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Structural, optical and electrical characterization of nanocrystalline CdO films for device applications

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ABSTRACT

Nanocrystalline CdO films were prepared onto glass substrate by employing an inexpensive, simple screen-printing method. Optimum conditions for preparing good quality screen-printed films were subsequently obtained. The grown films were characterized by X-ray diffraction (XRD), energy dispersive X-ray analysis (EDAX), scanning electron microscopy (SEM), UV–vis spectctroscopy and DC electrical resistivity measurement in vacuum by a two probe method. The XRD analysis reveals that the films were polycrystalline in nature, exhibiting cubic structure with preferential orientation of grains along (1 1 1) plane. EDAX analysis confirmed the presence of Cd and O element with some additional impurities. Scanning electron microscopy studies show that prepared films exhibited cauliflower like structures. Direct type of transition of band gap was confirmed by reflection spectra occurring at 2.5 eV. The DC electrical resistivity measurement reveals that the films were semiconducting in nature with activation energy ∼0.270 eV. Type of charge carriers of films were determined by Hall effect measurement.

1. Introduction

Recently transparent conducting oxides (TCOs) films have received considerable attention due to their potential applications in photovoltaic devices, gas sensors, transparent electrodes and other optoelectronic devices [1]. Among TCOs, Cadmium oxide (CdO) is an important material for fundamental studies [2]. It is now well conceived that CdO shows many excellent properties, which make it suitable as a TCO [2]. CdO is an II–VI compound n-type degenerate semiconductor possessing high electrical conductivity, high transmittance with a simple cubic structure having direct band gap of 2.2–2.7 eV [3].

It is generally renowned that any large-scale applications must rely on economical polycrystalline materials. The use of thin film polycrystalline semiconductors has attracted much attention in an expanding variety of applications in various electronic and opto-electronic devices. The technological interest in polycrystalline-based devices is mainly caused by their very low production costs.

Researchers investigated a number of methods to prepare CdO thin films viz Silar deposition [3], thermal evaporation [4], DC magnetron sputtering [5], chemical bath deposition [6], sol–gel method [7], spray pyrolysis [8,9]. Most of these methods involve the use of sophisticated deposition facilities, which increase the fabrication costs of the devices. In the present investigation we report screen-printed nanocrystalline CdO films on glass substrate with an aim to use these films in semiconductor device applications with low cost. To the best of our knowledge synthesis of CdO films by screen-printing method was not reported earlier. The prepared films have been characterized through X-ray diffraction (XRD), energy dispersive X-ray analysis (EDAX), scanning electron microscope (SEM), optical measurement and electrical resistivity measurement along with Hall effect measurement techniques. Screen-printing method is particularly attractive because of its simplicity in comparison with other methods. It is fast, inexpensive, less polluting and is suitable for mass production [10,11]. The cost effective method of producing such material would considerably enhance their industrial applications [12].

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2. Experimental details

In this investigation, CdO films were prepared on glass substrate using the screen-printing method followed by sintering process. A commercially available AR grade CdO powder was used as the starting material. A thixotropic paste was prepared by mixing of fine powder of CdO with 10 wt.% of cadmium chloride ($CdCl_2$) as an adhesive and an appropriate amount of ethylene glycol as a binder. The prepared paste was screen-printed on chemically cleaned corning microscopic glass slides of 1 mm thickness. The glass slides were first cleaned thoroughly by embry powder, acetone and then by deionised water. The prepared films were dried on a hot plate at 120 °C for 1 h to avoid the cracks in the films. For better stability of the films it is necessary that cadmium chloride and ethylene glycol must not be present in the films. Therefore the prepared films were further sintered at 500 °C for 10 min in a temperature controlled furnace. Sintering temperature and time were optimized by conducting the experiment for different values of these two parameters. All the films were synthesized under the same experimental conditions to confirm the reproducibility of the results. The thickness of films was determined after sintering by gravimetric weight difference method and it was found to be of the order of 15 μm. The crystalline structure of the films was analyzed by a Philips PW 1140/09 X-ray diffracto-meter using Cu*K*α radiation of wavelength λ = 1.5418 Å. The elemental analysis of the films was made by energy dispersive X-ray analysis (EDAX) attached to JEOL scanning electron microscope (SEM). The optical reflectance spectra versus wavelength of the films were recorded in wavelength range of 300–1300 nm using a double beam Hitachi U-3400 UV–vis spectrophotometer. DC electrical resistivity (in dark) of films was measured by two probe method. Measurement of electrical resistivity were carried out by depositing narrow thin film on glass substrate on which indium electrodes with narrow gap were pre deposited. Hall Effect measurements on the films were made by Ecopia Corp. (S. Korea) HMS-5000 setup.

3. Results and discussion

3.1. Structural analysis

The XRD pattern of CdO screen-printed films deposited on glass substrate is shown in Fig. 1. The presence of sharp peaks in the XRD pattern confirmed the polycrystalline nature of the films. The experimental *d*-values for CdO were evaluated from the Bragg's relation $2d_{hkl}\sin\theta = n\lambda$, by taking θ values from the peaks of the XRD pattern. These *d*-values were compared with the standard JCPDS card no. 75-0594 for the confirmation of the structure of the film material. The observed *d*-values are in close agreement with the standard values for the cubic structure of CdO with lattice constant a = 0.4695 nm. The most prominent peaks at 2θ = 33.08° and 38.50° corresponds to planes (1 1 1) and (2 0 0) along with some other less intense peaks identified as (2 2 0), (3 1 1) and (2 2 2) planes, respectively. Preferred orientation along (1 1 1) plane is usual growth of CdO films prepared by different methods on glass substrate [13]. The average crystallite size of the prepared CdO films was estimated by 'Debye–Scherrer' formula given as:

$$D = \frac{0.94\lambda}{\beta\cos\theta}$$

where D is average crystallite size of the particle, λ is the wavelength of the X-ray radiation, β is the full width half maxima (FWHM) and θ is the diffraction angle in degrees. The highest peak (1 1 1) was used to estimate the crystallite size of the film. In present investigation the estimated value of crystallite size of CdO was 26 nm.

The dislocation density of films for (1 1 1) plane is calculated using the relation:

$$\delta = \frac{1}{D^2}$$

Micro strain developed in the film was estimated from the relation:

$$\varepsilon = \frac{\beta\cos\theta}{4}$$

In present study the dislocation density and strain of CdO films were found in the order of 14.7 (10^{14} lines/m^2) and 5.6 (10^{-4} lines^{-2}/m^4). Films with lower strain and dislocation density improve the stoichiometry of the films.

3.2. EDAX analysis

The elemental analysis of prepared CdO films was carried out by EDAX technique. Fig. 2 shows the EDAX spectra of CdO films. EDAX analysis confirms the presence of Cd and O element with some additional impurities which may be due to glass substrate. The atomic percentage of constituents of Cd and O elements in the solid film was estimated as 54.8 and 45.2%, respectively, which shows that atomic composition of the prepared CdO film is nearly stoichiometric within the limits of experimental error.

3.3. SEM analysis

Scanning electron microscope micrographs of CdO screen-printed films deposited on glass substrate at optimized temperature is shown in Fig. 3. The SEM image shows that grain boundaries were not sharp and feeble porosity was observed between the grains. In nanoscale dimension, numerous structures like nanoparticles, nanowires, nanoneedles and nanocrystals were exhibited by CdO thin films [9]. SEM studies show that prepared films exhibited

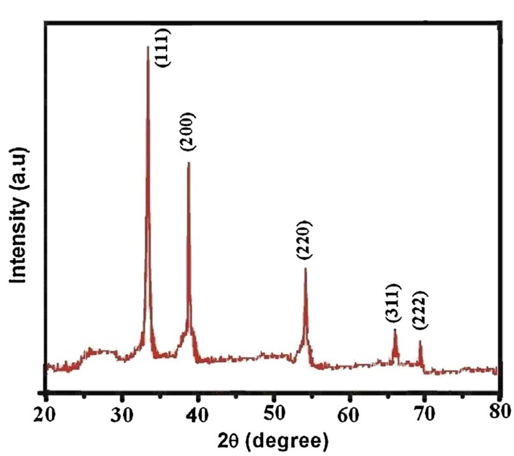

Fig. 1. X-ray diffraction pattern of screen-printed CdO film.

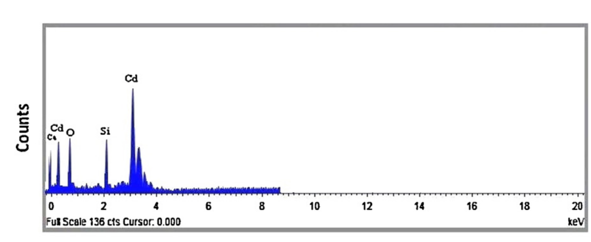

Fig. 2. EDAX spectra of screen-printed CdO film.