HL 79: Photovoltaics: Mainly Silicon

Time: Thursday 14:30–17:15 Location: FOE Anorg

HL 79.1 Thu 14:30 FOE Anorg

Microstructuring of silicon with femtosecond laser pulses — •Waldemar Freund, Jan P. Richters, Tobias Voss, and Jürgen Gutowski — Institute of Solid State Physics, Semiconductor Optics Group, University of Bremen

Silicon structured with ultrashort laser pulses which is called "black silicon" due to its dark appearance has been a field of intense studies in recent years. It exibits a nearly uniform absorptivity beyond 90% in the whole visible to near-infrared spectral region. Therefore, it is a promising material for applications in solar cells and photo diodes.

In this talk a brief introduction of microstructuring of silicon with ultrashort laser pulses will be given. Structuring is carried out in a sulfurhexafluoride (SF_6) atmosphere, which simultaneously allows doping of the silicon with sulfur far above the solubility limit. The structuring leads to a specific quasiperiodic surface morphology at which incident light is reflected multiple times. Thus light absorption in the silicon is considerably enhanced. The extremely high doping with sulfur results in the formation of a distinct defect band which is the origin of high absorptance in the near infrared. Furthermore, sulfur acts as a donor in silicon. Hence, microstructuring of p-doped silicon in SF_6 atmosphere leads to the formation of a p-n^+ junction. This is an important step towards the fabrication of efficient solar cells and photo diodes with increased infrared sensitivity on base of easy-to-produce black silicon.

HL 79.2 Thu 14:45 FOE Anorg

Potential of silicon nanoparticles for photovoltaic applications — •Martin Meseth[1], Pawel Ziolkowski[2], Nils Petermann[3], Gabi Schierning[1], Niels Benson[1], Hartmut Wiggers[3], and Roland Schmechel[1] — [1]University of Duisburg-Essen, Nanostrukturtechnik, 47057-Duisburg — [2]DLR (German Aerospace Center), Institute of Materials Research, 51147-Köln — [3]University of Duisburg-Essen, Institut für Verbrennung und Gasdynamik, 47057-Duisburg

To reduce costs per watt of commercial photovoltaics (PVs) silicon nanoparticles are considered as an interesting alternative to conventional PV thin films. To proof the principle concept a pn-junction is created by spark plasma sintering of highly p- and n-doped ($\approx 10^{20} cm^{-3}$) Si nanoparticles with diameters in the range of $10nm$ to $50nm$. While SEM-investigations of these sintered samples show still a nanocrystalline structure, density measurements result in a high compaction value of up to 95% of crystalline Si. The structural formation of a pn-junction is proven using microscopic Seebeck-coefficient- and EDX-measurements, each showing a clear separation of the respectively doped materials and a sharp interface in between. Furthermore electrical DC-characterization is done showing a clearly rectifying behaviour. This leads to the conclusion that this pn-junction behaves also electrically as a diode. Further, a small photovoltaic effect under illumination with a $1000W$-tungsten lamp indicates the presence of a built-in field between the p- and n-region.

HL 79.3 Thu 15:00 FOE Anorg

Simulation of polycrystalline silicon thin film solar cells - model calibration and sensitivity analysis — •Ana-Maria Teodoreanu, Caspar Leendertz, Tobias Sontheimer, and Bernd Rech — Helmholtz-Zentrum Berlin, Kekuléstr. 5. 12489 Berlin

To gain a better insight into the efficiency-limiting processes in polycrystalline silicon (poly-Si) thin film solar cells, we developed a simulation model for the J-V characteristics and minority carrier lifetime based on experimental results using the numerical 1D simulation program AFORS-HET. The calibration of the model has been achieved through simultaneously fitting the measured dark and light J-V curves of twelve poly-Si thin film minimodules with dissimilar thickness and absorber doping concentration. Effective defect density, capture cross section products of $10 \ldots 100 cm^{-1}$ have been determined in the poly-Si absorber by this procedure. Transient photoconductance decay measurements of the poly-Si absorbers have also been conducted in the low injection regime ($4.5 \cdot 10^{14} cm^{-3}$). High lifetimes of $100\mu s$ have been found which can be explained within our simulation model by field effect passivation. Furthermore simulations indicate that this field effect leads to a strong injection-dependence of carrier lifetime in the operation range of the solar cell. The sensitivity analysis performed with our calibrated model shows that the defects in the absorber layer are crucial for the cell efficiency. Thus, the improvement of the emitter and back surface field layers becomes important only if the absorber itself is of better quality. Moreover we discuss the optimum absorber thickness subject to different doping levels and absorber defect densities.

HL 79.4 Thu 15:15 FOE Anorg

Numerical 3D-Simulation of Micromorph Silicon Thin Film Solar Cells — •Stefan Geissendörfer, Jürgen Lacombe, Karsten von Maydell, and Carsten Agert — EWE-Forschungszentrum für Energietechnologie e.V. NEXT ENERGY, Carl-von-Ossietzky-Str. 15, 26129 Oldenburg

In this contribution 3-dimensional simulations of micromorph silicon thin film solar cells, which have a tandem structure consisting of amorphous and microcrystalline subcells, will be presented. The variety of different active layers leads to a very complex structure. Additionally, randomly textured surfaces and interfaces have to be taken into account. Our goal is to create physical models to describe the coupled optical and electrical behaviour of the whole structure in three dimensions to determine the theoretical limits and dominant material parameters. To simulate solar cells with rough interfaces, the surfaces topography was measured via atomic force microscopy (AFM) and transferred to the commercial software Sentaurus TCAD from the company Synopsys. The virtual structure includes layer thicknesses and optoelectronic parameters. Results of the space resolved optical generation rates by using the optical solver "Raytracer" will be presented. The space resolved optical generation rate inside the semiconductor layers depends on the structure of the TCO interface. Therefore, regions with higher charge charrier densities can be observed which has an influence on the current transport through the stack. These investigations and the influence to the IV characteristic will be presented.

HL 79.5 Thu 15:30 FOE Anorg

Modulated photoluminescence studies for lifetime determination in amorphous-silicon based passivation of crystalline-silicon wafers — •Florian Effenberg, Rudolf Brüggemann, and Gottfried H. Bauer — Institute of Physics, Carl von Ossietzky University Oldenburg, Germany

Efficient passivation of interface defects is crucial in the development of efficient amorphous silicon / crystalline silicon heterojunction solar cells. Pre-treatment of the crystalline silicon wafer prior to the amorphous-silicon deposition determines the density of interface defects to a large degree. In addition, the deposition of the passivation layer itself determines the density of interface defects. By modulated photoluminescence, we study the influence of these interface defects on the recombination of excess carriers in wafers with different passivation schemes. Emphasis is laid on the deposition of amorphous-silicon passivation layers, which will also be part of the final solar cell. The analysis of modulated photoluminescence shows that the effective lifetime can be determined from the frequency response of the photoluminescence signal. For the modulated photoluminescence measurements at room-temperature we detail the excitation-density dependence of the excess-carrier lifetime and compare its variation for different passivation schemes. From the excitation-density dependence we draw conclusions on the energetic variation in the density-of-states of the interface defects and the absolute density.

15 min. break

HL 79.6 Thu 16:00 FOE Anorg

Shunts in Thin-Film Photovoltaics — •Stephanie Malek[1], Uli F. Wischnath[2], Juan Rechid[3], Ingo Riedel[1], and Jürgen Parisi[1] — [1]Energy and Semiconductor Research Laboratory, Department of Physics, University of Oldenburg, 26111 Oldenburg, Germany — [2]aleo solar Deutschland GmbH, 26122 Oldenburg, Germany — [3]CIS Solartechnik GmbH & Co. KG, 20539 Hamburg, Germany

Shunts can lead to severe performance reduction in thin film solar cells. This work reports on a microscopic approach to locate and characterize the details of shunts in order to reveal their origin. Localization of hot spots and film disruptions is commonly addressed by lock-in infrared thermography (LIT) through visualization of the Joule heating. The resolution of this method is restricted to the μm-range. We use different methods of LIT for the fast localization of local-lateral peculiarities in order to identify positions of interest. For a more detailed analysis

of these features we use high resolution microscopy like Scanning Electron Microscopy (SEM) and AFM-based methods. These small-scale investigations can for example reveal whether areas of high heat dissipation are rather related to the inner structure of the involved thin films or to accidentally incorporated imperfections.

HL 79.7 Thu 16:15 FOE Anorg

Scanning Spreading Resistance Microscopy for Characterization of Laser Doped Selective Emitter Structures in Solar Cells — •Stefan Doering[1], Stefan Jakschik[1], Thomas Mikolajick[1,2], Jens Krause[3], Rico Böhme[3], and Marc Petri[3] — [1]NaMLab gGmbH, Dresden, Germany — [2]TU Dresden, Dresden, Germany — [3]Roth & Rau AG, Hohenstein-Ernstthal, Germany

Focus of our work is the visualization of local heavily laser doped selective emitter (LDSE) structures with a self-aligned metallization via plating in mono crystalline silicon solar cells. The LDSE process was developed at the University of New South Wales (UNSW) and enables high conductive metal fingers with a low contact resistance to the emitter, thus allowing the finger dimensions to be reduced significantly. As a result, the amount of light per area that is used for energy conversion is increased, leading to an increase in cell efficiency. The lower doped full area emitter leads to a better blue response and contributes to cell efficiency improvements, too.

Scanning Spreading Resistance Microscopy (SSRM) is known as a powerful tool for quantitative visualization of activated dopants in semiconductor materials. In this work we present SSRM measurements, showing the laser doped selective emitter diffusion into the bulk silicon. Dimensions of the LDSE as width and length can be extracted from the measured data. To our knowledge it is the first time the lateral dimensions of selective emitter activated dopants fabricated by laser annealing are visualized by SSRM in high lateral resolution.

HL 79.8 Thu 16:30 FOE Anorg

Comparison of the annealing treatments of PVD and ALD Al_2O_3 passivated silicon for solar cell applications — •Frank Benner[1], Maria Tarasova[1,3], Steve Kupke[1], Stefan Jakschik[1], and Thomas Mikolajick[1,2] — [1]NaMLab gGmbH, Dresden, Germany — [2]Lehrstuhl für Nanoelektronische Materialien, TU Dresden, Germany — [3]Institut für Elektronik- und Sensormaterialien, TU Bergakademie Freiberg, Germany

One reason for the electrical losses in solar cells is surface recombination, which decreases the effective carrier lifetime. A highly p-doped area is commonly used for the passivation of silicon solar cell rear surfaces. Alternatively, an electric field can be established to prevent the carriers from diffusing towards the surface. Negative charges need to be near the silicon surface in the passivation layer to repel the minority carriers in the p-doped silicon. We have investigated Al_2O_3 layers to determine the density of interface states and fixed charges. Different annealing times, temperatures and process gases were investigated and their impact on the electrical characteristics and carrier lifetimes compared. Annealing in forming gas (N_2/H_2) was preferable to nitrogen. Moderate temperatures decreased the density of interface states, increased the density of fixed charges and, therefore, increased the carrier lifetime. A high temperature treatment degraded the passivation layers significantly. Al_2O_3 layers deposited with ALD were superior to PVD in carrier lifetimes even though the internal charge characteristics are similar. Our results indicate a higher concentration of impurities and a thicker interface layer.

HL 79.9 Thu 16:45 FOE Anorg

Estimation of the excess carrier concentration from the spectral photoluminescence yield — •Sebastian Knabe and Gottfried H. Bauer — Carl von Ossietzky Universität Oldenburg, Institut für Physik, Oldenburg, Deutschland

The photoluminescence emitted from excited semiconductors provides access to parameters like splitting of quasi-Fermi-levels, optical absorption, etc. and it is furthermore based on the recombination of excess carriers. In this study we show one option to estimate from photoluminescence measurements parameters, such as recombination lifetime, surface recombination velocity of the excess carriers for crystalline silicon. Therefore we simulate the spectral photoluminescence emitted from an excited silicon wafer with consideration of the excess carrier concentration mostly governed by surface recombination velocities, excess carrier lifetimes, diffusion lengths, as well as by optical absorption and reflection; the simulated PL fed to the detector also contains propagation of pl-photons across surfaces and according phase accumulation through layers formulated by a matrix transfer approach. The input parameters determining the excess carrier concentration are optimized with a generic algorithm to minimize the differences in numerically simulated spectral response and experimentally recorded photoluminescence using different functions to calculate the differences between simulation and measured spectrum. The application of this approach yields excess carrier depth profiles and according influences on spectral luminescence.

HL 79.10 Thu 17:00 FOE Anorg

Charakterisierung von WS_2-Korngrenzen mit ortsaufgelösten Rasterkraftmikroskopietechniken (CAFM, KPFM) — •Roman Mankowsky, Klaus Ellmer und Stephan Brunken — Helmholtz-Zentrum, Berlin, Germany

Wolframdisulfid ist wegen seiner direkten Bandlücke von 1,8eV und dem hohen Absorptionskoeffizienten von $10^5 cm^{-1}$ ein interessantes Material für Absorberschichten in Dünnschichtsolarzellen. Zudem kommt WS_2 mit einem Anteil von $6 \cdot 10^{-3}$% in der Erdkruste sehr viel häufiger vor als andere für Dünnschichtsolarzellen verwendete Materialien. Aus diesen Gründen bietet es sich an zu untersuchen, ob WS_2 für die Produktion von Solarzellen in großem Umfang geeignet ist.

In vorangehenden Arbeiten wurde demonstriert, wie mit nickelinduzierter Kristallisation amorpher WS_{3+x}-Schichten photoaktive WS_2-Schichten auf einem metallischen Rückkontakt aus Ti(N,O) hergestellt werden können. Dennoch konnten wegen Kurzschlüssen in den WS_2-Schichten bisher keine Solarzellen präpariert werden.

Zur Bestimmung der elektrischen Eigenschaften der mikroskopischen Strukturen wurden ortsaufgelöste Leitfähigkeitsmessungen (CAFM) und Austrittsarbeitsmessungen (KPFM) kombiniert. Die Kombination von KPFM- und CAFM-Messungen erlaubt einen tiefen Einblick in die elektrischen Eigenschaften von Strompfaden mit nm Auflösung.

Mit diesen Techniken wurden Strompfade an WS_2-Korngrenzen und Fremdphasen in den WS_2-Schichten untersucht und mit Messungen an CdTe- und Cu(In,Ga)S_2-Schichten verglichen.