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Characterization of gallium-doped CdS thin films grown by chemical bath deposition

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ABSTRACT

Ga-doped CdS thin films, with different [Ga]/[Cd] ratios, were grown using chemical bath deposition. The effect of Ga-doping on optical properties and bandgap of CdS films is investigated. Resistivity, carrier density, and mobility of doped films were acquired using Hall effect measurements. Crystal structure as well as crystal quality and phase transition were determined using X-ray diffraction (XRD) and Micro-Raman spectroscopy. Film morphology was studied using scanning electron microscopy, while film chemistry and binding states were studied using X-ray photoelectron spectroscopy (XPS). A minimum bandgap of 2.26 eV was obtained at [Ga]/[Cd] ratio of 1.7×10^{-2}. XRD studies showed Ga^{3+} ions entering the lattice substitutionally at low concentration, and interstitially at high concentration. Phase transition, due to annealing, as well as induced lattice defects, due to doping, were detected by Micro-Raman spectroscopy. The highest carrier density and lowest resistivity were obtained at [Ga]/[Cd] ratio of 3.4×10^{-2}. XPS measurements detect an increase in sulfur deficiency in doped films.

1. Introduction

In-situ doping with group III elements has been widely used to decrease the dark resistivity of CdS thin films grown by chemical bath deposition (CBD) [1,2]. The need to such doping is attributed to the fact that CBD-CdS thin films are highly stoichiometric [3,4]. Accordingly, the dark resistivity of CdS films grown by CBD is so high that, in some cases, it was reported to be in the order of 10^8–10^{10} Ω cm [5–7]. In-situ doping using group III elements such as aluminum, indium, boron, and gallium, is the most suitable approach to tackle this problem where the need for post-deposition treatments, such as ion-implantation, is being eliminated.

In a previous work [8], we have shown that CBD is a suitable technique for aluminum in-situ doping of CdS. We have also shown that due to extremely low solubility product of indium sulfide ($K_{sp} = 10^{-73.24}$) compared to that of CdS ($K_{sp} = 10^{-27.94}$) [9], it is highly unlikely, if not impossible, to incorporate indium in CdS, using CBD. In another work [10], we have investigated boron in-situ doping of CdS using CBD, and proved it to be successful. We have found that, regardless of boron concentration used, B^{3+} ions tend to replace Cd^{2+} ions in the lattice substitutionally. However, Al^{3+} ions tend to enter the lattice substitutionally at low concentration, and interstitially at high concentration. In both cases, a dark resistivity in the order of 10^{-2} Ω cm and a carrier density as high as 10^{19} cm^{-3} were achieved. The effect of Al-doping as well as B-doping on the optical properties and bandgap of CdS films was investigated. In both cases, bandgap of doped films was found to be always less than that of undoped film. X-ray diffraction (XRD) did not detect any Al or B peaks in doped films indicating that incorporation of Al^{3+} or B^{3+} ions does not affect the crystal structure of CdS film. Phase transition, due to annealing, as well as induced lattice defects, due to doping, were detected in both cases by Micro-Raman spectroscopy. An increase in sulfur deficiency due to doping was detected by X-ray photoelectron spectroscopy (XPS). However, scanning electron microscopy (SEM) micrographs showed morphology of films unaffected by Al or B-doping.

In extension to this work, Gallium in-situ doping of CdS using chemical bath deposition is being reported. The same investigation methodology used in Al/B-doping work [8,10] is being implemented here as well. The objective of this work is mainly to provide a comparison between Ga-doping of CdS and Al/B-doping. Therefore, in addition to using the same characterization techniques, the [dopant]/[Cd] ratio used in this work was exactly the same as that used earlier in B-doping [10]. Similarly, transmittance and reflectance measurements of doped films were carried out to

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