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# Chemical bath deposition of $SnO_2$ and $Cd_2SnO_4$ thin films

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ABSTRACT

A new approach of chemical bath deposition (CBD) of $SnO_2$ thin films is reported. Films with a 0.2 μm thickness are obtained using the multi-dip deposition approach with a deposition time as little as 8–10 min for each dip. The possibility of fabricating a transparent conducting oxide layer of $Cd_2SnO_4$ thin films using CBD is investigated through successive layer deposition of CBD-$SnO_2$ and CBD-CdO films, followed by annealing at different temperatures. High quality films with transmittance exceeding 80% in the visible region are obtained. Annealed CBD-$SnO_2$ films are orthorhombic, highly stoichiometric, strongly adhesive, and transparent with an optical band gap of ~4.42 eV. $Cd_2SnO_4$ films with a band gap as high as 3.08 eV; a carrier density as high as $1.7 \times 10^{20}$ cm$^{-3}$; and a resistivity as low as $1.01 \times 10^{-2}$ Ω cm are achieved.



## 1. Introduction

Transparent conducting oxides (TCOs) such as indium tin oxide (ITO) play an important role in solar cells, light emitting diodes, as well as other optoelectronic devices. Seeking alternatives to ITO has been the focus of attention for a long time due to the rising costs of indium. As a result, other TCO layers fabricated from ZnO, CdO, $Cd_2SnO_4$, and $Zn_2SnO_4$ are heavily investigated [1,2]. Although several techniques are currently in use to grow such layers, chemical bath deposition (CBD) presents a simple, low temperature, and inexpensive large-area deposition alternative. For over forty years, it has been widely used to grow wide-band gap group II–VI semiconducting thin films, such as CdS [3–9], CdO [10–14], and ZnO [15–20].

In a previous work [15], we have investigated CBD of ZnO using six different complexing agents, four of which proved to be successful in growing high quality ZnO undoped thin films with a band gap of 3.3 eV, a carrier density as high as $2.24 \times 10^{19}$ cm$^{-3}$, and a resistivity as low as $6.48 \times 10^{-1}$ Ω cm. More recently, we have succeeded to grow CBD-CdO thin films using three different complexing agents [14]. Annealed CdO undoped films with a band gap of 2.53 eV, a carrier density of ~$1.89 \times 10^{20}$ cm$^{-3}$, and a resistivity ~$1.04 \times 10^{-2}$ Ω cm were obtained.

$SnO_2$ thin films reported in the literature, however, have been obtained mainly by RF magnetron sputtering [21], metal organic chemical vapor deposition [22], vacuum evaporation [23], pulsed laser deposition [24], pulsed electron beam deposition [25], spray pyrolysis [26], sol–gel [27], chemical vapor deposition [28], and successive ionic layer adsorption and reaction [29]. However, very few attempts to grow $SnO_2$ thin films using CBD have been reported [30,31]. In both cases, the deposition time was of the order of several hours; 15–24 h in the work of Tsukuma et al. [30] and 5–12 h in the work of Supothina and De Guire [31]. Tsukuma et al. [30] reported a growth rate that ranged from 2 nm/h at 40 °C to 50 nm/h at 80 °C. Supothina and De Guire [31] reported growing $SnO_2$ films, 60–70 nm thick, after 12 h of deposition, with a growth rate of approximately 9 nm/h during the first 4 h. Clearly, the slow growth rate is a major limitation to using CBD as a viable technique to grow $SnO_2$ thin films.

In this work, we report a new approach of CBD-$SnO_2$ that enabled us to grow a 0.2 μm thick film using multi-dip deposition, with a deposition time as little as 8–10 min for each dip. We also investigate the possibility of fabricating a TCO layer of CBD-$Cd_2SnO_4$ thin film through growing CBD-CdO layer on top of the CBD-$SnO_2$ layer followed by heat treatments in air at different temperatures. Transmittance, reflectance measurements and band gap calculations are carried out for as-grown films as well as annealed films. Resistivity, carrier density, and Hall mobility of annealed

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