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Thin films of tin sulphide for use in thin film solar cell devices

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ABSTRACT

SnS is of interest for use as an absorber layer and the wider energy bandgap phases e.g. SnS2, Sn2S3 and Sn/S/O alloys of interest as Cd-free buffer layers for use in thin film solar cells. In this work thin films of tinsulphide have been thermally evaporated onto soda–lime glass substrates with the aim of optimising theproperties of the material for use in superstrate configuration device structures. The thin films were characterised using energy dispersive X-ray analysis (EDS) to determine the film composition, X-raydiffraction (XRD) to determine the phases present and structure of each phase, transmittance versuswavelength measurements to determine the energy bandgap and scanning electron microscopy (SEM) to observe the surface topology and topography. These properties were then correlated to the depositionparameters. Using the optimised conditions it is possible to produce thin films of tin sulphide that arepinhole free and conformal to the substrate that are suitable for use in thin film solar cell structures.

KEYWORDS

Thermal evaporation;
Tin sulphide;
Solar cells;
Absorber layers.

INTRODUCTION

SnS has a direct energy bandgap around 1.3 eV, near the optimum for photovoltaic solar energy conversion, and a high optical absorptioncoefficient such that layers only a few microns thick are needed toabsorb most of the incident light.

The most advanced materials for making thin film solar cells are those based on the use of cadmium telluride (CdTe) or copper indium gallium diselenide (Cu(In,Ga)Se2 or CIGS) absorber layer materials. One promising candidate is tin sulphide (SnS), as in common with CdTe and CIGS, this material has a near optimum energy bandgap and it is amphoteric with a wideenergy bandgap oxide, promising the possibility of grain boundarypassivation. Not only does SnS consist of relatively abundant elementsbut large scale production processes already exist for producing thinfilms of tin and for converting metals into the corresponding sulphideusing a range of sulphidisation processes. In the literature thin films ofSnS have been deposited using a variety of techniques including spraypyrolysis,electrodeposition, chemical vapour deposition, vacuum evaporation and sulphidisation of pre-deposited tin precursor layers. The attempts to use SnS in device structuresare limited but previous studies have shown that cells with efficiencies up to 1.3% can be produced.

Despite the excellent achievements made with these materials problemsremain. There are concerns with respect to the environmental acceptability of using cadmium in the former devices andconcerns with respect to the lack of abundance of gallium and indiumfor the latter devices. SnS is also amphoteric such that arange of solar cell structures using SnS as an absorber layer can beenvisioned. These include p–n heterojunction devices using p-typeSnS as the absorber layer with a wide energy bandgap n-type partner,buried homojunction devices using both n and p-type SnS and p–i–ntype devices (using SnS as the i-layer). It is also likely that counterdopingor oxidising the SnS at the grain boundaries will lead toeffective grain boundary passivation, a vital process for enhancing efficiencies in cells made using polycrystalline materials

EXPERIMENTAL

The evaporations were carried out in an oil pumped vacuum system operated in the 10^-4 to 10^-5Torr range of vacuum pressures. Both the substrate and the source material were heated using resistiveelements with a shutter incorporated to control the deposition time. The source to substrate distance was 40 mm.

The SnSsourcematerialwas obtained fromAlfa–Aesar andwas 99.99% pure. Each substratewas cleaned in an ultrasonic bath containing a mixture of Decon 90and de-ionised water solution for 1.5 h. After a rinse with de-ionisedwater, the substrate was washed in propan-2-ol to remove anyremaining contamination. The evaporation source was a quartz,bottle-shaped crucible that was heated by a cylindrical tantalumheating element. The SnS evaporant was placed in the crucible and quartz wool placed above itto minimise the affects of “spattering”, i.e. the ejection of moltenlumps of material from the source that can damage the growing film.

Films were then deposited using source temperatures in the range 250 °C to 590 °C and for substrate temperatures in the range 90 °C to 370 °C. These temperatures were measured by thermocouples indirect

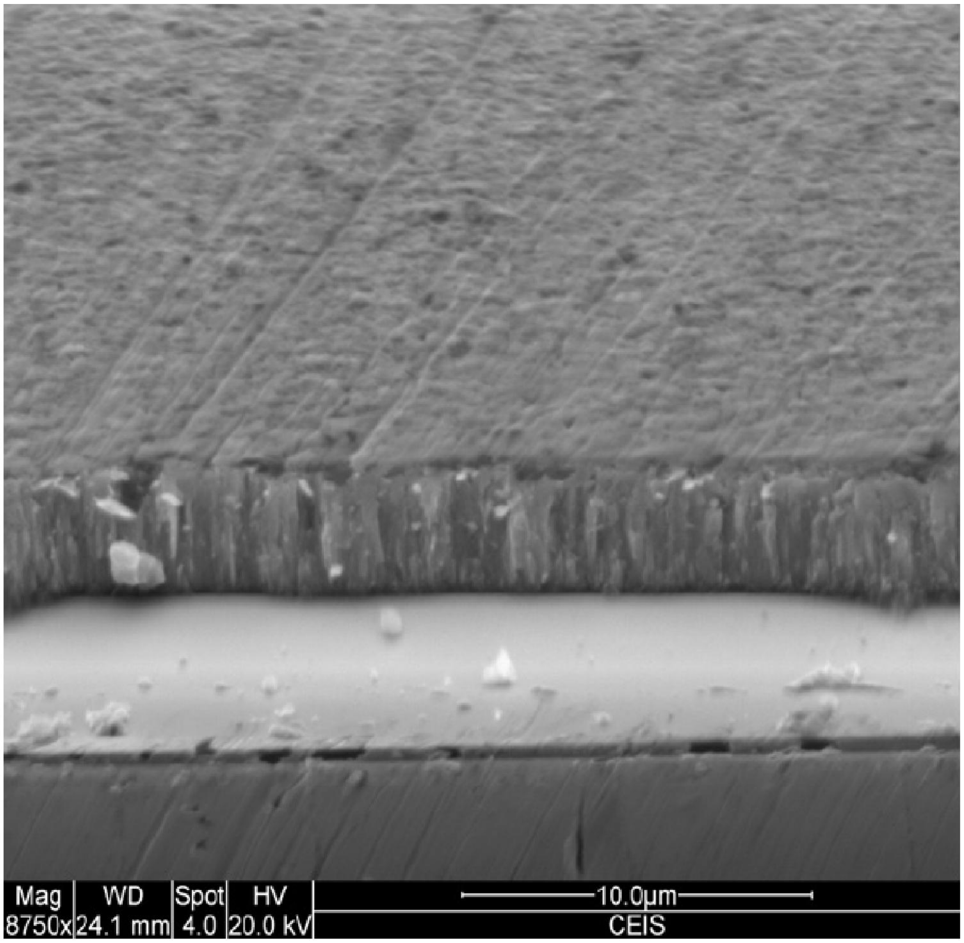

Figure 1 : SEM micrograph of a SnS layer deposited using a 250 °C substrate temperature, a 300 °C source temperature and a deposition time of 3 min.

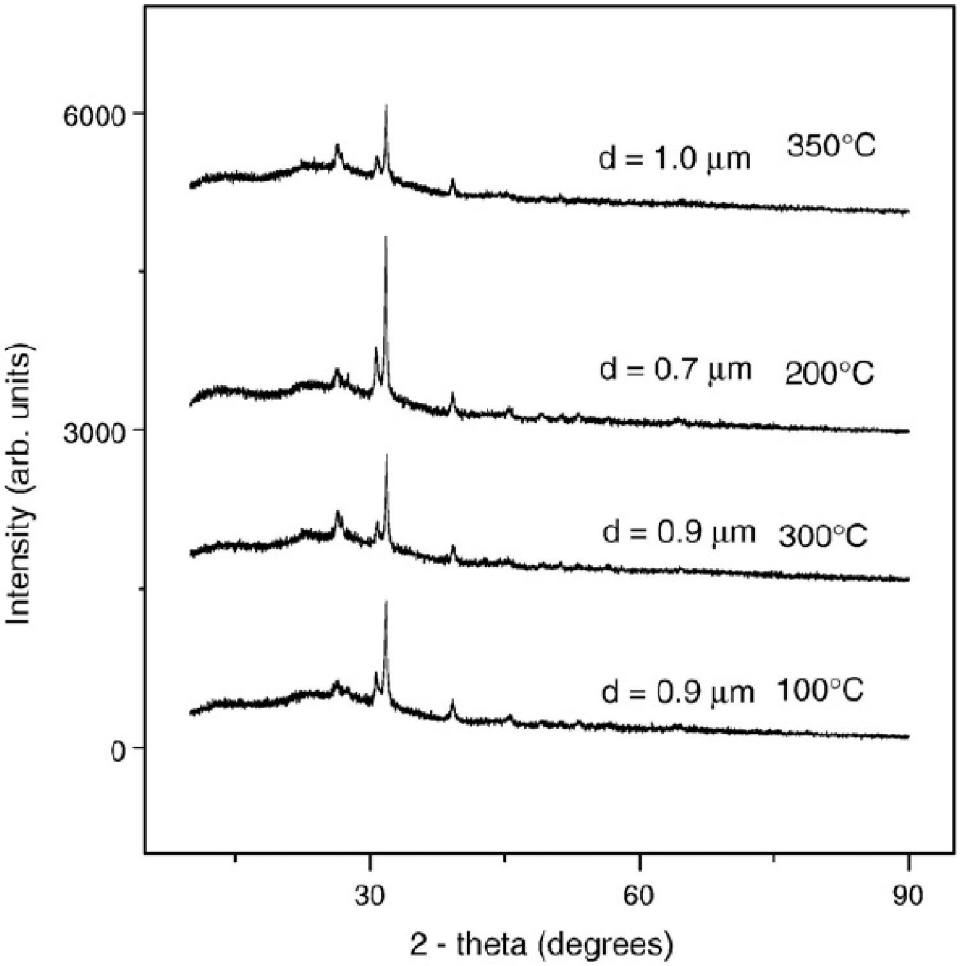

Figure 2 : XRD patterns for SnS layers grown at different substrate temperatures.

contact with the crucible and substrate respectively. Thedeposition time was typically less than 4 min.

RESULTS AND DISCUSSIONS

The tin sulphide films were deposited using source temperatures in the range 250 °C to 590 °C and for substrate temperatures in the range 90 °C to 370 °C. All the thin films deposited were adherent tothe substrate, uniformly thick and pinhole free. The films depositedwith thicknesses < 2µm had smooth surface topologies and wereyellow–brown in colour whereas films with thicknesses >9µm thickwere a darker black colour and had rougher surface textures. Theformer films were deposited using relatively short times and for thehigher substrate temperatures whereas the thicker films resulted for the lower substrate temperatures and for longer deposition times.

Figure 1 shows a cross-sectional view, taken with the SEM, of a layer of SnS deposited at a substrate temperature of 250 °C for a source temperature of 300 °C and for a deposition time of 2 min. The layer is approximately 3 ìm thick and it consists of densely packed columnar grains that extend throughout the film thickness. These observations were made for all the layers deposited with thicknesses no.6 µm. Theyindicate good potential for using such layers in solar cell devices, because with columnar grains, minority carriers generated by incidentlight can diffuse to the junction without crossing a grain boundary.

The change in stoichiometry with the deposition conditions is expected to alter theelectrical properties of the films. All the films deposited and testedwere found to be p-type, the resistivity tending to be lower for themore Sn-rich films. It should be noted that oxygenwas observed to bepresent in all the thin films deposited.

The 3 predominant peaks corresponding to SnS are the (121), (141), and (121) reflections clearlyindicating that the predominant phase present is SnS. It shouldhowever be noted that for most of films other less intense reflections were also observed. Some of the peaks can be attributed to reflections from the (141), (112), and (231) planes of SnS although it is possiblethat these and some of the other less intense reflections could be due to the presence of other phases in the films.

The shift in optical absorption edge and hence energy bandgapwith deposition conditions has been observed by other workers, themost detailed study having been made with layers produced using chemical spray pyrolysis

CONCLUSION

Using the thermal evaporation method it is possible to producestoichiometric thin films of SnS, that are conformal and highly adherent to the substrate and that consist of densely packed columnar grains. Despite the energy gap of the layers varying with the depositionconditions, it is possible to produce thin films of SnS, a fewìmthick,withenergy bandgaps in the range 1.3–1.7 eV i.enear to the optimum forphotovoltaic energy conversion (1.5 eV). The layers are also p-type givingflexibility to the device design to be used. Work is in progress to investigate in detail the electrical properties of the films, to investigatethe influence of post-deposition annealing on the structural, electricaland optical properties of the layers and to fabricate and characterize solar cells made using optimised layers.

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