DS 41: Focus Session: Sustainable Photovoltaics with Earth Abundant Materials II

Time: Thursday 15:00–17:30 Location: CHE 91

DS 41.1 Thu 15:00 CHE 91

Electroless deposition of porous zinc oxide films on sheets of aluminium — •Stephanie Künze and Derck Schlettwein — Institute of Applied Physics, Justus-Liebig-University Giessen, Germany

Metal foils, wires or metalized polymer fibres are of interest as substrate electrodes for porous wide band-gap semiconductors in dye-sensitized solar cells (DSC) if protected against corrosion by a passivating oxide layer. Here, aluminium sheets were used to deposit porous zinc oxide for DSC. For the deposition of ZnO, the natural insulating Al_2O_3 layer on Al was removed by chemical etching in hydrochloric acid (HCl). A subsequent treatment in alkaline zinc hydroxide (zincate stain) was used to grow Zn in order to protect the metal and to provide a reactive surface for the deposition of ZnO. Porous ZnO films were then prepared by electroless deposition without any electrical connections on such pre-treated Al substrates from aqueous $ZnCl_2$ saturated with O_2. The xanthene dye $EosinY$ was used to form pores in the growing crystalline ZnO. The film thickness of porous ZnO and the coverage of the metal surface increase with the deposition time and with the amount of Zn from the pre-treatment. These results were contrasted with the results from electrochemical depositions at an applied potential under otherwise identical conditions. For comparison purposes, depositions of porous zinc oxide on etched sheets of Zn were analyzed to provide a virtually unlimited supply of Zn. Al and Zn unlike other elements often used in photovoltaics offer the chance of large-scale applications since both are abundant on earth.

DS 41.2 Thu 15:15 CHE 91

Copper oxide for photovoltaic applications — Alexander Wagner, Nikolai Ehrhardt, Mathieu Stahl, Andreas Fahl, Johannes Ledig, Lorenzo Caccamo, Andreas Waag, and •Andrey Bakin — Institute of Semiconductor Technology, Technische Universität Braunschweig, Hans-Sommer-Strasse 66, 38106 Braunschweig, Germany

Oxides and related materials are extremely promising materials for sustainable photovoltaics providing abundance and nontoxicity. For an all-oxide solar cell p-type Cu2O is a promising absorber material with a high absorption coefficient and 2.1 eV band gap. Theoretically predicted efficiencies of Cu2O based solar cells are up to 20% but till now the devices on the base of copper oxide show significantly lower efficiencies. Further fundamental investigations are needed in order to understand in depth the physics behind the devices on the base of these materials and to improve the efficiency of the cells. Influence of different buffer layers on the performance of an all oxide solar cell is discussed. Controllably grown Cu2O layers are also prerequisites for fabrication of high efficiency solar cells and vapor phase epitaxial growth of Cu2O is presented.

DS 41.3 Thu 15:30 CHE 91

The effect of hydrogen in RF-sputtered copper oxide thin films — •Philipp Hering, Benedikt Kramm, Julian Benz, Peter Klar, and Bruno Meyer — 1. phys. Inst., JLU Giessen, Deutschland

Cuprous oxide (Cu2O), despite its band gap of 2.17 eV, is a promising material for photovoltaic applications, due to its high absorption coefficient, non-toxicity and the abundance of its composing elements. While recently more attention has been paid to heterojunctions, highest efficiencies were reached by employing copper sheets, which were oxidized and annealed at high temperatures. For technological applicability, a thin film deposition process with mass production capabilities, which provides decent film properties at low temperatures, has to be established. Such thin films however suffer from low carrier mobilities and lifetimes, due to their polycrystalline nature. It has been reported that post treatments with hydrogen can passivate grain boundaries. Copper oxide thin films were deposited from a metallic copper target via reactive radio frequency magnetron sputtering, utilizing gaseous argon and oxygen under the addition of hydrogen. The films were characterized and the influence of hydrogen was investigated via X-ray diffraction, X-ray photoelectron spectroscopy, Raman spectroscopy, photoluminescence and Hall effect.

DS 41.4 Thu 15:45 CHE 91

Improved Anchoring of Indoline Dyes for the Sensitization of ZnO — Felix Fiehler[1], •Jane Falgenhauer[1], Melanie Rudolph[1], Christoph Richter[1], Hidetoshi Miura[2], and Derck Schlettwein[1] — [1]Institute of Applied Physics, Justus-Liebig-University Giessen, Germany. — [2]Chemicrea Inc, Iwaki, Fukushima, Japan.

D149 is a well-established indoline dye for the sensitization of ZnO. Although high efficiencies can be obtained, the dye partly desorbs from the ZnO surface in contact with the redox electrolytes in dye-sensitized solar cells. Similar indoline dyes with a second carboxylic binding group at the molecule to attach to the ZnO surface showed higher stability [1]. In this work, sandwich-cells were built with electrodeposited ZnO on conductive glass as the working electrode which was sensitized with D149 or D149-derivatives DN91, DN216 and DN285 having two binding groups of different length of a hydrocarbon spacer. Current-voltage curves and dynamic measurements like electrical impedance spectroscopy at AM1.5 illumination and intensity-modulated photovoltage/photocurrent spectroscopy (IMVS/IMPS) were performed. The observed shift of effective band positions, the recombination resistance and the observed lifetime of the excited state were found to be comparable for the different sensitizers. DN216, however, showed higher photocurrent densities than the D149 reference and the cell characteristics were more reproducible. Implications for the future development of dye-sensitized solar cells based on solution-processed ZnO will be discussed. [1] J. Falgenhauer, C. Richter, H. Miura, D. Schlettwein *Chem.Phys.Chem.*, 13, 2893-2897 (2012).

DS 41.5 Thu 16:00 CHE 91

Silver nanowire networks for ITO replacement — •Julian Reindl and Lukas Schmidt-Mende — Department of Physics, University of Konstanz, Germany

Indium-tin oxide (ITO) is the state-of-the-art material for transparent electrodes in optoelectronic devices such as solar cells. However, Indium is a very scarce material and the increasing demand for transparent conductors drives the need for alternative materials.

Here we present networks of silver nanowires which are embedded in a matrix of the doped polymer PEDOT:PSS. This system enables a good conductivity through the metallic pathways, supported by the polymer. The latter also provides a good light transmission in the visible range.

DS 41.6 Thu 16:15 CHE 91

Study of the Crystalline Fraction Dependent Microstructure Characteristics of $\mu c - SiOx : H$ for Micromorph Solar Cells — •Max Klingsporn[1], Simon Kirner[2], Ioan Costina[1], and Daniel Abou-Ras[3] — [1]IHP, im Technologiepark 25, Frankfurt (Oder), Germany — [2]PVcomB, Schwarzschildstr. 3, 12489 Berlin, Germany — [3]Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin, Germany

Since some years $\mu c - SiOx : H$ attracted attention as a wide band gap material for the use in silicon based thin film solar cells. With material parameters tunable over wide ranges it qualifies for several applications. One of the most popular today is the use as an intermediate reflector layer in tandem solar cells. In the present work a SiOx sample series with a fixed elemental composition and a crystalline fraction (Fc) varied between 10 and 60 % was studied by X-ray photoelectron spectroscopy and scanning transmission electron microscopy combined with electron energy loss spectroscopy. The analysis reveals a transition from an amorphous phase of silicon suboxides to a two-phase system of silicon nanofilaments embedded in a SiO_2 matrix. A consistent correlation between Fc and electrical properties is found.

Keywords: $\mu c - SiOx : H$, STEM, EELS, Plasmon Imaging, XPS, ESCA, Raman, IRL, Micromorph, Solar Cells, Silicon Filaments

DS 41.7 Thu 16:30 CHE 91

High Vapour Pressure Selenization and Grain Growth Mechanisms of Sulfide-CZTS Precursors — •Justus Just[1], Steffen Kretzschmar[1], Stephan van Duren[1], Roland Mainz[1], Claudia Coughlan[2], Kevin Ryan[2], and Thomas Unold[1] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie — [2]University of Limerick, Irland

We report about the fundamental growth mechanisms and properties of CZTS,Se absorber layers, produced by selenization of various different precursors at high selenium partial pressures deposited in vacuum as well as in non-vacuum processes. We will compare the selenization and growth mechanisms of precursors consisting of PVD-

deposited CZTS at low temperature, CZTS nanoparticles and wurzite CZTS nanorods. Samples are characterized by scanning electron microscopy, depth resolved elemental analysis (energy dispersive X-ray fluorescence) and X-ray diffraction. In order to estimate the electronic quality of the selenized material, photoluminescence measurements are carried out additionally. While the selenization is similar depending on the temperature and selenium partial pressure for different types of precursors, the grain growth mechanisms are found to be substantially different, as the grain growth is depending on nucleation and interdiffusion of cations.

DS 41.8 Thu 16:45 CHE 91

Growth and characterization of polycrystalline $Cu_2ZnSnSe_4$ layers with a preferential grain orientation — •Christoph Krämmer[1], Johannes Sachs[1], Mario Lang[1], Chao Gao[1], Sabine Schuster[1], Michael Powalla[2], Heinz Kalt[1], and Michael Hetterich[1] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Light Technology Institute, KIT, and Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70565 Stuttgart, Germany

The absence of the technologically relevant metals indium and gallium makes the kesterite $Cu_2ZnSnSe_4$ (CZTSe) material system a promising alternative to the established Cu(In,Ga)Se_2. Hiqh-quality CZTSe layers on GaAs would be highly desirable for the study of basic material properties such as the band structure. We use selenization of a Sn/Cu/ZnSe(001) structure on GaAs(001) substrate in order to fabricate polycrystalline CZTSe layers with preferential grain orientation. In this contribution we present a detailed investigation of those layers by means of X-ray diffraction and Raman spectroscopy. These measurements prove that a highly preferential grain orientation in all three dimensions is indeed obtained in the formed CZTSe film.

DS 41.9 Thu 17:00 CHE 91

Raman investigation of $Cu_2ZnSnSe_4$ layers with and without preferential grain orientation — •Mario Lang[1], Christoph Krämmer[1], Johannes Sachs[1], Chao Gao[1], Sabine Schuster[1], Michael Powalla[2], Heinz Kalt[1], and Michael Hetterich[1] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Light Technology Institute, KIT, and Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70565 Stuttgart, Germany

$Cu_2ZnSnSe_4$ (CZTSe) is attracting more and more attention as an alternative to the well-established Cu(In,Ga)Se_2 material system for thin-film photovoltaics due to its composition of earth-abundant elements. Raman spectroscopy is a powerful technique to detect secondary phases in the thin-film absorber layers. Futhermore, using polarization-dependent measurements it is possible to gain information on the crystal orientation when performed on samples with a preferential grain orientation. We present a comparative study of polycrystalline absorber layers with and without a preferential grain orientation. The results are analyzed using theoretical modeling of the Raman line intensities.

DS 41.10 Thu 17:15 CHE 91

Radiative recombination in Cu2ZnGeSe4 single crystals — •Sergiu Levcenko[1], Maxim Guc[2], Steffen Kretzschmar[1], Ernest Arushanov[2], and Thomas Unold[1] — [1]Helmholtz Zentrum Berlin für Materialien und Energie, 14109 Berlin,Germany — [2]Institute of Applied Physics, Academy of Sciences of Moldova, MD 2028 Chisinau, Moldova

Cu2ZnGeSe4 (CZGSe) is considered as a promising absorber material for thin film solar cells, owing to its high absorption coefficient and its optimum band gap for the sunlight spectrum. While structure and optical properties of CZGSe are studied, little is known about its electronic structure. To reveal intrinsic defect properties of this semiconductor we carried out photoluminescence spectroscopy on the CZGSe single crystals grown by chemical vapour transport. At low temperature two defect related transitions at about 1.2 and 1.3eV were observed. These transitions are systematically investigated by means of temperature and excitation dependent measurements and the defect recombination model has been proposed.