Flexible $Cu_2ZnSn(S,Se)_4$ solar cells made from nanoparticle inks

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$Cu_2ZnSn(S,Se)_4$ (CZTSSe) Earth-abundant photovoltaic absorbers fabricated from Cu_2ZnSnS_4 (CZTS) nanoparticle inks have the advantages of being relatively low-cost and suitable for large area manufacture. In addition, fabrication on flexible substrates has the potential to create lightweight solar cells that offer a wide range of application. However, research on CZTS nanoparticle inks on flexible substrates is still comparatively rare [1]. A common choice of back contact in chalcogenide thin film solar cells is molybdenum (Mo) due to its capacity to withstand high temperature processing, high conductivity and high mechanical strength. Therefore, Mo foils are a natural choice of experimental substrate for flexible CZTSSe thin film solar cells.

In this work, CZTSSe photovoltaic absorbers are prepared from CZTS nanoparticle inks fabricated by injection of metallic precursors into a hot surfactant [2]. Both rigid and flexible substrates are used to prepare identical CZTSSe solar cells. For the rigid substrate a 500 nm thick layer of Mo is sputtered on soda lime glass (SLG) while for the flexible substrate a 0.1 mm flexible Mo foil is used and onto which CZTS nanoparticles are deposited directly. Subsequent annealing in a selenium rich atmosphere converts CZTS nanoparticle thin films into CZTSSe photovoltaic absorbers which are then integrated into a conventional thin film solar cell structure.

A range of characterisation techniques is used to study the behaviour of both CZTSSe photovoltaic absorbers and solar cells. Fig. 1 shows a cross-sectional scanning electron microscope image of a flexible CZTSSe thin film solar cell indicating a uniform CZTSSe absorber characterised by a bi-layer structure which is unique to the nanoparticle ink fabrication technique. Fig. 2 compares the performance of devices fabricated on rigid (SLG) and flexible (Mo) substrates under 100 mW/cm^2 irradiance. The device on SLG achieved an efficiency of 3.65%, while the device on Mo foil exhibited a lower efficiency of 1.47%. The reason for this reduction is caused by a drop in the short circuit current J_{sc} and the fill factor. A slightly thinner absorber layer and local variations in the material quality suggested by external quantum efficiency measurements may account for the reduction J_{sc} while the formation of a thick $MoSe_2$ layer on the Mo foil causes a significant increase in series resistance. Despite these losses, it is encouraging that the device open circuit voltage is preserved on the flexible substrate.

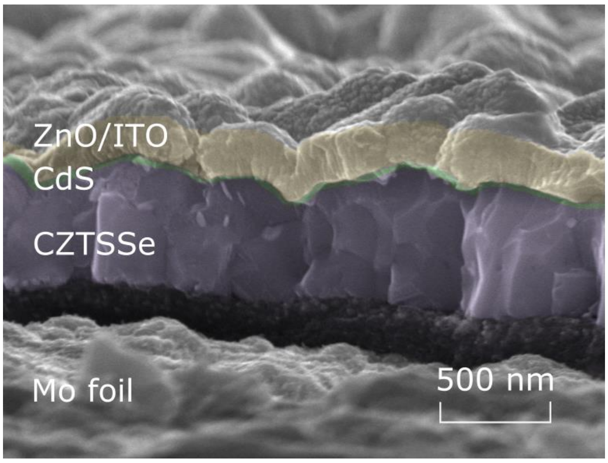

Fig. 1 SEM cross section image of CZTSSe solar cell on foil

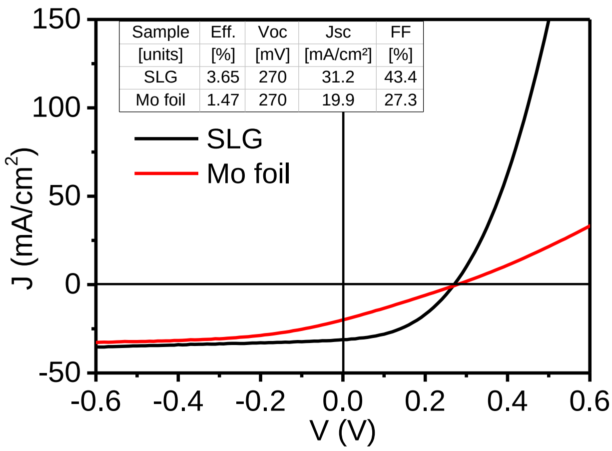

Fig. 2 *JV* curves of solar cells on rigid and flexible substrates

[1] Q. Tian, X. Xu, L. Han, M. Tang, R. Zou, Z. Chen, M. Yu, J. Yang, J. Hu, Hydrophilic Cu_2ZnSnS_4 nanocrystals for printing flexible, low-cost and environmentally friendly solar cells, *CrystEngComm* **14** (2012) 3847-3850.

[2] Y. Qu, G. Zoppi, N.S. Beattie, The role of nanoparticle inks in determining the performance of solution processed $Cu_2ZnSn(S,Se)_4$ thin film solar cells, *Prog. Photovolt: Res. Appl.* **24** (2016) 836-845.

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