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In situ TEM characterization of the effect of interfaces on charge transport in Cu(In,Ga)Se$_2$ thin film solar cells

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The multilayer structure and multicrystallinity of Cu(In,Ga)Se$_2$ (CIGS) thin film solar cells inevitably lead to a number of interfaces within the device. Interfaces, such as grain boundaries, directed along the charge transport path are not necessarily detrimental to the device performance. Indeed, it has been shown, theoretically as well as experimentally, that a doping type inversion can occur at the CIGS grain boundaries such that holes are repelled and recombination is suppressed . However, interfaces between different layers intercept the path of charge transport and may contain dangling bonds and other defects which can act as recombination centers. The charge transport is thereby hampered and the device performance is impaired.

In this study, effects of interfaces on charge carrier transport between different layers in a CIGS thin film solar cell were investigated. This was done by correlating interfacial atomic structure to electrical properties.

The cells were prepared by depositing a 1.5 µm CIGS absorbing layer mainly by sputtering on a SLG substrate covered with a 400 nm layer of Mo, used as back contact. On top of the CIGS, a 50 nm CdS buffer layer was grown by chemical bath deposition (CBD) and a 100 nm ZnO layer followed by a transparent top contact of indium tin oxide (ITO) were deposited by sputtering.

Cross-sectional thin foil transmission electron microscope (TEM) samples were prepared by in situ lift-out in an FEI FIB-SEM workstation and were attached to a supporting grid. Specimens for in situ scanning tunneling microscopy (STM) measurements inside the scanning electron microscope (SEM) were produced in the same way and, in order to control the path of charge transport, slits were cut through the foil with the FIB. The cuts were made in such a way that the charge transport was directed across the interfaces of interest (See Figure 1). For measurements in the TEM the sample was patterned with the electron beam at 300 kV. In this way detailed current paths could be defined with very high precision. In order to remove any surface oxides and to reduce the surface damage and Ga implantation from the FIB-SEM preparation, the foil was ion polished for 60 seconds in a Gatan PIPS system using ±10° beam angle at 2.0 keV.

Conductivity measurements were made in situ with two different STM devices. One was a TEM-STM holder from Nanofactory Instruments and the other was modified to be operated inside a SEM. Measurements in the SEM were performed across the layer interfaces of interest by sweeping an STM probe along cross-sectional samples of the solar cell (See Figure 2). Inside the TEM the conductivity across individual grain boundaries could be measured thanks to the detailed E-beam patterning. The atomic structure and chemistry of the interfaces and grain boundaries were examined by TEM, high resolution TEM (HRTEM), electron energy loss spectroscopy (EELS) and nanoprobe energy dispersive x-ray spectroscopy (EDX) [4].

References

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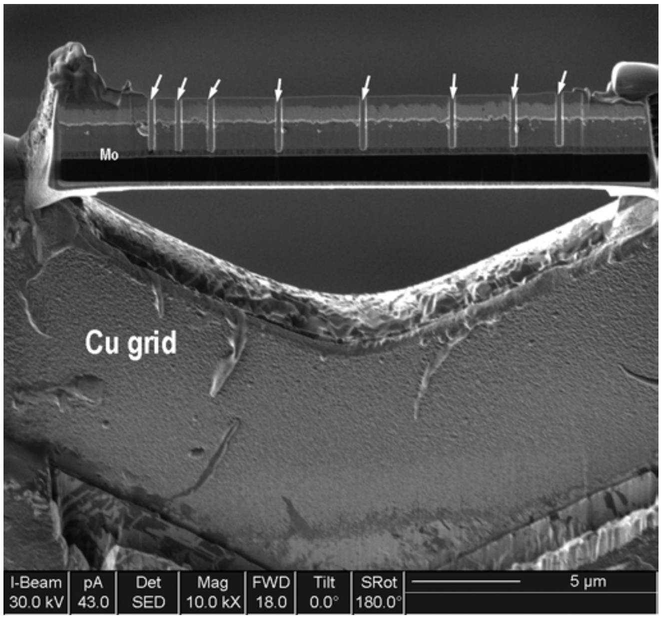

Figure 1. Ion induced secondary electron image of a thin foil specimen for in situ STM. Slits are cut through all the layers (marked by arrows) except the Mo back contact.

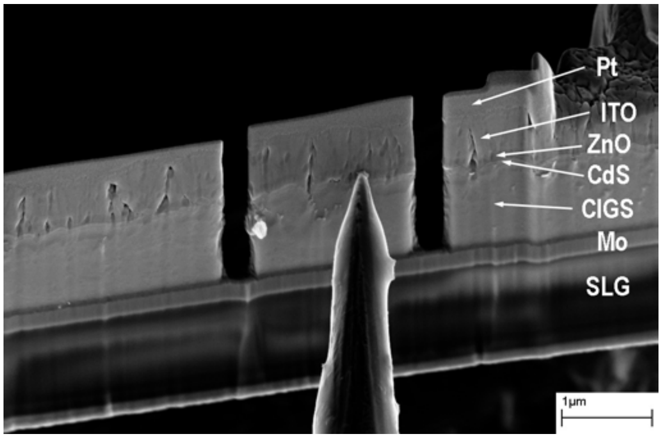

Figure 2. Secondary electron image showing a conductivity measurement across the solar cell pn-junction from the ZnO layer.