

In-situ boron doping of chemical-bath deposited CdS thin films

Hani Khallaf¹, Guangyu Chai², Oleg Lupan^{1,3}, Lee Chow^{*,1,4,5}, Helge Heinrich^{1,4,5}, S. Park¹, and Alfons Schulte¹

¹ Department of Physics, University of Central Florida, Orlando, FL 32816, USA

² Apollo Technologies, Inc., 205 Waymont Court, Suite 111, Lake Mary, FL 32746, USA

³ Department of Microelectronics and Semiconductor Devices, Technical University of Moldova, 168 Stefan cel Mare Boulevard, 2004 Chisinau, Republic of Moldova

⁴ Advanced Materials Processing and Analysis Center, University of Central Florida, Orlando, FL 32816, USA

⁵ Department of Mechanical, Materials, Aerospace Engineering, University of Central Florida, Orlando, FL 32816, USA

Received 15 July 2008, revised 25 October 2008, accepted 10 November 2008

Published online 5 January 2009

PACS 61.72.uj, 71.55.Gs, 73.61.Ga, 78.20.Ci, 81.16.Be

* Corresponding author: e-mail chow@mail.ucf.edu, Phone: +1 407 823 2333, Fax: +1 407 823 5112

In-situ boron doping of CdS using chemical-bath deposition (CBD) is reported. The effect of B doping on optical properties, as well as electrical properties, crystal structure, chemistry, and morphology of CdS films is studied. We present a successful approach towards B doping of CdS using CBD, where a resistivity as low as $1.7 \times 10^{-2} \Omega \text{ cm}$ and a carrier density as high as $1.91 \times 10^{19} \text{ cm}^{-3}$ were achieved. The bandgap of B-doped films was found to slightly decrease as the

[B]/[Cd] ratio in the solution increases. X-ray diffraction studies showed B^{3+} ions likely enter the lattice substitutionally. A phase transition, due to annealing, as well as induced lattice defects, due to B doping, were detected by micro-Raman spectroscopy and transmission electron microscopy. The chemistry and morphology of films were unaffected by B doping.

© 2009 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

1 Introduction Due to its wide bandgap (2.42 eV), photoconductivity, and high electron affinity, CdS has been widely used as a window material in high-efficiency thin-film solar cells based on CdTe and Cu(In,Ga)Se₂ [1, 2]. Chemical-bath deposition (CBD) is one of the most commonly used techniques to grow CdS thin films [3, 4]. It is known to be a simple, low-temperature, and inexpensive large-area deposition technique for group II–VI semiconductors such as CdS. CdS films grown by CBD are known to be highly stoichiometric and exhibit a high dark resistance. A dark resistivity as high as $10^8 \Omega \text{ cm}$ [5], $10^9 \Omega \text{ cm}$ [6], and $10^{10} \Omega \text{ cm}$ [7] has been reported earlier for CBD–CdS. In a previous study [3], we have established a direct relationship between Cd precursors used in the deposition of CBD–CdS and film resistivity. Film resistivity was found to vary from $3.88 \times 10^3 \Omega \text{ cm}$ to $8.01 \times 10^1 \Omega \text{ cm}$, depending on the Cd precursor used and film stoichiometry. Although a resistivity of $8.01 \times 10^1 \Omega \text{ cm}$ is low for CBD–CdS, a lower resistivity

is needed for solar cells and other optoelectronic applications.

One approach to reduce dark resistivity of CBD–CdS is in-situ doping. Over the past two decades, in-situ doping of CBD–CdS using Al [8–10], Cu [11, 12], Li [13, 14], and Na [15] has been reported. In this work, the effectiveness of B^{3+} doping through chemical-bath deposition is investigated. Transmittance and reflectance measurements of doped films were carried out to study the effect of B doping on the optical properties and bandgap of CdS films. Resistivity, carrier concentration, and Hall mobility of doped films were acquired using Hall effect measurements. Crystal structure as well as crystal quality and a phase transition were determined using X-ray diffraction (XRD), transmission electron microscopy (TEM), and micro-Raman spectroscopy. Film morphology was studied using scanning electron microscopy (SEM). Film chemistry and binding states were studied using X-ray photoelectron spectroscopy (XPS).