Optik 127 (2016) 3809–3819

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Characterization of jet nebulizer sprayed CdO thin films for solar cell application

Murugasamy Ramamurthy [a,*], Murugan Balaji [a], Perumal Thirunavukkarasu [b]

[a] Department of Physics, Sri Ramakrishna Mission Vidyalaya College of Arts and Science, Coimbatore 641020, Tamil Nadu, India
[b] Department of Electronics, Sri Ramakrishna Mission Vidyalaya College of Arts and Science, Coimbatore 641020, Tamil Nadu, India

ARTICLE INFO

Article history:
Received 15 October 2015
Accepted 4 January 2016

Keywords:
Transparent conducting oxide
CdO
Solar cell
Thin films
Jet nebulizer spray

ABSTRACT

The highly transparent conducting cadmium oxide (CdO) films were prepared by jet nebulizer spray pyrolysis. Characterization and optimization of CdO films have been scrutinized using various techniques such as X-ray diffraction (XRD) pattern, scanning electron microscope (SEM), energy dispersive analysis by X-ray (EDAX) spectroscopy, Atomic force microscopy (AFM), ultraviolet visible (UV-Vis) spectroscopy, hall Effect and current–voltage (*I*–*V*) characteristics. The sample prepared at 400 °C with 4 ml and 0.20 M of volume and concentration of the precursor solution respectively have the transmittance of about 70% with a band gap of 2.37 eV and the resistivity was found to be a minimum of $3.38 \times 10^{-3}\ \Omega$ cm. The XRD, SEM and AFM studies have implied the presence of CdO nanocrystallites with cubic structure and having smooth surface. The short circuit current (I_{sc}) = 5.90 mA/cm^2 and open circuit volatge (V_{oc}) = 429.3 mV values were established to be the maximum for the cell made with CdO films at 400 °C. The fill factor (FF) = 0.32 and conversion efficiency η = 0.8% was also maximum for this solar cell. The low fill factor and efficiency might be due to the formation of excess silicon dioxide (SiO_2) at the CdO/p-Si interface due to reaction between CdO and Si at 400 °C.

1. Introduction

In many recent developments, thin film technology is one of the inspiring fields. transparent conducting oxide (TCO) materials have a bizarre place among the thin film technology because of their various applications in electronics and opto-electronics. The essential n-type TCO films are indium tin oxide (ITO) [1], zinc oxide (ZnO) [2–4], cadmium oxide (CdO) [5,6], etc. Among them the CdO thin films are extensively favourable for many opto-electronic applications [7–10]. The special features of the CdO thin films are high transparency in the visible region and high conductivity at room temperature [11], narrow direct band gap from 2.2 to 2.5 eV [12], electron concentration higher than 10^{19}/cm^3 [13] and higher mobility value of μ = 130 cm^2/V s [14].

There are various techniques to prepare CdO films are chemical bath deposition, sol–gel method, sputtering, spray pyrolysis, vapour liquid solid, etc. Among these techniques, spray pyrolysis is considerably simple, quick, economical and a suitable method for large area deposition for many binary and ternary semiconducting thin films. The growth can easily be controlled by preparative parameters such as spray rate, substrate temperature, concentration of solution, nozzle to substrate distance, etc. [15,16]. In the present case, the process of Jet Nebulizer Spray (JNS) pyrolysis technique is optimized to prepare CdO films with good adherence, uniformity and stability. The structure, composition and opto-electronic properties of the CdO thin films depend on the heat treatment. A detailed study has been carried out to prepare CdO thin films by the JNS spray technique and their properties are presented.

2. Experimental conditions for CdO thin films preparation

The solution was prepared with different mole concentrations of cadmium acetate ($Cd(CH_3COO)_2{\cdot}2H_2O$) in 100 ml of triple distilled water. To increase the solubility of the solution few drops of concentrated hydrochloric acid were added to the solution. The mixed solutions were stirred well and heated for about 3 h at 60 °C. This solution was sprayed onto glass substrates heated at temperatures 300, 350, 400, 450 and 500 °C in air. So that pinhole free and uniform CdO films of thickness about 245–298 nm were obtained.

In order to fabricate the solar cell, the semiconductor used was a p-type single crystal silicon with a thickness of 600 μm and a resistivity of 5–10 Ωcm. The wafers are boiled in Tri-Chloroethylene (TCE) for about 20 min to remove grease and dust from the surface that get adhered to the surface during the process of wafer making

* Corresponding author. Tel.: +91 9363150944.
E-mail address: ramssrkv@gmail.com (M. Ramamurthy).

http://dx.doi.org/10.1016/j.ijleo.2016.01.031
0030-4026/

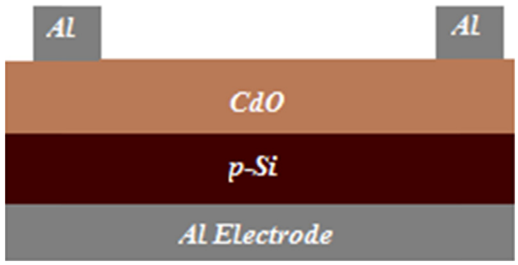

Fig. 1. The cross-section of Al/p–Si/n–CdO/Al.

from single crystal ingots and polishing processes. The TCE residues present on the silicon surface may react with water, making permanent stains on the surface and hence the wafers are ultrasonically agitated and rinsed with deionized (DI) water. To remove the metallic impurities that are left on the surface after the wafer cutting process, an acid treatment using a mixture of H_2O_2 and H_2SO_4 in the ratio of 2:1 is given for 10 min. Then the wafers are washed thoroughly in flowing DI water. The preceding cleaning steps might have formed some oxides on the silicon surface which should be removed before the deposition of CdO films. Hence the wafers are subjected to cleaning treatment in buffered hydrofluoric acid solution (which contains 34.6% NH_4 + 6.8% HF + 58.6% H_2O by weight) for 30 s to remove oxides present on the surface. Finally the wafers are once again washed in DI water and blown dry with nitrogen. These cleaned p-silicon wafers are used for solar cell formation. After the cleaning process, CdO films are deposited on p-silicon by JNS pyrolysis method for different temperatures at 350, 400 and 450 °C. After the deposition process, Al metal contacts were formed on CdO film deposited on p-type silicon using HIND HIGH VACUUM (12A4D) thermal evaporation in the pressure of 4.5×10^{-5} Torr and the contacts were formed with 2 mm in diameter and 100 nm in thickness. The contact area of the solar cell was found to be 3.14×10^{-2} cm^2. The cross section of Al/p–Si/n–CdO/Al solar cell is shown in Fig. 1.

The current–voltage (*I–V*) measurements in dark and under illumination conditions were performed using KEITHLEY 2400 sourcemeter and GPIB data transfer card for *I–V* measurements. Photovoltaic measurements were employed using a 650 W halogen lamp. Solar power meter (TM-206) was used to measure the intensity of light.

3. Results and discussion

3.1. Optimization of precursor volume of solution

3.1.1. Variation of resistivity with the volume of solution

The variation of resistivity of the CdO thin films with volume of solution was studied. Films were formed by keeping the temperature at 400 °C. The variation of resistivity values with solution volume of 2, 4, 6, 8 and 10 ml are shown in Fig. 2. The variations of resistivity (ρ) at room temperature of the films deposited at different volume of the solution were studied. The resistivity curve shows a minimum resistivity value of about 3.3×10^{-3} Ω cm for 4 ml solution. Above and below this the resistivities of the JNS prepared films are higher. These results confirm that 4 ml solution is the optimum which can produce uniform film thickness with good electrical properties. Films become more resistive at higher volume of the solution, which may be due to large terminal thickness. Increase in volume of the solution results into increment in amount of mass deposited onto the substrates at fixed temperature, thereby increasing thickness of the deposited layers. The increment in mass deposited above 4 ml might have produced lower layers with CdO and upper layers consist of cadmium acetate due to incomplete thermal decomposition, which induces more resistivity in the samples deposited above it [17].

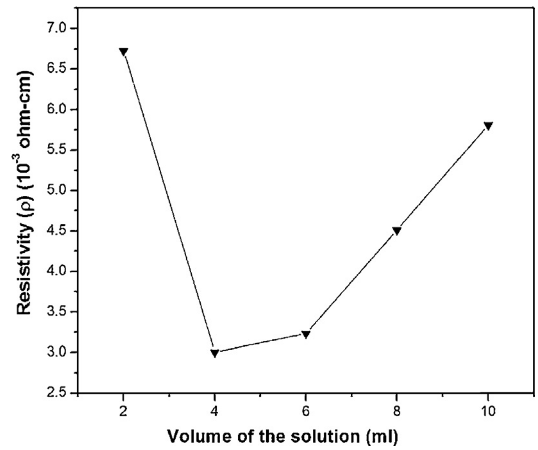

Fig. 2. Variation of Resistivity with volume of the solution.

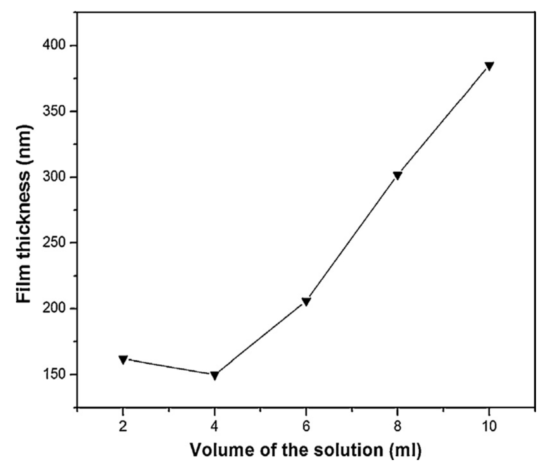

Fig. 3. Variation of thickness with volume of the solution.

3.1.2. Variation of film thickness with volume of spray solution

The variation in thickness of the JNS coated CdO films with the volume of solutions are shown in Fig. 3. The thicknesses of the coatings vary in the range of 150 to 385 nm when the volume is changed from 2 to 10 ml as measured using profilometer. The thickness was found to be decreasing for the films coated with 2 to 4 ml and thereafter it was found to be increasing with increase in volume of the precursor when the substrate was kept at a temperature of 400 °C. Hence, in the present case 4 ml volume of precursor solution was fixed for all other studies.

3.2. Structural characterization

For making uniform and well adherent films, the changes in the structure related properties with precursor volume, concentration of the precursor and deposition temperature were studied.

3.2.1. XRD results of CdO films deposited with different volume of solution

With the deposition temperature fixed at 400 °C, the volume of cadmium acetate precursor solution was changed as 2, 4, 6, 8 and 10 ml. Fig. 4 shows the XRD spectra, where broad peaks are observed at larger volume. Peaks at (1 1 1), (2 0 0) and (2 2 0) correspond to the formation of cubic structure. The well-defined, broad peaks and minimum noise were observed with the 4 ml points