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Crystallite growth and optical properties of cadmium oxide thin films annealed at various temperatures for various durations

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ABSTRACT

The crystallite growth and optical properties of cadmium oxide (CdO) thin films annealed at various temperatures and for various durations have been investigated using grazing incident X-ray diffraction (GID), high-resolution transmittance electron microscopy (HR-TEM), selected area electron diffraction, and ultraviolet-visible spectrometry. All the thin films were annealed between 573 and 773 K for 10 to 60 min, respectively. GID results showed that all thin films contain only a single phase of CdO with (111) preferential orientation. The crystallite size of CdO increases with increases in annealing temperature and duration. It was found that the CdO crystallites followed a normal growth with an average activation energy of 13.04 ± 1.34 kJ/mol when annealed at 573–773 K for 10–60 min. The transmission spectra showed that the band gap energies of CdO thin films decreased from 2.474 to 2.050 eV as the annealing temperature increased, while the thin films maintained highly transparent in the visible spectral range.

1. Introduction

It has been reported that cadmium oxide (CdO) has a rock salt structure with a direct band gap of about 2.2 eV and a narrow indirect bandgap of about 0.5 eV exhibiting *n*-type conduction [1,2]. In 1907, CdO thin films as a transparent conductor were first reported by Badeker [3]. From the point of view of applications, CdO films have been used in various fields such as solar cells [2,4], gas sensors [5,6], photodetectors [3,5], nonlinear optics [7], and so on.

The conductivity of CdO thin films can be is controlled by the production of Cd interstitials and/or oxygen vacancies and they can be fabricated by various processes with different metallic ions [8–17]. However, when CdO thin films with various doping elements were fabricated by liquid phase deposition techniques, only *n*-type CdO thin films were obtained due to the native oxygen vacancy in the CdO thin films [18].

In addition, many researchers also studied the carrier mechanism and properties of undoped CdO thin films fabricated using different processes [19–24]. Use of atmospheric pressure chemical vapor deposition to synthesize undoped CdO thin films has been reported by Terasako et al. [19]. They found that the *n*-type carrier concentrations were 2.4×10^{19} and 2.0×10^{20} cm^{-3} for CdO thin films grown on c- and r-plane sapphire substrates, respectively. The fundamental direct band gap decreased from 2.31 to 2.18 eV when the temperature rose from 0 to 300 K for CdO thin films deposited on sapphire substrates synthesized by the metal organic vapor phase epitaxy process [20]. Use of the successive ionic layer absorption and reaction (SILAR) method for preparation of CdO thin films has been reported by Salunkhe et al. [21]. They revealed that after annealing of CdO thin films, pure cubic CdO was obtained because the H_2O vapors from as-deposited $Cd(O2)_{0.88}(OH)_{0.24}$ were removed, creating CdO [21]. Bhosale et al. [22] also used the spray pyrolysis technique to synthesize undoped CdO thin films and reported that the films were polycrystalline with cubic structure, having better orientation along the (111) reflection of CdO after deposition at a substrate temperature and cadmium acetate concentration of 673 K and 0.1 M, respectively. A single-phase layer of CdO was obtained when CdO thin films were prepared by chemical spray pyrolysis at substrate temperatures higher than 448 K.

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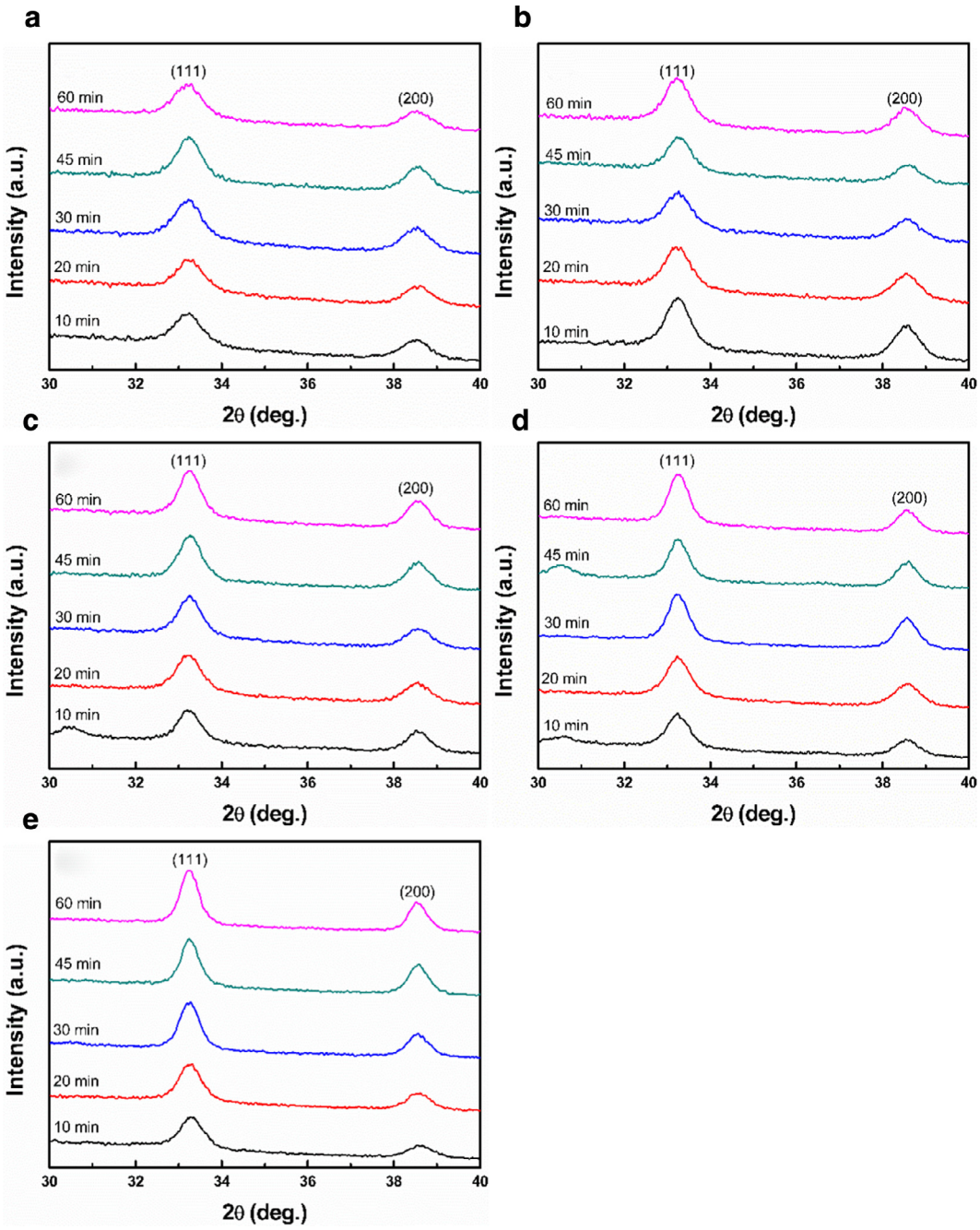

Fig. 1. GID patterns of CdO thin films after annealing at various temperatures for different durations: (a) 573 K, (b) 623 K, (c) 673 K, (d) 723 K, and (e) 773 K.

The optical band gap energy of CdO thin films increased from 2.32 to 2.54 eV when the substrate temperature rose from 373 to 523 K [23]. Undoped CdO thin films were successfully deposited on glass substrates by the direct current magnetron sputtering process at 623 K in a partial pressure range of oxygen from 1×10^{-4} to 5×10^{-3} mbar. The electrical resistivity and visible transmittance of the obtained thin films were $8.2 \times 10^{-4}\ \Omega$ m and 85%, respectively, when the oxygen partial pressure was 1×10^{-3} mbar.

Moreover, undoped CdO thin films synthesized by the sol-gel process and their properties have also been studied by various researchers [25–28]. Using the sol–gel process, undoped CdO thin films were synthesized, and the effect of annealing on the surface morphology and optoelectronic properties were investigated by Ziabari and Ghodsi [25]. After annealing, these films possessed a cubic structure of polycrystalline CdO and the crystallinity increased with rises in the annealing temperature. The band gap energy of these CdO thin films showed a blue-shift effect when they were annealed at temperatures between 523 and 623 K [25]. The effect of annealing temperature on the physical properties of undoped CdO thin films synthesized by a sol–gel spin coating process was also reported by Askoy et al. [26]. They revealed that the thin films contained polycrystalline CdO with (111) preferential orientation after annealing of the as-deposited thin films at 673, 773, and 873 K for 1 h, respectively. The optical band gap energies decreased from 2.47 to 2.22 eV with increases in the annealing temperature from 673 to 873 K [26]. Ghosh et al. [27] pointed out that the direct band gap energy lay in the range of 2.86 to 3.69 eV when CdO thin films were deposited on glass and Si substrates using the sol–gel dip coating process. These thin films have nearly 75% transparency in the wavelength range of 500 to 800 nm. In addition,