HL 62: Poster II: Photovoltaics and Organic Semiconductors

Time: Thursday 18:00–20:00 Location: Poster D2

HL 62.1 Thu 18:00 Poster D2

Charge transport in organic semiconductors — •Vera Stehr[1], Carsten Deibel[1], Vladimir Dyakonov[1], Johannes Pfister[2], and Reinhold Fink[2] — [1]Experimentalphysik 6, Institut für Physik und Astronomie, Universität Würzburg — [2]theoretische organische Chemie, Institut für organische Chemie, Universität Würzburg

We have analysed the mobility and the diffusion of charge carriers in organic semiconductors by means of a Monte Carlo simulation and the master equation approach. In disordered amorphous materials, deviations from the Einstein relation, which states that the ratio of the diffusion constant to the mobility equals the thermal voltage, are found. The impact of our findings on experimental charge transport measurements will be discussed. We furthermore determined the anisotropy of the mobility in organic crystals by means of quantum chemical calculations and the Marcus theory for charge carrier hopping.

HL 62.2 Thu 18:00 Poster D2

Inverse and direct photoemission spectroscopy measurements of inorganic-organic interfaces. — •Daniil D. Karnaushenko, Daniel Lehmann, Axel Fechner, and Dietrich R.T. Zahn — Chemnitz University of Technology, Semiconductor Physics, 09107 Chemnitz, Germany

The combination of inverse (IPES) and direct (PES) photoemission spectroscopy is a powerful approach for studying the electronic structure of surfaces and interfaces. Applied to organic materials information on the position of lowest unoccupied (LUMO) and highest occupied molecular orbital (HOMO) as well as on energy level alignment on interfacial states and dipoles can be obtained. More over the two techniques are sensitive to chemical interaction between surfaces and molecules. Here, IPES and PES measurements of several interfaces between inorganic substrate and molecules of the phthalocyanine family are presented. The dependence of the interfaces electronic and chemical structure on deposition conditions is obtained.

HL 62.3 Thu 18:00 Poster D2

Electronic and Transport Properties of Quasi-1D Wires of Biological Molecules — •Björn Oetzel[1,2], Lars Matthes[1,2], Falk Tandetzky[1,2], Frank Ortmann[1,2], Friedhelm Bechstedt[1,2], and Karsten Hannewald[1,2] — [1]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena — [2]European Theoretical Spectroscopy Facility, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena

In the search for organic materials with good charge-transport properties, artificial stacks of biological molecules are considered attractive candidates [1,2]. In this spirit, we present ab-initio DFT calculations of the structural, electronic, and quantum-transport properties of quasi-1D wires based on guanine and eumelanin molecules [3]. Hereby, a special focus is put on the results for the electronic bandwidths and the consequences for potential applications.

[1] R. di Felice et al., Phys. Rev. B 65, 045104 (2001)
[2] P. Meredith et al., Pigment Cell Res. 19, 572 (2006)
[3] B. Oetzel et al. (unpublished)

HL 62.4 Thu 18:00 Poster D2

Electrons, Holes, and Polarons in Durene-Based Materials — •Martin Krause, Frank Ortmann, Friedhelm Bechstedt, and Karsten Hannewald — Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena

Durene crystals are interesting candidates for high-mobility organic semiconductors [1,2,3]. Here, we present ab-initio studies of the structural and electronic properties of various durene-based molecules and crystals. Special attention is paid to the inclusion and calculation of polaronic effects (e.g., reorganization energies) due to intramolecular electron-phonon and hole-phonon coupling in durene molecules [4].

[1] Z. Burshtein et al., Phys. Rev. B **15**, 5769 (1977)
[2] C. Arndt, F. Ortmann, K. Hannewald, F. Bechstedt, and J. Pflaum, Poster DPG Spring Meeting 2008
[3] F. Ortmann, K. Hannewald, and F. Bechstedt, Appl. Phys. Lett. **93**, 222105 (2008)
[4] M. Krause, F. Ortmann, F. Bechstedt, and K. Hannewald (unpublished)

HL 62.5 Thu 18:00 Poster D2

Degradation of solution-processed pentacene field-effect transistors — •Teodor Toader, Claudia Bock, and Ulrich Kunze — Werkstoffe und Nanoelektronik, Ruhr-Universität Bochum

In this work 13,6-N-Sulfinylacetamidopentacene (NSFAAP) [1] is used to study degradation of solution-processed bottom-contact pentacene transistors. We use conventional UV lithography and lift-off technique to structure Ti/Pd (1 nm/25 nm) electrodes on n-type oxidised silicon wafer. The pentacene thin films are deposited by spin-coating NSFAAP from a $CHCl_3$ solution (1 wt%) and thermally converting the precursor to pentacene in a nitrogen environment. After processing the samples are stored in a glovebox under nitrogen atmosphere and for comparison in ambient dark atmosphere at $T = 21$ °C and 50 % humidity. From two-terminal current-voltage ($I-V$) measurements characteristic transistor parameters like the effective and field-effect mobility, the On/Off ratio and the threshold voltage are extracted with respect to the time after processing. Additionally the degradation of samples stored under envorinmental conditions and protected with PMMA is studied. The $I-V$ measurements are correlated with scanning electron micrographs.

[1] Ali Afzali, *et al.*, J. Am. Chem. Soc. **124** (30), 8812 -8813, (2002).

HL 62.6 Thu 18:00 Poster D2

Transport and recombination in the low band gap polymer APFO-Green 9 — •David Vocke[1], Jens Lorrmann[1], Alexander Foertig[1], Carsten Deibel[1], L. Matthias Andersson[2], Olle Inganäs[2], and Vladimir Dyakonov[1,3] — [1]Experimental Physics VI, Physical Institute, Julius-Maximilians University of Würzburg, Am Hubland, D-97074 Würzburg — [2]Biomolecular and Organic Electronics, IFM, Linköping University, S-5813 Linköping, Sweden — [3]ZAE Bayern, Div. Functional Materials for Energy Technology, Am Hubland, D-97074 Würzburg

Increasing the short-circuit current is one way of improving power conversion efficiencies (PCE) of organic solar cells. This could be achieved by using a polymer with a low band gap like the novel copolymer APFO-Green 9. Organic solar cells based on APFO-Green 9 and [6,6]-phenyl-C71-butyric acid methyl ester ($PCBM_{70}$) show a high photo current of 6.5 mA/cm^2 and a PCE of 2.3%. We investigated how charge carrier transport and recombination contribute to the performance. Photo-CELIV (charge extraction by linearly increasing voltage), transient photo voltage- and transient photo current-methods are used to measure pure APFO-Green 9 and solar cells blended with $PCBM_{70}$ in different stoichiometries at various temperatures. Fitting the recombination dynamics with a continuity equation shows a strong charge carrier density dependent Langevin prefactor. Furthermore, we do not observe a relaxation-time dependent mobility, which is sometimes observed in poly(3-hexyl thiophene):[6,6]-phenyl-C_{61} butyric acid methyl ester.

HL 62.7 Thu 18:00 Poster D2

Dissociation of singlet excitons in PPV derivatives with varying dielectric constant — •Julia Kern[1], Michael Binder[1], Markus Mingebach[1], Andreas Baumann[1], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Physical Institute, Julius-Maximilians-University of Würzburg, Am Hubland, D-97074 Würzburg — [2]Center for Applied Energy Research (ZAE Bayern e. V.), Am Hubland, D-97074 Würzburg

In bulk heterojunction solar cells, the low relative permittivity of conjugated polymers such as poly (p-phenylene vinylene) (PPV) is considered to be a limiting factor of the charge separation process. The lower the dielectric constant, the stronger the bond of the primary photoexcitations, i.e., singlet excitons. Here, we investigate the influence of the relative permittivity on the exciton binding energy. For this purpose, three PPV derivatives exhibiting similar charge carrier mobilities but different relative permittivities of 3.0, 4.0 and 5.5, respectively, are characterized by means of external quantum efficiency and field dependent photoluminescence measurements. We discuss our experimental results in terms of the two-step dissociation process from exciton via polaron pair to polarons as well as the impact on solar cell performance.

HL 62.8 Thu 18:00 Poster D2

Influence And Optimization Of The Exciton Blocking Layer In Diindenoperylene Based Photovoltaic Cells — •E. Runze[1], A.K. Topczak[1], M. Meseth[1], T. Roller[2], and J. Pflaum[1,3] — [1]Inst. Exp. Phys. VI, Julius-Maximilians-University, 97074 Würzburg — [2]3rd Phys. Inst., Stuttgart University, 70550 Stuttgart — [3]ZAE Bayern, 97074 Würzburg

The power conversion efficiency of small molecule Organic Photovoltaic Cells (OPVCs) strongly depends on the exciton diffusion length as well as on the respective energy level positions at the donor acceptor and the metal-organic interface. We discuss two major aspects determining the OPVC performance: the exciton blocking and the exciton diffusion. As bilayer systems, OPVCs based on Diindenoperylen (DIP) as donor and C_{60} as acceptor material were employed. We analyse the influence of various exciton blocking layers (EBL) like Batho-Phenanthrolin (BPhen) or 1,4,5,8-Naphthalene-Tetracarboxylic Acid Dianhydride (NTCDA). Beside the position of the electronic levels the nucleation behavior of the metal contact on the EBL is a critical factor. The second part addresses the comparatively large exciton diffusion lengths in DIP of about 100nm [1]. We performed complementary studies on OPVC photocurrent as well as on photoluminescence (PL)-quenching on layered stacks of similar composition. A strong correlation between the exciton transport characteristics and the crystalline morphology of the DIP layer is demonstrated. Financial support by DFG (project PF385/4) is gratefully acknowledged.

[1] D. Kurrle and J. Pflaum, Appl. Phys. Lett. 92 (2008) 133306

HL 62.9 Thu 18:00 Poster D2

Femtosecond Transient Absorption Spectroscopy of Organic Semiconductors — •Björn Gieseking[1], Daniel Kreier[1], Moritz Liedtke[1,2], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Faculty of Physics and Astronomy, Julius-Maximilians-University Würzburg, D-97074 Würzburg — [2]Bavarian Centre for Applied Energy Research (ZAE Bayern), D-97074 Würzburg

Organic solar cells based on conjugated polymers exhibit great potential for photovoltaic applications due to their low fabrication costs. Bulk heterojunction devices comprised of regioregular poly(3-hexylthiophene) and the [6,6]-phenyl-C_{61} butyric acid methyl ester fullerene derivative have approached efficiencies of more than 5 %. A further optimization requires a deeper insight into the elementary processes following the photoexcitation of these blends. For such studies a very high time resolution is crucial.

We present investigations applying a transient absorption spectroscopy setup based on two optical parametric amplifiers which are tunable from the visible to the infrared spectral range and provide a sub picosecond time resolution. By probing the different transient species we are able to get a better understanding of photogeneration of free charge carriers and their loss mechanisms in order to improve the performance of organic solar cells.

HL 62.10 Thu 18:00 Poster D2

Recombination kinetics of charge carriers and trap states in P3HT:PCBM blends studied by transient Electron Spin Resonance — •Magdalena Zawadzki[1], Andreas Sperlich[1], Hannes Kraus[1], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]Julius-Maximilians-Universität of Würzburg, D-97074 Würzburg — [2]ZAE Bayern, Div. Functional Materials for Energy Technology, D-97074 Würzburg

The combination of poly(3-hexylthiophene) (P3HT) and [6,6]-phenyl-C_{61}-butyric acid methylester (PCBM) has shown promising performance in organic solar cells. In order to understand the fate of photoexited charge carriers in P3HT:PCBM blends, cw- and transient electron spin resonance (ESR) were used to investigate the recombination kinetics of the light induced charges. Using cw-ESR the negative and positive polarons and trap states related to impurities and oxygen contamination can be detected as separate signals, while transient ESR allows access to the life and recombination times of the different species, which are in a time scale from μs to minutes. We recorded the ESR signal intensity of the polarons and the decay of the photoluminescence after excitation by a pulsed LED. With the transient ESR technique, in addition to the cw-ESR, more detailed information about the P3HT:PCBM blends could be gained.

HL 62.11 Thu 18:00 Poster D2

Decay of excited species in P3HT:PCBM blends studied by transient absorption — •Matthias Gunz[1], Julien Gorenflot[1], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Physical Institute, Julius-Maximilians-University of Würzburg, D-97074 Würzburg — [2]Bavarian Centre for Applied Energy Research (ZAE Bayern), D-97074 Würzburg

One important parameter for improving the efficiency of organic solar cells is to understand the involved processes of charge generation and recombination, as well as their time dependence. Transient absorption spectroscopy enables us to observe the dynamics of photoexcited species. The investigations are carried out on blends of P3HT:PCBM on a timescale from nanoseconds to milliseconds. Pump intensity and temperature dependencies are studied, as well as the influence of different acceptor materials. The experimental results are compared to the charge carrier continuity equation, accounting for monomolecular and bimolecular recombination.

HL 62.12 Thu 18:00 Poster D2

Charge Transfer States in Polymer:Fullerene Solar Cells — •Michael Binder[1], Daniel Rauh[2], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]Julius-Maximilians-University of Würzburg, Institute of Physics, Experimental Physics VI, D-97074 Würzburg — [2]Bavarian Centre for Applied Energy Research e.V. (ZAE Bayern), D-97074 Würzburg

In the field of organic photovoltaic power conversion efficiencies as high as 6% have been achieved. One of the key factors is a high exciton dissociation yield. It is crucial to understand the processes involved in charge carrier separation such as the relaxation of the exciton to the so called charge transfer state (CTS). A possibility to investigate those states is to measure the external quantum efficiency (EQE) of solar cells in the near-infrared region as shown by Vandewal et al [1]. With additional EQE measurement of diodes consisting only of the pure acceptor or donor we confirm that the CTS are solely found in donor/acceptor blend systems. The energies we determined from the charge transfer-tails can be directly linked to the open circuit voltage of the solar cell. We investigated the CTS for polythiophene:fullerene blends with varying electron acceptor strength. Furthermore we discuss their energy and magnitude in view of solar cell preparation conditions and the impact on the device performance.

[1] K. Vandewal et al. Adv. Funct. Mater. 2008,18, 2064–2070

HL 62.13 Thu 18:00 Poster D2

Nanotomography of organic heterojunction solar cells — •Mario Zerson[1], Andreas Sperlich[2], Hannes Kraus[2], Carsten Deibel[2], Vladimir Dyakonov[2], and Robert Magerle[1] — [1]Chemische Physik, TU Chemnitz, D-09107 Chemnitz — [2]Experimental Physics VI, Julius-Maximilians-University Würzburg, D-97074 Würzburg

The morphology of organic heterojunction solar cells based on blends of P3HT and PCBM is an important factor determining the power conversion efficiency. For a good charge carrier generation the interface between the two components should be as large as possible. Furthermore, bicontinuous networks of both components are required for an efficient charge carrier extraction. We investigate the three-dimensional structure of P3HT and blends of P3HT and PCBM with Nanotomography based on scanning force microscopy (SFM). The specimen is ablated layer by layer using plasma etching and imaged with tapping mode SFM after each etching step. From the resulting series of images the three-dimensional structure is reconstructed. We will present first volume images of P3HT:PCBM blends and discuss the structure of the interface between donor and acceptor components in view of the charge generation efficiency. Furthermore we investigate the morphology of P3HT and P3HT/PCBM blends using SFM with super-sharp tips and the electro-optical properties at the same samples. We aim at comparing the microstructure of the polymer with the photoluminescence-detected magnetic resonance (PLDMR) which provides information on the recombination kinetics of photoinduced charges.

HL 62.14 Thu 18:00 Poster D2

The effect of a cathode interlayer on the performance of polymer-fullerene bulk heterojunction solar cells — •Antonietta De Sio, Elizabeth von Hauff, and Jürgen Parisi — Energy and Semiconductor Research Laboratory, Institute of Physics, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg, Germany

We report on the impact of different cathode configurations on the performances of polymer-fullerene photovoltaic devices. The operation of the standard bulk heterojunction solar cell structure, in which the active layer consists of a blend of poly-3-hexylthiophene (P3HT) and [6,6]-phenyl-C61-butyric acid methyl ester (PCBM) 1:1 in weight ratio and the metal cathode is a 150nm thick Al layer, was first recorded as the reference. The electrical behavior of the devices upon inserting an interlayer between the organic active layer and the metal cathode was investigated. We also explored the effect of different kinds of interlayers on device performance, i.e. conductive materials like Ca and Mg, as well as insulating materials such as LiF. The effect of the interlayer is reflected in the solar cell parameters, in particular on the open circuit voltage.

HL 62.15 Thu 18:00 Poster D2

From organic single carrier diodes to bulk heterojunction solar cells: an electrical characterization by impedance spectroscopy — •Bernhard Ecker, Elizabeth von Hauff, and Jürgen Parisi — Energy and Semiconductor Research Laboratory, Institute of Physics, University of Oldenburg, 26129 Oldenburg, Germany

Impedance spectroscopy is a widely used and powerful tool for investigating electrical characteristics on the frequency scale of batteries, fuel cells and solar cells. For new materials and novel devices impedance spectroscopy can be used to gain information about material parameters as well as interface characteristics. We aim to understand polymer-fullerene bulk heterojunction solar cells using this method. In this study we first investigate single carrier diodes consisting of P3HT or PCBM to supply the understanding of the P3HT:PCBM heterojunction, which is a promising candidate for highly efficient organic solar cells. The characterization of the materials gives insight to the dielectric behavior and provides understanding of the resistive and capacitive response of the devices. Here we present results from impedance spectroscopy measurements on the single carrier devices.

HL 62.16 Thu 18:00 Poster D2

Charge Transport Investigations of P3HT:PCPM Bulk Heterojunction Solar Cells using the CELIV Method — •Ralph Huber, Antonietta De Sio, Elizabeth von Hauff, and Jürgen Parisi — University of Oldenburg, Department of Physics, Energy and Semiconductor Research Laboratory, Carl-von-Ossietzky Str. 9-11, 26129 Oldenburg, Germany

The performance of organic solar cells is strongly influenced by the charge transport properties of the active layer. In this study we employed the charge extraction by linearly increasing voltage (CELIV) method to investigate charge carrier mobilities in blends of regioregular poly(3-hexylthiophene) (P3HT) and [6,6]-phenyl-C_{61}-butyric acid methyl ester (PCBM). The CELIV method allows for mobility measurements on the solar cell device directly. The field dependence of the charge carrier mobility and the conductivity of P3HT:PCBM blends was investigated. The CELIV results are presented along with the results from the solar cells.

HL 62.17 Thu 18:00 Poster D2

Study of poly(3-hexylthiophene) by cyclic voltammetry — •Sabrina Jüchter, Holger Borchert, Joanna Kolny-Olesiak, Elizabeth von Hauff, and Jürgen Parisi — University of Oldenburg, Department of Physics, Energy and Semiconductor Research Laboratory, 26111 Oldenburg

The working principle of organic solar cells involves charge transfer reactions at a donor/acceptor interface as one important elementary step of the energy conversion process. Both the absolute and relative positions of the HOMO and LUMO energy levels of the donor and acceptor material are of importance for successful charge transfer. Cyclic voltammetry is an electrochemical method suitable to study redox reactions. One can obtain information on the absolute values of HOMO and LUMO levels, the thermodynamics, the kinetics of electron transfer reactions and downstream chemical reactions. The possibility of the investigation of electron transfer reactions is especially important for photovoltaics. In the work to be presented here, a measurement place for cyclic voltammetry was set up, including the design of the measurement cell. First measurements were performed with different samples of the electron donor material poly(3-hexylthiophene) (P3HT), in order to investigate if the HOMO and LUMO levels can be influenced by the molecular weight or different impurities. The P3HT is processed from solution to thin films by spin-coating. Another part of the work is the measurement of HOMO and LUMO levels in inorganic semiconductor nanoparticles of CdSe that can be used as electron acceptor material in organic-based solar cells.

HL 62.18 Thu 18:00 Poster D2

The influence of the morphology of the active layer on inorganic/organic hybrid solar cells studied by electron spin resonance — •Florian Witt, Nicolay Radychev, Irina Lokteva, Joanna Kolny-Olesiak, Holger Borchert, and Jürgen Parisi — University of Oldenburg, Department of Physics, Energy and Semiconductor Research Laboratory (EHF), 26111 Oldenburg, Germany

In the last decade the method of exchanging the fullerene acceptors in organic bulk heterojunction solar cells by inorganic semiconducting nanocrystals has been studied to improve their performance. So far only few promising results in such structures, especially related to power conversion efficiencies, were achieved. One of the main factors for this lack of functionality is connected to the poor morphology in comparison pure organic cells. By consequence, the percolation pathways for charge transport are not well pronounced, and the interface area for charge carrier generation is reduced. It was shown that the generation of charge carriers on light excitation can be characterized by light induced electron spin resonance. With this technique the amount of long living polaron states in the donor polymer can be observed over time, with and without light excitation. This method is suitable to show the influence of the materials morphology to its charge generation and recombination dynamics. At deep temperatures also an analysis of polaron trap states in the material blends is possible. The results of comparative studies of P3HT/CdSe nanoparticle layers with different morphologies as well as of P3HT:PCBM blends will be presented.

HL 62.19 Thu 18:00 Poster D2

Recombination in P3HT based solar cells with different acceptor materials — •Sebastian Hafner[1], Andreas Baumann[1], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Julius-Maximilians-University of Würzburg, D-97074 Würzburg, Germany — [2]Functional Materials for Energy Technology, Bavarian Centre for Applied Energy Research (ZAE Bayern), D-97074 Würzburg

In order to improve the performance of organic solar cells, it is indispensable to understand the recombination mechanisms in those devices. In previous investigations, a reduced Langevin polaron recombination could be observed [1]. We apply the experimental technique of Photo-CELIV (Charge Carrier Extraction by Linearly Increasing Voltage) to study the recombination dynamics in organic bulk heterojuction solar cells. With this technique, the charge carrier concentration and the mobility of the carriers can be determined simultaneously.The recombination processes in the material system of P3HT with different fullerene acceptors (PC[61]BM, bis-PC[61]BM, PC[71]BM) was investigated in dependence on the temperature and laser intensity. We relate our experimental findings concerning recombination to the performance of polymer:fullerene solar cells.

[1] C. Deibel, A. Baumann, V. Dyakonov: Polaron recombination in pristine and annealed bulk heterojunction solar cells, Applied Physics Letter 93, 163303 (2008)

HL 62.20 Thu 18:00 Poster D2

Limits for the efficiency improvement of hybrid dye- microcrystalline silicon solar cells — •Sven Burdorf[1], Max Meessen[1], Rudolf Brüggemann[1], Andreas Decker[2], Thomas Mayer[2], Wolfram Jägermann[2], and Gottfried H. Bauer[1] — [1]Institut für Physik, Carl von Ossietzky Universität, 26111 Oldenburg — [2]Fachbereich Materialwissenschaften, Technische Universität Darmstadt, 64287 Darmstadt

Recently hybrid solar cells consisting of dye sensitizers embedded in a microcrystalline silicon thin film matrix have been proposed and even recently processed [1]. The dye sensitizers are introduced to the matrix due to their high absorption coefficients and therefore enhance the absorption of the dye-matrix-system. A microcrystalline silicon matrix is chosen because it is fairly "forgiving" to distortions introduced by the dye molecules and transport properties of charge carriers are still acceptable. In this contribution we present calculations for the efficiency improvement of hybrid dye-microcrystalline silicon solar cells compared to pure microcrystalline solar cells. The calculations were performed for varying thicknesses of the microcrystalline silicon layer, dye concentrations and wavelength of maximum absorption of the dye.

[1] T. Mayer et al., Renewable Energy 33, 262-266 (2008)

HL 62.21 Thu 18:00 Poster D2

Spectrally and angle resolved emission of a Rh6G based fluorescence collector — •Hendrik Sträter[1], Sebastian Knabe[1], Nazila Soleimani[2], Tom Markvart[2], and Gottfried H. Bauer[1] — [1]Institute of Physics, Carl von Ossietzky University Oldenburg, D-26111 Oldenburg — [2]School of Engineering Sciences, University of Southampton, SO17 1BJ, UK

Concentration of light based on the fluorescence of well-chosen dyes offers the possibility to decrease the cost of multispectral solar cells. Unfortunately the theoretical efficiency has not been achieved, mainly because of photon transport losses via the loss cone of emission. With increasing dye concentration the effect of reemission of fluorescence light rises and thereby the losses of photons due to the loss cone.

To understand the reemission as a major loss mechanism we measure the spectrum of the light that leaves the edge of the concentrator as a function of the distance between illumination position and edge when illuminating perpendicularly to the surface. For the measurement we used a thin layer of Rhodamine 6G embedded in a Poly(methyl methacrylate) matrix on a glass substrate. The results of spectrally and angle resolved fluorescence emission are compared with those under homogeneous illumination. We compare our data with the results of a theoretical model, which analytically formulates the effects of absorption and subsequent reemission of fluorescence photons in the collector.

HL 62.22 Thu 18:00 Poster D2

Charge transport in thin layers of nanocrystalline mesoporous Titania — •Steve Albrecht, Sylvia Paul, and Dieter Neher — Universität Potsdam, D-14476 Potsdam, Germany

Nanocrystalline mesoporous Titania (nc-TiO_2) has been shown to function as a very good electron acceptor in combination with common electron-donating polymers like poly(para-phenylene vinylene) or poly(3-hexylthiophene). However, charge transport in nc-TiO_2 layers is not well understood, though it might severely affect the energy conversion efficiency of those hybrid cells. Here, we present measurements of the electron mobility using the technique of charge extraction by linearly increasing voltage (CELIV). Layers of ca. 100 nm in thickness were prepared via dip-coating from a dispersion of 5 nm sized Titania particles. These layers were then annealed at different temperatures to remove the organic compounds. Unexpectedly, a pre-bias needed to be applied during the CELIV-measurements in order to obtain a measurable extraction peak. Apparently, those layers possess a high density of traps, which requires a certain number of electrons to be accumulated within the layer prior to the injection of mobile carriers. This interpretation was nicely confirmed by results from dark-injection measurements. We observed a significant increase of free carrier mobility with annealing temperature, reaching ca. 10^{-5} cm^2/Vs for a layer annealed at 600°C, while the trap density decreased with temperature. In accordance to these results, the performance of hybrid solar cells improved largely when the nanocrystalline Titania layer was annealed at higher temperatures prior to the deposition of the polymers.

HL 62.23 Thu 18:00 Poster D2

Influence of pyridine treatment on the ligand shell of OA-capped CdSe nanoparticles and the impact on polymer/CdSe hybrid solar cells — •Irina Lokteva, Nikolay Radychev, Holger Borchert, Jürgen Parisi, and Joanna Kolny-Olesiak — University of Oldenburg, Oldenburg, Germany

This study describes the surface modification of the original oleic acid (OA) capped CdSe colloidal quantum dots (QDs) with pyridine molecules and application of the pyridine coated CdSe QDs for the preparation of polymer/CdSe hybrid solar cells.

The composition of the ligand shell was investigated by means of nuclear magnetic resonance (NMR) spectroscopy and thermal gravimetric analysis (TGA). It was shown that after one-fold pyridine treatment some amount of OA was still present in the sample, which motivated us to fulfil repeated steps of the ligand exchange. The absorption spectra after repeated pyridine treatment revealed that no aggregation or oxidation of the nanoparticles in solution occurred. TEM images were used as well to characterize the successive steps of the ligand exchange.

The hybrid CdSe-P3HT solar cells were fabricated using the pyridine capped CdSe QDs and I-V characteristics of these solar cells were collected to characterize the sequential steps of the pyridine treatment. Although repeated ligand exchange was found to have a beneficial effect in the sense that they led to more complete ligand exchange which in turn enabled more efficient charge transfer, the main characteristic parameters of the solar cells were found to deteriorate. Correlations of this behavior with the morphology of the hybrid blends were analyzed.

HL 62.24 Thu 18:00 Poster D2

Transmission electron microscopy analyses of binary and ternary iron silicides in the system Al:Fe:Si — •Patrick Schwager, Doaa Abdelbarey, and Michael Seibt — Georg-August-Universität Göttingen, IV. Physikalisches Institut, Friedrich-Hund-Platz 1, 37077 Göttingen

In order to use low-cost multicrystalline silicon for photovoltaic applications it is essential to eliminate metal impurities. One technique to remove device-degrading impurities is aluminum gettering which exploits segregation of metal impurities into the forming Al:Si liquid for annealing above the eutectic temperature of 577°C. The segregation coefficient can be estimated by consulting the binary Al:M and Si:M phase diagrams where M is the metal impurity, here Fe. Experimental data yield instead values which are lower by two orders of magnitude. It has been proposed that this discrepancy stems from a higher solubility of Fe in Si in equilibrium with the ternary Al-doped $\alpha - FeSi_2 : Al$ compared to that in equilibrium with the binary $\alpha - FeSi_2$ (D.Abdelbarey et al., Appl. Phys. Lett. **94**, 061912 (2009)). Due to the slow Al diffusion in Si, the solution of iron in silicon in equilibrium with a $\alpha - FeSi_2 : Al$ surface layer would be unstable against precipitation into $\alpha - FeSi_2$. In this work, we use transmission electron microscopy techniques to analyze the structure and chemistry of ternary Al:Fe:Si surface layers after high temperature formation as well as extended defects formed in the bulk of the wafers.

HL 62.25 Thu 18:00 Poster D2

Optimization of Cu(In,Ga)Se2 solar cells under different irradiance — •Sebastian Jander[1,2], Stefan Puttnins[1,2], 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

$Cu(In,Ga)Se_2$ (CIGSe) solar cells on flexible substrates open up new fields of applications for photovoltaics. This could be building integrated photovoltaics, lightweight construction photovoltaic modules or integrated modules in clothes or pockets for charging iPods, mobile phones or laptops.

Depending on their application these solar cells operate at different irradiances und types of illumination. Therefore real working conditions have to be considered besides the standard test conditions (AM 1.5 spectrum with 1000 W/m^2).

The influences of parallel and series resistance, the diode quality factor and other parameters were evaluated in detail on the basis of measurements and model calculations for different irradiances. Additionally, influences of various production parameters in the manufacturing of solar cells from the Solarion AG were investigated and analyzed. We show correlation between Cu/III ratio of CIGSe, i-ZnO layer thickness and metallic grid design with low light intensity performance.

Using these results optimized solar cells and modules can be manufactured for the mentioned applications and illumination conditions.

HL 62.26 Thu 18:00 Poster D2

Photoelectric characterization of $Cu(In,Ga)S_2$ Photovoltaic Devices with Varying Ga-Content — •Julia Riediger[1], Jan Keller[1], Jörg Ohland[1], Martin Knipper[1], Ingo Riedel[1], Jürgen Parisi[1], Roland Mainz[2], Saoussen Merdes[2], and Alexander Meeder[3] — [1]Uni Oldenburg — [2]Helmholtz-Zentrum Berlin für Materialien und Energie Berlin GmbH — [3]SULFURCELL Solartechnik GmbH

An increased efficiency of $CuInS_2$-based solar cells is expected for absorber films doped with gallium which enlarges the band gap and therefore the open circuit voltage (V_{OC}). We investigated $Cu(In,Ga)S_2$ solar cells prepared under different rapid thermal processing (RTP) conditions. Depending on the RTP temperature profile, the films exhibit $CuInS_2/CuGaS_2$ (top/bottom) segregation which is detrimental for a large V_{OC}. Solar cells prepared with different RTP-temperatures were investigated by temperature-/illumination-dependent current-voltage measurements (IV(T)), external quantum efficiency (EQE) and admittance spectroscopy (AS). Only precursors sulfurized at sufficiently high temperatures exhibited the desired interdiffusion of the segregated $CuInS_2/CuGaS_2$ system. The activation energies derived from IV(T) measurements suggest carrier losses due to interface recombination. The current collection in cells with substantial $CuInS_2/CuGaS_2$ segregation is limited over a wide temperature range up to 300K whereas the photocurrent is independent of temperature for T>200K. Admittance spectroscopy revealed a set of defect states, each of them representing different response to variation of the RTP process.

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Surface roughness, optical and spectroscopic properties of thin film systems based on Cu(In,Ga)Se$_2$ absorbers — •Oliver Neumann[1], Florian Heidemann[1], Stephan J. Heise[1], Rudolf Brüggemann[1], Wolfram Witte[2], and Gottfried H. Bauer[1] — [1]Institute of Physics, Carl von Ossietzky University Oldenburg, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Stuttgart, Germany

We study the behaviour of the local properties like surface roughness, splitting of the quasi Fermi levels and optical threshold energies of thin film systems based on Cu(In,Ga)Se$_2$ absorbers and consisting of substrate, back electrode, Cu(In,Ga)Se$_2$ absorbers, buffer layer and front electrode. We imitate in-situ experiments with lateral resolution such as afm-topology, spectral transmission/absorption and spectral photoluminescence, which announces the splitting of the quasi-Fermi levels by statistical methods for feature extraction like 2D Fourier transforms and/or Minkowski-operations (opening functions) by analyzing films from different states of the growth process, say of different thicknesses. We moreover correlate the above mentioned lateral features for the identification of the origin of final grainy structures as well as for that of lateral inhomogeneities.

HL 62.28 Thu 18:00 Poster D2

Maximum voltage determined by appropriate superposition of photoluminescence from polycrystalline Cu(In,Ga)S$_2$ absorber layers — •Florian Heidemann[1], Rudolf Brüggemann[1], Saoussen Merdes[2], Alexander Meder[3], and Gottfried H. Bauer[1] — [1]Institute of Physics, CvO University Oldenburg, Germany — [2]SE2, Helmholtz-Zentrum Berlin, Germany — [3]SULFURCELL Solartechnik GmbH, Berlin, Germany

Thin film solar cells based on the chalcopyrite Cu(In,Ga)S$_2$ offer an alternative to the predominant Cu(In,Ga)Se$_2$ with the benefit of higher band-gap and thus of nominal higher open circuit voltage V_{oc}. We have performed calibrated photoluminescence (PL) studies on absorbers to characterize their optoelectronic quality. To record spectrally resolved PL with sufficient photon fluxes we collect PL signals from a homogeneously illuminated area of 1 mm^2. Due to absorber polycrystallinity the collected PL-signal is composed of contributions of individual sites in the μm-scale varying in intensity and spectral shape. Since the splitting of quasi-Fermi levels ($E_{Fn} - E_{Fp}$) according to Planck's generalized law is derived from the logarithm of the spectral PL yield, measuring without sufficient local resolution leads to an overestimation of $E_{Fn} - E_{Fp}$. With a second confocal setup we analyze spectrally resolved PL with a lateral resolution of less than 1 μm. For detection limitations we need excitation fluxes in the order of 10^4 AM1.5 to extrapolate from distribution functions of PL signals recorded at 300 K and high excitation towards AM1.5. We correct $E_{Fn} - E_{Fp}$ from the calibrated setup, which corresponds to the maximum achievable V_{oc}.

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Investigations of defects after indiffusion of iron and nickel into float-zone silicon — •Philipp Saring, Nils Hildebrand, Marie Aylin Falkenberg, and Michael Seibt — IV.Physikalisches Institut der Georg-August-Universität, Friedrich-Hund-Platz 1, D-37077 Göttingen, Germany

The electrical properties of silicon are strongly influenced by fast diffusing transition metal impurities such as iron, nickel and copper, which are unintentionally brought into and distributed inside the material during high temperature treatments. Under certain conditions these metals cluster by forming recombination active silicide precipitates. Whereas homogeneous precipitation has been observed for nickel or copper, iron precipitation generally requires the presence of preexisting nucleation sites. Recent studies deal with the simultaneous coprecipitation of these elements.

In this work we focus on the distribution of the electrically active defects after indiffusion of nickel and iron into float-zone silicon. We investigate the recombination properties of these defects by LBIC- and EBIC-measurements as well as their concentration and majority charge carrier kinetics by DLTS experiments. By suitable annealing conditions we established quite small concentrations of precipitates ($< 10^8$cm^{-3}) and metal denuded zones below the sample surfaces. Single precipitates were extracted by Focussed-Ion-Beam technique for TEM-investigations.

HL 62.30 Thu 18:00 Poster D2

Defect characterisation of thin a-Si:H- and μc-Si:H-films with FTPS ("Fourier Transform Photocurrent Spectroscopy") — •Dominik Schael[1], Armin Brechling[1], Ulrich Heinzmann[1], Thomas Westerwalbesloh[2], and Helmut Stiebig[2] — [1]Molecular and Surface Physics, Bielefeld University, Germany — [2]Malibu GmbH & Co. KG, Bielefeld, Germany

An important characteristic of silicon semiconductors is the defect concentration. Acting as recombination centers, defects lead to a reduced carrier lifetime, which strongly influences the performance of a solar cell. One way to get information about the defect concentration is the determination of the optical absorption coefficient $\alpha(E)$ in the subband range. Obtaining $\alpha(E)$ of thin a-Si:H- and μc-Si:H-layers is a challenge since $\alpha(E)$ varies over several orders of magnitude. A very sensitive method to determine the absorption coefficient is the Fourier Transform Photocurrent Spectroscopy. Here, the a-Si:H- or μc-Si:H-sample acts as an external detector in a FTIR setup, which enables very fast measurements. By calibrating the FTPS-signal with reflectance and transmittance data, absolute values for $\alpha(E)$ are obtained. Depending on the characteristics of $\alpha(E)$, a defect concentration can be calculated.

We will present the measurement setup and will discuss the subband gap distribution of different Si based (a-Si:H, μc-Si:H and c-Si) samples.

HL 62.31 Thu 18:00 Poster D2

Morphological studies of microcrystalline silicon for thin-film solar cells by raman spectroscopy and TEM — •Vitalij Schmidt[1], Daniel Janzen[2], Wiebke Hachmann[1], Marc Sacher[1], Stefan Gruss[2], Helmut Stiebig[2], and Ulrich Heinzmann[1] — [1]University of Bielefeld, 33615 Bielefeld — [2]Malibu GmbH & Co. KG, 33609 Bielefeld

Thin-film amorphous and microcrystalline silicon are promising materials for photovoltaics as they have the potential to reduce the solar cell costs. In case of microcrystalline silicon the crystalline volume fraction is an important issue for the quality of solar cells as it is related to the microstructure of the material and the defect density.

Using an AKT PECVD system optimized for amorphous silicon layer deposition we deposited microcrystalline silicon diodes on 1300 mm ×1100 mm glas-TCO superstrates under variation of deposition time, RF power, silane concentration and distance of the electrodes.

Focusing on the crystalline fraction and especially its lateral homogenity over the 1,4 m^2 area we analyzed the intrinsic layer by Raman spectroscopy on different positions. Two excitation wavelength (473 nm and 633 nm) are used in ordner to get depth dependent information of the crystallinity. TEM observations of cross-section of chosen samples confirmed the spectroscopy given results.

Based on the lateral information achieved the process was optimized and a correlation between crystalline volume fraction and local cell efficiency will be disussed.

HL 62.32 Thu 18:00 Poster D2

Estimation of excess carrier depth profile from spectral photoluminescence yield in c-Si absorbers — •Sebastian Knabe and Gottfried H. Bauer — Institure of Physics, University Oldenburg, Germany

The photoluminescence (PL) emitted from excited semiconductors provides access to parameters like the splitting of quasi-Fermi-levels, optical absorption, etc and is based on the recombination of excess carrier. In this study we show one strategy to estimate parameters like excess carrier lifetime, surface recombination velocity, etc. of the excess carrier density depth profile from photoluminescence measurements in the model system crystalline silicon. We simulate the spectral PL and fit these results to experimental ones with respect to an optimally selected carrier depth profile with a Nelder-Mead algorithm.

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Verbesserung der Materialqualität von Galliumindiumnitridarsenid (GaInNAs) durch Ausheilen zur Optimierung von hocheffizienten III-V-Mehrfachsolarzellen — •Sebastian Rönsch, Elke Welser, Tobias Roesener, Frank Dimroth und Andreas W. Bett — Fraunhofer Institut für Solare Energiesysteme (ISE), Freiburg

Hocheffiziente Mehrfachsolarzellen aus III-V-Verbindungshalbleitern werden bereits für die Weltraumanwendung und für die Verwendung in terrestrischen Konzentratorsystemen industriell gefertigt. Der theoretische Wirkungsgrad der etablierten, gitterangepassten Ga$_{0,50}$In$_{0,50}$P/Ga$_{0,99}$In$_{0,01}$As/Ge-Dreifachsolarzelle wird durch Erweiterung mit einer Ga$_{0,92}$In$_{0,08}$N$_{0,03}$As$_{0,97}$-Teilsolarzelle unter extraterrestrischen AM0 Standardbedingungen und einfacher Sonnenlichtkonzentration von 40,6 % auf 52,3 % deutlich gesteigert. Diese vielversprechende Vierfachsolarzelle wird derzeit durch die geringe Materialqualität des GaInNAs stark limitiert. Zur Verbesserung der Materialqualität wurde das thermische Ausheilen wachstumsbedingter Defekte mittels Photolumineszenzmessungen (PL), elektronenstrahlinduzierten Strommessungen (EBIC) und kapazitiver Transientenspektroskopie (DLTS) untersucht. Mit EBIC konnten im GaInNAs ausgeprägte, punktförmige Defektstrukturen im Mikrometerbereich beobachtet werden. Ein Hochtemperaturschritt löst die Defektstrukturen auf. Gleichzeitig nimmt der EBIC-Strom zu, die PL-Intensität steigt und der mit DLTS bestimmte Einfangquerschnitt der Defekte nimmt um mehrere Größenordnungen ab.

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Entwicklung alternativer Prozesstechnologien zur Herstellung monolithisch integriert serienverschalteter Konzentratorsolarzellen (MIMs) — •Henning Helmers[1], Eduard Oliva[1], Wolfgang Bronner[2], Frank Dimroth[1] und Andreas W. Bett[1] — [1]Fraunhofer-Institut für Solare Energiesysteme ISE, Freiburg — [2]Fraunhofer-Institut für Angewandte Festkörperphysik IAF, Freiburg

Monolithisch integriert serienverschaltete Module (MIMs) sind großflächige Solarzellbauelemente für den Einsatz unter hohen Lichtintensitäten in konzentrierenden Photovoltaiksystemen. MIMs bestehen aus mehreren III-V basierten Solarzellsegmenten, die während der Prozessierung durch Verschaltungsgräben in Serie verschaltet werden. Die Breite dieser Gräben, sowie der damit verbundene Verlust an aktiver Solarzellfläche sind durch die verwendete Herstellungstechnologie limitiert.

Es wurden verschiedene Prozesstechniken zur Minimierung dieser Verluste untersucht. Neben einer optimierten herkömmlichen Technologie, mit nasschemischem Ätzen und photostrukturiertem Polyimid als Dielektrikum zur Isolation der pn-Übergänge, wurde ein alternativer Trockenätzprozess mittels RIE-ICP sowie ein Prozess zur Strukturierung von Siliziumnitrid als Dielektrikum entwickelt. Damit wurden die Grabenbreiten von über 100 μm auf 57 μm reduziert. Dies entspricht nahezu einer Halbierung der Flächenverluste von 11% auf unter 6%. Der höchste erzielte Wirkungsgrad beträgt für eine Tandemstruktur η=24,7% bei einer Einstrahlung von 1037 MW/m^2. Dabei wurden folgende Kenngrößen gemessen: V$_{oc}$=53,7 V, I$_{sc}$=2,60 A, FF=80,1%.