HL 4: Photovoltaics I: mainly CIGS

Time: Monday 10:15–12:45 Location: H15

HL 4.1 Mon 10:15 H15

Investigation of Cu(In,Ga)Se_2 using Monte Carlo and the Cluster Expansion technique — •Christian D. R. Ludwig[1], Thomas Gruhn[1], Claudia Felser[1], and Johannes Windeln[2] — [1]Institute of Inorganic and Analytical Chemistry, Johannes Gutenberg-University, 55099 Mainz — [2]IBM Germany, Mgr. Technology Center ISC EMEA, 55131 Mainz

CIGS based solar cells are among the most promising thin-film techniques for cheap, yet efficient modules. They have been investigated for many years, but the full potential of CIGS cells has not yet been exhausted and many effects are not understood. For instance, the band gap of the absorber material Cu(In,Ga)Se_2 varies with Ga content. The question why solar cells with high Ga content have low efficiencies, despite the fact that the band gap should have the optimum value, is still unanswered. We are using Monte Carlo simulations in combination with a cluster expansion to investigate the homogeneity of the In-Ga distribution as a possible cause of the low efficiency of cells with high Ga content. The cluster expansion is created by a fit to ab initio electronic structure energies. The results we found are crucial for the processing of solar cells, shed light on structural properties and give hints on how to significantly improve solar cell performance. Above the transition temperature from the separated to the mixed phase, we observe different sizes of the In and Ga domains for a given temperature. The In domains in the Ga-rich compound are smaller and less abundant than the Ga domains in the In-rich compound. This translates into the Ga-rich material being less homogeneous.

HL 4.2 Mon 10:30 H15

CdS-Photodoping in Quantum Efficiency Spectra of Chalcopyrite Thin Film Solar Cells — •Heiner Lendzian[1], Janet Neerken[1], Martin Knipper[1], Ingo Riedel[1], Jürgen Parisi[1], Stefan Jost[2], Thomas Dalibor[2], Jörg Palm[2], and Alejandro Avellán[2] — [1]Energy- and Semiconductor Research Laboratory, Department of Physics, Carl von Ossietzky University of Oldenburg, D-26111 Oldenburg, Germany — [2]AVANCIS GmbH & Co. KG, Otto-Hahn-Ring 6, Gebäude 31, D-81739 Munich, Germany

Understanding the electronic properties of the CdS buffer layer typically employed in chalcopyrite thin film solar cells is a key challenge in the pursuit of high device performance. Photodoping of the CdS layer appears to alter the conduction band offset at the CdS/absorber interface by more than 100meV and causes substantial changes in the spectral shape of the external quantum efficiency under forward voltage bias. This contribution examines the nature of CdS-photodoping by means of quantum efficiency measurements for varied temperatures, photon flux densities and excitation frequencies. Rapid photodoping is linked to hole traps inside the CdS buffer similar to those believed to be responsible for cross-over in current-voltage-measurements. The results emphasize the strong influence of CdS-photodoping on chalcopyrite solar cell performance and grant insight into its dynamic nature.

HL 4.3 Mon 10:45 H15

Characterisation of CuInSe2-based solar cells with different buffer layers — •Anton Werth[1], Jörg Ohland[1], Ingo Riedel[1], Jürgen Parisi[1], and Juan Rechid[2] — [1]Abteilung EHF, Institiut für Physik, Carl von Ossietzky Universität, Carl-von-Ossietzky-Straße 9-11, D-26129 Oldenburg — [2]CIS Solartechnik GmbH & Co. KG, c/o Aurubis AG Hovestr. 50 20539 Hamburg

The optoelectronic properties of the buffer layer in chalcopyrite solar cells may present strong efficiency limitation due to parasitic absorption, interface states and band discontinuities in respect of the light absorber. In this work we investigated CuInSe2-based (CIS) solar cells processed on flexible steel substrates with In2S3 and CdS buffer layers by means of temperature dependent current-voltage (J-V) measurements at varying illumination intensity and external quantum efficiency (EQE) measurements. Under illumination the J-V curves of both cell types exhibit distinct "s"-shape non-ideality (roll over) at temperatures below 260K. The occurrence of the "s"-shape in the 4th and/or 1st quadrant is explained by an heuristic model which relates the band discontinuity being present at the buffer CIS interface to limitation of the minority carrier extraction and injection. Further, we employed the suns-Voc method to extract the diode parameters saturation current and diode ideality from the J-V characteristics under illumination (small effect of series resistance) in order to identify clues on dominant surface or bulk recombination. We conclude that interface recombination is less dominant in the investigated samples independent of the used buffer material.

HL 4.4 Mon 11:00 H15

Optoelectronic properties of Cu(In,Ga)(S,Se)$_2$ thin film solar obtained from varied chalcogenization processes — •Robin Knecht, Martin Knipper, Ingo Riedel, and Jürgen Parisi — Energy and Semiconductor Research Laboratory, Department of Physics, University of Oldenburg, 26111 Oldenburg, Germany

Thin film solar cells made of the chalcopyrite compound semiconductor Cu(In,Ga)(S,Se)$_2$ (CIGSSe) exhibit strong potential for achieving high efficiency at relatively low production costs. While large scale production of CIGSSe-modules has been launched in different companies the transfer of high laboratory cell efficiencies to the module scale is still a major challenge. In order to improve module efficiencies optimisation of the large scale production process presents a major issue.

In this work the influence of chalcogenization (selenisation and sulfurisation) parameter variation on the device characteristics was studied using temperature and illumination dependent current-voltage profiling, external quantum efficiency measurements as well as temperature dependent capacitance-voltage measurements. From these measurements we derived important characteristics of the light absorber like activation energy of the recombination current, estimation of the absorber band gap as well as the doping concentration along with the diffusion potential. These studies were completed by defect spectroscopy for analysis of defect formation in the absorber material. The results obtained from these investigations are compared for samples exposed to different conditions of the chalcogenization process.

15 Min. Coffee Break

HL 4.5 Mon 11:30 H15

Vergleichende Charakterisierung von Homo- und Heterojunction- $CuIn_{0,4}Ga_{0,6}Se_2$ **Solarzellenstrukturen auf Glassubstrat** — •Kristin Wendt[1], Thomas Hempel[1], Jürgen Christen[1], Kay-Michael Günther[1], Mutsumi Sugiyama[2] und Shigefusa Chichibu[3] — [1]Institut für Experimentelle Physik, Otto-von-Guericke Universität Magdeburg, Deutschland — [2]Department of Electrical Engineering, Tokyo University of Science, Japan — [3]Institute of Multidisciplinary Research of Advanced Materials, Tohoku University, Japan

Das Materialsystem $Cu(In,Ga)Se_2$ ist aufgrund des variablen Bandabstandes, ein vielversprechendes Material für die Herstellung von Dünnschichtsolarzellen. Das Interesse liegt dabei auf der Entwicklung alternativer Pufferschichten und der Realisierung einer Homojunction durch Dotierung des Absorbers $Cu(In,Ga)Se_2$. In den vorgestellten Untersuchungen werden optische und elektrooptische Messungen an Homojunction- bzw. Heterojunction- $CuIn_{0,4}Ga_{0,6}Se_2$ -Strukturen auf Glassubstrat mit unterschiedlichen Pufferschichten vorgestellt. Durch temperatur- und anregungsdichteabhängige Photolumineszenzmessungen wird das Lumineszenzverhalten der über thermische Evaporation prozessierten $CuIn_{0,4}Ga_{0,6}Se_2$ -Schichten verglichen. Die $CuIn_{0,4}Ga_{0,6}Se_2$ -Strukturen zeigen dabei eine breitbandige Lumineszenz im Bereich von 1,08eV bis 1,28eV mit einer Halbwertsbreite im Bereich von 0,08eV bis 0,10 eV. Eine spektrale Änderung der Lumineszenz wurde weder mit veränderter Anregungsleistung noch mit Veränderung der Temperatur beobachtet.

HL 4.6 Mon 11:45 H15

Influence of sodium on the electrical properties of flexible CIGSe solar cells — •Felix Daume[1,2], Stefan Puttnins[1,2], Hendrik Zachmann[1], Andreas Rahm[1], and Marius Grundmann[2] — [1]Solarion AG, Ostende 5, 04288 Leipzig, Germany — [2]Institut für Experimentelle Physik II, Universität Leipzig, Linnéstraße 5, 04103 Leipzig, Germany

Thin film solar cells based on Cu(In,Ga)Se_2 (CIGSe) absorbers can be deposited on flexible substrates such as metal or plastic foils hence making new innovative applications and a fabrication in continuous roll-to-roll production lines feasible. Efficiencies up to 15.6 % were demonstrated for CIGSe cells on polyimide foil. The extrinsic incorpo-

ration of sodium into CIGSe solar cells based on sodium free substrates such as polyimide is indispensable to achieve high efficiencies. Despite its significance there is no comprehensive understanding of how sodium exactly influences the electrical and structural properties of CIGSe yet.

Via capacitance spectroscopy and I-V-measurement we characterized CIGSe solar cells on polyimide from a roll-to-roll fabrication with different amounts of sodium introduced during the CIGSe deposition. The net doping profiles were derived from C-V-measurements. An increase of the net doping with higher sodium content in the CIGSe is observed along with the decrease of the width of the space charge region. Additionally, differences in the spatial distribution of the doping for those CIGSe absorbers were found. These observations from capacitance spectroscopy are supplemented by I-V data showing an increase in V_{OC} and thus in efficiency with increasing sodium content.

HL 4.7 Mon 12:00 H15

Current blocking and current collection in CIGSe solar cells depending on sodium content — •Stefan Puttnins[1,2], Felix Daume[1,2], Hendrik Zachmann[1], Andreas Rahm[1], and Marius Grundmann[2] — [1]Solarion AG, Ostende 5, 04288 Leipzig, Germany — [2]Institut für Experimentelle Physik II, Universität Leipzig, Linnéstr. 5, 04103 Leipzig, Germany

IV-curves of thin film solar cells often show non-idealites like voltage dependent carrier collection and current blocking behaviour. Sodium is long known to improve the efficiency of $Cu(In,Ga)Se_2$ solar cells by increasing V_{OC} and FF. However, the way in which sodium influences the electrical properties is still under discussion.

We investigated the influence of sodium on voltage dependent carrier collection and current blocking behaviour. Losses caused by incomplete photocurrent collection can be reduced by increased sodium content in the CIGSe layer. Current blocking behaviour like the rollover effect is less pronounced with increased sodium content.

The influences were analyzed both in detailed illumination intensity and temperature dependent IV-measurements as well as by extensive statistical analysis over thousands of produced flexible CIGSe solar cells. Theoretical models for this dependency were simulated with SCAPS-1D and show good agreement with respective measurements.

HL 4.8 Mon 12:15 H15

Cu poor phases at Cu(In,Ga)Se2/CdS interfaces — Andreas Klein, Thomas Schulmeyer, Ralf Hunger, and •Tobias Adler — TU Darmstadt, Institute of Materials Science, Petersenstrasse 32, 64287 Darmstadt

The absorber surfaces and interfaces in Cu(In,Ga)Se2 (CIGS) thin film solar cells are affected by Cu-poor phases like Cu(In,Ga)3Se5 or Cu(In,Ga)5Se8, which are often referred to as ordered vacancy compounds. We have performed photoemission studies of de-capped CIGS surfaces and their interface with CdS. The band alignments and temperature dependent binding energy shifts provide evidence that interfaces of In-rich CIGS films are Cu-poor, while interfaces of Ga-rich CIGS films are stoichiometric.

HL 4.9 Mon 12:30 H15

Interface properties of Cd-free buffer layers on on CIGSe thin film solar cells — •J.P. Theisen[1], F. Erfurth[1], L. Weinhardt[1], R. Duarte[2], M. Bär[2], T. Niesen[3], J. Palm[3], N. Barreau[4], F. Couzinié-Devy[4], J. Kessler[4], and F. Reinert[1,5] — [1]University of Würzburg, Experimental Physics VII, Würzburg, Germany — [2]Helmholtz Institut, Berlin, Germany — [3]Avancis GmbH, München, Germany — [4]Institut des Matériaux , Nantes, France — [5]Forschungszentrum Karlsruhe GmbH, Gemeinschaftslabor für Nanoanalytik, Karlsruhe, Germany

In order to replace the toxic Cadmium, the substitution of the CdS buffer layer in thin film solar cells based on $Cu(In,Ga)(S,Se)_2$ (CIGSSe) is of great interest. Alternative buffer layers like $(In,Al)_2S_3$, In_2S_3, or $(Zn_{1-x},Mg_x)O$ deposited by conventional sputter and chemical bath deposition techniques, have shown efficiencies close to or comparable to those of CdS containing solar cells. To understand the chemical and electronic properties of these buffer layers and its influence on the absorber, we studied the buffer-absorber interface using photoelectron spectroscopy (XPS, UPS) and inverse photoelectron spectroscopy (IPES). The combination of these non-destructive techniques provides detailed information about the chemical properties of the studied surface, as well as can be used for a direct determination of the conduction and valence band alignment at the heterojunction. Band-gap values at the surface as derived by UPS and IPES are also verified by electron energy loss spectroscopy (EELS). The results will be discussed in conjunction with the respective cell parameters.