HL 55: Photovoltaics: mainly Technology and Photon Management

Time: Wednesday 14:30–17:45 Location: FOE Anorg

HL 55.1 Wed 14:30 FOE Anorg

Spectral down-conversion in Sm-doped borate glasses for photovoltaic applications — •Marcel Dyrba[1], Katharina Baumgartner[2], Reinhard Carius[2], Paul-Tiberiu Miclea[3,4], and Stefan Schweizer[1,3] — [1]Centre for Innovation Competence SiLi-nano®, Martin Luther University of Halle-Wittenberg, Karl-Freiherr-von-Fritsch-Str. 3, 06120 Halle (Saale) — [2]Institut für Energieforschung 5 (Photovoltaics), Forschungszentrum Jülich GmbH, 52425 Jülich — [3]Fraunhofer Center for Silicon Photovoltaics, Walter-Hülse-Str. 1, 06120 Halle (Saale) — [4]Institute of Physics, Martin Luther University of Halle-Wittenberg, Heinrich-Damerow-Str. 4, 06120 Halle (Saale)

A class of Sm-doped borate glasses has been developed for photovoltaic applications. The fluorescent glass is placed on top of a solar cell and, in the case of Sm^{3+} doping, converts the incident violet/blue part of the solar spectrum to visible red light which is efficiently converted to a photocurrent and enhances the solar cell efficiency. Borate glasses are good candidates as a matrix material since they offer a high optical transparency and they are robust and inexpensive. The chemical base composition of borates glasses consists of the network former boron oxide and metal oxides as network modifiers. The system can easily be doped with Sm^{3+} ions. However, the spectroscopic properties of Sm^{3+}, in particular the fluorescence efficiency, are significantly influenced by the electron negativity of the network modifier. The external quantum efficiency (EQE) and spectral response of amorphous thin film silicon solar cells covered with fluorescent borate glasses have been evaluated.

HL 55.2 Wed 14:45 FOE Anorg

Spectral and angle dependent emission of solar fluorescence collectors — •Hendrik Sträter, Sebastian Knabe, and Gottfried H. Bauer — Institute of Physics, Carl von Ossietzky University Oldenburg, D-26111 Oldenburg

Fluorescence collectors (FCs) provide the option for concentration and simultaneous spectral selection of solar photons of direct or diffuse light. The energetic and commercial benefit of these systems depend on the yield of the conversion of solar photons into luminescence photons and on the efficiency of their respective conductance to the edges of the FC where they are coupled into appropriate solar cells. For the characterization of the performance of FCs and the identification of losses, we have performed angle and spectrally resolved measurements of fluorescence photons from FC with two different types of optical designs, a PMMA substrate with homogeneous depth dependent dye concentration and a novel type of FC, which consist of a transparent substrate with a thin overlayer containing the absorbing and emitting dye. We have recorded the edge fluorescence when illuminating the entire FC surface laterally homogeneously, as well as for slit-like excitation on the front surface with variation of the distance of the illuminated slit from the edge. We compare the experimental fluorescence results with a 2-dimensional ray-tracing approach and verify the spectral and angle dependent edge emission. Moreover we illuminate the FC with long wavelength photons which are not absorbed and conclude, again from angle dependent and spectrally resolved edge emission, on scattering losses at surfaces and in the bulk.

HL 55.3 Wed 15:00 FOE Anorg

Light scattering by rough surfaces for increase of absorption of low band gap light in solar cells — •Konstantin Kloppstech, Sebastian Knabe, and Gottfried H. Bauer — Institute of Physics, Carl von Ossietzky University Oldenburg, Germany

Scattering of low band gap light for the increase of the absorption of low band gap photons is commonly formulated in phenomenological magnitudes such as haze factors resulting from experiments at particular scattering media. We have formulated analytically and described by numerical simulations the scattering of light by the interaction of photons with rough surfaces based on wave numbers of photons k_λ and wave numbers of the topological surface contour k_s that has been derived in 2 dimensions via AFM analyses of the contour function $h(x, y)$ of the scattering medium, e.g. a glassy diffusor. We have distinguished two regimes: **i)** $k_\lambda < k_s$ in which we apply a ray tracing approach with respect to *Snellius' Law* for photon propagation at phase border between different media, and **ii)** $k_\lambda \propto k_s$, where the propagation of photons after scattering has been formulated on *Huygens' Principle* with generation of spherical waves at the respective position $h(x, y)$. The experimental scattering of photons with different wavelengths - recorded with a standard type goniometer - are compared with the simulation of numerically generated far field results in dependence of distance r from the scattering medium and scattering angle β. In particular for the wave optical approach we find a "scattering function" that contains the contour function $h(x, y)$ however that substiantially departs from its puristic *Fourier Transform*.

HL 55.4 Wed 15:15 FOE Anorg

Silver nanoparticles for enhanced light absorption in thin film amorphous silicon solar cells — •Florian Lükermann[1], Frank Hamelmann[2], Helmut Stiebig[2], and Ulrich Heinzmann[1] — [1]Molecular and Surface Physics, Bielefeld University, 33615 Bielefeld, Germany — [2]Malibu GmbH & Co. KG, 33609 Bielefeld, Germany

Illuminating metal nanoparticles (NPs) with electromagnetic radiation leads to collective dipolar oscillations of the conduction electrons. Depending on the size, shape and surrounding material strong wavelength dependent resonances in the absorption and scattering spectra are the consequence. This so called localized surface plasmon (LSP) resonances go along with an enhanced electromagnetic field inside and in the close proximity of the NPs.

We fabricated silver NPs by thermal evaporation respectively sputtering of silver to gain thin metallic films in the range of a few nm. These films are subsequently annealed at temperatures in the order of 150 °C which leads to the formation of nanosized silver islands from a few nm to approximately 50 nm average diameter, depending on the film thickness. The nanoparticle films are incorporated in direct contact to the active layer of photosensitive amorphous silicon (a-Si) devices to investigate the influence of the enhanced electromagnetic field on the generation of photoexcited charge carriers.

External quantum efficiency measurements demonstrate an enhanced photocurrent in the near infrared region where a-Si in general shows no absorption. MIE simulations indicate that this effect can be associated to the LSP resonances of the incorporated NPs.

HL 55.5 Wed 15:30 FOE Anorg

Conformal Al doped ZnO on rough silicon surfaces — •Martin Otto[1], Matthias Kroll[2], Thomas Käsebier[2], Roland Salzer[3], Paul T. Miclea[1], and Ralf B. Wehrspohn[1,3] — [1]Martin-Luther-University Halle-Wittenberg, μMD Group - Institute of Physics, Heinrich Damerow Str. 4, 06120 Halle, Germany — [2]Friedrich-Schiller-University Jena, Institute for Applied Physics, Max-Wien-Platz 1, 07743 Jena, Germany — [3]Fraunhofer Institute for Mechanics of Materials Halle IWM, Walter-Hülse-Str.1, 06120 Halle, Germany

The feasibility of perfectly conformal deposition of transparent but highly conductive ZnO thin films on rough silicon surfaces for photovoltaic applications has been investigated. Aluminum doped zinc oxide (AZO) deposited via thermal ALD was used as a conformal cover layer for plasma etched black silicon. The coated structures achieve reflectances as low as 2.5% throughout the whole visible spectrum whereas the films exhibit resistivities of only $1.1 \cdot 10^{-3}\Omega$cm. An absorption enhancement of nearly a factor of 10 at a wavelength of 1150 nm compared to a simulated perfect ARC was observed.

HL 55.6 Wed 15:45 FOE Anorg

Comparative characterisation of sputtered ZnO:Al TCO-layers on float glass produced by large ceramic and metallic targets — •Sebastian Wohner[1], Hartmut Witte[1], Fahri Uslu[2], Jörg Günther[2], Jürgen Bläsing[1], Martin Bähr[2], and Alois Krost[1] — [1]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg — [2]Euroglas GmbH, Haldensleben

One of the main parts of photovoltaic cells is the conductive and transparent front contact which is often realized by wide bandgap ZnO. D.C magnetron sputtering with ceramic $ZnO{:}Al_2O_3$ targets is one of the commonly used processes to produce ZnO-layers on float glass. Disadvantages are the fixed stoichiometric proportions and the high temperatures.

Alternatively, Al-doped ZnO-layers were deposited by reactive d.c. magnetron sputtering from a large, planar Zn(Al) under oxygen ambience. Hereby the operating point has to be within the unstable transition region of the power - oxygen pressure characteristic.

For comparison ZnO layers were produced by reactive and by ceramic magnetron d.c. sputtering using large targets. The ZnO layers were characterized and compared by resistivity, Hall-effect as well as by optical transmission- and reflection measurements to get the electron concentration using the Drude-model. The surface and the crystal structure were analysed by AFM and Bragg-Brentano X-ray diffraction, respectively. The results show the potential for the production of qualitatively good ZnO-layers as TCO by reactive d.c. magnetron sputtering on large cathodes using adapted process controlling.

15 min. break

HL 55.7 Wed 16:15 FOE Anorg

Time Resolved Measurement of Interface and Bulk Recombination of Solar Cell Materials — •Anja Dobrich, Nadine Szabó, Klaus Schwarzburg, and Thomas Hannappel — Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin, Germany

Today's state-of-the-art multi-junction solar cells are based on III-V semiconductor compounds grown by MOVPE. The current record multi junction solar cell grown on germanium, having Ge, Ga(In)As and GaInP subcells, have reached a record efficiency of 41.6%. This could be improved further if the low bandgap Ge subcell would be replaced by a more efficient double junction solar cell. For this purpose the low bandgap absorbers InGaAs and InGaAsP grown lattice-matched on InP(100) are suitable. Due to the enhanced bandgap composition a better yield of the solar spectrum is feasible.

Here, we study how the preparation routine of the critical InGaAs to InP interface effects the spatial homogeneity. As a probe for bulk and interface defects time resolved photoluminescence (TRPL) was used. For the lifetime measurements we have grown double hetero (DH) test structures. Due to the arsenic carry over in the InP layer, the InGaAs/InP interface is well-known to be critical with respect to the quality of the interface. The interfaces were prepared via different preparation routes starting with either III- or V-rich InGaAs surface terminations. In order to evaluate the interface formation we analysed the surface reconstruction in situ with reflection difference (RD) spectroscopy and via a contamination-free transfer to UHV with LEED.

HL 55.8 Wed 16:30 FOE Anorg

Nanowire based heterojunction Semiconductor-Insulator-Semiconductor solar cells — •Björn Hoffmann[1], Vladimir Sivakov[1], Florian Talkenberg[1], Gerald Brönstrup[1], and Silke Christiansen[1,2] — [1]Institut für Photonische Technologien, Jena — [2]Max-Planck-Institut für die Physik des Lichts, Erlangen

Semiconductor-Insulator-Semiconductor (SIS) solar cells based on wet-chemically etched silicon nanowires are promising candidates for 3rd generation photovoltaics due to very good electro-optical properties and low production costs. Atomic layer deposition (ALD) is used to form a homogeneous layer of Al_2O_3 as a tunnel barrier around the nanowires followed by a thick layer of Al doped ZnO as transparent front contact. Electron beam induced current (EBIC) is used to visualize the areas of effective charge carrier separation which happens in the bulk wafer as well as in the nanowires. The cells reach short-circuit current densities of $J_{SC} = 33\,mA/cm^2$, open-circuit voltage of $V_{OC} = 470\,mV$ and power conversion efficiencies of up to $\eta = 8,6\%$.

HL 55.9 Wed 16:45 FOE Anorg

From Point to the Line: The Incubation Effect during Laser Scribing of Silicon Thin-Film Photovoltaic Modules — •Michael Richter[1], Christof Schultz[1], Frank Fink[1], Volker Quaschning[1], Bert Stegemann[1], Hans-Ulrich Pahl[2], Heinrich Endert[2], and Bernd Stannowski[3] — [1]Hochschule für Technik und Wirtschaft Berlin, Wilhelminenhofstr. 75a, 12459 Berlin, Germany — [2]Newport Spectra-Physics GmbH, Ruhlsdorfer Strasse 95, 14532 Stahnsdorf, Germany — [3]PVcomB - Kompetenzzentrum Dünnschicht- und Nanotechnologie für Photovoltaik Berlin, Schwarzschildstr. 3, 12489 Berlin, Germany

Serial interconnection of thin film solar cells by laser ablation requires precise and layer-selective scribing of narrow grooves. We have determined the ablation energy fluence thresholds by variation of spot overlap and laser fluence for different photovoltaic materials used for silicon based thin-film solar cells and derived the respective incubation coefficients as a function of the laser pulse duration. The results provide a detailed description of the incubation behavior and allow an accurate prediction of the specific laser scribing results. Moreover, we found good agreement between experiment and theoretical estimations.

HL 55.10 Wed 17:00 FOE Anorg

Numerical simulations for the effiency improvement of hybrid dye-microcrystalline silicon pin-solar cells — •Sven Burdorf, Gottfried Heinrich Bauer, and Rudolf Brüggemann — Institut für Physik, Carl von Ossietzky Universität Oldenburg, Germany

Hybrid solar cells consisting of dye sensitizers incorporated in the i-layer of microcrystalline silicon pin solar cell have been proposed and even recently processed [1,2]. The dye sensitizer molecules are embedded in the matrix and enhance the overall absorption of the dye-matrix system due to their high absorption coefficient in the spectral range interesting for photovoltaic applications. However, the charge transport properties of dyes are quite poor. Microcrystalline silicon on the other hand has acceptable charge transport properties, while the absorption, given a layer thickness in the micron range, is relatively poor. This contribution investigates the effiency improvement of hybrid dye-microcrystalline solar cells compared to pure microcrystalline solar cells by simulation. The results indicate that, under optimal conditions, the effiency can be improved by more than 20 % compared to a pure microcrystalline silicon cell. The thickness reduction for the hybrid system can be as large as 50 % for the same effiency. [1] T. Mayer, U. Weiler, C. Kelting, D. Schlettwein, S. Makarov, D. Wöhrle, O. Abdallah, M. Kunst and W. Jaegermann 2007 Solar Energy Materials and Solar Cells 91 1873-1886. [2] T. Mayer, U. Weiler, E. Mankel, W. Jaegermann, C. Kelting, D. Schlettwein, N. Baziakina and D. Wöhrle 2008 Renewable Energy 33 262-266.

HL 55.11 Wed 17:15 FOE Anorg

Picosecond Excited State Spectroscopy of Organic Bulk Heterojunctions — •Björn Gieseking[1], Berthold Jäck[1], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]11Experimental Physics VI, Faculty of Physics and Astronomy, Julius- Maximilians-University Würzburg, D-97074 Würzburg — [2]2Bavarian Centre for Applied Energy Research (ZAE Bayern), D-97074 Würzburg

Bulk heterojunction solar cells comprised of conjugated polymers and fullerene derivatives approach efficiencies of 8 % making this composite system a promising candidate for the application in organic photovoltaics. Different approaches for improving the device performance aim at the physical properties of the material system itself, but a further optimization requires a deeper insight into the elementary processes following the photoexcitation of these blends.

Here we present recent time-resolved spectroscopic studies on the conjugated Polymer P3HT blended with different fullerene derivatives employing femtosecond transient absorption (TA) and photoluminescence (PL) spectroscopy. For both methods we use an Ti:sapphire-based femtosecond laser system together with two optical parametric amplifiers and a streak camera providing a time resolution in the sub picosecond (TA) and picosecond (PL) regime, respectively. Applying these techniques we studied the recombination dynamics of singlet excitons and polarons after photoexcitation. We will discuss our results in terms of performance optimisation of organic solar cells.

HL 55.12 Wed 17:30 FOE Anorg

Defect and charge transfer studies on hybrid solar cells with silicon nanocrystals — •Sabrina Niesar[1], Daniel Herrmann[2], Wolfgang Fabian[1], Nadine Erhard[1], Andre Stegner[1], Rui Pereira[3], Hartmut Wiggers[4], Martin Brandt[1], Eberhard Riedle[2], and Martin Stutzmann[1] — [1]Walter Schottky Institut, Technische Universität München, 85748 Garching — [2]Ludwig-Maximilians-Universität München, 80538 München — [3]University of Aveiro, 3810-193 Aveiro, Portugal — [4]Institut für Verbrennung und Gasdynamik, Universität Duisburg-Essen, 47057 Duisburg

Hybrid inorganic nanoparticle-polymer solar cells are a promising alternative to purely organic devices due to the broad spectral range of absorption of the inorganic material. In this work, a combination of P3HT and silicon nanocrystals (Si-ncs), which are synthesized in a microwave plasma reactor, is studied. In particular, we focus on methods to decrease the concentration of silicon dangling bond defects which negatively affect the electronic properties of the hybrid solar cells. HF etching in combination with vacuum annealing at 200°C leads to the lowest defect densities. Conductivity measurements in vacuum show that the defect reduction results in improved electrical properties of Si-nc thin films. Electron paramagnetic resonance and Fourier transform infrared spectroscopy are used to study the stability of the different post-growth treatments. The charge transfer across the

organic-inorganic interface is investigated via broadband-femtosecond optical pump-probe spectroscopy. We find that the addition of the Sincs leads to an increase of the charge separation as compared to pure P3HT.