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Characterization of the CIGS Solar Cell System in the FIB-SEM Laboratory

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In this work, we exploited the vast possibilities offered by modern FIB-SEM and FIB-HIM (helium ion microscopy) to study high-efficiency copper indium gallium selenide (CIGS) based solar cells.

Today, CIGS solar cell efficiency is above 22% [1] reaching the performance levels of modern polycrystalline silicon solar cells. Strong development efforts are ongoing to further increase cell efficiency. Microscopy plays a crucial role in this development as it is used to analyze the solar cell microstructure through all relevant length scales and with very high resolution [2].

Depending on their application, CIGS solar cells can be deposited on different substrates like glass, alumina, polymers or even metals. In-situ cross section preparation in the FIB-SEM offers a convenient alternative to conventional cleaving or tearing to allow fast access to the constituent layers of the cell. This is because the same FIB milling recipe works for all substrates. Figure 1 shows detail images of cross sections prepared by FIB of three CIGS cells on glass, alumina and polyimide. After FIB milling a speckle pattern is observed on the CIGS layer, which is attributed to copper segregation [3]. Different techniques were employed to reduce this preparation artefact including milling at ion beam energies lower than 30 kV, at low temperatures or using different ion species in the HIM.

Scanning transmission electron microscopy (STEM) on FIB prepared lamellas revealed fine details of the front and back electrodes – zinc oxide (ZnO) and molybdenum (Mo), respectively. For example, at the ZnO level intrinsically doped ZnO (i:ZnO) can be distinguished from the Al-doped ZnO, because of their different grain morphology. At the Mo layer the extent of unwanted $MoSe_2$ formation during the CIGS coating process can be determined. Further, the STEM geometry enables energy dispersive spectroscopy (EDS) measurements with a spatial resolution below 10 nm.

Finally, secondary ion mass spectrometry (SIMS) was conducted using gallium and neon source ions to detect traces of alkali elements (Na, K) in the CIGS active material due to diffusion from the substrate during growth. The presence of these trace elements is known to have a beneficial impact on cell performance. Figure 2 compares SIMS depth profiles measured on a CIGS on glass and a CIGS on alumina sample. As expected, for glass Na and K signals are strong from the substrate up to the ZnO layer in contrast to the reference alumina sample, because only the glass substrate contains alkali elements.

References:

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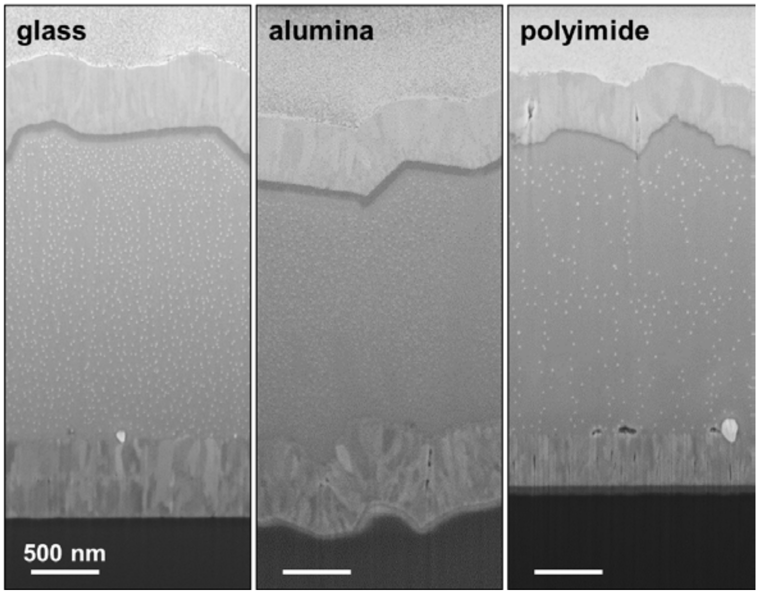

Figure 1. Cross sections of CIGS solar cells on glass, alumina and polyimide (from left to right).

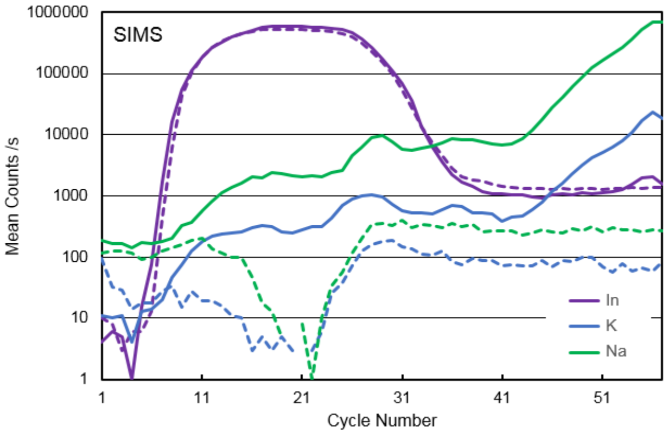

Figure 2. SIMS depth profiles for In, K, and Na for two CIGS solar cells with glass (solid lines) and alumina (dashed lines) substrates.