Combination of various scanning electron microscopy techniques: applications for thin-film solar cells

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Thin-film solar cells based on CdTe or Cu(In,Ga)$(S,Se)_2$ absorbers have been developed for several decades now. Since they provide a low-cost perspective, solar modules based on these materials have been produced industrially on large scales. For research and development, it is essential to study the microstructure, the composition, the charge-carrier collection and the optoelectronic properties of CdTe and Cu(In,Ga)$(S,Se)_2$ layers and the corresponding thin-film stacks of completed solar cells.

This information may be gathered by the combination of electron backscatter diffraction (EBSD), energy-dispersive X-ray spectrometry (EDX), electron-beam-induced current (EBIC) and cathodoluminescence (CL) measurements in a scanning electron microscope (SEM). Preliminary results of these measurements have recently been published [1]. It is especially interesting to relate the charge-carrier collection and optoelectronic properties of a specific sample region in a polycrystalline solar absorber with the corresponding local orientations and compositions. Specifically, such a combination of techniques on identical sample regions may give evidence on the collection and the recombination behavior at grain boundaries in CdTe and Cu(In,Ga)$(S,Se)_2$ layers.

The present contribution shows results from combinations of EBSD, EDX, EBIC and CL on identical sample regions. Various preparation methods for cross-sectional samples of CdTe and Cu(In,Ga)$(S,Se)_2$ solar cells, i.e., mechanical and Ar-ion polishing, as well as focused-ion beam (FIB) milling in a SEM, were applied. Combination of EBSD and EDX on CdTe solar cells allows for the phase identification of individual layers (Fig. 1). Fig. 2 shows EBSD, EDX, and EBIC results from the identical sample position of a cross-sectional $CuInS_2$ solar-cell sample. A cross-section from a solar cell produced in the same run was prepared by SEM-FIB and then analyzed in-situ by EBSD (Fig. 3). Apparently, the EBSD patterns from the Mo back contact exhibit high qualities, in contrast to the corresponding EBSD patterns obtained on the polished samples (Fig. 2). CL images from contiguous $CuInS_2$ grains (as found by EBSD) contain lines of reduced CL intensity (Fig. 4). Probably, the CL is sensitive to electronic defects, which are not related to the structural information provided by EBSD.

1. D. Abou-Ras, U. Jahn, J. Bundesmann, R. Caballero, C.A. Kaufmann, J. Klaer, M. Nichterwitz, T. Unold, H.W. Schock, in: M. Luysberg, et al. (Eds.), EMC 2008, Vol 1: Instrumentation and Methods, Proceedings of the 14th European Microscopy Congress 2008, Aachen, Germany, September 1-5, 2008 (Springer, 2008) p. 523.

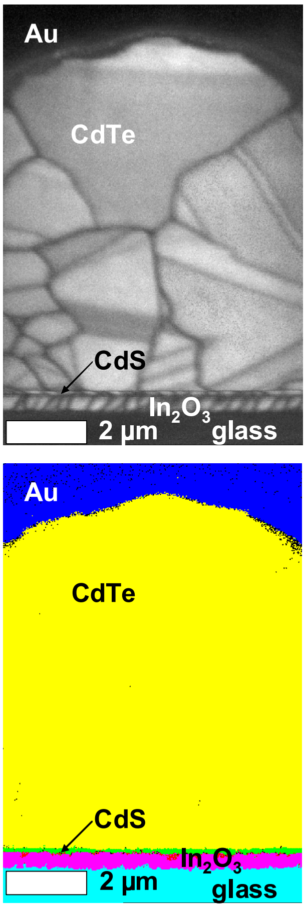

Figure 1. EBSD pattern quality map (top) and phase map (bottom) from the identical sample position on a cross-section of a CdTe thin-film solar cell. The phase map was generated from the combined EBSD and EDX results.

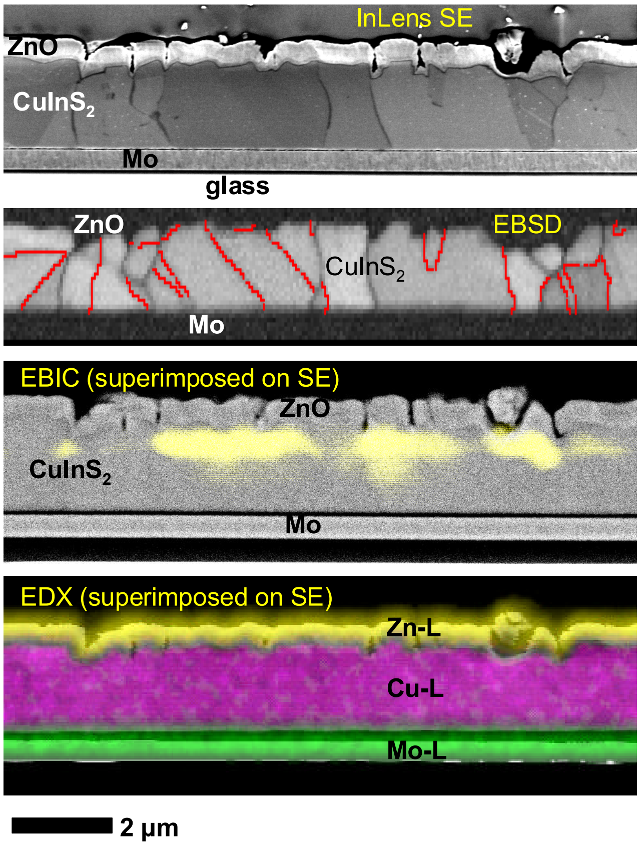

Figure 2. Inlens secondary electron (SE) image (3 kV), EBSD pattern quality map (20 kV) with Σ3 grain boundaries highlighted by red lines, EBIC map (8 kV, superimposed on SE image), and EDX elemental distribution maps (7 kV, superimposed on SE image) from Zn-L, Cu-L and Mo-L signals, from the identical sample position.

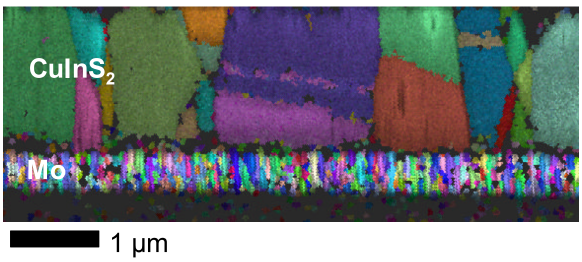

Figure 3. Cross-sectional EBSD map (IPF colors) from a $CuInS_2$ solar-cell produced in the same run as the one shown in Fig. 2. This cross-section was prepared by SEM-FIB and studied by EBSD without breaking the vacuum. Apparently, the microstructure of the Mo back contact is well resolved, in contrast to the sample prepared by mechanical and Ar-ion polishing (Fig. 2).

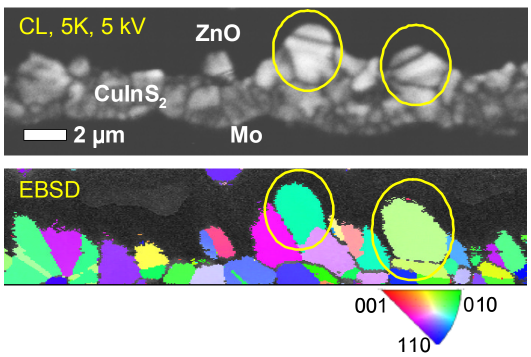

Figure 4. CL image at 820 nm (band-band transition) from a completed $CuInS_2$ solar cell at 5 K and 5 kV, and EBSD orientation distribution map (identical sample area). Two contiguous grains are highlighted by yellow circles.

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