

## CPP 68: Focus Session Hybrid Photovoltaics and Perovskites (joint session CPP, HL)

Time: Thursday 15:00–18:15

Location: C 130

**Invited Talk** CPP 68.1 Thu 15:00 C 130  
**Photophysics of organic-inorganic hybrid lead iodide perovskite single crystals** — ●MARIA ANTONIETTA LOI — Zernike Institute for Advanced Materials, University of Groningen, The Netherlands

Hybrid organometal halide perovskites have been demonstrated to have outstanding performance as semiconductors for solar energy conversion. Further improvement of the efficiency and stability of these devices requires a deeper understanding of their intrinsic photophysical properties. Here we address the intrinsic material physics by investigating the structural and optical properties of high quality single crystals of Methyl Ammonium Lead Iodide from room temperature to 5K. X-ray diffraction reveals an extremely sharp transition at 163 K from a twinned tetragonal I4/mcm phase to a low-temperature phase characterized by complex twinning and possible frozen disorder. Above the transition temperature the photoluminescence is in agreement with a band-edge transition, explaining the outstanding performances of the solar cells. Whereas below the transition temperature, three different features arise, one of which is attributed to a singlet-free-exciton and the other two to bound-triplet excitons. The bound-triplet excitons are characterized by a decay dynamics of about 5 $\mu$ s and by a saturation phenomenon due to many-body interactions. This results in a description of the room temperature recombination as being due to spontaneous band-to-band radiative transitions and weak non-radiative Auger processes, whereas a diffusion-limited behaviour is expected for the low temperature range.

**Invited Talk** CPP 68.2 Thu 15:30 C 130  
**Exciton stabilization in hybrid lead-halide perovskites: photophysical versus structural properties** — ●ANNAMARIA PETROZZA — Istituto Italiano di Tecnologia, Milan, Italy

Hybrid perovskites represent a new, disruptive technology in the field of optoelectronics. Hybrid halide perovskites, e.g. CH<sub>3</sub>NH<sub>3</sub>PbX<sub>3</sub> [X = Cl, Br, or I], are usually deposited as polycrystalline thin-films with variable mesoscale morphology depending on the growth conditions. The obtained grain size ranges from tens to thousands of nm. Over the last two years the impressive improvement of photovoltaic performance has been driven by radical empirical evolution of the device architecture and processing methodologies. However, there is a considerable lack of understanding of material properties, both as pristine films and their embodiment in a device. Here we demonstrate, through a combination of femto-second transient absorption spectroscopy, structural analysis and multi-scale modeling as a function of crystal size and temperature, that the electron-hole interaction is sensitive to the microstructure of the material. We find that by control of the material processing during fabrication both free carrier and Wannier excitonic regimes are accessible. Thus, a definitive classification excitonic or free carrier semiconductor is not possible. The long-range order of the organic cation dipole field is disrupted by polycrystalline disorder introducing domain walls where dipole twinning breaks down. The variations in electrostatic potential found for smaller crystallites suppress exciton formation, while larger crystals of the same composition demonstrate an unambiguous excitonic state.

CPP 68.3 Thu 16:00 C 130  
**Morphology-dependent ultrafast spectroscopy of lead-halide perovskite for electro-optical applications** — ●SIMON BRETSCHNEIDER, MELIKE KARAKUS, VALENTIN KAMM, ENRIQUE CÁNOVAS, and FRÉDÉRIC LAQUAI — Max Planck Institut für Polymerforschung, Mainz

Lead-halide perovskite have emerged as a new class of materials for electro-optical, especially photovoltaic applications with power conversion efficiencies now up to 20% [1]. High-performance electro-optical devices rely on perovskite films without pinholes, flat surface and well-defined thickness. Due to the organic/inorganic nature of the lead-halide perovskite and the criticalness of a pure perovskite phase without impurities of the precursors, utilization of solution-processing is non-trivial.

The combination of time-resolved photoluminescence and transient absorption spectroscopy is a powerful tool, which allows for the investigation of generation and recombination of charge carriers in lead-halide perovskite films on a femto- to microsecond timescale and across a

spectral range from Vis to NIR. In this work, we present pump-probe transient absorption measurements of solution-processed lead-halide perovskite films grown in ambient and dry nitrogen atmosphere using different post-processing annealing schemes. The findings of ultrafast spectroscopy suggest that the performance of lead-halide perovskite films for electro-optical applications relies more on homogeneous films than on specific crystal sizes.

[1]NREL Chart of record cell efficiencies (28.11.2014).

CPP 68.4 Thu 16:15 C 130  
**Time-resolved confocal microscopy of hybrid metal halide perovskite thin films** — ●KATHRIN BADER, RICHARD CIESIELSKI, NADJA GIESBRECHT, JOHANN M. FECKL, IRENE GRILL, FABIAN C. HANUSCH, THOMAS BEIN, PABLO DOCAMPO, MATTHIAS HANDLOSER, and ACHIM HARTSCHUH — Department Chemie and CeNS, LMU Munich, Germany

Organic-inorganic metal halide perovskite solar cells (PSCs) have seen an unprecedented development over the past 4 years due to their potential to fulfill most requirements for large scale production. Extremely fast progress in the field of perovskite absorbers has taken solar cell efficiencies from 10 % in 2012 [1] to over 19 % in 2014 [2]. A crucial parameter for the functioning of solar cells is a long charge carrier diffusion length that allows to effectively collect photogenerated charges. To determine this diffusion length several experimental methods have been reported that either provide indirect information or use electrical contacts [3,4]. We used time-resolved laser scanning confocal microscopy to visualize the transport range and timescale of photo-excited species within the film. The experimentally observed transport length range up to several microns under high light intensity conditions. Our results help to explain the high short circuit currents that can be achieved in PSCs. Financial support by the DFG through the Nanosystems Initiative Munich (NIM) is gratefully acknowledged. [1] M. M. Lee et al., Science 338, 643 (2012) [2] H. Zhou et al., Science 345, 542 (2014) [3] S. D. Stranks et al., Science 342, 6156 (2013) [4] E. Edri et al., Nat. Commun. 5, 3461 (2014)

CPP 68.5 Thu 16:30 C 130  
**Preparation and characterization of methylammonium lead halide perovskite solar cells in planar-type configuration** — ●PHILIPP RIEDER<sup>1</sup>, MATTHIAS FISCHER<sup>1</sup>, STEFAN VÄTH<sup>1</sup>, ANDREAS BAUMANN<sup>2</sup>, KRISTOFER TVINGSTEDT<sup>1</sup>, and VLADIMIR DYAKONOV<sup>1,2</sup> — <sup>1</sup>Experimentelle Physik 6, Julius-Maximilians-Universität Würzburg, 97074 Würzburg — <sup>2</sup>Bayerisches Zentrum für Angewandte Energieforschung, 97074 Würzburg

In recent years, the use of organometal halide compounds as the photoactive layer in solar cells has attracted a lot of attention, with power conversion efficiencies (PCE) reaching up to 20.1% already. The performance and properties of this material class are strongly dependent on the crystallinity of the layer, with the working principles still being unclear and part of ongoing research. By synthesizing our own methylammoniumiodide as the organic precursor, we are able to fabricate solution processed planar heterojunction perovskite solar cells with an active layer consisting of CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub> or CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3-x</sub>Cl<sub>x</sub>. PCE values of the working devices exceeding 10% under solar illumination are achieved. The crystallinity and surface quality of the films are analyzed via scanning electron microscopy, atomic force microscopy and x-ray diffraction. The solar cells are characterized by means of current-voltage measurements, external quantum efficiency and photoluminescence.

CPP 68.6 Thu 16:45 C 130  
**Spatially resolved photocurrent generation in organolead halide perovskite solar cells** — THOMAS J.K. BRENNER, ANDREAS PAULKE, NATALIE SCHÖN, ROBERTA SAPONARO, and ●DIETER NEHER — Institute of Physics & Astronomy, University of Potsdam, Germany

Hybrid perovskite solar cells have shown to be efficient in various device structures, for example in planar, vapour deposited films, in and on mesostructured metal oxides and in solution-processed films of different crystallinity. Here, we study ITO/PEDOT:PSS/CH<sub>3</sub>NH<sub>3</sub>PbI<sub>3</sub>/PCBM/C60/BCP/Al devices with different perovskite crystallinity and identify regions of efficient photocurrent generation with submicrometer resolution. We establish a

relationship between crystallinity and device performance and study the role of grain boundaries for photocurrent generation. We correlate our results to time delayed collection field (TDCF) measurements of charge generation to identify ways to further enhance photocurrent generation in this class of photovoltaic devices.

**15 min. break.**

CPP 68.7 Thu 17:15 C 130

**Unbalanced Charge Distribution Inside a Perovskite-Sensitized Solar Cell in Real Space** — •VICTOR W. BERGMANN<sup>1</sup>, STEFAN A.L. WEBER<sup>1</sup>, F. JAVIER RAMOS<sup>2</sup>, MOHAMMAD KHAJA NAZEERUDDIN<sup>3</sup>, MICHAEL GRÄTZEL<sup>3</sup>, DAN LI<sup>1</sup>, ANNA L. DOMANSKI<sup>1</sup>, INGO LIEBERWIRTH<sup>1</sup>, SHAHZADA AHMAD<sup>2</sup>, and RÜDIGER BERGER<sup>1</sup> — <sup>1</sup>Max Planck Institute for Polymer Research, Mainz, Germany — <sup>2</sup>Abengoa Research, Seville, Spain — <sup>3</sup>Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

Solar cells based on perovskite light absorbing materials reached power conversion efficiencies >20%. Today, the knowledge about the local charge generation processes inside these solar cells is limited. We prepared smooth cross sections by means of focused ion beam milling such that the full structure and functionality of the devices were preserved [1]. This way, the internal interfaces between the different materials in the cell are accessible for frequency modulation Kelvin Probe Force Microscopy (FM-KPFM). Upon illumination under short-circuit conditions, holes accumulate in front of the hole transport layer, which is proof of an unbalanced charge transport. This potential barrier reduces the charge transfer towards the electrode. Furthermore after light illumination, we measured remaining charges inside the active device area. These charges were attributed to traps in the material. In conclusion, the FM-KPFM method allows us not only to map the local contact potential variation but also to correlate it with the local structure of the functional layers.

[1] Bergmann et al. Nature Communications 5, 5001 (2014).

CPP 68.8 Thu 17:30 C 130

**Charge Transport in Dye-sensitized Solar Cells: What do J-transients really depend on?** — •FRANK MARLOW, ABIGAIL HULLERMANN, and LISANNE MESSMER — MPI für Kohlenforschung, 45470 Mülheim an der Ruhr, Germany

J-transients (electrical current transients) following a laser excitation are considered as a powerful tool for the understanding of the action of dye-sensitized solar cells. In the last years, a sophisticated model for their understanding has been established which, however, turns out to be in contradiction with a number of experimental findings including the J-signal shape and the signal dependences on experimental parameters. It is especially remarkable that there are the always delays of the

electrical signal after the laser excitation and that the possible diffusion times do not follow an Einstein diffusion relation which is a-priori assumed in many works.

CPP 68.9 Thu 17:45 C 130

**Spray deposition of titania films with introduction of crystalline nanoparticles for solid-state dye-sensitized solar cells** — •LIN SONG<sup>1</sup>, WEIJIA WANG<sup>1</sup>, VOLKER KÖRSTGENS<sup>1</sup>, DANIEL MOSEGUÍ GONZÁLEZ<sup>1</sup>, YUAN YAO<sup>1</sup>, NORMA K. MINAR<sup>2</sup>, DINA FATTAKHOVA-ROHLFING<sup>2</sup>, STEPHAN V. ROTH<sup>3</sup>, and PETER MÜLLER-BUSCHBAUM<sup>1</sup> — <sup>1</sup>TU München, Physik-Department, LS Funktionelle Materialien, James-Franck-Str. 1, 85748 Garching — <sup>2</sup>LMU München, Department of Chemistry and Center for NanoScience, Butenandtstr.5-13 (E), 81377 Munich — <sup>3</sup>Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany

Solid-state dye-sensitized solar cells (ssDSSCs), using solid-state hole transporting materials (HTM) as alternatives for dye generation and hole transport, have received immense attention because such photovoltaic devices avoid the leakage and corrosion problems in conventional DSSCs. In particular, ssDSSCs based on TiO<sub>2</sub> and organic HTM are of great interest due to the combined advantages of both organic and inorganic components. We investigate this kind of solar cells fabricated using mesoporous titania films as electron transporting materials, a metal-free dye D149 as a light harvester, and P3HT as HTM. For optimizing the device performance, we introduce crystalline titania nanoparticles into the titania film in order to obtain a more effective titania photoanode. Moreover, spray coating is employed for the film deposition because it is simple, low cost, and usable for large-scale production. The morphology and crystallinity of titania films are investigated, showing a crucial influence on final device performance.

CPP 68.10 Thu 18:00 C 130

**ZnO coated TiO<sub>2</sub> photoanodes with improved electron transfer for dye sensitized solar cells** — •BO LIU<sup>1</sup>, PETER LEMMENS<sup>1</sup>, ANDREY BAKIN<sup>2</sup>, ANDREAS WAAG<sup>2</sup>, AIDIN LAK<sup>3</sup>, MEINHARD SCHILLING<sup>3</sup>, WINFRIED DAUM<sup>4</sup>, and SAMIR KUMAR PAL<sup>5</sup> — <sup>1</sup>IPKM, TU-BS, Braunschweig — <sup>2</sup>IHT, TU-BS, Braunschweig, Germany — <sup>3</sup>EMG, TU-BS, Braunschweig, Germany — <sup>4</sup>IEPT, TU Clausthal — <sup>5</sup>SNBC, Kolkata, India

ZnO coated TiO<sub>2</sub> photoanodes for cost efficient dye sensitized solar cells are prepared using anodization of a metal electrode leading to an array of TiO<sub>2</sub> nanotubes. Atomic layer deposition is used for the conformal covering by ZnO. Following hematoporphyrin sensitization the improved electron transfer is probed using time resolved fluorescence. Work supported by RTG-DFG 1953/1, Metrology for Complex Nanosystems and the Laboratory for Emerging Nanometrology, TU Braunschweig.