Area: Thin-Film Compound Semiconductor PV.

A CORRELATIVE MICROSCOPY APPROACH TO DELINEATE THE IMPACT OF STRUCTURAL DEFECTS ON THE LOW MINORITY CARRIER LIFETIME IN TIN SULFIDE THIN FILMS

Amanda Youssef[1], Rupak Chakraborty[1], Paul Rekemeyer[1], Austin Akey[2], Silvija Gradečak[1], Tonio Buonassisi[1]

[1]Massachusetts Institute of Technology, USA, [2]Harvard Center for Nanoscale Systems, USA

Tin (II) sulfide (SnS) is an earth-abundant, non-toxic material with a high absorption coefficient and a near-optimal bandgap making it a well-suited solar absorber in single junction solar cells. With an indirect bandgap around 1.1 eV and a direct bandgap of 1.3 eV, the theoretical maximum efficiency of SnS is calculated to fall between 32% and 34%. Coupled with a high absorption coefficient exceeding 10^4 cm^{-1} at the direct transition, more than 90% of the light above the bandgap can be absorbed within only 1.2 μm of the thin film. However, experimental efficiency records have reached only 4.4% compared to the 32% theoretical maximum, mainly due to low minority carrier lifetime.

In this work, we present the first correlative microscopy study on SnS thin-films to determine what type of defects are behind the low minority carrier lifetime, and study the effect of structural defects such as stacking faults, dislocations, and grain boundaries on the minority carrier collection length. SnS thin-films investigated in this study are thermally evaporated on Si/SiO_2/Mo substrates with a deposition rate of 1-2 Å/s and at substrate temperatures of 240ºC and 285ºC. To promote grain growth, films are subsequently annealed at 400ºC in 4% H_2S atmosphere for 60 minutes. We first perform cross-sectional electron-beam-induced current (EBIC) measurements to extract information about the local minority carrier collection. We then prepare a 100 nm thin lamella from the same cross-section measured by EBIC. We perform transmission electron backscattered diffraction (t-EBSD) to map the grain boundaries and the grain orientations at the cross-section of interest. Finally, we scan through the entire lamella using transmission electron microscopy (TEM) to image extended structural defects and calculate their density. This allows a direct correlation between structural defects and the electronic properties of the thin films.

The EBIC results show a short collection length ubiquitously throughout the imaged cross-section, with current collection limited to 100 – 200 nm from the SnS/buffer heterojunction. The t-EBSD data demonstrate that not all grain boundaries are recombination active and that they are unlikely to be the dominant cause for the short minority carrier collection length. Finally, the low density (4 /μm^3) of intragranular stacking faults and dislocations found from TEM measurements dismisses intragranular extended structural defects from being the primary cause of the short carrier collection length across the thin film device. As a result, we postulate that a homogeneously distributed point defect is likely the root cause of the ubiquitously short minority carrier collection length. Possible candidates of this lifetime-limiting defect are intrinsic point defects such as sulfur vacancies and extrinsic point defects caused by contaminants.