HL 27: Focus Session: Perspectives in Cu(In,Ga)Se 1

The chalcopyrite Cu(In,Ga)Se2 is currently one of the few photovoltaic materials with an active participation in the market share of thin-film technologies, offering also the advantage of having a low production carbon footprint. After a rapid increase in its record power conversion efficiency during the last decade, the technology seems to have stagnated at 23.4 percent, a record achieved in 2019. Several strategies, which have been partially responsible of the newest record efficiencies, have been developed in order to push Cu(In,Ga)Se2 further by targeting the improvement of the bulk properties and the interfaces: post-deposition treatments with heavy alkali metal fluorides, incorporation of other metals like silver and the mixture with other chalcogens like sulfur, are just some examples. The aim of this focus session is to bring Cu(In,Ga)Se2 experts together in order to discuss the current limitations and propose new routes and concepts that could lead to a further improvement in this technology.

Organized by AK-jDPG (Aubin Prot, Omar Ramirez and Taowen Wang)

Time: Thursday 9:30–11:00 Location: H33

Invited Talk HL 27.1 Thu 9:30 H33

What limits state-of-the-art chalcopyrite solar cells? —
•Susanne Siebentritt — Laboratory for Photovoltaics, Department of Physics and Materials Science, University of Luxembourg

Chalcopyrite solar cells have reached 23.4% efficiency, less than Si solar cells. Why are chalcopyrite solar cells not better? State of the art chalcopyrite solar cells are based on an absorber with a band gap gradient in depth, to keep electrons from the back contact and to reduce non-radiative recombination at the back contact. However, this graded band gap profile can decrease the short circuit current because of a rather low absorptance near the absorption edge. Additionally, the gradual increase of the absorptance leads to radiative loss in the open circuit voltage (VOC). Additional fluctuations and disorder lead to exponential band tails and to radiative and non-radiative VOC losses. These Urbach tails are larger in polycrystalline films than in epitaxial films, indicating a contribution of grain boundaries, however, the difference is only a few meV in Urbach energy, indicating a common source independent of grain boudaries. The dependence of the Urbach energy on the net doping level hints to electrostatic fluctuations as a main source of tail states. In addition to these limitations of the short circuit current and the open circuit voltage, the diode factor of most chalcopyrite solar cells is high, implying a low fill factor. It became only recently clear, that metastable defects contribute massively to the increased diode factor of these solar cells.

Invited Talk HL 27.2 Thu 10:00 H33

Approaches to improve CIGS absorber quality and the CIGS/buffer interface to reach 24% efficiency and beyond —
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Cu(In,Ga)Se2 (CIGS) thin-film solar cells with polycrystalline absorber layers exhibit high power conversion efficiencies above 23% for small-area devices. The bandgap energy (Eg) of CIGS is tunable and the material can be used either as bottom cell within a tandem device, e. g. in combination with perovskite as a top cell or the CIGS cell can be applied as wide-bandgap top cell and combined with e. g. a silicon bottom cell. In spite of their excellent photovoltaic (PV) performance, it is apparent, when comparing the PV parameters of record single junction CIGS devices with the theoretical radiative limit, that various loss mechanisms are present in the devices. As few examples, the open-circuit voltage (Voc) and the fill factor (FF) are limited by non-radiative recombination and additional parasitic absorption takes place in the buffer and adjunct high-resistive (HR) layer, which can limit the short-circuit current (Jsc).

This contribution gives an overview on approaches to improve CIGS single-junction solar cells beyond 24%. Increasing grain size and/or eliminate the Ga/(Ga+In) grading in the absorber can reduce Voc losses and alloying of silver to CIGS can increase FF values.

To overcome parasitic absorption of the standard buffer system CdS/i-ZnO, the application of wide-bandgap buffer or HR materials such as Ga2O3 with Eg>4 eV can be an option to increase Jsc further.

HL 27.3 Thu 10:30 H33

Role of Na in interconnection between chemical composition and electrical properties of grain boundaries in Cu(In, Ga)Se2 —
•Azam Karami[1], Marcin Morawski[2], Heiko Kempa[2], Roland Scheer[2], and Oana Cojocaru-Mirédin[1] — [1]RWTH Aachen University, Aachen, Germany — [2]Martin-Luther-Universität Halle-Wittenberg, Halle, Germany

Nowadays, the polycrystalline Cu(In,Ga)Se2 thin-film solar cells have attained increased interest due to their lower costs and higher cell efficiency in energy conversion. These polycrystalline absorbers contain a large ratio of grain boundaries which can be detrimental (increase in recombination activity compared to the bulk), neutral (no change in electrical properties relative to grains) or benign (increase in electrical properties) for the cell performance. In the present work, different techniques such as atom probe tomography and electron backscattered diffraction are used to investigate different grain boundaries in order to illustrate the relation between the chemical composition and the electrical properties of the grain boundaries. It is shown that the elemental changes at the grain boundaries such as Cu depletion, In enrichment and segregation of alkali dopants like Na, can directly affect their beneficial behavior in favor of cell performance. The experimental findings prove the significant role of Na addition in improving the cell parameters such as open circuit voltage and fill factor. Although it is also shown that the excessive addition of Na dopant can have a detrimental effect on the cell efficiency by increasing the density of dislocations and interference of deep defects with dopants.

HL 27.4 Thu 10:45 H33

Electronic properties of the back contact in Cu(In,Ga)Se2 solar cells —
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Cu(In,Ga)Se2 solar cells are interesting for single junction and multi-junction (tandem) photovoltaic energy conversion. Although not being ideal, their back contact may exhibit a secondary junction. This is the case for low bandgap Cu(In,Ga)Se2 with a molybdenum back contact. Here, the secondary junction leads to a certain admittance step, a saturation in the Voc(T) plot, but has little impact on the device performance for thick Cu(In,Ga)Se2 layers: The barrier typically is small enough to allow for majority carrier transport and sufficiently far away from the main junction to impede minority carrier recombination. Only for ultrathin Cu(In,Ga)Se2 solar cells, the barrier can limit the device performance. For wide bandgap Cu(In,Ga)Se2 on molybdenum, the barrier appears to be even smaller. The situation is much less clear for Cu(In,Ga)Se2 on a transparent ITO back contact for tandem applications. For low bandgap Cu(In,Ga)Se2, no barrier is to be detected by admittance and Voc(T) experiments. For widegap Cu(In,Ga)Se2, the barrier formation in addition depends on the type of dopant. In this contribution, we used different experimental techniques in order to develop electronic models for opaque (Molybdenum) and transparent (ITO) back contacts.