HL 39: Photovoltaics: Chalcopyrites I

Time: Tuesday 13:30–15:15 Location: FOE Anorg

HL 39.1 Tue 13:30 FOE Anorg

Excess carrier depths profiles in Cu(In,Ga)(S,Se)$_2$ absorbers from spectral photoluminescence — •Nils Könne[1], Sebastian Knabe[1], Wolfram Witte[2], Dimitrios Hariskos[2], Alexander Meeder[3], and Gottfried H. Bauer[1] — [1]Institute of Physics, CvO University Oldenburg, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), Stuttgart, Germany — [3]SULFURCELL Solartechnik GmbH, Berlin, Germany

The polycrystalline structure of chalcopyrite absorbers, such as Cu(In,Ga)(S,Se)$_2$ and their complex metallurgical composition results in lateral and depth dependent inhomogeneities. The spectral photoluminescence (PL) recorded from front and rear side of these chalcopyrite thin-film systems shows a distinct different behavior in particular of the high energy PL-wing which is strongly governed by absorption/emission approaching unity, as well as by re-absorption of emitted PL-photons and their depth dependent origin, say excess carrier depth profile. We define a contrast parameter for the high energy PL-yield of the fluxes recorded from front side and rear side and we proof the origin of the experimental contrast with numerical simulations of spectral PL-yields via Planck's generalized law for different depth profiles of excess carriers and band gap/absorption coefficients. By comparison of experimental contrast parameters with results from numerical simulations we conclude a set of regimes of realistic combinations of depth profiles for excess carriers and band gaps.

HL 39.2 Tue 13:45 FOE Anorg

Investigation of recombinatoric loss mechanisms in Cu(In,Ga)Se$_2$ Thin Film Solar Cells — •Robin Knecht[1], Torben Klinkert[1], Jürgen Parisi[1], Ingo Riedel[1], Raymund Schäffler[2], and Bernhard Dimmler[2] — [1]Thin Film Photovoltaics, Energy- and Semiconductor Research Laboratory, University of Oldenburg, D-26111 Oldenburg — [2]Würth Solar GmbH & Co. KG, Alfred-Leikam-Straße 25, D-74523 Schwäbisch-Hall

Today solar cells based on the compound semiconductor Cu(In,Ga)Se$_2$ (CIGSe) present the highest lab scale efficiency among all thin-film technologies. The performance of elementary cells in photovoltaic modules might however be different due to thicker conductive ZnO:Al window layers, missing anti-reflection coating and occasionally less defined absorber formation on large scales. One approach to improve the elementary cell efficiency is to fine-tune the absorber composition and the in-depth band gap grading. In this work we investigated CIGSe samples with varied absorber composition in order to quantify the minority carrier collection efficiency (CE). CE is directly related to the electron diffusion length $L_{D,n}$ and the characteristics of the space charge region (SCR). $L_{D,n}$ was deduced by relating the inverse internal quantum efficiency to the penetration depth of incident photons and the SCR characteristics were obtained from capacitance-profiling of the samples. Based on these results we discuss the different photovoltaic performance observed for samples with varied CIGSe absorber composition.

HL 39.3 Tue 14:00 FOE Anorg

Dynamics of light-induced changes in CIGSe2 solar cells with electroplated absorber — •Anton Werth[1], Janet Neerken[1], Jörg Ohland[1], Jürgen Parisi[1], Ingo Riedel[1], and Juan Rechid[2] — [1]Carl-von-Ossietzky Universität Oldenburg, Carl-von-Ossietzky-Straße 9-11, D-26129 Oldenburg — [2]CIS Solartechnik GmbH & Co. KG, c/o Aurubis AG, Hovestr. 50, D-20539 Hamburg

In this work we studied the transient evolution of the J-V-characteristics of CIGSe2 solar cells during light soaking (LS). The failure of the dark-light superposition (cross over - CO) evolves already within seconds whereas the positive effect of the LS procedure shows up on large time scales (several hours up to days). We focus on the evolution and relaxation dynamics of these mechanisms in CIGSe2-solar cells with CdS and an alternative buffer layer. The investigations include IV-analysis and space charge profiling on different time scales (miliseconds up to several hours). The influence of the spectral composition of the irradiation used for LS was also considered. We discuss our results in terms of photoinduced changes of the conduction band offset and the metastable interface characteristics of the buffer-absorber interface.

HL 39.4 Tue 14:15 FOE Anorg

Impact of thickness reduction of the ZnO:Al window layer on opto-electronical properties of CIGSSe solar cells — •Jan Keller[1], M. Knipper[1], J. Parisi[1], I. Riedel[1], T. Dalibor[2], and A. Avellan[2] — [1]Thin Film Photovoltaics, University of Oldenburg, D-26111 Oldenburg — [2]AVANCIS GmbH & Co. KG, D-81739 Munich

The application of highly doped transparent conducting oxides in chalcopyrite solar cells requires an optimized trade-off between optical transmission and sheet-conductivity. In this respect we studied the thickness variation of ZnO:Al films used as window layer in Cu(In,Ga)(Se,S)$_2$ (CIGSSe) thin film solar cells. Thin ZnO:Al layers (200nm) on glass exhibit significantly enhanced transmission at wavelengths λ<400nm while a considerable sub-bandgap absorption at λ>800nm appears in thicker films which is attributed to free charge carrier absorption. The IV-characteristics of CIGSSe solar cells with $d_{ZnO:Al}$=200nm exhibit a strong enhancement of the short-circuit current density J_{SC} (ΔJ_{SC}=3mA) as compared to samples with conventional ZnO:Al-film thickness. However, the reduced parallel (R_p) and increased series (R_s) resistance of samples with thin ZnO:Al-layer cause reduction of the fill factor, which has direct consequences for the series connection of cells in a CIGSSe-module. XRD-diffractograms suggest that the high R_s in thin ZnO:Al is not only related to the thickness but also due to reduced (002)-texture that appears to be beneficial for lateral conductivity. By thermographic investigations we are able to directly locate the cell-regimes responsible for the decreased R_p.

HL 39.5 Tue 14:30 FOE Anorg

Investigation of the initial interface formation between CuInSe2 (112) and ZnO grown by ALD — •Eike Janocha and Christian Pettenkofer — Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Deutschland

The interface between a solar cell absorber and its transparent conductive oxide (TCO) defines the electrical properties and thus the efficiency of chalcopyrite solar cells. Since large conduction band offsets lower the solar cell photocurrent usually a CdS buffer layer is deposited by chemical bath deposition (CBD) between chalcopyrite absorber and TCO. Due to its toxicity and the interruption of the in-line production process by CBD an alternative buffer layer material would be advantageous.

To improve the efficiencies of chalcopyrite solar cells a detailed understanding of the electronic band structure between absorber and TCO is necessary. Therefore, we investigated a model system of a single crystalline CuInSe2 absorber material grown in the technological important (112) orientation by molecular beam epitaxy and an epitaxial ZnO TCO grown layer-by-layer via atomic layer deposition (ALD). ALD is known for being a deposition technique allowing the growth of a single monolayer due to its self-limiting growth characteristics.

In situ characterization of the initial growth has been performed after each ZnO deposition step by photoelectron spectroscopies (XPS/UPS/SR-PES) in an UHV growth and analysis system resulting in a detailed view of the interface formation and binding characteristics of the involved elements.

HL 39.6 Tue 14:45 FOE Anorg

Spatially and time resolved cathodoluminescence spectroscopy of CuGaSe$_2$ — •Torsten Schwarz[1], Mathias Müller[1], Frank Bertram[1], Jürgen Christen[1], Daniel Abou-Ras[2], Thorsten Rissom[2], Thomas Unold[2], and Hans-Werner Schock[2] — [1]Otto-von-Guericke-University Magdeburg, Germany — [2]Helmholtz Zentrum Berlin for Materials and Energy, Germany

The luminescence properties of polycristalline CuGaSe$_2$ as an efficient absorber material for thin film solar cells has been studied comprehensively using spatially and time resolved cathodoluminescence (CL) spectroscopy. The Mo/glass substrate of a complete solar cell grown by a three-stage process was lifted off to investigate the back side of the absorber layer. CL spectra recorded at 6 K, exhibit a strong, dominating emission at 1.64 eV. In addition, an emission peak around 1.57 eV as well as a peak around 1.45 eV is found in several microscopic regions. In excitation density dependent CL measurements a blueshift of 6.4 meV/decade and 4.3 meV/decade for the peaks at 1.64 eV and 1.57 eV is observed as well as a sublinear increase of the peak intensities

with slopes of 0.66 and 0.77. ps-time resolved CL was performed using a long rectangular shaped electron excitation pulse of 710 ns width to ensure reaching steady state and a low repetition rate (200 kHz) to reach the thermal equilibrium between the pulses. A redshift in onset (6 meV) and decay (36 meV) is found. Furthermore, monochromatic transients show an increase of the initial lifetime of carrier recombination processes from 10 ns at 1.67 eV up to 150 ns at 1.55 eV. Both are characteristic fingerprints for strong relaxation processes.

HL 39.7 Tue 15:00 FOE Anorg

Luminescence investigation of Cu(In,Ga)Se_2solar cells with different Ga-contents grown in a three-stage-process on glass substrate — •Kristin Wendt[1], Mathias Müller[1], Thomas Hempel[1], Frank Bertram[1], Jürgen Christen[1], Daniel Abou-Ras[2], Thorsten Rissom[2], Thomas Unold[2], and Hans-Werner Schock[2] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Helmholtz-Zentrum Berlin for Materials and Energy, Germany

A fundamental advantage of Cu(In,Ga)Se_2 (CIGS) alloys as absorber materials in thin-film solar cells is their direct band gap energies which can be varied between 1.04 eV ($CuInSe_2$) and 1.68 eV ($CuGaSe_2$). Photoluminescence (PL) spectra of complete CIGS solar cells with a systematic variation of the Ga-content in the absorber layer will be presented. The CIGS cells investigated were grown on a Mo back contact sputtered on soda lime glass and have a Ga-concentration ranging over the entire range from $CuInSe_2$ to $CuGaSe_2$. Samples with Ga-contents between 100 % and 33 % show two broad luminescence bands. In contrast, $CuInSe_2$ exhibits only one broad luminescence band. Each band is composed of two or three different transitions. Varying excitation density over four orders of magnitude results for samples with Ga-content of 0 % and 33 % in a blueshift of the main peak with increasing excitation density. For higher Ga-concentrations, first a blue- and then a redshift of the dominating peak with increasing excitation density is visible. The temperature dependence of the PL spectra is investigated going from 4 K to 300 K.