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Characterization of *n*-Type and *p*-Type ZnS Thin Layers Grown by an Electrochemical Method

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Electrodeposition of *n*-type and *p*-type thin-film layers of ZnS was carried out using a simple two-electrode system and aqueous solutions of $ZnCl_2$ and $(NH_4)_2S_2O_3$ with different Zn^{2+} concentrations. X-ray diffraction measurements show that the ZnS layers deposited from both solutions are amorphous. Optical absorption measurements show low absorbance of the layers with energy bandgap in the range of 3.68 eV to 3.78 eV after postdeposition annealing. Photoelectrochemical cell measurements show that both *n*-type and *p*-type ZnS thin layers can be electrodeposited by simply changing the concentrations of the deposition solutions. With higher Zn^{2+} concentration in the bath, *n*-type ZnS films were deposited, while *p*-type ZnS films were deposited with lower Zn^{2+} concentration. The estimated resistivity of layers from both solutions using *I*–*V* measurements were $3.0 \times 10^4\ \Omega$ cm and $2.0 \times 10^4\ \Omega$ cm, respectively, for *n*-ZnS and *p*-ZnS. Scanning electron microscopy shows that the deposited films consist of particles with good surface coverage of the glass/fluorine-doped tin oxide substrate.

Key words: Electrodeposition, *n*-type ZnS, *p*-type ZnS, thin films, semiconductors

INTRODUCTION

Group II–VI semiconductor materials have been studied extensively due to their interesting properties and applications in areas such as solar cells,[1] electroluminescence devices,[2] optical windows,[3] sensors, lasers, thin-film polarizers, and thermoelectric cooling materials.[4]

Zinc sulfide is a nontoxic, II–VI semiconductor with a wide direct bandgap of about 3.68 eV for the bulk material.[5] This property makes it a potential candidate for replacement of CdS window material in single-heterojunction solar cells (such as CdS/CdTe and CdS/CIGS solar cells) as well as for use in multilayer graded-bandgap solar cells.[6] The bandgap of ZnS is larger than that of CdS (E_g = 2.42 eV), and so ZnS can act as a buffer layer for CdS/CdTe solar cells as well as a window layer for ZnS/CdTe cells or even ZnS/CdS/CdTe multilayer graded-bandgap solar cells. With a wider bandgap and low absorption, ZnS has the advantage of allowing more higher-energy photons into the absorber material as well as minimizing window absorption losses with a resultant improvement in the short-circuit current of the solar cell. In addition, ZnS has optoelectronic properties which make it suitable for applications in light-emitting diodes, electroluminescence, and phosphorescence devices.[7]

Several techniques have been employed by researchers over the years for deposition of ZnS thin films. These include chemical bath deposition (CBD),[8] electrochemical atomic-layer epitaxy (ECALE),[9] molecular-beam epitaxy (MBE),[10] metalorganic chemical vapor deposition (MOCVD),[11] thermal evaporation,[12] spray pyrolysis,[13] successive ionic layer adsorption and reaction (SILAR),[14] as well as electrodeposition (ED).[4,15] However, ED of chalcogenides of Zn from standard aqueous solutions has been reported to be difficult,[16] and hence not many reports on ED of ZnS are available in the

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