Effect of copper on physical properties of CdO thin films and n-CdO: Cu / p-Si heterojunction

B. H. Hussein*, H. K. Hassun, B. K.H. Al-Maiyaly, S. H. Aleabi
Department of Physics, College of Education for Pure Science / Ibn Al-Haitham, University of Baghdad, Baghdad, Iraq

Transition metal Copper doped Cadmium oxide and (Cu: CdO and n-CdO: Cu / p-Si) thin films were prepared onto glass and p-type single crystal (111) Si substrates at temperature 300 K by thermal evaporation technique with thickness (400±30) nm. The effects of different Cu ratios on the CdO thin films and heterojunction of n-CdO / p-Si.. The X-ray diffraction analysis approves the CdO films are polycrystalline and cubic structure with lattice parameter of 0.4689 nm. The optical transmittance exhibits excellent optical absorption for 6% Cu doping. Decreased of optical band gap from 2.1 to 1.8 eV. Hall measurement approves that CdO material n type with a maximum carrier mobility of 144.6 (cm^2/Vs) with resistivity of 0.107991 (Ω.cm) were achieved for 6% Copper (Cu) doping. The I-V characteristics of heterojunction prepared under illumination was carried out by(100 mW/cm2) incident power density at different Cu doping.

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1. Introduction

Metal doped and pure semiconductor cadmium oxide that used in a varied range of optoelectronic application like solar cell, optical communication and smart window [1]. Cadmium oxide is a pretty toxic by inhalation, oral, and dermal materials but we use it giving to its various applications and different features. Thin films deposition methods have been reported to doped un-doped, doped, and co-loaded CdO thin films containing chemical bath coating [2][3], vacuum evaporation [4,5], successive ionic layers adsorption, and reaction technique [6], sol gel technique [7], magnetron sputter [8], organic chemical vapor deposition system [9], chemical spray pyrolysis [10] and pulsed laser deposition, [11], Doping of CdO thin films including several materials for example Al [1,12], F [13], In [14], Sn [15,16], Pt [17], Uranium [18], Ga [19], Pb [20], Mn [21], Co [22], Zn [23], and yttrium(Y) [24]. have already been studied. The type of conductivity of semiconductor Cadmium oxide is n - type [5] Optical energy-gap value between (2.2 - 2.8) eV [16]. The ionic radii is a major factor uses for choosing applicable contribution materials [25] Structural, optical and electrical properties of CdO film could be controlled for example the ionic radii of Cu doping being smaller than the ionic radius of cadmium ions[26]. Cu is suitable dopant for CdO lattice because the lower ionic radii Cu (0.71Å) than Cd^{+2} (0.95Å) [27][28]. To not reason the tension of CdO lattice to be deformed. Because there is no work Copper doped cadmium oxide films as of now, this work, its aim was to study the specific influence Cu on the fabricate (n-CdO/p-Si) heterojunction by using vacuum evaporating technique.

* Corresponding author: bushrahhz@yahoo.com
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2. Experimental

Pure and Cu doped CdO, n-CdO: Cu/ p-Si heterojunction films have been deposited on the substrates by thermal evaporation technique under high vacuum of ($3x10^{-6}$) torr using Edward coating unit. These films were deposited by two steps: First for the preparing of CdO, pure metal Cadmium thin films with thickness (400 ± 30) nm was deposited on glass and on substrates of p-type single crystal (111) Si wafers at room temperature (300K) , then using thermal oxidation processes at temperature (673K) for one hour with exist air flow to get CdO thin films. In the second step, these films have been doped with ratios 2 ,4 and 6% (Cu).

The crystallographic structure of pure and doped CdO thin films was observed by using X-ray diffraction XRD technique when X-ray diffractometer (SHIMADZU Japan XRD 600) with ($\lambda_{Cu\ K\alpha}$ =1.5418740 Å) radiation of wavelength for 2θ values between 20° and 80° to calculated the crystalline size be using the Scherrer's equation [29]. The optical properties coated samples were carried out with UV/VIS spectrophotometer to obtain the transmittance T and absorbance A spectrum in the range of wavelengths (400 – 1000) nm then estimate the energy gap by Tauc equation [30,31]. The electrical properties were determined by Van der Pauw Ecopia-HMS -3000 for Hall measurements. Shockley equation applied to study I-V Current voltage characteristic of n-CdO /p-Si and n-CdO:Cu /p-Si hetrojunction [32]. The efficiency of solar cell was calculated [33].

3. Results and discussion

3.1. Structural Properties

Fig. 1 represents the XRD analysis of pure CdO and Cu doped. From XRD graph, the samples have a polycrystalline with a cubic structure of the CdO (111) plane being the preferential direction at according to (ASTM card No.05-0640[34]. Diffractions rising up of Cu metal, their oxidations form, or any Cu contributed patterns have not been monitored in the XRD pattern of the (2% , 4% and 6%) of Cu this mean that the Cu doped scattered uniformly in the CdO structure and the peaks become sharper due to the crystallinity of these films being better after doped. The lattice constant (a), d (hkl) and Average Crystallite size (D) values are presented in Table 1. These results are in good settlement with [5].

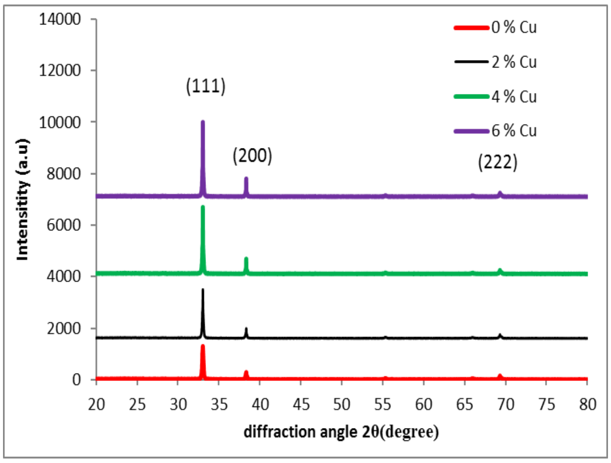

Fig. 1. The XRD pattern of CdO pure and Cu doped thin film with different ratios of Cu.

Table 1. Structural parameters of CdO pure and Cu doped thin films with different ratios of Cu.

Thin films	2θ(°)	d (Å)	Average Crystallite Size (D) (nm)	Lattice Constant (a)(Å)	(hkl)
Pure CdO	33.05	2.707	35.22	4.689	111
2% Cu	33.08	2.705	43.45	4.685	111
4% Cu	33.10	2.703	49.01	4.681	111
6% Cu	33.18	2.699	52.69	4.675	111
ASTM	33.00	2.7120	_	4.695	111

3.2. Optical Properties

Optical transmittance and absorbance spectra of pure CdO and Cu doped films with different ratios of Cu are displayed in Fig. 2. It can be observed that the absorbance has increased with increasing ratios of Cu in the wavelength between 400 nm to 600 nm, this might be because of the aids of Cu ions in the CdO lattice and improved crystallinity as increasing in average crystallite size. For all samples the transmittance is decreased when ratios of Cu increased this might be due to higher absorption which might be attributed to the deformation caused by Cu ions in the CdO. The decreased transmittance (50% to 30%) observed for the ratios of Cu (0, 2,4 and 6) % doped CdO films might be because of high crystallite size values (35-52) nm for this films as in Table 1.

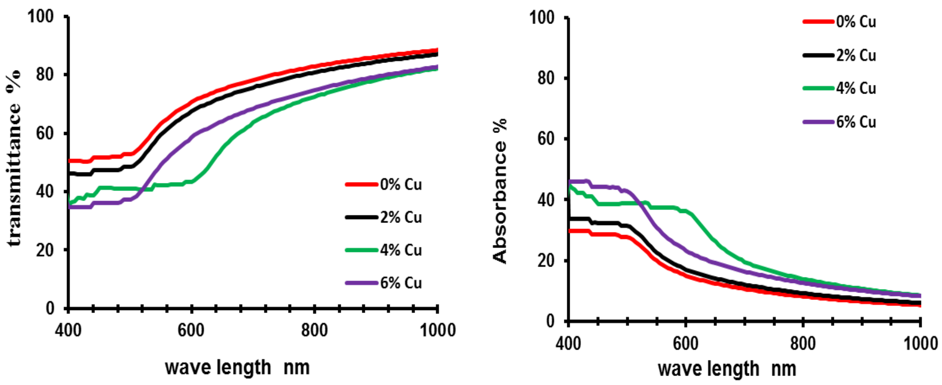

Fig. 2. Optical transmittance and absorbance of pure CdO and Cu doped thin film with different ratios of Cu.

Optical energy- gap of the prepared films was displayed in Fig. 3. The optical energy- gap was result by using of the Tauc equation [30,31] in high absorption region. The values of energy band-gap were 2.1, 2, 1.9, and 1.8, respectively for pure CdO and Cu doped thin films with different ratios of Cu as in Table 2. The decreased energy-gap values observed due to increase in the defects number in films, increase the density of localized states in the Eg after doped. The shifting of optical energy gap near longer wavelength red. The value of the is in agreement with [5]. The high absorbance of samples CdO thin films with Cu doped create them good as an optical material for solar-cells application.

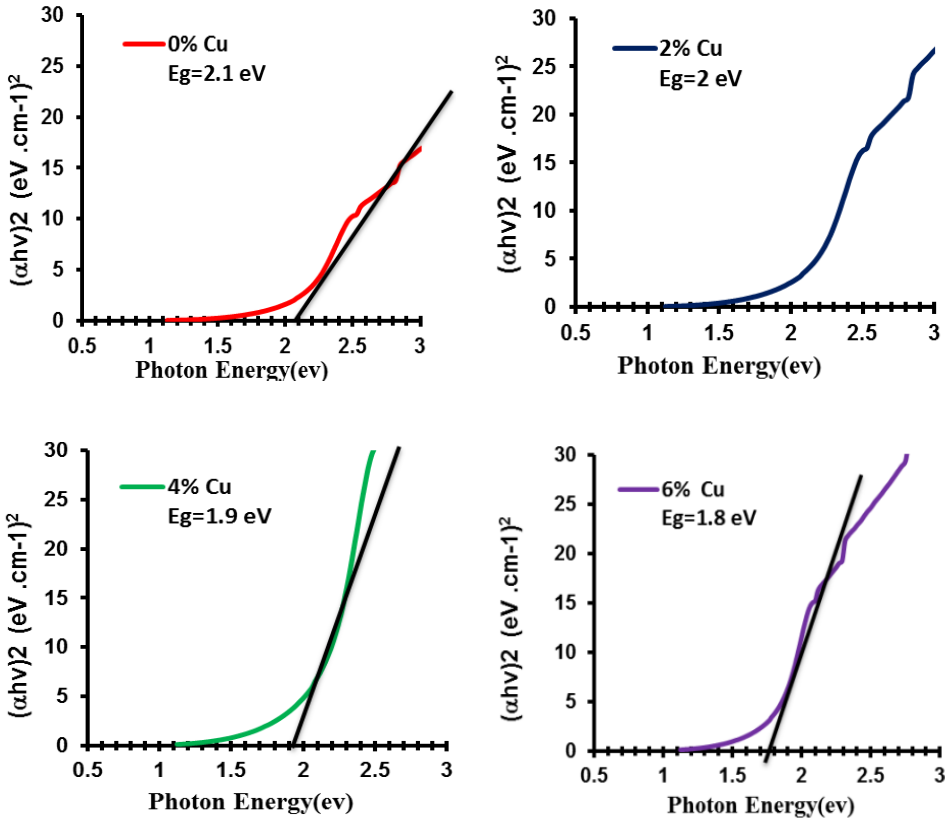

Fig. 3. The $(\alpha h\nu)^2$ versus (hν) spectrum of pure CdO and Cu doped thin film with different ratios of Cu coated on glass substrates.

Table 2. Direct optical Energy gap and absorption coefficient for pure CdO thin film and doped Cu.

λ=500nm		
Sample	**E_g^{opt} (eV)**	**$\alpha\times10^4$ cm^{-1}**
Pure CdO	2.1	1.2
2% Cu	2	1.6
4% Cu	1.9	1.98
6% Cu	1.8	2.19

3.3. Electrical Properties

Fig. 4 illustrates the carrier concentration (N_D), resistivity(ρ), and carrier mobility (μ) as a function of ratios of Cu in CdO films. The electrical parameters were influenced with ratios of Cu, the values of all factors were presented in Table 3.

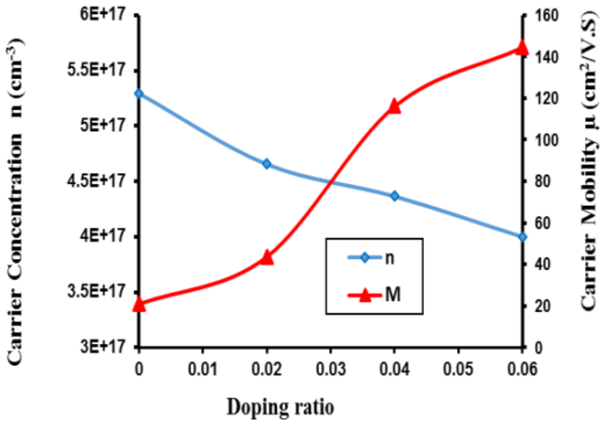

Fig. 4. The carrier concentration, and mobility of pure CdO and Cu doped thin films with different ratios of Cu.

Table 3. The electrical parameters of pure CdO and Cu doped thin films with different ratios of Cu.

Sample	Carrier concentrations N_D (cm^{-3})*10^{17}	Mobility (μ_H) (cm^2/Vs)	Resistivity (ρ) (ohm.cm)	Average Hall coefficient
Pure CdO	5.2	20.11	0.597501	-12.01
2% Cu	4.6	43.7	0.3125	-13.58
4% Cu	4.3	116.2	0.125	-15.5
6% Cu	4	144.6	0.107991	-15.625

Electrical parameters shown the improvement in the electrical characteristic of CdO these film by doping Cu. From the negative signs of Hall coefficients for both pure CdO and Cu doped films confirmed that the prepared samples have conductivity n-type this result is in agreement with references [5,35]. The enhanced electrical features by increased values of carrier mobility's, and conductivities for all samples CdO thin films might be attributed to replacement of Cu with the ones of Cd. [1,16].

In illumination condition the density of current and voltage of n- CdO:Cu/p-Si is displaying in Fig. (5), the J-V of solar cell PV where voltage range from 0 to 300 mV. Solar cell device with Jsc– 14 mA/cm^2 & Voc ~ 300 mV. The efficiency was calculated gain the conversion efficiency for solar cell 2.09% when Cu ratio is 6% as in Table 4. When the doping ratios increases in sample, the amount of Cu molecules could be absorbed increase because of increasing surface of area. Therefore, sunlight can be useful to improve faster electron transport with lessening the probability of electron-hole pair recombination because of develop the efficiency of solar cell fabricate.

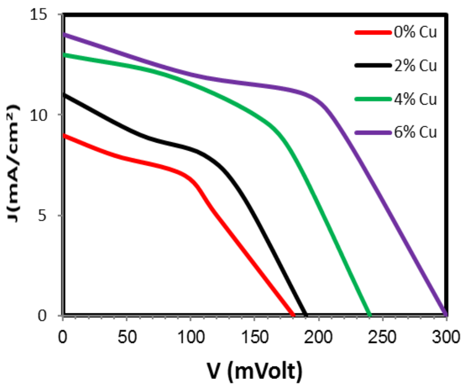

Fig. 5. J-V characteristic for CdO:Cu /Si heterojunction for pure CdO and Cu doped thin film.

Table 4. Solar cell factors of CdO:Cu /Si heterojunction for pure and Cu doped CdO thin films.

Thickness(400 nm)	V_{oc} (mV)	J_{sc} (mA/cm^2)	V_{max} (mV)	J_{max} (mA/cm^2)	FF	η %
Pure CdO	180	9	95	7	0.41	0.667
2% Cu	190	11	110	8	0.42	0.88
4% Cu	240	13	150	10	0.48	1.5
6% Cu	300	14	190	11	0.497	2.09

4. Conclusion

The pure CdO and Cu doped thin film were coated through the thermal evaporation process. The effects of Cu doping level on structural, optical, and electrical of CdO thin films were considered. The XRD patterns shown cubic structure with polycrystalline nature of all the deposited. The crystallite size increased from 35 to 52 nm with Cu ratios. The optical band-gap of un-doped CdO films decreased from 2.1 eV to 1.8 eV , Hall Effect revealed that the electrical property was effect by Cu ratios. A maximum carrier mobility value and minimum resistivity were obtained. I-V characteristic under illumination 100 mW/cm2 incident power density with maximum value of efficiency (2.09%) and fill factor 0.497 for heterojunction (n- CdO:Cu/p-Si) because this has good size of crystallite, better absorption coefficient, low resistivity with high mobility values.

References

[1] Ngamnit Wongcharoena, Thitinai Gaewdang, Tiparatana Wongcharoen, Energy Procedia 15, 361 (2012); https://doi.org/10.1016/j.egypro.2012.02.044

[2] R. R. Salunkhe, V. R. Shinde, C. D. Lokhande, Sensors Actuators B Chem. 133(1), 296 (2008); https://doi.org/10.1016/j.snb.2008.02.024

[3] H. Khallaf et al., Appl. Surf. Sci. 257(22), 9237 (2011); https://doi.org/10.1016/j.apsusc.2011.04.060

[4] A. A. Dakhel, J. Mater. Sci. 46(21), 6925 (2011).; https://doi.org/10.1007/s10853-011-5658-6

[5] Bushra Kadhim Hassoon Al-Maiyaly, J. for Pure & Appl. Sci. 29(3), 14 (2016).

[6] B. Gokul, P. Matheswaran, R. Sathyamoorthy, J. Mater. Sci. Technol. 29(1), 17 (2013); https://doi.org/10.1016/j.jmst.2012.11.015

[7] Z. A. Alahmed, H. A. Albrithen, A. A. Al-Ghamdi, F. Yakuphanoglu, Optik 126(5), 575 (2015); https://doi.org/10.1016/j.ijleo.2015.01.005

[8] S. Cheemadan, A. Rafiudeen, M. C. S. Kumar, J. Nanophotonics 10(3), 33007 (2016); https://doi.org/10.1117/1.JNP.10.033007

[9] L. M. Guia, V. Sallet, S. Hassani, M. C. Martínez-Tomás, V. Munoz-Sanjose, Cryst. Growth Des. 17(12), 6303 (2017); https://doi.org/10.1021/acs.cgd.7b00989

[10] M. Anitha, K. Saravanakumar, N. Anitha, L. Amalraj, Opt. Quantum Electron. 51(6), 1 (2019); https://doi.org/10.1007/s11082-019-1901-1

[11] A. A. Menazea, A. M. Mostafa, E. A. Al-Ashkar, Opt. Mater. 100, 109663 (2020); https://doi.org/10.1016/j.optmat.2020.109663

[12] B. Saha, S. Das, K. K. Chattopadhyay, Sol Energy MaterSol Cells 91, 1692 (2007); https://doi.org/10.1016/j.solmat.2007.05.025

[13] R. J. Deokate, S. M. Pawar, A. V. Moholkar, V. S. Sawant, C. A. Pawar, C. H. Bhosale et al., Appl Surf Sci. 254, 2187 (2008); https://doi.org/10.1016/j.apsusc.2007.09.006

[14] R. K. Gupta, K. Ghosh, R. Patel, S. R. Mishra, P. K. Kahol, Mater Lett. 62, 3373 (2008); https://doi.org/10.1016/j.matlet.2008.03.015

[15] L. R. de Leon-Gutierrez, J. J. Cayent-Romero, J. M. Peza-Tapia, E. Barrera-Calva, J. C. Martinez-Flores, M. Ortega-Lopez, Mater Lett. 60, 3866 (2006); https://doi.org/10.1016/j.matlet.2006.03.131

[16] M. Thirumoorthi, J. Thomas Joseph Prakash, Journal of Asian Ceramic Societies 4, 39 (2016); https://doi.org/10.1016/j.jascer.2015.11.001

[17] Z. Serbetci, B. Gunduz, A. A. Al-Ghamdi, F. Al-Hazmi, K. Arik, F. El-Tantawy, F. Yakuphanoglu, W. A. Farooq, Acta Physica Polonica A 126, 798 (2014); https://doi.org/10.12693/APhysPolA.126.798

[18] Zafer Serbetçi, Materials Science-Poland 38, 23 (2020); https://doi.org/10.2478/msp-2020-0017

[19] M. Thambidurai, N. Muthukumarasamy, A. Ranjitha, D. Velauthapillai, Superlattices Microstruct. 86, 559 (2015); https://doi.org/10.1016/j.spmi.2015.08.020

[20] G. Turgut, J. Mater. Sci. Mater. Electron. 28(22), 16992 (2017); https://doi.org/10.1007/s10854-017-7621-z

[21] N. Manjula, M. Pugalenthi, V. S. Nagarethinam, K. Usharani, A. R. Balu, Mater. Sci. 33(4), 774 (2015); https://doi.org/10.1515/msp-2015-0115

[22] K. V. Kannan Nithin, M. R. M. Krishnappa, J. Phys. Conf. Ser. 1362(1), 2019; https://doi.org/10.1088/1742-6596/1362/1/012118

[23] V. K. Gupta, A. Fakhri, S. Tahami, S. Agarwal, J. Colloid Interface Sci. 504, 164 (2017); https://doi.org/10.1016/j.jcis.2017.05.026

[24] S. Ahmed, M. S. I. Sarker, M. M. Rahman, M. Kamruzzaman, M. K. R. Khan, Heliyon 4(8), (2018); https://doi.org/10.1016/j.heliyon.2018.e00740

[25] K. T. R. Reddy, G. M. Shanthini, D. Johnston, R. W. Miles, Thin Solid Films 427(12), 397 (2003); https://doi.org/10.1016/S0040-6090(02)01183-5

[26] P. Velusamy, R. R. Babu, K. Ramamurthi, E. Elangovan, J. Viegas, J. Alloys Compd. 708, 804 (2017); https://doi.org/10.1016/j.jallcom.2017.03.032

[27] N. N. Greenwood, A. Earnshaw, Chemistry of the Elements. Elsevier, 2012.

[28] R. D. Shannon, Acta Crystallogr A 32(5), 751 (1976); https://doi.org/10.1107/S0567739476001551

[29] I. H. Khudayer, B.H. Hussien, Ibn Al-Haitham J. for Pure & Appl. Sci. 29(2), 41 (2016).

[30] Bushra H. Hussein, Hanan K. Hassun, NeuroQuantology 18(5), 77 (2020); https://doi.org/10.14704/nq.2020.18.5.NQ20171

[31] B. K. H. AL-Maiyal, B. H. Hussein and H. K. Hassun, Journal of Ovonic Research, 16 (5), (2020).

[32] Hanan K. Hassun, Bushra H. Hussein, Bushra K. H. Al-Maiyaly, Auday H. Shaban, Key Engineering Materials 886, 66 (2021); https://doi.org/10.4028/www.scientific.net/KEM.886.66

[33] Bushra H. Hussein, Iman Hameed Khudayer, Mohammed Hamid Mustafa, Auday H. Shaban, Progress in Industrial Ecology - An International Journal 13(2), 173 (2019); https://doi.org/10.1504/PIE.2019.099358

[34] JCPDS, "International Center for Diffraction Data," ASTM data files 5-64 card No. 05-0640, 1997.

[35] Yu Yang, Shu Jin, Julia E. Medvedeva, John R. Ireland, Andrew W. Metz, Jun Ni, Mark C. Hersam, Arthur J. Freeman, Tobin J. Marks, J. Am. Chem. Soc. 127, 8796 (2005); https://doi.org/10.1021/ja051272a