HL 32 Photovoltaic

Time: Wednesday 14:30–19:15 Room: BEY 118

HL 32.1 Wed 14:30 BEY 118

InP-based tandem solar cell with low band gaps — •U. Seidel, H.-J. Schimper, U. Bloeck, K. Schwarzburg, F. Willig, and T. Hannappel — Hahn-Meitner-Institute, Glienicker Str. 100, 14109 Berlin, Germany

III-V multi-junction solar cells already represent a kind of third generation solar cells and are currently the most efficient photovoltaic devices worldwide. In a multi-junction solar cell multiple single p/n solar cells with different band gaps are connected in series. At the present time the world record multi-junction cell is epitaxially grown on the lattice constant of GaAs or rather Ge. However, regarding the highest theoretical efficiencies there is a lack of an appropriate material with a band gap in the range of 1eV. A monolithic tandem solar cell with optimized low band gaps was designed for its application in a four junction cell as the low band gap part. It could be combined with a high band gap tandem or triple via different techniques. Our tandem cell was grown lattice-matched to InP via metalorganic vapor phase epitaxy (MOVPE). Only alternative precursors were used, i.e. TBAs, TBP and TESb. InGaAs (Egap = 0.75eV) was used for the bottom cell and InGaAsP for the absorber material around 1eV. To connect these two sub cells a new tunnel junction was produced including n-InGaAs and p-GaAsSb.

HL 32.2 Wed 14:45 BEY 118

Ga incorporation into $CuInS_2$ solar cell absorbers fast sulfurization processes — •Roland Mainz and Reiner Klenk — Hahn-Meitner-Institut, Glienicker Strasse 100, 14109 Berlin, Germany

It has been shown previously, that the performance of CuInS2-based (CIS) solar cells can be improved by incorporation of Ga into the absorber [1]. Industrial production requires a cheap and fast preparation method such as sulfurization of sputtered metal precursor films in a rapid thermal processor (RTP). This works well for pure $CuInS_2$ but various problems have been encountered with this particular preparation method after adding gallium to the precursor. We have therefore studied the influence of gallium on phase formation by in-situ energy dispersive x-ray diffraction (XRD) using synchrotron radiation. Results indicate that the phase formation sequence during sulfurization strongly depends on the layer sequence in the precursor as well as on the time dependence of the sulphur pressure in the reaction chamber. The information gained from these experiments is used to establish a process that works within the constraints imposed by the industrial application. Furthermore, results indicate that it is possible to influence the depth profile of the Ga in the film. Partial replacement of In by Ga increases the band gap of $CuInS_2$. Control over the Ga depth profile allows the implementation of an optimum (in terms of solar cell performance) band gap grading.
[1] R. Kaigawa A. Neisser R. Klenk M. Ch. Lux-Steiner. Improved performance of thin film solar cells based on $Cu(In,Ga)S_2$. Thin Solid Films, page 415 pp., 2002.

HL 32.3 Wed 15:00 BEY 118

Electronic Metastabilities in Cu(In,Ga)Se_2 Solar Cells — •Michael Reuter, Julian Mattheis, and Uwe Rau — Institut für Physikalische Elektronik, Pfaffenwaldring 47, D-70569 Stuttgart, Germany

Due to metastable electronic states, Cu(In,Ga)Se_2 solar cells show an electrical degeneration after being exposed to reverse voltage in the dark. While the degeneration effect first results in the shift of the dark current voltage characteristic towards larger voltages, the shift is reversed for prolonged degrading duration. This finding indicates that two competing processes with different time constants are involved in the mechanism leading to the observed metastable behavior. Subsequent illumination experiments reveal an increase of the open-circuit voltage V_{OC} under illumination with a power density of 100 mW/cm^2 and a decrease of V_{OC} under reduced illumination with 1 mW/cm^2. This intensity dependence of the change in V_{OC} supports the notion of two competing processes being involved in the creation and annihilation of metastable states. It points out that the injection level of minority carriers decides about whichever process will be dominant.

HL 32.4 Wed 15:15 BEY 118

Influence of grain boundaries on electric transport in chalcopyrites — •Mark Wimmer, Susanne Siebentritt, Thorsten Rissom, Tobias Eisenbarth, and Martha Lux-Steiner — Hahn-Meitner-Institut, Glienicker Str. 100, 14109 Berlin

The chalcopyrite Cu(In,Ga) Se_2 is successfully used as an absorber in photovoltaic devices. The chalcopyrite photoactive layers have, among others, the advantage of being useful in the polycrystalline form. Although grain boundaries, as the essential difference between single- and polycrystalline materials, may play an important role for the performance of the devices there is currently no commonly accepted model for the electronic structure of the grain boundaries. To analyze the specific influence of grain boundaries on the carrier transport we grew $CuGaSe_2$-bicrystals by metal organic vapour phase epitaxy and studied them by Hall-measurements. Hall-Measurements allow to identify the barrier height for the majority carriers which is found to be at about 100meV in polycrystalline materials. The bicrystals allow the investigations of single grain boundaries. The behaviour of the bicrystals under illumination will be discussed as well as the behaviour of annealed samples.

HL 32.5 Wed 15:30 BEY 118

Carrier recombination dynamics in 1 eV band gap (GaIn)(NAs)/GaAs solar cell material as a function of epitaxial growth conditions and post-growth annealing processes — •Swantje Horst, Kristian Hantke, Sangam Chatterjee, Kerstin Volz, Wolfgang Stolz, and Wolfgang Rühle — Faculty of Physics and Material Sciences Center, Philipps-Universität Marburg, Renthof 5, D-35032 Marburg, Germany

We measure time-integrated as well as time-resolved photoluminescence (PL) at room temperature of series of as-grown and post-growth annealed $Ga_{0.92}In_{0.08}N_{0.03}As_{0.97}$/GaAs epilayers grown by metal-organic vapour-phase epitaxy (MOVPE) using either trimethylgallium (TMGa) or triethylgallium (TEGa) as Ga precursors in combination with tertiarybutylarsine (TBAs) and 1,1-dimethylhydrazine (UDMHy). The samples are nominally undoped or intentionally doped with Mg (p-doping) or Te (n-doping) with doping levels typically used for solar cell applications. Post-growth thermal annealing significantly improves the optical quality of the (GaIn)(NAs) material. The PL of the p-doped samples show, at low excitation densities, an increased initial PL intensity and a slightly faster PL decay compared to the undoped samples, whereas the n-doped samples have a reduced initial PL signal and a much faster PL decay. The p-doped layers thus have a larger minority carrier lifetime and therefore a longer minority carrier diffusion-length. In addition, the PL-characteristics in particular of the as grown (GaIn)(NAs) material is improved by annealing with intense laser light. Possible reasons for this observation will be presented and discussed.

HL 32.6 Wed 15:45 BEY 118

Influence of grain boundaries on electrical and structural properties of chalcopyrites — •Tobias Eisenbarth, Susanne Siebentritt, Sascha Sadewasser, Jürgen Albert, Ferdinand Streicher, and Martha Lux-Steiner — Hahn-Meitner-Institut, Glienicker Str.100, 14109 Berlin

Thin film solar cells made from chalcopyrites (e.g. $CuGaSe_2$) are based on polycrystalline absorber layers with grains of different orientation. The influence of grain boundaries on recombination and electrical transport is not yet completely understood. But it can be assumed, that grain boundaries have a significant effect on the efficiency. Different models are discussed for the electronic structure of grain boundaries. In the present work, we grow epitaxial (MOVPE= Metal Organic Vapour Phase Epitaxy) $CuGaSe_2$ on a bicrystal GaAs-wafer with a single grain boundary. Depending on the Cu-content of the epitaxial film the epitaxy leads to two separate crystals or to a genuine grain boundary with defined orientation. This allows the detailed analysis a single grain boundary. We present results of scanning tunnelling microscopy, giving information about the crystalline and electronic structure of the grain boundary.

HL 32.7 Wed 16:00 BEY 118

Efficiency limitations in dye-sensitized solar cells with ionic liquids — •F. Einsele[1], M. Hlusiak[1], U. Rau[1], R. Sastrawan[2], R. Kern[2], and A. Hinsch[2] — [1]Institut für Physikalische Elektronik, Universität Stuttgart, Pfaffenwaldring 47, 70569 Stuttgart — [2]Fraunhofer Institut für Solare Energiesystem (ISE), Heidenhofstraße 2, 79110 Freiburg

Dye-sensitized solar cells (DSCs) consist of a layer of nanoporous TiO_2. A monolayer of dye molecules covers the TiO_2 nanoparticles. Photoexcitation of the dye and electron transfer into the conduction band of the TiO_2 makes up the primary photovoltaic action. The I^-/I_3^- redox couple of an electrolyte (EL) oxidizes the dye molecule. Standard high-efficiency DSCs use an EL with highly volatile acetonitrile as a solvent. One major research goal is the replacement of this EL by a non-volatile EL. Here the use of ionic liquids is a major option. Unfortunately, the efficiencies, especially the short circuit current densities j_{SC}, obtained with these EL so far are much lower than those of the standard devices. The present contribution investigates possible limitations to j_{SC} by means of electrical measurements. We find that the diffusion constant D_T of I_3^- in ionic liquids is $1.8x10^{-7}$ cm^2/s, i.e. about two orders of magnitude smaller than $1.2x10^{-5}$ cm^2/s in acetonitrile. A further limitation is provided by the TiO_2 network and in an additional light-scattering ZrO_2 layer. We observe that the effective diffusion constant D_{eff} in the TiO_2 network is about 40% of the bulk value and reduces to 16% in the ZnO_2 layer. A simple model unveils that the maximum achievable short circuit current density $j_{SC,max}$ is about 8 to 10 mA/cm^2 in this case.

HL 32.8 Wed 16:15 BEY 118

1. Doping induced structural changes in CuInS2 thin films and the effects on the optical and electrical properties — •Tobias Enzenhofer, Thomas Unold, and Hans-Werner Schock — Hahn-Meitner-Institut, Glienicker Strasse 100, 14109 Berlin

In this contribution we connect structural and optical changes induced by doping with group-II elements in CuInS2 thin films. The admixture of small amounts of zinc and/or magnesium (<1 at. %) results in significant changes of the absorber and solar cell properties of the chalcopyrite system Cu-In-S2. With Zn/Mg doping, solar cells show an enhancement of the open circuit voltage from 700mV to more than 800mV. The systematical study of the effect of incorporation of dopants into the absorber layers by annealing with Raman and photoluminescence spectroscopy reveal an increase in the Raman response of the cation-anion vibration modes accompanied with the generation of a new broad emission band at 1.35eV in the photoluminescence spectra. From photoluminescence measurements we find a change of the nature of bulk and surface defects for Zn/Mg doped samples. Moreover the electronic transport in doped and undoped absorber layers is compared by in-situ conductivity measurements during the annealing process.

HL 32.9 Wed 16:30 BEY 118

Manufacturing Photonic Crystals for Photovoltaic Applications — •Andreas Bielawny, Paul Miclea, Andreas von Rhein, Andreas Redler, Siegmund Greulich-Weber, and Ralf Wehrspohn — University of Paderborn, Department of Physics,

Inpired by the wide range of possible applications of photonic crystals, we are aiming for their contribution to the field of photovoltaics. Whether spectral photonmanagement between a multigap-cell's different layers or waveguiding in thin film cells, opaline photonic crystals offer a tempting way of producing large scale diffractive elements.

We present our work on fabrication of artificial opals made of Silica or PMMA, with focus on our experimental approaches to the main preparation methods of augmented sedimentation and vertical deposition, closely accompenied by investigation and characterization of their structural and optical properties with electron microscopy and angular resolved spectroscopy. We present some promising applications for their use in photovoltaic energy conversion.

— 15 min. break —

HL 32.10 Wed 17:00 BEY 118

Shunt Imaging and Characterization in Industrial Silicon Solar Cells using Polymer-dispersed Crystal Foils — •Stelio Correia and Jan Lossen — ErSol Solar Energy AG, Wilhelm-Wolff-Str. 23, 99099 Erfurt

Shunts reduce the efficiency of solar cells, especially under low light conditions. Besides that, shunts are responsible for the hot spot phenomena in modules under shading conditions that can result in the destruction of the device. The shunt conductance represents recombination effects and parasitic current paths parallel to the diode current. It affects the FF and Voc parameters. The identification of an increased shunt conductance, especially in large area surface state-of-the-art industrial solar cells, requires a spatial resolved analysis. Local power dissipation can be imaged with thermographic techniques. Polymer dispersed crystal foils are a simple tool to visualise temperature, when a high sensitivity is not relevant. With this method, shunts are detected by increased power dissipation under an external bias. In this work a cheap and easy-to-use system was built and used as a quality assessment and improvement tool for shunt analysis in industrial solar cells. Different types of shunts where identified. After a detailed characterization their causes could be overcome.

HL 32.11 Wed 17:15 BEY 118

Monitoring the sulfurization of (Ga,S)-Cu-In photovoltaic precursor layers by energy dispersive X-ray diffraction — •Alfons Weber, Immo Koetschau, and Hans-Werner Schock — Hahn-Meitner-Institut, Glienicker Str. 100, 14109 Berlin, Germany

Phase transformations of Cu_xIn-(Ga,S) thin film stacks were investigated in annealing experiments under sulfur vapor using in-situ energy dispersive X-ray diffraction (EDXRD). So far the formation of $CuInS_2$ absorbers for photovoltaic applications has been studied in similar annealing experiments using metallic Cu_xIn precursor layers[1]. In the present study a (Ga,S) layer was deposited in addition to the elemental Cu and In precursor layers to study the phase formation of $Cu(In,Ga)S_2$ alloys. The addition of Ga is expected to enhance the Voc of $CuInS_2$-based solar cells. The sulfurization was carried out in a specially designed chamber installed at the synchrotron beamline F3 at Hasylab in Hamburg. Using the synchrotron source it is possible to get spectra with high resolution at short integration times and to trace fast structural changes during the sulfurization process. The study shows that the annealing process does not lead to a homogeneous $Cu(In,Ga)S_2$ alloy, but to a separation of a Ga-rich and an In-rich phase. We will discuss the effect of (Ga,S) on the electronic properties of complete devices made of these films.
[1] Djordjevic J., Rudigier E., Scheer R, Materials Research Society symposium proceedings 763, (2003) p. 383-389

HL 32.12 Wed 17:30 BEY 118

Shunt Imaging and Characterization in Industrial Silicon Solar Cells using Polymer-dispersed Crystal Foils — •Stelio Correia and Jan Lossen — ErSol Solar Energy AG, Wilhelm-Wolff-Str. 23, 99099 Erfurt

Shunts reduce the efficiency of solar cells, especially under low light conditions. Besides that, shunts are responsible for the hot spot phenomena in modules under shading conditions that can result in the destruction of the device. The shunt conductance represents recombination effects and parasitic current paths parallel to the diode current. It affects the FF and Voc parameters. The identification of an increased shunt conductance, especially in large area surface state-of-the-art industrial solar cell requires a spatial resolved analysis. Local power dissipation can be imaged with thermographic techniques. Polymer dispersed crystal foils are a simple way to visualise temperature, when a high sensitivity is not relevant. With this method, shunts are detected by increased power dissipation under an external bias. In this work a cheap and easy-to-use system was built and used as a quality assessment and improvement tool for shunt analysis in industrial solar cells. Different types of shunts where identified. After a detailed characterization their causes could be overcome.

HL 32.13 Wed 17:45 BEY 118

Electronic structure of gold- and iron-decorated dislocations in silicon — •Oliver Voss[1], Vitaly Kveder[2], and Michael Seibt[1] — [1]IV. Physikalisches Institut der Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen — [2]permanent address: Institute of Solid State Physics RAS, Chernogolovka,*142432 Moscow reg., Russia

The recombination activity of dislocations in silicon strongly depends on their decoration with transition metal impurities in different states e.g. as precipitates or as isolated point defects. In this study the influence of Au and Fe as decoration of dislocations in fz-Si was measured by deep level transient spectroscopy (DLTS). We compared the effects of different Au concentrations. In addition to the DLTS-lines of dislocated n-Si we found a line with the emission characteristics of the Au-acceptor-level but with a capture barrier only with a high Au concentration. In

dislocated p-Si we found comparable results for a defect similar to the Au-donor-level and an additional line whose amplitude depends in the same way on the Au concentration. It was shown that these lines are point-defect-like lines with a logarithmic capture dependence. We tentatively attribute this behaviour to substitutional Au atoms in the strain field of dislocations. After indiffusion of Fe into dislocated p-Si and storage of 30 hours we found two point-defect DLTS-lines: the FeB-pair-line and the intertitial Fe line. After soft annealing both lines almost disappeared, another capture dependent line appeared and the total amount of active sites was significantly reduced.

HL 32.14 Wed 18:00 BEY 118

Symmetry of defects in chalcopyrites - a polarized photoluminescence study — •Sven Augustin, Susanne Siebentritt, and Martha Lux-Steiner — Hahn-Meitner-Institut, Glienicker Str. 100, 14109 Berlin

Defects in the chalcopyrite CuGaSe_2 are analysed. CuGaSe_2 is used as an absorber in thin-film solar cells. As is known for a p-n junction, an important contribution to the efficiency is made by choosing the concentration of defects. So one way to improve efficiency is to find the optimal fraction of defects in the material. The first step in achieving this goal for CuGaSe_2 is to determine the nature of the dopants, i.e. the chemical and the structural (lattice site) character. By pursuing this aim the method of polarization resolved photo luminescence (PL) and PL excitation (PLE) spectroscopy is used to obtain information on the symmetry of the defects. The measurements of epitaxial samples of different orientation show, that the emission from two of the acceptors is polarized mainly parallel to the c-axis of the tetragonal crystal and the third acceptor on the other hand radiates with polarization predominantly perpendicular to the c-axis. Employing a classical oszillator model allows to ascertain the symmetry of the defects.

HL 32.15 Wed 18:15 BEY 118

Interface properties of Cu(In,Ga)(S,Se)$_2$ absorbers with various bufferlayers in thin film solar cells — •F. Erfurth[1], L. Weinhardt[1], T.P. Niesen[2], S. Visbeck[2], C. Heske[3], and E. Umbach[1] — [1]Experimentelle Physik II, Universität Würzburg — [2]Shell Solar GmbH, München — [3]Department of Chemistry, University of Nevada, Las Vegas

To better meet the environmental requirements of thin film solar cells based on Cu(In,Ga)(S,Se)$_2$ (CIGSSe), the substitution of the CdS buffer layer is of great interest. By depositing alternative layer compositions like (Zn,Mg)O or Zn(S,OH), using conventional sputter and chemical bath deposition techniques, efficiencies close to or comparable to those of CdS containing solar cells are obtained. To understand the chemical and electrical characteristics of the buffer layer and its influence on the absorber, we investigated the absorber-buffer interface using photoelectron spectroscopy and inverse photoemission. The combination of both techniques provides the determination of the chemical and stoichiometric properties as well as the alignment of the conduction and valence band at the heterojunction.
We analyze the pure and Cd-treated absorber surface and the interface to alternative buffer layers. Measurements are presented observing diffusion and accummulation processes of certain absorber elements at the interface, which depend on temperature treatments. Furthermore the alignment of both, the valence and conduction band at the interface is deduced. In conclusion, we attempt to explain differences in cell efficiencies arising from different buffer layers.

HL 32.16 Wed 18:30 BEY 118

Electrochemical grown ZnO/EosinY hybrid films on oriented substrates — •Thomas Loewenstein[1], Christian Neumann[2], Thorsten Kraemer[2], Bruno K. Meyer[2], Tsukasa Yoshida[3], and Derck Schlettwein[1] — [1]Institut für Angewandte Physik, JLU Giessen, Heinrich Buff-Ring 16, 35392 Giessen — [2]Experimentalphysik I, JLU Giessen, Heinrich Buff-Ring 16, 35392 Giessen — [3]Graduate School of Engineering, Gifu University, Yanagido 1-1, Gifu 501-1193, Japan

The sensitization of wide-bandgap semiconductors is an attractive approach to a photoelectrochemical photovoltaic cell. Porous, yet crystalline ZnO electrodes were deposited in electrochemical reactions from aqueous zinc salt solutions induced by a local pH-increase at the working electrode during the reduction of oxygen, a reaction compatible with a large number of conductive substrates. Single crystalline substrates allow to investigate the structure and texture to far higher extent than typical polycrystalline or amorphous substrates. (0001) GaN offers good possibilities of epitaxial growth of ZnO. In this study, ZnO/dye hybrid materials were electrodeposited on (0001) GaN and on (0001) ZnO. Scanning electron microscopy (SEM) revealed domains of different crystal sizes that were correlated to fluctuations in the substrate work function. Crystalline ZnO was deposited on GaN as proven by X-ray diffraction (XRD). The intensity pattern showed a preferential orientation with the c- plane of ZnO parallel to GaN (0001). XRD rocking curves indicated a high level of in-plane orientation of the grown ZnO crystalline domains. The peak position spoke in favour of a modification of the ZnO crystal lattice by the dye molecules adsorbed during the growth of ZnO.

HL 32.17 Wed 18:45 BEY 118

Analysis of Charge Carrier Dynamics in Cu(In, Ga)Se$_2$ **from Sub-Micron Resolved Luminesence and Photocurrent Studies** — •Levent Gütay and Gottfried H. Bauer — Institute of Physics, Carl von Ossietzky University, D-26111 Oldenburg, Germany

We have analysed thin film Cu(In, Ga)Se$_2$ solar cells by sub-micron resolved photoluminescence (PL) and light induced photocurrents. Respective scans show significant lateral variations of PL-yield (Y_{PL}) in the few micron scale, which correspond to locally varying quality of the photoexcited state of the absorber. PL-scans performed, both, under open and short circuit conditions (oc and sc) show differences of lateral signal profiles reflecting local variations of excess charges and consequently signalizing the influence of differences in carrier dynamics between these two modes of operation. Additionally simultaneously recorded local photocurrents (I_{sc}) exhibit a substantial local anti-correlation with PL. Since locally resolved PL quantitatively reflects local excess carrier densities and I_{sc} their respective product with their speed of extraction (perpendicular to the surface of the junction) we get experimental access to this magnitude and observe e.g. fast extraction of photoexcited carriers at the edges of the regimes with high Y_{PL} and comparatively low one in their respective centers.

HL 32.18 Wed 19:00 BEY 118

Investigation of the correlation between charge carrier lifetime of multicrystalline silicon raw wafer and solar cell efficiency — •Kevin Lauer[1], Stefan Dauwe[1], and Jan Lossen[2] — [1]SolarZentrum Erfurt, CIS Institut für Mikrosensorik, Konrad-Zuse-Str. 14, D-99099 Erfurt — [2]ErSol Solar Energy AG, Wilhelm-Wolff-Str. 23 D-99099 Erfurt

The correlation between multicrystalline silicon raw wafers and solar cell efficiency depends both on wafer quality and on the solar cell process. It is of large scientific and economic interest to understand these influencing factors in order to predict the solar cell efficiency.
In this work the electrical properties of multicrystalline silicon wafers are characterized by minority carrier lifetime measurements. We measured the lifetime of adjacent wafers from one column before emitter diffusion. Subseqeuntly, these wafers were processed to solar cells. As expected, a higher carrier lifetime of a raw wafer results in a higher solar cell efficiency. However, the position of the wafer within the column needs to be known additionally for a more precise prediction of the solar cell efficiency. We attribute this to the defect distribution across the column.
The content of one of the dominating defects, interstitial iron, was measured before and after diffusion. The standard method based on carrier lifetime measurements before and after light soaking was extended to improve the measurement sensitivity.