Cu(In,Ga)Se₂ (CIGSe) thin-film solar cells have generated interest with their high power-conversion efficiencies of more than 20% [1,2]. However, in many cases, efficiencies obtained with polycrystalline CIGSe solar cells fall behind this value. This is particularly true for solar cells with CIGSe layers produced in multi-stage coevaporation processes without a Cu-rich stage at low temperatures [3]. The reason behind these energy losses and the limitations for the further efficiency increase are not fully understood. In order to gain a better understanding of the compositional properties of the structural defects, which can be relevant for solar cell performance, we analysed the CIGSe absorber layers by high-resolution scanning transmission electron microscopy (HR-STEM) in combination with electron energy-loss spectroscopy (EELS). We obtained Z-contrast images with sub-nanometer resolution and chemical data from the corresponding regions.

Thin foils are prepared by using a focused ion beam (FIB) machine, which produces homogeneously thick TEM lamellae along the CIGSe layer. HR-STEM and EELS analyses show striking chemical characteristics for a number of defects present in Cu-poor CIGSe thin films. The elemental distributions at {112} twin planes, which are very frequent in these samples, are the same ones as in the grain interiors, with a homogeneous distribution of all matrix elements (Figure 1). By contrast, within the complex defects, which are closely related to stacking faults, Cu enrichment in combination with In and Se depletion are observed. Cu enrichment and In depletion are also detected at random grain boundaries. However, Se is homogeneously distributed in this case. Finally, Cu-Se-rich channels seem to form immediately outside (not within) dislocation cores (Figure 2). The present contribution provides a discussion on the impact of the growth process on the chemical properties of extended structural defects in CIGSe thin films.

References:

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Fig. 1: Z-contrast image (a) of the twin boundary along the (112) plane and corresponding elemental map (b) from the EEL spectrum image. Green, blue and red colours show the Cu, In, Se elements respectively.

Fig. 2: Z-contrast image (a) of a dislocation core, corresponding elemental map (b) from the EEL spectrum image. Green, blue and red colours indicate the Cu, In, Se elements respectively.