,” Nano Vis., vol. 1, no. 1, pp. 47–53, 2011.
[5] K. C. Lalithambika, K. Shanthakumari, and S. Sriram, “Optical properties of CdO thin films deposited by chemical bath method,” Int. J. ChemTech Res., vol. 6, no. 5, pp. 3071–3077, 2014.
[6] S. Kondawar, “Electrical Conductivity of Cadmium Oxide Nanoparticles Embedded Polyaniiline Nanocomposites,” Adv. Appl. Sci. Res., vol. 2, no. 4, pp. 401–406, 2011.
[7] J. Reithmaier, P. Petkov, W. Kulisch, and C. Popov, Nanostructured Materials for Advanced Technological Applications. University of Kassel Germany: Springer, 2009.
[8] Y. Ammaih, “Structural, optical and electrical properties of In doped CdO thin films for optoelectronic applications,” Opt Quant Electron, vol. 62, no. 19, pp. 3373–3375, 2014.
[9] T. Soga, Nanostructured materials for solar energy conversion, 1st Edito. UK: Elsevier B.V. All rights reserved, 2006.
[10] W. H. Bragg and W. L. Bragg, X Rays and Crystal Structure. London: G. Bell and Sons, LTD., 1918.
[11] P. Yang, The Chemistry of Nano Structured Materials. Printed in Singapore.: World Scientific Publishing Co. Pte. Ltd., 2003.
[12] D. A. Newman, Semiconductor Physics and Devices- Basis Principles. USA: McGraw-Hill companies, Richard D. & Irwin, Inc., 1990.
[13] M. H. Brodisky, Amorphous Semiconductors. Berlin Heidelberg: Springer-Verlage, 1979.
[14] Z. L. Wang, Nanomaterials for Nanoscience and Nanotechnology, vol. 1. 2000.
[15] D. Riccardo, F. Pietro, K. Yoshinobu, and I. Hideo, Advanced plasma thechnology. Germany: WILEY-VCH Verlag GmbH & Co. KGaA, 2008.
[16] A. S. Aldwayyan, B. Hammouti, T. B. Hadda, and M. Suleiman, “Synthesis and Characterization of CdO Nanoparticles Starting from Organometalic Dmphen-CdI 2 complex,” Int. J. Electrochem. Sci., vol. 8, pp. 10506–10514, 2013.