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FABRICATION AND CHARACTERIZATION OF n-CdO:In/p-Si THIN FILM SOLAR CELL

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ABSTRACT

A CdO:In/Si solar cell film was fabricated via deposition of a CdO:In thin film on p-type silicon substrate with approximately 254 nm thickness using spray pyrolysis deposition. Atomic force microscopy indicated that the film was an n-CdO:In nanocrystalline. The nanocrystalline thin film had a grain size of 35.6 nm. X-ray diffraction was used to characterize the structural properties of the solar cell film. It preferentially orientated along(111) crystallographic directions. CdO:In/Si solar cell photovoltaic properties were examined under 27.96 mW/cm^{-2} intensity illumination. The cell showed an open circuit voltage (Voc) of 250 mV, a short-circuit current (Isc) of 45×10^{-3}mA, a fill factor (FF) of 0.28 and a conversion efficiency (η) of 11.2%.

Keywords: CdO thin films, photovoltaic, solar cell, fill factor, conversion efficiency.

I. INTRODUCTION

Transparent conducting thin films are a class of material which achieve large values of electrical conductivity, whilst maintaining a high transmission in the visible range of the electromagnetic spectrum [1]. For these two properties, transparent conductive oxides are essential parts of all thin film solar cells [2] and other optoelectronic devices [3,4]. Most of the TCO films have n-type conductivity. High transparency combined with useful electrical conductivity is achieved by selecting a wide-band gap oxide. CdO is n- type of TCOs and it has a relatively low intrinsic band gap of 2.3 eV [5]. Despite of its low band gap, it can reach a high band gap value owing to its low effective carrier mass [6], giving rise to relatively large shifts due to doping.

There are several methods developed for the synthesis of CdO films such as spray pyrolysis [7-10], sputtering [11], chemical bath deposition (CBD) [12], pulsed laser deposition [13,14], MOCVD [15,16] sol-gel spin coating method [17,18] and thermal evaporation technique [19] .

The effect of doping various elements such as Sn, In, F, Cu and Ga on the physical properties of CdO thin films has already been reported [20-24]. Doping increases its free electron concentration and electrical conductivity. Indium has been used as a suitable dopant for other transparent conducting films to increase the concentration of conduction electrons and improve the electrical conductivity, but there were few studies about In-doped CdO (In-CdO) films. Recently, Gupta et al. have deposited In-CdO thin films for optoelectronic applications [25].These In-CdO (2 at% In) film grown at 200˚C under an oxygen pressure of 5.0×10^{-4} mbar shows high mobility

(155 cm^2/V s), high carrier concentration(1.41×10^{21} cm^{-3}), and low resistivity (2.86×10^{-5} Ω .cm). The spray pyrolysis technique has some advantages when compared with other methods. It is quite simple and the required setup is less expensive and flexible for process modifications. It is used for the preparation of a large number of semiconducting and insulating thin films [26,27]. This article deals with the fabrication of n-CdO:In/p-Si heterojunction diode using spray pyrolysis technique and reports its properties.

II. EXPERIMENTAL

In the case of heterojunction, the properties of the interface vary greatly from material to material and largely depend on the method of formation [28]. The of CdO/Si film has been prepared by spray pyrolysis technique from 0.3 M solution of cadmium acetate $Cd(CH_3COO)_2.2H_2O$ diluted with methanol and distiller water in the ratio 1:1 of the single crystal silicon wafers of p-type with (100) orientation as substrate which has a thickness of 600 μm and a resistivity in the range of 14-22 Ω.cm of one polished face. CdO:In thin films were prepared by doping CdO solution in a ratio of (2%) with 0.1 M from mixture of $InCl_3$ and water distiller. The wafers were chemically etched in dilute hydrofluoric acid in the water with a ratio of 1:10 to remove the native oxide. The deposition of CdO: In the film was carried by spraying an aqueous solution onto a heated silicon substrate of 1cm^2 area at (350±10˚C).The optimized deposition parameters such as spray nozzle substrate distance (31cm), spray time (7s) and the spray interval (70s) were kept constant. The pressure of the carrier gas (N_2) was 4 mbar. The film thicknesses were measured by using Michelson Interferometer and found to be 254 nm. For the electrical measurements of n-CdO:In /p-Si heterojunction diode, the metal electrodes of aluminum and silver paste were formed both back surface of the Si wafer and top of the CdO:In film respectively. Figure 1 shows the schematic diagram of an n-CdO/p-Si heterojunction diode. Crystal structure as well as crystal quality of CdO:In/Si heterojunction was examined using X-ray diffraction (XRD) and Atomic force microscopy (AFM). X-ray diffraction (XRD) measurements were carried out using Rigaku MiniFlex II desktop x-ray diffractometer. SPM model AA 3000 Angstrom Advanced Lns. ,USA was used to determine the nanocrystalline topography. Current-Voltage (I-V) measurements were performed in forward bias using KEITHLEY 4200 SCS/CVU under 27.96 mW/cm^{-2} illumination.

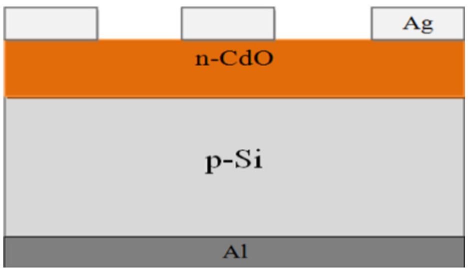

Figure 1: Schematic illustration of the (n-CdO/p-Si) solar cell thin film

III. RESULTS AND DISCUSSION

Figures 2 and 3 shows the X ray diffraction (XRD) patterns of the prepared CdO and CdO:In films respectively. All the patterns show polycrystalline of cubic CdO structure (NaCl structure) and CdO:In films are composed of crystallites of CdO (JCPDS Card No:05-0640) [29]. XRD shows neither the formation of CdO_2 and In_2O_3 nor mixed phases even at In-doping level. It can be clearly seen that all films are preferentially orientated along(111) crystallographic directions and the preferential orientation peak for In doped films became sharper and more intense. This may be attributed to the crystallinity of the CdO films being improved with In doping.

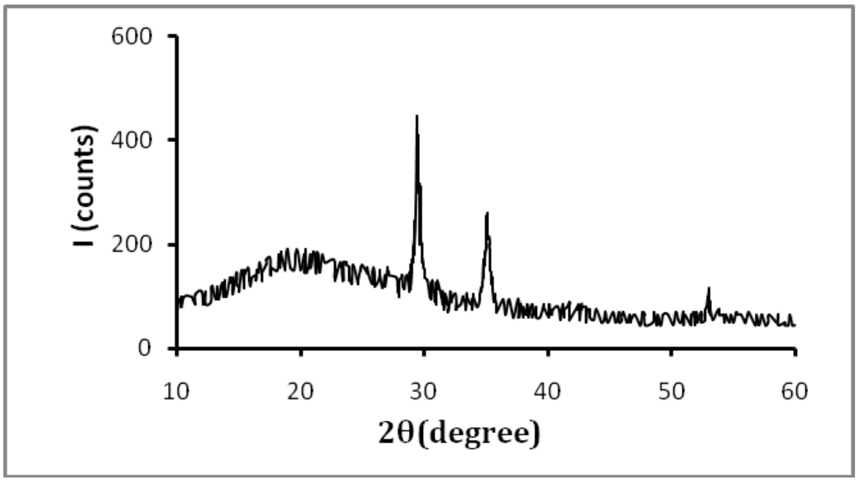

Figure 2: (XRD) patterns of the prepared undoped CdO

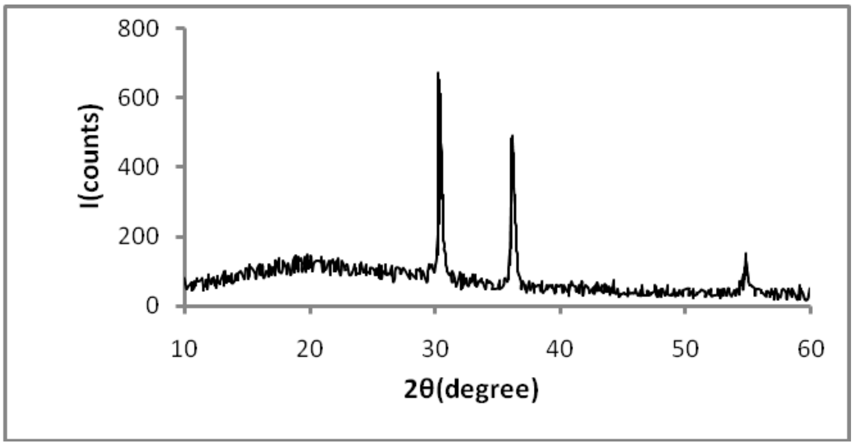

Figure 3: (XRD) patterns of the prepared CdO:In

Table 1: The diffraction angle (2Θ), interplaner distance (d), relative intensity of the peaks ($I / I_{\circ}$) , (FWHM), intensity (I) and the phases identified along with (hkl) planes of CdO:In film.

Material	2θ(deg)	d(A˚)	I/I_o	FWHM (deg)	I(counts)	Identification with (hkl) values
CdO:In	33.04	2.709	100	0.329	680	(111)
	38.34	2.346	73	0.353	491	(200)
	55.34	1.659	24	0.376	163	(220)

For CdO:In films, the grain size (D) was calculated from the full width at half maximum (FWHM) (β) of the preferred orientation diffraction peak by using the Scherrer equation [30]:

$$D = \frac{k.\lambda}{\beta.\cos\theta} \qquad (1)$$

where k denotes the Scherrer constant (the shape factor of the average crystallite and can be considered k = 0.90) , λ= 1.5418 Ǻ is the wavelength of the incident Cu Kα radiation. The calculated value of D equals to 24.1nm, which gives an indication that the size lie within the nanocrystal range. The calculated lattice constant (a) for the dominant peak of (1 1 1) of CdO:In equals to 4.692 Ǻ which is very close to the reported value ($a_{\circ}$) 4.695 Ǻ [27]. The strain ε_{zz} of the CdO:In thin film grown on the Si substrate along the c-axis can be calculated using the following equation [31]:

$$\varepsilon_{zz}(\%) = \frac{a - a_{\circ}}{a_{\circ}} \qquad (2)$$

The negative value of the strain (- 0.063%) revealed the compressive strain of the CdO:In thin film. This low value of compressive strain suggests that the synthesized nanocrystalline CdO:In has high-quality crystal geometry. These values of grain size (D), lattice constant (a) and the strain ε_{zz} (%) are similar to those which are reported by M. Zaien et al [32]. The texture coefficient TC(h k l) for the preferential crystallite orientation (111) was expressed by [33]:

$$TC(h,k,l) = \frac{I(hkl)/I_{\circ}(hkl)}{N^{-1} \sum_N I(hkl)/I_{\circ}(hkl)} \qquad (3)$$

A sample with randomly oriented crystallite presents TC(h,k,l) = 1, while the larger value, the larger abundance of crystallites oriented at the (h k l) direction. The texture coefficient was calculated for the (111) peak and it was found to be 1.26. To have more information on the amount of defects in the film, the dislocation density (δ) was evaluated from the formula [34]:

$$\delta = \frac{1}{D^2} \qquad (4)$$

where D is the grain size. This quantity, δ, is defined as the number of dislocations intersecting a unit area of a random section. The δ value of CdO:In film was found to be 1.72×10^{-3} nm^{-2}. That means there was a strong decreasing of the defects in the film and improving in the crystallite quality.

AFM images of CdO:In/Si film are shown in figure 4. The In the doped CdO film show smooth surface. The 1510 nm×1510 nm image is utilized for measuring the average roughness(Ra) and root mean square roughness surface (Rq) of the film. The (Ra) and (Rq) of the CdO:In/Si film are measured to be 0.106 nm and 0.129 nm respectively. These low values of (Ra) and (Rq) refer to a reduction in the light reflection and increase in light absorption of the visible region in the solar spectrum of solar cells.

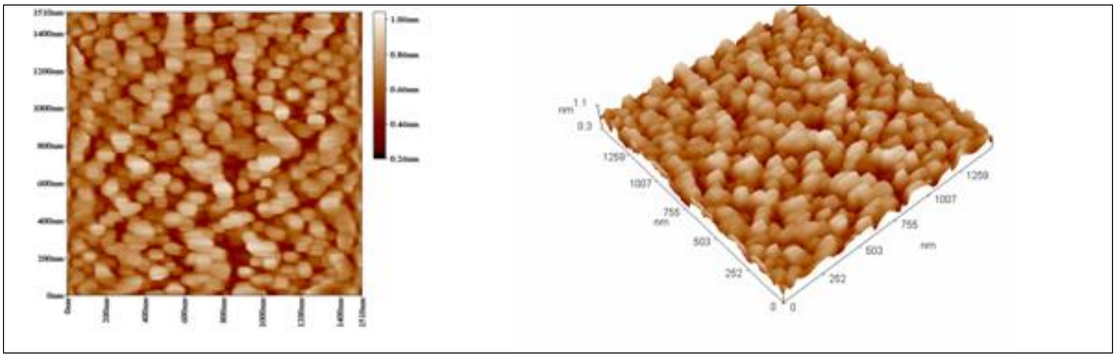

Figure 4: AFM image of CdO:In / Si heterojunction

Figure 5 shows the granularity accumulation distribution of 603 grains. From this distribution the average diameter of the grains was found to be 35.6nm.

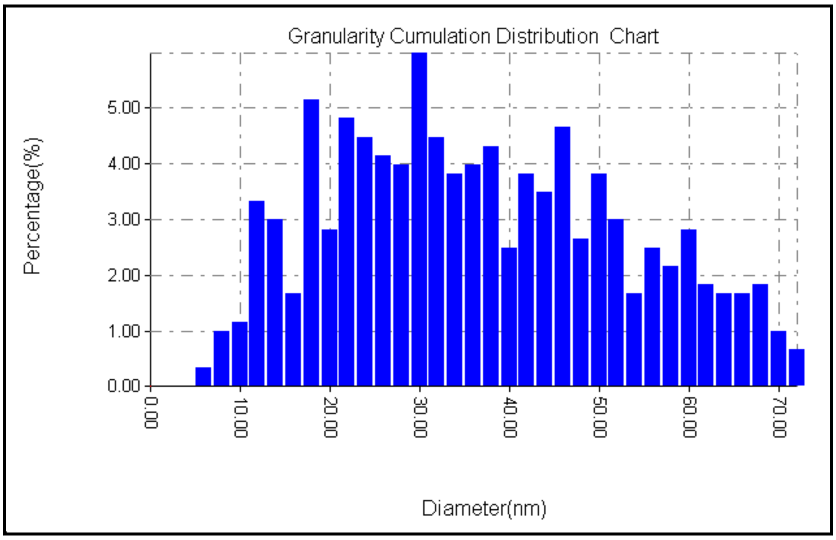

Figure 5: Granularity accumulation distribution of n-CdO/p-Si film

To determine the photovoltaic characterization of the CdO:In/Si film, the current–voltage characteristics of the film under dark and illumination conditions were studied as shown in figure 6. Under dark condition the developed heterojunction shows a good rectifying behavior. The dark current increases with increase in the applied voltage. In the reverse bias condition, the photocurrent exhibits a flat dependence. Under the illumination condition, the reverse current strongly increases with illumination intensity of 27.96 $mWcm^{-2}$ and the diode gives a maximum open circuit voltage Voc of 250 mV and short-circuits current Isc of 45×10^{-3} mA. These values indicate that the n- CdO/p-Si diode exhibits a photovoltaic behavior, because the photovoltaic effect involves the creation of a voltage and current in a p–n heterojunction upon exposure to light intensity. The fill factor (FF) and the efficiency (η) were calculated from figure 6 using the following relations[35]

$$FF = \frac{I_{max} V_{max}}{I_{sc} V_{oc}} \quad (5)$$

$$\eta = \frac{P_{max}}{P_{in}} \quad (6)$$

where I_{max} and V_{max} are the current and the voltage at the maximum power output respectively and P_{in} is the power input to the cell defined as the total radiant energy incident on the surface of the cell.

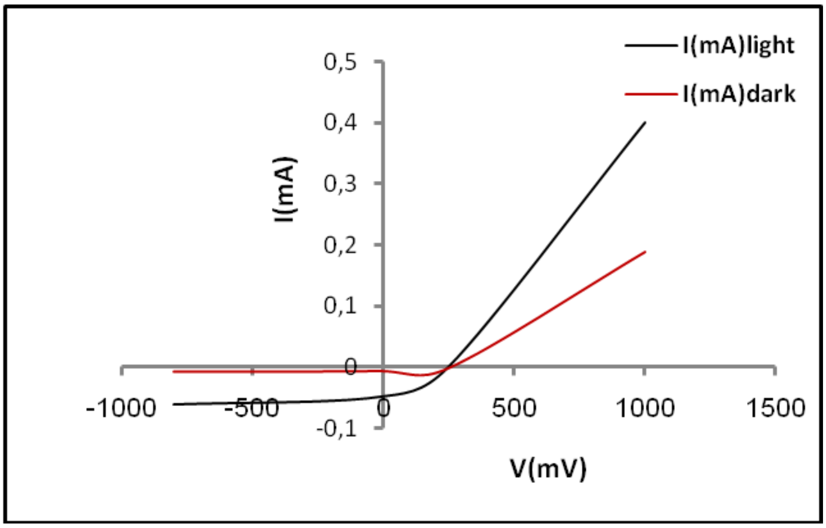

Figure 6: Current–Voltage characteristics of the CdO:In film under dark and illumination conditions

The I_{max} and V_{max} values were found to be 25×10^{-3} mA and 125 mV respectively. The calculated fill factor was 0.28 and this low value due to the presence of high series resistance. The efficiency was 11.2% and it is accepted and high value comparing with other researches [32,35].

IV. CONCLUSION

An n-CdO:In thin film was successfully deposited on a p-Si substrate to yield a solar cell by spray pyrolysis technique. The XRD pattern showed that the thin film was polycrystalline in nature with a cubic structure and that the prepared film has a (111) preferred orientation. AFM image showed that the thin film exhibited a uniform surface morphology over the entire substrate and has a good quality and nanocrystalline structure. Moreover, the solar cell conversion efficiency (n-CdO/p-Si) was 11.2% under a 27.96 mW/cm^{-2} illumination condition using spray pyrolysis deposition method.

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