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Characterizing the Back-Contact Interface of Poly-Crystalline Cd(Se)Te Devices with XEDS, EELS, and HRSTEM

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Poly-crystalline Cd(Se)Te based thin film solar cells prove to be highly competitive technology because of the high absorption coefficient, nearly optimum direct band gap energy and simplicity of manufacturing. Yet, the presence of hetero-interfaces in Cd(Se)Te structure and low minority carrier lifetime have limited the thin film devices from reaching are still below the theoretical efficiency limit (30%)[1]. The back contact of the CdTe Photovoltaic (PV) cell has been a serious limit to performance due to a deep valence band at 5.8 eV, much higher than the work function of many metals (e.g. Ni at 5.2 eV)[2]. This makes it impossible to create an Ohmic contact with the CdTe absorber. Here, we will explore novel back-contact film layers in an effort to overcome this energy band mismatch. Atomic-resolution imaging in a scanning transmission electron microscope (STEM) combined with electron energy-loss spectroscopy (EELS) and energy-dispersive X-ray spectroscopy (XEDS) are used to characterize these devices and to inform the production process. The goal is to identify the ideal atomic and electronic structures, as well as any interfacial diffusion of elements.

The structural characterization of the CdSeTe devices and back-contact layers is performed using a JEOL ARM200CF aberration-corrected scanning transmission electron microscope (STEM) operated at acceleration voltage of 200 kV. The STEM images were acquired using a probe semi-convergence angle of 24 mrad and two annular detectors, a high-angle annular darkfield (HAADF) detector and low-angle annular dark-field (LAADF) detector. The X-ray energy dispersive spectroscopy (XEDS) maps and line-scans were obtained using a windowless XEDS silicon drift detector X-MaxN 100 TLE from Oxford Instruments. Electron energy-loss spectroscopy (EELS) is performed using a Gatan post-column spectrometer, the GIF-Continuum. The combination of these techniques allows for spatially resolved characterization of interfacial atomic structures and chemical compositions with atomic resolution. High-resolution TEM data is acquired using a JEOL 3010 operated at an acceleration voltage of 300kV. Cross-sectional TEM samples were prepared using the focused ion-beam (FIB) lift-out technique in a FEI Helios Nanolab 600 dual-beam FIB/SEM system.

A HAADF image overview of a particular CdSeTe PV cell is shown in figure 1, with the back contact at the bottom of the image. Platinum is deposited during the FIB liftout procedure and forms a shield from the ion beam. Between the CdTe absorber and the Pt are thin films of CdMgTe and pure Te, these are labeled as back-contact (BC) films in the figure. The absorber is a Cd(Se)Te hybrid with the Se concentration largely localized in the first 500nm of the absorber sharing an interface with the MgZnO layer of the junction and the transparent conductive oxide front contact. The absorber is approximately 1.5 microns thick.

Figure 2 shows a HRSTEM HAADF image of the CdTe absorber in the (110) zone-axis orientation and its interface with the CdMgTe back-contact layer, separated by the ~5 nm thick amorphous oxide layer (i.e. MgO, see as the dark region of the image). Figure 2b shows the O K-edge taken from the interfacial layer, conforming the presence of an amorphous MgOx compound. The CdMgTe layer does not appear to be in any epitaxial relationship with the CdTe grain. In fact, it appears that the grain size of the CdMgTe layers is of the order of ~10 nm, with not preferential grain orientation detected. In this contribution, we will discuss the atomic and electronic structures of several different back-contact layer chemistries and their effect on the carrier lifetimes and surface recombination rates. [3]

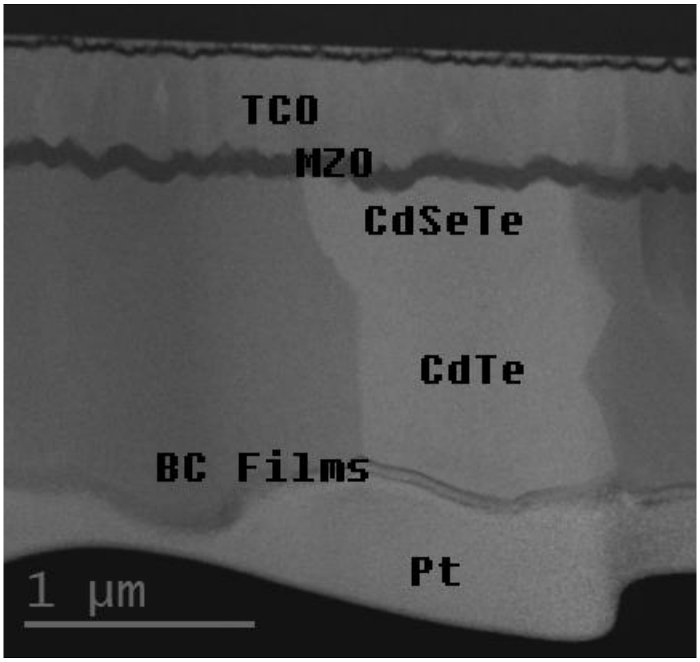

Figure 1. HAADF image of Cd(Se)Te device stack, with elemental regions labeled.

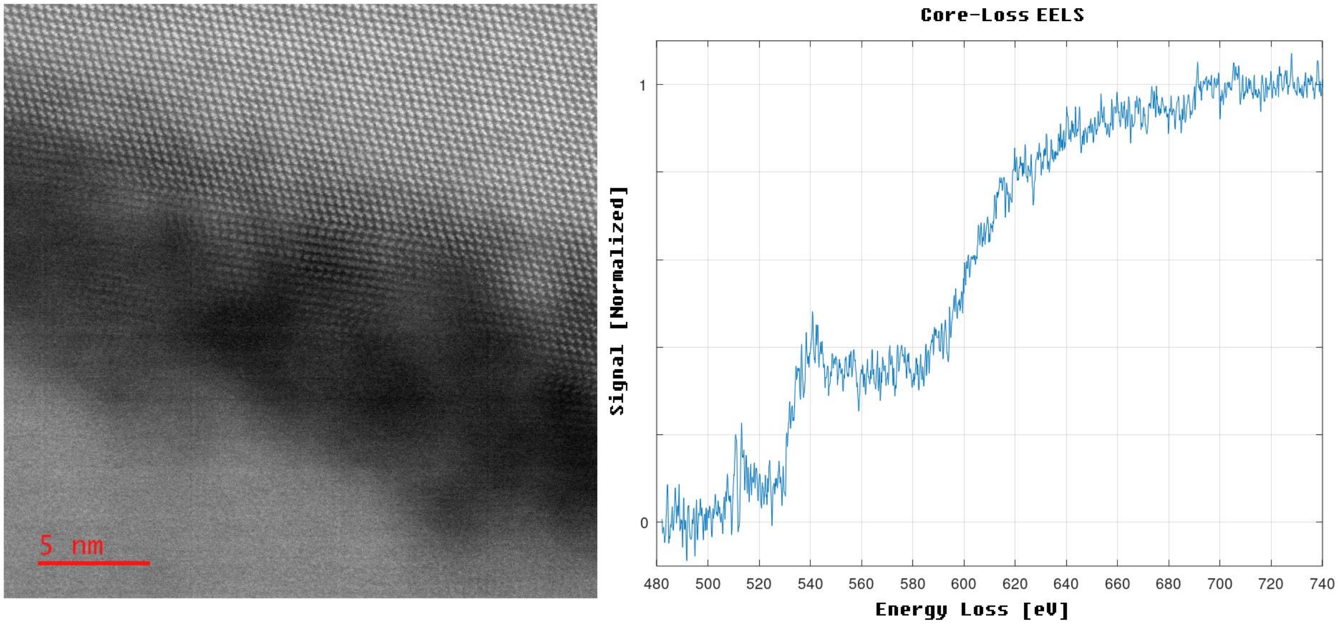

Figure 2. HAADF HRSTEM showing the absorber lattice from a region of the back contact of the specimen in Fig 1. The back contact CdMgTe film does not deposit epitaxially to the absorber. Te and O signals are extracted from the EELS spectrum.

References

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