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Photovoltaic properties of SnS based solar cells

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Abstract

Polycrystalline thin films of tin sulphide have been synthesised using spray pyrolysis. The layers grown at a temperature of 350 °C had the orthorhombic crystal structure with a strong (1 1 1) preferred orientation. The films had resistivities ~30 Ω cm with an optical energy band gap (E_g) of 1.32 eV. Heterojunction solar cells were fabricated using sprayed SnS as the absorber layer and indium doped cadmium sulphide as the window layer and the devices were characterised to evaluate the junction properties as well as the solar cell performance. The current transport across the junction has been modelled as a combination of tunnelling and recombination. The best devices had solar conversion efficiencies of 1.3% with a quantum efficiency of 70%.
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Keywords: SnS films; Spray pyrolysis; Heterojunction; Conversion efficiency

1. Introduction

Solar cells based on the use of CuIn(Ga)Se_2 and CdTe absorber materials have been produced with efficiencies of 18.8% and 16.5%, respectively [1]. These results clearly indicate that high efficiency solar cells can be achieved using polycrystalline materials. Problems however remain with these technologies. It is generally perceived that the lack of abundance of In and Ga may limit the large scale use of chalcopyrite-based technology. There are also concerns with respect to the toxicity of cadmium leading to problems with the disposal of CdTe modules after use [2]. It is possible that other materials could be used to produce thin films cells without these problems. One such candidate is SnS. This *IV–VI*

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compound material has a direct optical energy band gap (E_g) of 1.3 eV, close to the optimum value required for efficient light absorption and it has a high optical absorption coefficient for photons with energies greater than 1.3 eV [3]. It is a p-type semiconductor and its electrical properties can be suitably controlled by doping [4]. Furthermore the constituent elements of this compound, Sn and S are non-toxic and abundant in nature. Although the theoretical studies indicate that solar conversion efficiencies $>25\%$ [5] could be achieved using this material, to our knowledge there are no detailed reports on the development of thin film heterojunction solar cells in the literature. Our earlier work on SnS showed that single phase layers can be produced using chemical spray pyrolysis with suitable electrical and optical properties for solar cell fabrication [6,7]. This paper is a continuation of our studies on SnS and includes the production and characterisation of SnS/CdS heterojunction solar cells.

2. Experimental

Thin films of SnS were prepared by chemical spray pyrolysis using 0.1 M equimolar solutions of $SnCl_2$ and *n*, *n*-diethyl thiourea. The solution was mixed and sprayed onto SnO_2 coated glass substrates which had been preheated to a temperature of 350 °C keeping the source–substrate distance fixed at 25 cm. Compressed purified nitrogen was used as the carrier gas (flow rate of 8 l/min.) and the solution flow rate was maintained at 6 ml/min. The spray head was attached to the microprocessor controlled stepper motor system in order to move it in the x–y plane to achieve a uniform coating of the film. The thickness of the SnS layers formed was approximately 0.6 μm. CdS films, approximately 0.6 μm thick and doped with 2 at.% indium were grown on the SnS layers using two source vacuum evaporation keeping the substrate temperature at 180 °C during the deposition. Finally a thin layer of indium with a thickness of 0.4 μm was formed on the CdS to act as the top contact. The junctions were characterised using current–voltage, capacitance–voltage, and spectral response measurements in order to evaluate the junction properties and the photovoltaic performance.

3. Results and discussion

3.1. SnS films

The SnS films were uniform, pin-hole free and dark reddish brown in colour. EDAX composition studies indicated that the layers were nearly stoichiometric with Sn = 50.84 at% and $S = 49.16$ at%. X-ray diffraction data revealed that the layers were polycrystalline with a strong (1 1 1) preferred orientation. The spectrum also contained peaks that correspond to (1 2 0), (1 3 1), (1 5 1), (0 6 1), (0 4 2) and (2 5 1) orientations. The presence of these planes indicated that SnS layers had the ortho-rhombic crystal structure. The films had densely packed grains and the calculated grain size was ~0.35 μm. A detailed analysis of the structural properties has been reported elsewhere [7]. The films had electrical resistivities of 30 Ω cm with a free carrier density of $1.65\times10^{15}\,cm^{-3}$ and a Hall mobility of $128\,cm^2V^{-1}s^{-1}$. These electrical parameters are comparable with the values reported on evaporated SnS layers [8]. The temperature dependence of the electrical conductivity had an activation energy that varied in the range, 0.38–0.45 eV. The films were highly absorbing with an optical absorption coefficient, $\alpha>10^4\,cm^{-1}$ above the fundamental

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