DS 37: Focus Session: Sustainable Photovoltaics with Earth Abundant Materials I

Energy conversion technologies, especially photovoltaics, exibit enormous growth aiming at extremely high power capacities per year. Therefore nontoxicity, low energy footprint and abundance of the materials used for photovoltaic devices are among the key requirements to a sustainable photovoltaic technology. Binary and ternary oxides and related materials are promising as the key materials to reach these goals. From this point of view copper and zinc based materials like ZnO, ZnS, Cu_2O, $ZnSnN_2$, Cu_2S, Zn_3P_2, $Cu(In,Ga)Se_2$, $Cu_2ZnSn(S,Se)_4$ are of special interest. For instance, the combination of ZnO and Cu_2O has been shown to be one of the promising approaches for next generation photovoltaics. Theoretical predictions promise efficiencies of such solar cells of up to 18%. Recently a breakthrough has been reported demonstrating of ZnO/Cu_2O thin film solar cell with efficiency of ca. 5%. Nevertheless, the fabricated devices are still far from commercial application. Further fundamental investigations are needed in order to understand the relevant materials and device physics in detail and to improve the efficiency of the cells. Progress on the growth of thin films, heterostructures and nanostructures, as well as new fabrication approaches will be discussed. Special attention will be given to the effect of the materials properties on the device efficiency, phenomena at interfaces, band gap alignment and surface passivation. This topical session aims to give an overview over the latest developments in the dynamic field of sustainable photovoltaics with earth abundant materials. (Organizers: Andrey Bakin and Andreas Waag, Technische Universität Braunschweig)

Time: Thursday 9:30–12:45 Location: CHE 91

Invited Talk DS 37.1 Thu 9:30 CHE 91

Photovoltaics with Copper Oxides — •Bruno Meyer — 1. Physikalisches Institut, JLU Giessen

The p-type conducting Copper-oxide compound semiconductors (Cu2O, Cu4O3 and CuO) provide a unique possibility to tune the band gap energies from 2.1 eV to the infrared at 1.40 eV into the middle of the efficiency maximum for solar cell applications. They appear to be an attractive alternative absorber material in terms of abundance, sustainability, and non-toxicity of the elements. Heterostructures with n-type AlGaN and MgZnO will be the basis of the solar cells. We present experimental results on the band offsets between the three copper oxides and the transparent conducting oxides and nitrides. Based on these finding various combinations of thin-film solar-cells are fabricated and compared to each other. The role of intrinsic defects and interface properties are discussed.

Invited Talk DS 37.2 Thu 10:00 CHE 91

Energy band alignment at interfaces of polycrystalline semiconductors for thin film solar cells — •Andreas Klein — Technische Universität Darmstadt, Germany

Thin film solar cells utilizing CdTe or $Cu(In,Ga)Se_2$ chalcogenide semiconductors have reached conversion efficiencies close to or even above 20%, respectively. The device structure of these cells is characterized by a sequence of an ohmic back contact, an unintentionally doped medium-gap chalcogenide as light absorber, a wide-gap chalcogenide buffer layer, and a transparent conducting oxide (TCO) front contact. Critical for high conversion efficiencies of such heterojunction devices is the energy band alignment at the various interfaces, which enable or block current transport. Historically, suitable interface properties have been achieved mainly by empirical device optimization. Photoelectron spectroscopy (PES) can provide detailed information on the chemical and electronic interface properties. This contribution introduces the experimental approach of interface analysis using PES and reviews available experimental data and understanding of interfaces for various thin film solar cells. In addition to interface properties of CdTe, $Cu(In,Ga)Se_2$, metallic back contacts, and TCO front contacts, the challenge of finding new absorber materials and device structures will be particularly addressed.

Invited Talk DS 37.3 Thu 10:30 CHE 91

Use of doped oxides for enhanced performance solar cells — •Judith MacManus-Driscoll — Dept. Materials Science, University of Cambridge, U.K.

ZnO and TiO2 are two of the most commonly used n-type metal oxide semiconductors in new generation solar cells due to their abundance, low-cost and stability. ZnO and TiO2 can be used as active layers, photoanodes, buffer layers, transparent conducting oxides, hole-blocking layers and intermediate layers. Doping is essential to tailor the materials properties for each application. The dopants used and their impact in hybrid solar cells and all inorganic solar cells are presented. In addition, the advantages, disadvantages and commercial potential of the various low energy fabrication methods of these oxides are presented.

Coffee break (15 min)

Invited Talk DS 37.4 Thu 11:15 CHE 91

Nanowire device concepts for thin film photovoltaics — •Silke Christiansen — Helmholtz Zentrum für Materialien und Energie, Berlin — Max-Planck-Institute for the Science of Light, Erlangen

Aligned silicon nanowire (SiNW) arrays to aim for power conversation efficiencies >>15% are fabricated on multi-crystalline Si layers on glass substrates using reactive ion etching with prior lithographic patterning using densely packed polystyrene (PS) spheres. Diameter, length, density and shape of SiNWs can be controlled and tuned for highest absorptions (close to 90%). Cell concepts with SiNWs are realized: (i) a hybrid organic/inorganic cell using SiNWs as absorber and PEDOT:PSS as a hole conducting polymer; (ii) a semiconductor-insulator-semiconductor (SIS) cell with SiNWs as absorbers, oxide (few Å thick Al2O3 by atomic layer deposition-ALD)) tunneling barriers for charge carrier separation and a transparent conductive oxide (TCO here: Al:ZnO, by ALD). Initial thin film solar cell prototypes reached open-circuit voltages of > 680 mV, short-circuit current densities of even > 35 mA/cm2 and efficiencies >13%. Advanced analytics to improve materials and cells are: (i) electron beam induced current (EBIC) to study charge carrier distributions; (ii) electron backscatter diffraction (EBSD) to study structural quality of the multi-crystalline Si layer; (iii) integrating sphere measurements to study optical properties and (iv) 4-point nano-probing to study electrical properties. Alternative electrodes such as graphene or silver nanowire webs are studied to even further improve the cells.

Invited Talk DS 37.5 Thu 11:45 CHE 91

Core shell ZnO nanowire heterostructures for solar cells — •Vincent Consonni — Laboratoire des Matériaux et du Génie Physique, Grenoble INP - CNRS, Minatec, 3 parvis Louis Néel 38016 Grenoble, France

ZnO nanowires (NWs) have received increasing interest due to their potential applications for instance in photovoltaic devices via core shell heterostructures. The core can be composed of ZnO NWs as electron transporting layer and the shell can comprise an absorbing layer such as a direct band gap semiconductor or a chemical dye in order to form type II heterostructures [1,2]. In this work, the structural properties and electron scattering mechanisms are investigated for SnO2:F thin films acting as front electrodes in nanostructured solar cells made from ZnO NW heterostructures [3]. A special emphasis is made on the formation mechanisms of ZnO NWs in solution by specifically focusing on polarity and crystal orientation effects [4]. Also, the light absorption properties of core shell ZnO NW heterostructures are studied by rigorous coupled wave analysis in order to design nanostructured solar cells. Eventually, several types of solar cells made from core shell ZnO

NW heterostructures are fabricated by using different types of absorbing layers and their photovoltaic performances are tested under dark and AM 1.5G standard illumination conditions [1,2].

[1] V. Consonni et al., Appl. Phys. Lett. 98, 111906 (2011). [2] E. Puyoo et al., J. Phys. Chem. C 116, 18117 (2012). [3] V. Consonni et al., Acta Mater. 61, 22 (2013). [4] S. Guillemin et al., J. Phys. Chem. C 117, 20738 (2013).

Invited Talk DS 37.6 Thu 12:15 CHE 91

Potential and challenges of kesterite-type materials for thin film solar cells — •Thomas Unold — Helmholtz-Zentrum Berlin für Materialien und Energie

$Cu_2ZnSn(S,Se)_4$ thin film semiconductors have attracted much interest recently because of their potential application as absorber layers in thin-film solar cells. These kesterite-type materials can be derived from the chalcopyrite semiconductor $CuInSe_2$ by replacing the relatively rare element indium alternatingly with the more abundant elements tin and zinc, which would allow sustainable deployment of this technology on the terawatt scale. The close relation of their crystal structures raises the hope that also for the kesterite materials the excellent optoelectronic properties of their chalcopyrite cousins can be achieved. Although conversion efficiencies of 12% have now been demonstrated for kesterite-type solar cells, this value is still substantially lower than the record efficiencies above 20% for $Cu(In,Ga)Se_2$. One major challenge with kesterite materials lies in the control over defects and secondary phases imposed by the quartenary nature of this semiconductor. Interestingly, solution-based synthesis methods so far have yielded electronically superior material compared to vacuum-based deposition methods, in contrast to previous experience with the synthesis of almost any other inorganic semiconductor.