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Effect of deposition temperature on structural, surface, optical and magnetic properties of pulsed laser deposited Al-doped CdO thin films

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ABSTRACT

The objective of this work is to study the influence of deposition temperature on structural, surface, optical and magnetic properties of the Al doped CdO thin films prepared by pulsed laser deposition (PLD) technique. KrF excimer laser (λ = 248 nm, τ_l = 20 ns, ν = 10 Hz, ϕ_l = 2.5 J/cm^2) was employed for the deposition of thin films. It is observed by XRD results that films grown at room temperature and 100 °C show preferential growth along (1 1 1) and (2 0 0) directions while high temperatures (200–400 °C) lead to preferential growth along the (2 0 0) direction only. The optical constants (n, k, α, and optical band gap energy) of films measured by spectroscopic ellipsometry show strong dependence upon deposition temperature. M–H loop of films, measured by vibrating sample magnetometer, deposited at 25 °C and 100 °C show paramagnetic nature while films deposited at temperatures (200–400 °C) exhibit ferromagnetic character. Scanning electron micrographs show degraded elongated grains at lower deposition temperatures, while smooth and compact surface is observed for films deposited at higher deposition temperatures.

1. Introduction

When short and high power laser pulses are focused onto the surface of a target material, a fraction of the laser pulse energy is absorbed resulting in heating, melting, vaporization and plasma formation of the material. The removed material forms a thin film upon condensing on the substrate surface under suitable conditions. The whole process is called pulsed laser deposition (PLD). PLD can be successfully employed to many classes of materials such as metals, semiconductors, dielectrics, ferroelectrics, electro-optic and giant magneto-resistance oxides, organic materials, polymers, magnetics, composites etc. [1]. Phase pure and doped CdO thin films exhibit some extraordinary properties due to which they are popular in various semiconducting, optoelectronic industries, and for the fabrication of IR mirrors, thin film resistors, low emissive windows etc. [2–8]. Deposition parameters in PLD process play key role in determining various properties of CdO thin films. Gupta et al. reported the effect of deposition parameters on various properties of Sn, Ti, Al and In doped CdO films prepared by PLD technique [9–13]. To our knowledge, the effect of deposition temperature on optical constants by spectroscopic ellipsometry (SE) and magnetic properties by vibrating sample magnetometer (VSM) of Al doped CdO has not been studied yet. In this work, influence of deposition temperature on structural, surface, optical and magnetic properties of Al–CdO thin films has been studied.

2. Experimental

2 at.wt.% Al-doped CdO target for PLD was prepared by solid-state reaction method. Required amounts of 99.99% pure CdO and Al_2O_3 were weighed by micro-electrical balance and mixed thoroughly using a fine quality mortar and pestle, then heated in air using electric furnace (Ogawa Seiki Co. Ltd. Japan) at 850 °C for 12 h. The grinding was done again and then powder mixture was cold pressed at 5 tons load using hydraulic press. The pellets were then sintered in oxygen at 900 °C for 12 h. The density of the pellets was 82% of the original density of CdO unit cell.

KrF excimer laser (Ex50, GAM LASER INC, USA) of wavelength 248 nm, pulse length 20 ns, repetition rate 10 Hz and fluence 2.5 J/cm^2 was tightly focused by 20 cm UV lens onto Al-doped CdO target at an angle of 45° from the target normal inside PLD chamber. P-type, single crystal, one side polished silicon (1 1 1) substrates of size $1 \times 1 \times 0.2$ cm^3 were ultrasonically cleaned in acetic acid and acetone; and placed at a distance of 50 mm to the target surface. The PLD chamber was evacuated down to base pressure of $\sim 10^{-5}$ mbar by rotary and turbomolecular pumps. Target holder was rotated and translated to avoid the formation of different structures on the target surface, which helps in uniform ablation along with smooth surface profile of target. Target was irradiated with 6000 laser shots to deposit thin films. The thin films of Al-doped CdO were deposited at four different temperatures. i.e. 25, 100, 200, 300 and 400 °C. Schematic of the experimental setup used for PLD is show in elsewhere [14]. The thickness of the films was found to be 200 ± 5 nm by ellipsometric method.

Structural analysis of thin film was done by X-ray diffractometer (XRD), surface morphology by scanning electron microscope (SEM), optical and magnetic properties were investigated by spectroscopic ellipsometer (SE) and vibrating sample magnetometer (VSM) respectively.

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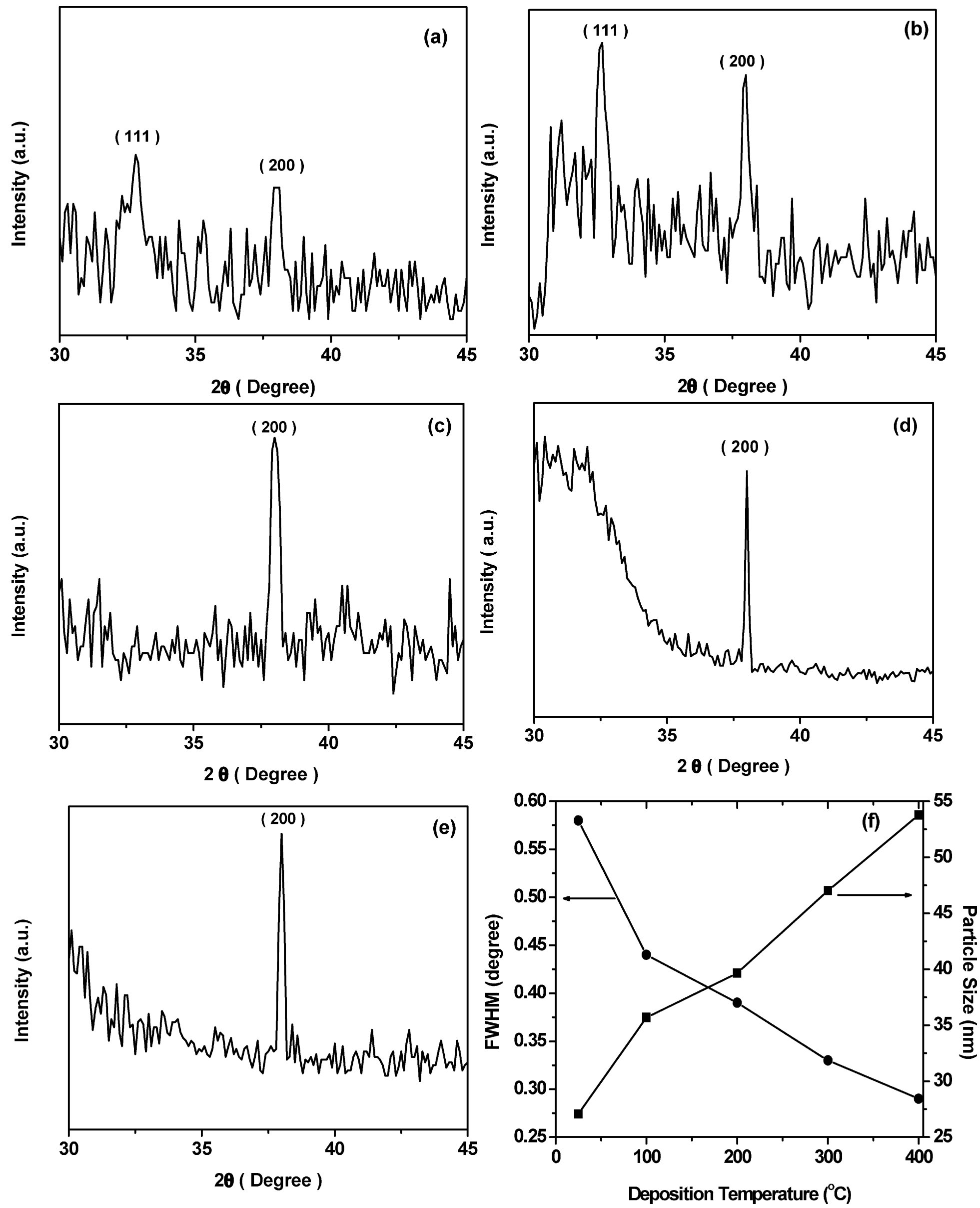

Fig. 1. XRD patterns of Al-doped CdO films grown at (a) 25 °C, (b) 100 °C, (c) 200 °C (d) 300 °C, (e) 400 °C and (f) variation of FWHM and particle size of CdO (2 0 0) as a function of temperature.

3. Results and discussion

3.1. Structural characterization

The structural characterization was done with X-ray diffractometer (D8 Discover, Bruker, Germany). The diffraction patterns of Al-doped CdO thin films grown under different deposition temperatures are shown in Fig. 1. The films grown at room temperature and 100 °C show growth along (1 1 1) and (2 0 0) planes (polycrystalline), while the films grown at higher temperatures (200–400 °C) show preferential growth along the (2 0 0) direction only (single crystal like structure). The 2θ of peaks are in good agreement with JCPDS X-ray file data. No extra peaks due to addition of aluminium in cadmium oxide films were observed, which indicates the absence of any other phase in the films. The planar density of (2 0 0) plane of single CdO unit cell (2-lattice points) is higher than that of (1 1 1) plane (1.875-lattice points). Hence, CdO (2 0 0) plane exhibits lower surface energy. Hence the evolution of sharper and intense (2 0 0) plane at higher deposition temperatures (200–400 °C) reveals that the deposition and growth was done in effective state of equilibrium. The CdO (2 0 0) peak becomes sharper, intense and reduced full width at half maximum (FWHM) with increasing deposition temperature depicting highly oriented CdO thin films with improved crystallinity.

The average X-ray particle size (D) can be determined using Scherrer's formula from FWHM [15]

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

Here the constant k is the shape factor ≈0.94, λ is the wavelength of the X-rays (1.5406 Å for CuK_{α}), θ is the Bragg's angle, and β is the FWHM. The particle size increases with increasing deposition temperature as shown in Fig. 1. The amount of defects can be estimated by calculating the dislocation line density (δ) which is related to particle size (D) as

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