HL 112: Energy materials: CIGS and related photovoltaics

Time: Friday 9:30–12:30 Location: POT 112

HL 112.1 Fri 9:30 POT 112

Depleted heterojunction solar cells with $CuInS_2$ and ZnO nanocrystals - optical modeling and electrical characterization — •Dorothea Scheunemann, Sebastian Wilken, Jan Keller, Michael Richter, Ingo Riedel, Holger Borchert, and Jürgen Parisi — University of Oldenburg, Department of Physics, Energy and Semiconductor Research Laboratory, 26111 Oldenburg

Colloidal quantum dot (CQD) solar cells with solution-producible absorber layers have made rapid progress in the last few years. In particular, the so-called depleted heterojunction concept, consisting of a wide band gap n-type semiconductor and a p-type CQD film as absorber, appears promising. Here, we study the potential of $CuInS_2$ nanocrystals (NCs) as a relevant alternative to the toxic Pb or Cd compounds for usage in depleted heterojunction solar cells. Two different layer stacks, based on a bilayer heterojunction between CIS and ZnO NCs, were investigated by means of high resolution electron microscopy and optical modelling. We applied variable-angle spectroscopic ellipsometry to derive the optical constants of the involved layers. These data served as input parameters into optical simulations in order to estimate light absorption in the individual layers of the device stack with the transfer matrix formalism. Here, we present the simulated data in comparison with experimental results. Furthermore, we studied the dependence of the current-voltage characteristics, as well as the external quantum efficiency on illumination conditions, i.e., the presence of UV light.

HL 112.2 Fri 9:45 POT 112

Application of S^{2-} stabilized $CuInS_2$ nanocrystals in inorganic and hybrid organic/inorganic nanocrystal solar cells — •Christopher Krause, Rany Miranti, Dorothea Scheunemann, Holger Borchert, and Jürgen Parisi — University of Oldenburg, Department of Physics, Energy and Semiconductor Research Laboratory, 26129 Oldenburg

Semiconductor nanocrystals have attracted much attention for application in inorganic/organic hybrid solar cells as well as all-inorganic solar cells during past years. $CuInS_2$ (CIS) nanocrystals are especially promising for solar cell application because of their absorption extending into the near infrared region, providing a suitable overlap with the solar spectrum. The nanocrystals prepared by colloidal synthesis are usually stabilized by long-chained organic molecules hampering the charge transport between adjacent nanocrystals and the charge transfer between donor and acceptor in hybrid devices. To overcome this problem the nanocrystal surface can be exchanged by inorganic ligands, like S^{2-}-ions. These ligands are small, facilitating charge transport and provide electrostatic stabilization of the colloidal solution. In this contribution I will present the application of S^{2-} stabilized CIS nanocrystals in inorganic/organic hybrid solar cells as well as all-inorganic nanocrystal solar cells.

HL 112.3 Fri 10:00 POT 112

EDX - measurements on lamellae of CIGSe solar cells — •Sven Schönherr, Alexander Kusch, Philipp Schöppe, Michael Oertel, Udo Reislöhner, and Carsten Ronning — Institut für Festkörperphysik, Friedrich Schiller Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Cu(In, Ga)Se_2 solar cells were processed in a sequential process. First, a multi-layer system containing copper, indium and gallium on top of a molybdenum back contact was deposited by DC - magnetron sputtering with different Ga profiles. Afterwards, the metallic precursor was reactively annealed in two steps in a selenium vapour atmosphere where it converted to an about 2 μm thick CIGSe absorber layer. Completing the solar cell, a CdS buffer layer was deposited via chemical bath deposition and as front contact a ZnO layer was sputtered on top. From these cells lamellae with a thickness of about 200 nm were prepared using a focused ion beam (FIB) system. The thin cross sections lead to a high spatial resolution which is mainly limited by the diameter of the electron beam. Energy dispersive X-ray spectroscopy measurements were taken at lamellae with different sputtered Ga profiles in the precursors and annealed with different selenization temperatures in the first annealing step.

HL 112.4 Fri 10:15 POT 112

X-ray fluorescence on Cu(In,Ga)Se_2-lamellas — •Philipp Schöppe[1], Alexander Kusch[1], Michael Oertel[1], Claudia Sarah Schnohr[1], Andreas Johannes[1], Stefanie Eckner[1], Manfred Burghammer[2], and Carsten Ronning[1] — [1]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]European Synchrotron Radiation Facility, B.P. 220, F-38043 Grenoble Cedex, France

Compositional and structural properties of the absorber affect significantly the efficiency of Cu(In,Ga)Se_2 solar cells. The integral composition is commonly determined using X-ray fluorescence (XRF) with high resolution. However, the absorber is typically inhomogeneous and thus there is a particular interest in collecting information from defined spatial regions in the nanometer range. Hence, XRF mapping with an X-ray beam diameter of approximately 200 to 300 nm was used to investigate cross sections of Cu(In,Ga)Se_2 solar cells. In order to implement this improved spatial resolution in the measurement, thin lamellas were prepared using a focused ion beam. Best results were obtained using a lamella thickness of about 250 nm. This enabled us to determine quantitatively the depth dependent composition of the absorber, particularly the Ga gradient, and its spatial distribution.

HL 112.5 Fri 10:30 POT 112

Impact of Gallium on chemical gradients in Cu(In,Ga)Se_2 thin film solar cells grown on flexible polyimide substrate — •Stefan Ribbe[1,2], Andreas Rahm[1], Frank Bertram[2], and Jürgen Christen[2] — [1]Solarion AG, Ostende 5, 04288 Leipzig, Germany — [2]Institute for Experimental Physics, Otto-von-Guericke-Universität Magdeburg, Germany

Cu(In,Ga)Se_2(CIGS) thin film solar cells on polyimide substrate receive a high interest for many applications due to its flexibility and weight-lightness. Lower growth temperatures - a requirement of using polyimide substrate - are a challenge for producing high efficiency CIGS material. In particular the proper adjustment of the vertical gallium gradient directly affects amongst other properties the collection of photogenerated carriers.

CIGS layers were grown on flexible polyimide foil by using an ion-beam assisted roll-to-roll process. Sodium was provided by an additional source of NaF during the three-stage process to ensure high conversion efficiency. Gallium content was varied by the growth rate controlled by XRF (x-ray fluorenscence).

Lateral microscopical fluctuations of the GGI (Ga/(Ga+In)-ratio) and changes of the vertical gallium gradient within the CIGS absorber layers have been studied by highly spatially resolved cathodoluminescence microscopy (CL) at low temperature (T = 5K). Spectral Linescans on cross sections directly show a change of a smooth vertical gradient to a discontinuous shift of the peak wavelength in dependence of the gallium content in the CIGS layers

HL 112.6 Fri 10:45 POT 112

Band alignment at the In_2S_3/Cu(In,Ga)(S,Se)$_2$ interface in thin-film solar cells — •Dirk Hauschild[1], Katharina Treiber[1], Stephan Pohlner[2], Robert Lechner[2], Jörg Palm[2], Clemens Heske[3,4,5,6], Lothar Weinhardt[3,5,6], and Friedrich Reinert[1] — [1]Experimental Physics VII, University of Wuerzburg, Germany — [2]AVANCIS GmbH & Co. KG, Munich, Germany — [3]Institute for Photon Science and Synchrotron Radiation, KIT, Germany — [4]Department of Chemistry, University of Nevada, Las Vegas (UNLV) — [5]Institute for Chemical Technology and Polymer Chemistry, KIT, Germany — [6]ANKA Synchrotron Radiation Facility, KIT, Germany

Both on laboratory scale as well as in large area industrial production, Cu(In,Ga)(S,Se)$_2$ (CIGSSe) based solar cells have been processed for many years with a CdS buffer layer between absorber and transparent front contact, using a chemical bath deposition process. However, CdS is toxic and therefore its usage increases the production and recycling costs. A substitution of CdS by In_2S_3 provides a Cd-free alternative that can be integrated in a dry inline production. The In_2S_3/CIGSSe interface has been investigated using ultraviolet (UPS) and X-ray photoelectron spectroscopy (XPS), as well as inverse photoemission (IPES). The combination of these techniques allows the determination of the conduction and valence band extrema and reveals a complete picture of the band alignment at the In_2S_3/CIGSSe interface. In this contribution we will compare the band alignments with and without tempering of the In_2S_3/CIGSSe interface structure and discuss the implications for the performance of the device.

Coffee break (15 min.)

HL 112.7 Fri 11:15 POT 112

Transient photoluminescence investigations on meta-stable Cu(In,Ga)Se2 thin-film solar cells and absorbers — •Viktor Gerliz, Stephan Heise, Jörg Ohland, Jürgen Parisi, and Ingo Riedel — Carl von Ossietzky University of Oldenburg, Germany

Light soaking and dark annealing can significantly affect the device performance of Cu(In,Ga)Se2 (CIGSe) thin film solar cells. Depending on the conditioning time we observe considerable improvements of the device performance in effect of thermal stress at 90°C under simulated AM1.5 illumination as reflected in an increased open circuit voltage (Voc) and doping concentration (ND). Contrarily, dark annealing of devices results in an opposed trend until a relaxed state is reached. It can be speculated that the conditioning has also impact on the minority carrier decay kinetics. Thus, we studied the time-resolved photoluminescence (TR-PL) decay for CIGSe solar cells and CdS-passivated CIGSe absorbers which were light-soaked/annealed for different conditioning times. Based on our results we discuss the change of Voc and ND of completed CIGSe solar cells with respect to the corresponding TR-PL decay characteristics

HL 112.8 Fri 11:30 POT 112

Investigation of contact barriers of co-evaporated Cu(In,Ga)Se_2 and Molybdenum — •Nils Neugebohrn, Maria S. Hammer, Jürgen Parisi, and Ingo Riedel — Energy and Semiconductor Research Laboratory, Department of Physics, University of Oldenburg, 26111 Oldenburg, Germany

Cu(In,Ga)Se_2 (CIGSe) solar cells have recently reached a record efficiency of 20,8%. Nevertheless, the electronic properties of the back contact which forms between CIGSe and molybdenum are poorly understood. For this interface Schottky-type as well as ohmic behavior has been reported previously. In particular, the intermediate $MoSe_2$ layer which forms between the absorber and the metal during growth of the CIGSe layer determines the contact characteristics and might be critical for the device performance. The energy band alignment at the CIGSe/$MoSe_2$/Mo interfaces depends on the growth conditions and material properties (absorber composition, Na-content of the absorber and Mo). In this study Au/CIGSe/$MoSe_2$/Mo samples have been prepared via etching of the ZnO/CdS window layer of the complete cell and subsequent deposition of Au contacts on top of the CIGSe layer. To study a potential barrier-induced current limitation we performed temperature-dependent current-voltage measurements between 80 and 300 K. We observed an exponential dependence of the injection current indicating the presence of a contact barrier. The barrier height is determined by employing the thermionic emission model. Based on these results we will discuss the location of this barrier, e.g. at the CIGSe/MoSe2 or at the $MoSe_2$/Mo interfaces.

HL 112.9 Fri 11:45 POT 112

Systematic investigation of the influence of intentionally created shunts on the cell performance of CIGS-thin film solar cells by lock-in thermography — •Finn Babbe, Jan Keller, Ingo Riedel, Jörg Ohlad, and Jürgen Parisi — Energy- and Semiconductor Research Laboratory, Department of Physics, University of Oldenburg

The efficiency of thin film solar cells and modules can be considerably reduced by local shunts, which may have been introduced in the production process. The corresponding output losses are diverse and depend on the properties of the defect (e.g. the distance to patterning lines). To investigate the effect of its position, size and shape artificial shunts were systematically prepared with a focused ion beam. This method allows the introduction of a broad variety of defined shunt structures in the micrometer range to realize different shunt configurations. The impact of the shunts was studied by lock-in thermography. Applying this technique the local heat (power) dissipation in the modified regions, caused by illumination or bias voltage excitation, was imaged and quantified. The aim of this work is to correlate the heat signatures to the output performance (especially the open circuit voltage and shunt resistance) of CIGS solar cells.

HL 112.10 Fri 12:00 POT 112

Simulation of temperature dependent admittance spectra of Cu(In,Ga)(Se,S)2 solar cells and interpretation of capacitance steps — •Michael Richter[1], Christian Schubbert[1], Patrick Eraerds[2], Jürgen Parisi[1], Ingo Riedel[1], Thomas Dalibor[2], and Jörg Palm[2] — [1]Energy and Semiconductor Research Laboratory, Department of Physics, University of Oldenburg, Carl-von-Ossietzky-Strasse 9-11, 26129 Oldenburg, Germany — [2]AVANCIS GmbH, Otto-Hahn-Ring 6, 81739 Munich, Germany

Reproducing the complex electronic device response of Cu(In,Ga)(Se,S)2 thin film solar cells by comprehensive numerical modeling is a feasible way to gain information about the device physics. Based on extensive material and device characterization we built up a simulation model that reflects not only room-temperature measurements of the current voltage and quantum efficiency but also temperature dependent admittance spectra in the temperature range from 130 K to 330 K. The individual contributions to the device admittance could be assigned to the carrier freeze out, relaxation of defects located in the bulk and in the space charge region. One dominant signature, commonly termed N1 signature, is ascribed to a second depletion region formed by a valence-band barrier at the Cu(In,Ga)(Se,S)2/Mo(Se,S)2 interface. The latter assumption is further evidenced by the correlation of the N1 signature with the roll-over behavior in temperature dependent current-voltage measurements. Furthermore, simulation of sulfur content fluctuations at the back region of the absorber shows the dependence of the roll-over on back contact properties.

HL 112.11 Fri 12:15 POT 112

Comparative study of different extraction methods of diode parameters of chalcopyrite solar cells — •Jose Fabio Lopez Salas, Jan Keller, and Ingo Riedel — Laboratory for Chalcogenide Photovoltaics (LCP), Energy and Semiconductor Research Laboratory, Department of Physics, University of Oldenburg

The current-voltage (IV) characteristics of solar cells are typically described by Shockley's equation. Here, the ideality factor n and saturation current density J_0 determine the properties of the diode. They are usually evaluated to reveal electronic loss mechanisms of the investigated solar cell, such as the localization of dominant recombination paths. If these parameters are not properly derived, the simulated diode characteristics may not reflect the real IV characteristics which leads to misinterpretation of internal electrical losses. In this work a number of methods for extraction of the mentioned parameters are applied to different CIGS solar cells and quantitatively compared. The accuracy of the parameters is verified for the cases of light, dark, temperature-dependent and intensity-dependent measurements, while the mean square error of the corresponding fits serves as the quality indicator. The necessity of an extented two-diode model will be discussed. The objective of this work is to find a method for reliable extraction of parameters of CIGS solar cells which yields the best possible reproduction of their real IV behaviour and to quantify the inaccuracy of each approach.