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Solar Energy Materials & Solar Cells 90 (2006) 2616–2629
Solar Energy Materials & Solar Cells
www.elsevier.com/locate/solmat

Highly conducting transparent nanocrystalline $Cd_{1-x}Sn_xS$ thin film synthesized by RF magnetron sputtering and studies on its optical, electrical and field emission properties

P.K. Ghosh, U.N. Maiti, Sk.F. Ahmed, K.K. Chattopadhyay*

Thin Films & Nanoscience Lab, Department of Physics, Jadavpur University, Kolkata 700 032, India

Received 27 October 2005; received in revised form 18 November 2005; accepted 17 February 2006
Available online 3 April 2006

Abstract

Transparent conducting $Cd_{1-x}Sn_xS$ thin films have been synthesized by radio frequency magnetron sputtering technique on glass and Si substrates for various tin concentrations in the films. X-ray diffraction studies showed broadening of peaks due to smaller crystal size of the $Cd_{1-x}Sn_xS$ films, and SEM micrographs showed fine particles with average size of 100 nm. Sn concentration in the films was varied from 0% to 12.6% as determined from energy-dispersive X-ray analysis. The room-temperature electrical conductivity was found to vary from 8.086 to 939.7 $S\,cm^{-1}$ and corresponding activation energy varied from 0.226 to 0.076 eV. The optimum Sn concentration for obtaining maximum conductivity was found to be ~9.3%. The corresponding electrical conductivity was found to be ~939.7 $S\,cm^{-1}$, and the mobility ~49.7 $cm^2\,V^{-1}\,s^{-1}$. Hall measurement showed very high carrier concentrations in the films lying in the range of $\sim 8.0218\times 10^{18}$–$1.7225\times 10^{20}\,cm^{-3}$. The conducting $Cd_{1-x}Sn_xS$ thin films also showed good field emission properties with a turn on field 4.74–7.86 $V\,\mu m^{-1}$ with variation of electrode distance 60–100 μm. UV–Vis–NIR spectrophotometric studies of the films showed not needed the optical band gap energy increased from 2.62 to 2.80 eV with increase of Sn concentration in the range 0–12.6%. The optical band gap was Burstein–Moss shifted, and the corresponding carrier concentration obtained from the shift also well matched with that obtained from Hall measurement.

Keywords: CdS:Sn; Conducting; Transparent; EDX; Optical; Field emission; Hall measurement

*Corresponding author. Tel.: +91 33 2867 1350.
E-mail address: kalyan_chattopadhyay@yahoo.com (K.K. Chattopadhyay).

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doi:10.1016/j.solmat.2006.02.015

1. Introduction

Transparent semiconducting materials, which can be grown efficiently as thin films with low cost, are used extensively for a variety of applications, including architectural windows, solar cells, heat reflectors, light transparent electrodes, and thin-film photo-voltaic and many other opto-electronic devices [1,2]. Electrically high conducting and optically transparent sulfide materials, like CdS:In [3,4], CdS:B [5], etc. can be well utilized as a transparent conducting sulfide (TCS) as well as luminescent devices. There are several n-type transparent conducting oxides (TCOs) such as tin oxide [6], zinc oxide [7], indium tin oxide [8], cadmium oxide [9], cadmium stannate [10], etc. and p-type such as $CuAlO_2$ [11], Cu_xScO_{2+x} [12], $SrCu_2O_2$ [13], etc., which have great technological interest due to their high quality of electrical and optical properties. The TCSs may also be utilized as a complement of TCOs having high conducting property and transparency in the visible range. The TCS can be well utilized as gas sensors, as the change in conductance is large and caused primarily by changes of carrier concentration due to charge exchange with the species absorbed from the gas phase.

Previously, CdS nanostructures have been synthesized through different routes by different groups [14–19]. The studies of the electrical and optical properties of undoped CdS thin films have been reported by Uda et al. [20] via chemical solution deposition process. They obtained maximum conductivity of $0.1\,S\,cm^{-1}$ with the corresponding carrier concentration and electron mobility of $1.4\times10^{17}\,cm^{-3}$ and $4.1\,cm^2\,V^{-1}\,s^{-1}$, respectively. Oumous et al. [21] also studied the electrical properties of CdS thin films at low temperature, but their films were highly resistive. Electrical measurements on undoped CdS showed n-type conductivity lying in the range 10^{-4}–$10^{-1}\,S\,cm^{-1}$. Previous works on CdS have proven that CdS always contains excess Cd and point defects are created due to either Cd interstitial or sulfur vacancies, which act as doubly charged donors. To increase the electrical conductivity, CdS films were doped by different elements, such as In, B, Al, etc. and the maximum conductivity obtained was $4\times10^2\,S\,cm^{-1}$ with the corresponding carrier concentration $2\times10^{20}\,cm^{-3}$ obtained by In doping via thermal evaporation process by Bertain et al. [3]. Plafox et al. [4] also synthesized CdS:In thin films via chemical spray and the highest conductivity value obtained was $\sim10^2\,S\,cm^{-1}$. p-type CdS:Cu thin films have also been synthesized by Abe et al. [22] via vacuum deposition process. Lee et al. [5] studied the electrical and optical properties of boron-doped CdS thin films prepared via chemical bath deposition technique. Although polycrystalline CdS thin films are not so popular TCS materials due to their small electrical conductivity, but CdS:In thin films have demonstrated high conductivity than that of other TCS. Having low electrical resistivity, high electron mobility and low visible absorption, these materials are suitable for a wide range of applications. In this work, we have synthesized $Cd_{1-x}Sn_xS$ thin films via radio frequency (RF) magnetron-sputtering technique and studied its structural, compositional, electrical, optical and field emission properties. To our knowledge, there is no published report on $Cd_{1-x}Sn_xS$ thin film synthesis and in this work we have shown that these thin films have very interesting properties. As these films are highly conducting and also optically transparent in the visible region, these can be applied into various fields such as the top layer of solar cells. For example, using the structure glass/Mo/p-$CuInSe_2$/n-CdS/$Cd_{1-x}Sn_xS$ for a photovoltaic device, one can avoid the use of ZnO as a top conducting layer.