

CPP 13: Poster: Fundamentals of Perovskite Photovoltaics (joint session CPP, DS, HL)

Time: Monday 18:30–21:00

Location: P1A

CPP 13.1 Mon 18:30 P1A

Hybrid photovoltaics based on diblock copolymer structured, mesoporous Ge thin films — ●ANDREAS HETZENECKER¹, NURI HOHN¹, MICHAEL GIEBEL², THOMAS F. FÄSSLER², and PETER MÜLLER-BUSCHBAUM¹ — ¹TU München, Physik-Department, LS Funktionelle Materialien, James-Franck-Str. 1, 85748 Garching — ²TU München, Chemie-Department, LS Anorganische Chemie mit Schwerpunkt Neue Materialien, Lichtenbergstr. 4, 85748 Garching

Hybrid photovoltaics opens new possibilities in solar cell design, combining the mechanical stability and high charge carrier mobility of semiconductors with the potentially cost-efficient, large scale production and flexibility of organic materials. The usage of poly(styrene-*b*-ethylene oxide) as a template and K₄Ge₉ Zintl clusters as an inorganic precursor [1] for sol-gel synthesis is a novel approach to produce mesoporous germanium structures. This method offers control over pore size and degree of porosity via the block lengths of the template and the reactant concentrations. Sponge-like germanium thin films were synthesized and characterized regarding their absorption behavior with UV/Vis spectroscopy. Structural analysis was performed via SEM and profilometry.

[1] M. M. Bentlohner et al., *Angewandte Chemie International Edition*, 55, 2441-2445 (2015).

CPP 13.2 Mon 18:30 P1A

Ultrafast charge and exciton dynamics in CH₃NH₃PbI₃ — ●KESTUTIS BUDZINAUSKAS¹, YAJUN GAO¹, ELINA PATSIKATHEODOROU¹, TOBIAS SCHNEIDER², SELINA OTLHOFF², KLAUS MEERHOLZ², and PAUL H.M. VAN LOOSDRECHT¹ — ¹University of Cologne, II physics institute — ²University of Cologne, Institute of chemical physics

Solar cells based on organic-inorganic perovskite semiconductors show a surprisingly high conversion efficiency. Despite tremendous progress in the field of perovskite based devices, the fundamental photophysics responsible for the good performance are still not well understood. In order to obtain a better insight of the charge separation and recombination dynamics in these materials we have performed ultrafast time resolved absorption experiments in the VIS/NIR spectral range on pure MAPbI₃ (CH₃NH₃PbI₃) films, as well as on multilayer systems which use PEDOT:PSS and PC₆₁BM as charge selective extraction layers. Our experiments allow to selectively monitor diffusion and recombination processes as well as interfacial charge transfer and the formation of interfacial charge transfer states with a sub-100 fs time resolution

CPP 13.3 Mon 18:30 P1A

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CPP 13.4 Mon 18:30 P1A

morphology evolution of titania films during in situ spray coating for perovskite solar cells — ●BO SU¹, HERBERT A. CALLER-GUZMAN¹, VOLKER KÖRSTGENS¹, YICHUAN RUI², YUAN YAO¹, STEPHAN V. ROTH³, and PETER MÜLLER-BUSCHBAUM¹ — ¹TU München, Physik-Department, LS Funktionelle Materialien, James-Franck-Str. 1, 85748 Garching, Germany — ²College of Chemistry and Chemical Engineering, Shanghai University of Engineering

Science, Shanghai 201620, P. R. China — ³DESY, Notkestr. 85, 22607 Hamburg, Germany

We combine a sol-gel route with spray coating to obtain porous titania films. Spray coating is used as deposition method since it is allowing for scaling-up to large scale production. A block copolymer template assisted sol-gel process is used to form nanostructured titania films. The structure evolution is probed with in situ GISAXS during the spray coating process, enabling the detection of characteristic length scales during fabrication. The morphology of the sprayed films is characterized ex-situ with SEM, TEM and optical microscopy as well. In addition, the crystalline structure of the titania films is probed with XRD. The perovskite solar cells based on sprayed titania films are characterized under AM 1.5G standard condition. We extract a structure-function relationship for different spray parameters.

CPP 13.5 Mon 18:30 P1A

Influence of processing parameters on the morphology of perovskite solar cells — ●ARMIN SCHREIBER, JOHANNES SCHLIPF, and PETER MÜLLER-BUSCHBAUM — TU München, Physik-Department, LS Funktionelle Materialien, James-Franck-Str. 1, 85748 Garching

Over the last decade, especially lead halide perovskites as an organic-inorganic hybrid compound received attention due to the exceptional rise in the power conversion efficiency (PCE) of research cells from 3.8 % in 2009 to more than 20 % in early 2016. The most common active layer material is methylammonium lead iodide (MAPbI₃). It can be fabricated using a solution conversion method consisting of firstly spin-coating lead iodide (PbI₂) and secondly immersing it in a solution of dissolved methylammonium iodide. This leads to strong preferential crystal orientations as evidenced by grazing-incidence small angle X-ray scattering (GIWAXS) measurements. The crystal orientation is tunable via temperature variation of precursors of the perovskite and the use of additives into the precursor or conversion solution [1]. We expand this study by the use of mixed solvent approaches with processing additives in order to further tune the time scales of the crystallization processes and gain more control of the film morphologies of perovskite thin films as well as improving the reproducibility and long-term stability.

[1] L. Oesinghaus et al., *Adv. Mater. Interfaces* 2016, 1600403

CPP 13.6 Mon 18:30 P1A

Morphology of Perovskite-Based Hybrid Solar Cells — ●KIRAN MATHEW JOHN, JOHANNES SCHLIPF, and PETER MÜLLER-BUSCHBAUM — TU München, Physik-Department, LS Funktionelle Materialien, James-Franck-Str. 1, 85748 Garching

Organometal halide perovskites, have been shown to be great candidates for photovoltaics, owing to the strong solar absorption and the high mobility and low recombination rates of photo-generated charge carriers in these compounds. Subsequently, solar cells made from perovskites have reached efficiencies of more than 20%, making them comparable with commercially available silicon solar cells. The performance of the perovskite cells greatly depend on their crystal morphology. We fabricate and characterise different cells by varying processing parameters including film deposition methods, annealing temperature and solvent media. By means of X-ray scattering methods, we gain insight into the inner film morphology and thus are able to correlate morphology and photovoltaic performance, with the target to get better fundamental understanding.

CPP 13.7 Mon 18:30 P1A

Polarisation resolved optical spectroscopy of single CsPbI₃ nanocrystals — ●MIRKO GOLDMANN^{1,2}, DANIELA TÄUBER^{1,5}, JUANZI SHI¹, JUNSHENG CHEN³, MARIA E. MESSING^{4,5}, KAIBO ZHENG³, and IVAN G. SCHEBLYKIN^{1,5} — ¹Single molecule spectroscopy group, Lund University, Sweden — ²TU Ilmenau, Germany — ³2D spectroscopy group, Lund University, Sweden — ⁴Solid State Physics, Lund University, Sweden — ⁵NanoLund, Lund University, Sweden

Semiconducting metal halide nanocrystals are promising candidates for optoelectronic devices due to their high quantum yield and solution processability. Fully inorganic CsPbI₃ is more stable than CH₃NH₃PbI₃. Polarization resolved optical spectroscopy of single CsPbI₃ nanocrystals probes their cubic crystal structure and spirical

shapes. Photoluminescence emission from freshly synthesized $CsPbI_3$ nanocrystals was found to be almost unpolarized. Several weeks old nanocrystals showed an increased appearance of polarized photoluminescence in agreement with the observation of elongated crystal shapes by TEM.

CPP 13.8 Mon 18:30 P1A

Gold cluster growth kinetics at the metal-polymer interface of water-processed hybrid solar cells studied by in-situ GISAXS sputter deposition — ●ADRIAN HAUSSMANN¹, VOLKER KÖRSTGENS¹, FRANZISKA LÖHRER¹, MARTIN WÖRLE², HRISTO IGLEV², REINHARD KIENBERGER², MATTHIAS SCHWARTZKOPF³, ALEXANDER HINZ⁴, OLEKSANDR POLONSKY⁴, THOMAS STRUNSKUS⁴, FRANZ FAUPEL⁴, STEPHAN V. ROTH³, and PETER MÜLLER-BUSCHBAUM¹ — ¹TU München, Physik-Department, LS Funktionelle Materialien, James-Franck-Str. 1, 85748 Garching — ²TU München, Physik-Department, LS Laser- und Röntgenphysik, James-Franck-Str. 1, 85748 Garching — ³DESY, Notkestr. 85, 22607 Hamburg — ⁴CAU Kiel, Institut für Materialwissenschaft, Kaiserstr. 2, 24143 Kiel

In this work the metal-polymer interface between gold contact and active layer of water-processed hybrid solar cells is investigated. The active layer consists of an aqueous soluble polythiophene and laser-ablated titania nanoparticles. Gold sputter deposition is applied to the active layer. To obtain full information of gold cluster growth kinetics during sputter process, in-situ time resolved grazing incidence small angle X-ray scattering (GISAXS) experiments and grazing incidence wide angle X-ray scattering (GIWAXS) are carried out. Different growth regimes of gold clusters are observed from the GISAXS and GIWAXS data analysis and discussed.

CPP 13.9 Mon 18:30 P1A

Reduction of Hysteresis through PCBM in Planar Perovskite Solar Cells — ●YU ZHONG¹, CARLOS ANDRES MELO LUNA², RICHARD HILDNER², CHENG LI¹, and SVEN HÜTTNER¹ — ¹Organic and Hybrid Electronics, Macromolecular Chemistry I, University of Bayreuth — ²Experimental Physics IV, University of Bayreuth, Germany

Despite the development of organometal perovskite in solar cells, some problems still restrict its large-scale industrial application. Among these questions, it is urgent to address the hysteresis to realize highly efficient and reliable perovskite solar cells (PSC). The hysteresis is the discrepancy between two voltage-sweeping directions when performing a current-voltage (J-V) measurement. To suppress hysteresis, the introduction of [6,6]-phenyl-C61-butyric acid methyl ester (PCBM) in the planar PSC has proved as an effective way. However, there is still no comprehensive understanding on it, which is the topic of this poster.

Evidences consistently show that the iodide ion migration is critical for the hysteresis behavior. Herein, we employ PL microscopy to in-situ investigate the ion migration process. By comparing the mobility of the ions in perovskite films with and without PCBM, it shows the decrease of ionic migration velocity when PCBM molecules are involved. Furthermore, temperature-dependent J-V measurements show that the activation energy of iodide ions increases in presence of PCBM molecules. Our experiment suggests that PCBM molecules passivate the iodide related defects and reduce the migration of iodide ions, thus suppressing the hysteretic behavior in PSC.

CPP 13.10 Mon 18:30 P1A

Impact of additional PbI_2 and the grain size on optical properties in hybrid lead halide perovskites — ●TOBIAS MEIER¹, FABIAN PANZER^{1,2,3}, TANAJI GUJAR⁴, MUKUNDAN THELAKKAT⁴, and ANNA KÖHLER^{1,2} — ¹Experimental Physics II — ²Bayreuth Institute of Macromolecular Research (BIMF) — ³Department of Functional Materials — ⁴Applied Functional Polymers, Macromolecular Chemistry, University of Bayreuth, 95440 Bayreuth, Germany

Hybrid lead halide perovskites are a promising candidate for the absorbing layer in solar cells due to their excellent optical properties i.e. a direct band gap, a high absorption coefficient throughout the entire visible spectrum and a low exciton binding energy. It is known that the precise stoichiometry of the additives during film preparation is important for the device performance. For example a small amount of typically 10% extra PbI_2 was found to be beneficial for the performance. However, the mechanism of how incorporations of additional PbI_2 influences the optical and electronic properties and the role of grain boundaries are not completely understood yet. We therefore performed temperature dependent steady-state absorption and photoluminescence spectroscopy to investigate the impact of additional PbI_2

and the grain size on the fundamental optical properties in thin films of $CH_3NH_3PbI_3$.

CPP 13.11 Mon 18:30 P1A

Tuning the pore size of mesoporous titania films for hybrid solar cells — ●STEFFEN SCHLOSSER, NURI HOHN, LORENZ BIESSMANN, SENLIN XIA, and PETER MÜLLER-BUSCHBAUM — TU München, Physik-Department, LS Funktionelle Materialien, James-Franck-Str 1, 85748 Garching

Hybrid solar cells combine the mechanical stability of inorganic and the versatility of organic semiconductors. Due to their potential for large-scale application, hybrid solar cells are especially interesting for low-cost industrial production. As an inorganic compound, mesoporous titania films are common for application in high-efficiency hybrid solar cells. The mesoporous character offers a high interfacial contact with the organic surfactant, usually a conjugated polymer. Challenges concerning these cells arise due to the difficulty of controlling their nanoscale structure, which affects conductivity and degree of backfilling. We focus on the tuning of the pore size of mesoporous titania nanostructures and its impact on the infiltration of the polymeric compound. Tuning of the pore sizes provides the possibility of enhancing the backfilling and thus has a positive impact on solar cell performance. In our experiments, a solution composed of an amphiphilic block copolymer and a precursor dissolved in an organic solvent is applied as a film. Immersion in an antisolvent leads to a structure formation process in the composite film, so that after calcination, a mesoporous titania film is obtained. Depending on the parameters used, the pore size can be controlled.

CPP 13.12 Mon 18:30 P1A

Scanning force microscopy on perovskites — ILKA M. HERMES¹, VICTOR W. BERGMANN¹, DAN LI¹, ALEXANDER KLASSEN¹, SIMON BRETSCHNEIDER¹, MARKUS MEZGER^{1,2}, RÜDIGER BERGER¹, WOLFGANG TREMEL², and ●STEFAN A.L. WEBER^{1,2} — ¹Max Planck Institute for Polymer Research, 55128 Mainz, Germany — ²Johannes Gutenberg University, 55128 Mainz, Germany

In perovskite solar cells, nanoscale structures can have a huge impact on the device performance. For understanding this interplay, electrical scanning force microscopy (SFM) methods can correlate the nanoscale morphology with various surface properties: electrical conductivity (conductive SFM), surface potential in Kelvin probe force microscopy (KPFM) or electromechanical coupling in piezoresponse force microscopy (PFM). This poster provides an overview on our activities in SFM on perovskite films and solar cells. We used KPFM to map the potential distribution on cross sections of perovskite solar cell devices in dark and under illumination, revealing distinct differences in the charging dynamics at different interfaces [1,2]. With PFM on micron-sized perovskite grains we observed a periodically alternating structure reminiscent of ferroelastic domain patterns [3]. Using a SFM under controlled humidity, the effects of reversible hydration in perovskite films on the morphology were studied [4]. Such experiments provide valuable information for the optimization of the light harvesting abilities in these materials and the fabrication processes. [1] Nat. Comm. 2014, 5. [2] ACS AM&I, 2016, 8 (30), 19402. [3] J. Phys. Chem. C (2016), 120, 5724. [4] J. Phys. Chem. C, 2016, 120 (12), 6363.

CPP 13.13 Mon 18:30 P1A

Investigating the organometal halide perovskite crystallization in mesoscopic hole-conductor-free perovskite solar cells — ●OLIVER FILONIK^{1,2}, JIA HAU LEW², ANISH PRIYADARSHI², NRIPAN MATHEWS², and EVA M. HERZIG¹ — ¹TU München, Munich School of Engineering, Herzig Group, 85748 Garching, Germany — ²School of Materials Science and Engineering, Nanyang Technological University, Nanyang Avenue, Singapore 639798, Singapore

Organometal halide perovskite based solar cells have emerged as the fastest-advancing photovoltaic technology to date, reaching certified solar cell efficiencies of up to 22.1%. Recently, the focus of research broadened beyond high efficiencies to key values like prolonged device lifetime and stability that are required for industrial implementation. A novel perovskite cell architecture utilizing a mesoporous scaffold with embedded perovskite addresses these challenges and is furthermore adaptable for industrial scale production. However, little is known about the perovskite crystal formation in mesoscopic scaffolds.

In this project, we fabricate a mesoscopic scaffold comprised of a mesoporous triple-layer of titania, zirconia and carbon by screenprinting and are investigating the influence of the processing additive 5-

ammonium valeric acid iodide (5-AVAI) on the perovskite solution infiltration and perovskite crystallization. Hereby, our results grant us a better understanding of the perovskite crystallization processes in a mesoscopic scaffold and are of key importance for further developments.

CPP 13.14 Mon 18:30 P1A

Fabrication and Characterization of Mesoscopic Perovskite Solar Cells — ●MARGRET EVA THORDARDOTTIR^{1,2}, OLIVER FILONIK¹, PETER MÜLLER-BUSCHBAUM², and EVA M. HERZIG¹ — ¹TU München, Munich School of Engineering, Herzig Group, 85748 Garching, Germany — ²TU München, Physik-Department, LS Funktionelle Materialien, 85748 Garching, Germany

Photovoltaic solar cells have been regarded as a promising energy conversion method to keep up with the worlds increasing energy consumption. Organic solar cells yield promising prospects due to their low cost fabrication, light weight and mechanical flexibility. However, the efficiency of organic solar cells are inferior to commercial silicon solar cells. Organometal halide perovskite solar cells are a product of combining the advantages of organic and inorganic systems. The steep rise of the efficiency makes them the fastest-advancing solar cell technology to date. Properties of the perovskite material like large carrier diffusion lengths, high charge-carrier mobilities and low exciton binding energy all contribute to superior performance.

In this work, we fabricated mesoscopic perovskite solar cells by using a screenprinter. We analyze processing parameters and investigate the influence on the efficiency of the solar cell. To obtain fully printed solar cells, slot die coating is compared to drop casting of the perovskite materials onto the printed layers.

CPP 13.15 Mon 18:30 P1A

Two-Photon Photoluminescence from Quantum-Dot-Like Perovskite Nanocubes — ●ALEXANDER BIEWALD^{1,2}, VEIT GIEGOLD^{1,2}, RICHARD CIESIELSKI^{1,2}, FATMA MELTEM AYGÜLER^{1,2}, NICOLAI FRIEDRICH HARTMANN^{1,2}, PABLO DOCAMPO³, and ACHIM HARTSCHUH^{1,2} — ¹LMU Munich, Department Chemie and CeNS, 81377 Munich — ²Nanosystems Initiative Munich, 80799 Munich — ³Newcastle University, Newcastle upon Tyne, UK

Perovskites are a promising material class for new solar cell and LED applications. Especially perovskite nanocubes, with sizes below 10 nm, are interesting because they exhibit quantum confinement which allows for tuning their optical transition energies similar to other inorganic semiconducting nanocrystals. We investigated the photoluminescence (PL) of individual *CsPbBr₃* nanocubes deposited on glass upon pulsed two-photon excitation. Our setup combines a scanning confocal microscope and a pulse shaper in 4f geometry for amplitude and phase shaping of sub-20 fs laser pulses. We found that individual nanocubes show pronounced PL blinking, which we investigated in detail with respect to the characteristic on- and off-times. We also confirmed the non-linear intensity dependence of the PL that provides the basis for the coherent control of two-photon absorption in single nanocubes.

CPP 13.16 Mon 18:30 P1A

Investigation of planar perovskite solar cells by means of electrical impedance spectroscopy — ●MARKUS JAKOB¹, DAVID KIERMASCH¹, MATHIAS FISCHER¹, PHILIPP RIEDER¹, ANDREAS BAUMANN², and VLADIMIR DYAKONOV^{1,2} — ¹Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — ²Bavarian Center for Applied Energy Research (ZAE Bayern) Bayern, 97074 Würzburg

Hybrid organic-inorganic perovskites have been recognized as a promising material for photovoltaic devices and became a hotspot in this research field over the last years. Toward the common goal of developing more efficient and stable devices better insight into the working principles is required. The interface between the crystalline perovskite and the charge selective layer has been found to be a crucial factor for the solar cell device performance. An accumulation of charged particles, either charge carriers or ions at the interface may lead to extraction barriers leading to a decrease in the overall efficiency. We investigate highly efficient solution processed perovskite solar cells in planar configuration by means of electrical impedance spectroscopy. The cells are fabricated with the well-known two step interdiffusion method using PbI₂ and CH₃NH₃I. We discuss our results for different device configurations and transport materials to identify their impact on the dielectric properties.

CPP 13.17 Mon 18:30 P1A

Transient absorption spectroscopy of hole transport materials for perovskite solar cells — JONAS HÖLZER, JOHANNES KLEIN, MIRKO SCHOLZ, THOMAS LENZER, and ●KAWON OUM — Universität Siegen, Physikalische Chemie, Adolf-Reichwein-Str. 2, 57076 Siegen

Perovskite-based photovoltaic devices consist of multilayer arrangements containing mesoporous TiO₂, an organic-inorganic perovskite and a hole transport material (HTM) as central elements. We present a steady-state and time-resolved UV-Vis-NIR absorption study of such devices featuring different triarylamine-based HTMs, enabling us to quantify the efficiency and time scale of the hole transfer process. In addition, direct photoexcitation of the HTMs on mesoporous TiO₂ and Al₂O₃ thin films and in different organic solvents is investigated to understand their photophysics. They exhibit photoinduced electron injection into TiO₂ and form radical cation-radical anion pairs on Al₂O₃ by exciton-splitting. Implications of these processes for the performance of HTMs in photovoltaic devices will be discussed.

CPP 13.18 Mon 18:30 P1A

Investigation of the photophysical properties of methylammonium lead halide perovskite solar cells by electroluminescence spectroscopy — ●SIMON BERGER¹, PHILIPP RIEDER¹, DAVID KIERMASCH¹, MATHIAS FISCHER¹, KRISTOFER TVINGSTEDT¹, ANDREAS BAUMANN^{1,2}, and VLADIMIR DYAKONOV^{1,2} — ¹Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — ²Bavarian Center for Applied Energy Research ZAE, 97074 Würzburg

Organo lead halide perovskite solar cells are in the focus of current research as one of the most promising materials in thin film photovoltaics. With many cell configurations being presented so far, we evaluated solution-processed planar as well as mesoporous perovskite solar cells in terms of their corresponding ability to emit light, using the technique of electroluminescence spectroscopy. In that manner, we probed the impact of different transport materials in regular as well as inverted layouts by evaluating the radiative efficiency of devices. Additionally, we studied the effect of incorporating bromine as well as chlorine to partly replace the iodine in the crystal structure of the perovskite layer on the processes relevant for the operation of a solar cell.

CPP 13.19 Mon 18:30 P1A

Doping design for hole transport materials in perovskite solar cells — ●LORENA PERDIGÓN TORO, CHRISTIAN M. WOLFF, MALAVIKA ARVIND, and DIETER NEHER — University of Potsdam, Soft Matter Physics

In planar perovskite solar cells, the active perovskite semiconductor is usually sandwiched between an organic hole transport material (HTM) and an electron transport material (ETM). The correct choice of these materials has been shown to be crucially important when aiming at high device efficiencies. A promising HTM is the polymeric hole conductor poly(triaryl amine) (PTAA), which given its energetic levels has been shown to be a suitable choice as hole transport and electron-blocking layer. Nonetheless, the relatively low hole mobility of PTAA can be limiting to the performance of the devices, particularly the fill factor and open-circuit voltage. In order to provide sufficient coverage and prevent shunt pathways, thicker hole transport layers (>20 nm) can be efficiently applied provided their mobility can be increased. Therefore, we employ the widely studied electron acceptor F4TCNQ and the strong Lewis acid tris(pentafluorophenyl)borane as dopants for PTAA. Optical spectroscopy of doped solutions and layers insights into the underlying doping mechanisms. The impact of doping on layer morphology is studied by AFM, while the electrical properties are studied with systematic conductivity measurements at different operational conditions (e.g. elevated temperatures). Doped layers are optimized in working devices for highly efficient perovskite solar cells, reaching efficiencies above 18%.

CPP 13.20 Mon 18:30 P1A

Temperature-dependent optical spectra of (CH₃NH₃)PbBr₃ single-crystals cleaved in ultrahigh vacuum — ●OSKAR SCHUSTER¹, MAX WILHELM¹, DANIEL NIESNER¹, IEVGEN LEVCHUK², ANDRES OSVET², SHREETU SHRESTHA², MIROSLAW BATENTSCHUK², CHRISTOPH BRABEC^{2,3}, and THOMAS FAUSTER¹ — ¹Lehrstuhl für Festkörperphysik, FAU Erlangen-Nürnberg, Staudtstr. 7, D-91058 Erlangen, Germany — ²I-MEET, Department of Materials Science and Engineering, FAU Erlangen-Nürnberg, Martensstr. 7, D-91058 Erlangen, Germany — ³ZAE Bayern, Haberstr. 2a, D-91058 Erlangen, Germany

Temperature-dependent optical spectroscopy determines basic properties like band gap, exciton binding energy, and direct or indirect character of the gap. Differences have been reported between freshly cleaved crystals compared to as-grown ones or thin films. We present an approach that determines the absorption of cleaved crystals from measured one-photon and two-photon induced photoluminescence spectra. The extracted low-temperature band gap and exciton binding energy of 22 meV are in excellent agreement with the ones determined from other techniques. The direct band gap increases with temperature at < 200 K, and decreases at higher temperature. The behavior is well described by the Bose-Einstein model. The associated exciton binding energy decreases for temperatures > 200 K. We find a second transition 60 meV (90 meV) below the direct gap in the orthorhombic (tetragonal) phase, consistent with a slightly indirect gap. Emission from this transition is significantly reduced after exposing the crystals to air.

CPP 13.21 Mon 18:30 P1A

Photoinduced Charge Generation and Dynamics in Mixed Formamidinium Methylammonium Lead Halide Perovskite Thin Films as Observed by fs Transient Absorption Spectroscopy — ●JONAS HORN^{1,2,3}, IULIA MINDA², HEINRICH SCHWOERER², and DERCK SCHLETTWEIN^{1,3} — ¹Justus-Liebig-University Giessen, Institute of Applied Physics — ²Stellenbosch University, Laser Research Institute, South Africa — ³Justus-Liebig-University Giessen, Laboratory for Materials Science

Hybrid organic inorganic perovskite materials, in particular $FA_{1-x}MA_xPbI_{3-y}Br_y$ using formamidinium and methylammonium cations, are of great interest not only due to the rapid increase in power conversion efficiencies when applied in photovoltaic devices but also due to their astonishing optoelectronic properties. By means of transient absorption spectroscopy in the visible and near infrared spectral regions, temporal evolution of the population and depopulation of various electronic states and their associated spectral signatures was monitored. The detailed interpretation of the results leads to a consistent charge dynamic model of the initial photo-processes. Upon photoexcitation with 3.2 eV photon energy, hot electrons and holes are generated in the lowest conduction band and second highest valence band and relax to the band edges with a time constant of approximately 500 fs. Subsequently recombination, occurring on gradually faster time scales for hot versus cold electrons was shown and assigned to Auger- and bimolecular recombination.

CPP 13.22 Mon 18:30 P1A

Dye-Sensitized Solar Cells based on Low-Temperature Electrodeposited ZnO and Co(II/III) Redox Electrolyte — ●RAFFAEL RUESS^{1,2}, SEBASTIAN HAAS^{1,2}, ANDREAS RINGLEB^{1,2}, and DERCK SCHLETTWEIN^{1,2} — ¹Justus-Liebig-University Giessen, Institute of Applied Physics — ²Justus-Liebig-University Giessen, Laboratory for Materials Science (LaMa)

Emerging photovoltaics, such as dye-sensitized solar cells (DSSCs), have received great interest in the recent years because of quite high record efficiencies (<14.3%) and low energy payback times. The present work is focused on DSSCs based on electrodeposited, porous zinc oxide which allows low preparation temperatures to further reduce energy consumption of cell production and allows the preparation on flexible polymer substrates. To reduce voltage loss in the cell and thus improve the power conversion efficiency, the commonly used I^-/I_3^- redox electrolyte in these DSSCs is replaced by a $Co(II/III)$ redox couple. Recombination, electrolyte diffusion and electron transport in the DSSC devices are studied by impedance spectroscopy, intensity modulated photocurrent and photovoltage spectroscopy and charge extraction techniques. It was found that the interaction of the cobalt redox mediator with zinc oxide at the interface lowers the conduction band position of ZnO and, thus, leads to a lower open-circuit photovoltage. However, efficient dye regeneration can be achieved due to sufficient mass transport through the nanoporous system resulting in high photon-to-electron conversion efficiencies.

CPP 13.23 Mon 18:30 P1A

Temperature and illumination intensity dependent photoluminescence of methylammonium lead iodide perovskites — ●FABIAN MEIER, SEBASTIAN REICHERT, SETH NIKLAS SCHUMANN, ALEXANDER WAGENFAHL, and CARSTEN DEIBEL — Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany
Understanding recombination mechanisms of electrical charge carriers is of tremendous importance for understanding the extraordinary power conversion efficiencies, which increased from 4 % up to 21 %. We

investigate thin films of methylammonium lead iodide perovskite on top of PEDOT:PSS layer and an ITO layer in terms of their stoichiometric ratio of methylammonium iodide and lead iodide. By confocal photoluminescence measurements we determine direct recombination of electric charges as function of time and spatial location. We discuss our results in terms of illumination intensity as well as temperature dependence and compare it to the energetically resolved emission spectra. We discuss recombination by tail states, also visible in EQE spectra, in view of the performance of solar cells based on the investigated perovskite layers.

CPP 13.24 Mon 18:30 P1A

Stability and Performance of ZnO-based Dye-Sensitized Solar Cells in Contact to a Co(II/III) Redox Electrolyte — ●SEBASTIAN HAAS^{1,2}, RAFFAEL RUESS^{1,2}, and DERCK SCHLETTWEIN^{1,2} — ¹Justus-Liebig-University Giessen, Institute of Applied Physics — ²Justus-Liebig-University Giessen, Laboratory for Materials Science (LaMa)

The use of $Co(II/III)$ electrolytes instead of the commonly used I^-/I_3^- redox electrolyte represents an attractive way to increase the efficiency of dye-sensitized solar cells (DSSCs). By this approach, attractive efficiencies of up to 14.3 % were reached for TiO_2 -based cells. The present work is focused on DSSCs based on low temperature electrodeposited porous zinc oxide, to decrease further the already attractive energy payback time of DSSCs and allow preparation on temperature-sensitive substrates, e.g. polymer foils. Dye stability, electrolyte diffusion and recombination in the DSSC devices are studied by UV-Vis-spectroscopy, impedance spectroscopy and photocurrent-transients. It was found that the dyes $D149$ and $DN216$ are not stable at the ZnO surface in the presence of the $Co(II/III)$ redox couple. Furthermore, a small influence of a hindered diffusion in the DSSCs based on $Co(II/III)$ redox couple compared with DSSCs based on I^-/I_3^- redox electrolyte was observed.

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Temperature-dependent transient photocurrent measurements on organic-inorganic halide perovskite solar cells — ●INA KELZ¹, NICO WEBER¹, FABIAN RUF¹, TOBIAS ABZIEHER², NADJA GIESBRECHT³, MELTEM F. AYGÜLER³, PABLO DOCAMPO³, HEINZ KALT¹, and MICHAEL HETTERICH^{1,2} — ¹Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — ²Light Technology Institute (LTI), Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — ³Department of Chemistry, Ludwig-Maximilians-Universität München (LMU), 81377 Munich, Germany

Organic-inorganic halide perovskites as absorber material in solar cells show high power conversion efficiencies exceeding 20%. This is due to their promising properties such as a strong absorption coefficient and a low non-radiative carrier recombination. Additionally fabrication by low-cost production methods is possible. However, basic material properties of perovskite solar cells are not fully understood yet.

In order to gain a deeper insight into the electro-optic material properties temperature-dependent j-V-characteristics are measured. Organic-inorganic halide perovskites exhibit scan rate-dependent hysteresis effects which vary with various parameters such as illumination, bias voltage or temperature. Temperature dependent photocurrent transients show two regimes with different time constants, a fast component with a multi-exponential behaviour and a slow component which can be described by a single exponential function. The time constant of the slow component decreases for increasing temperature.

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High Energy Resolution Fluorescence Detected X-ray Absorption Spectroscopy on Lead Halide Perovskite Precursors — ●PASCAL BECKER^{1,2}, JUSTUS JUST¹, CHARLES J. HAGES¹, OLIVER MÜLLER², and THOMAS UNOLD¹ — ¹Helmholtz-Zentrum Berlin für Materialien und Energie, Germany — ²Bergische Universität Wuppertal, Germany

Perovskites as photon absorbers in thin film solar cells have drawn immense attention resulting in a rapid rise in the achieved power conversion efficiencies exceeding 20 % within a few years. Despite the intensive research in this field little is known about the formation process of these perovskite thin films on an atomic level. X-Ray Absorption Spectroscopy (XAS) is a well suited method to investigate electronic and structural properties of thin film materials. Also, residual precursor phases can be identified by this method even when X-Ray Diffraction (XRD) fails to detect. By using high quality and high resolution

reference spectra in a linear combination analysis the amount of these secondary phases can be quantified.

Therefore High Energy Resolution Fluorescence detected XAS (HERFD-XAS) measurements were performed on PbI_2 , $PbBr_2$, $PbCl_2$ as well as $NH_3CH_3PbI_xCl_{3-x}$ at the $Pb-L_2$ edge. The data reveal a clear fine structure in near edge region as opposed to data from total yield fluorescence detected spectra.

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Capacitance spectroscopy on perovskite solar cells and MIS devices — ●DAVID DIERING^{1,2}, CHRISTIAN M. WOLFF², CHARLES J. HAGES¹, THOMAS UNOLD¹, and DIETER NEHER² — ¹Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany — ²Institute of Physics and Astronomy, University of Potsdam, Potsdam, Germany

Hybrid organic-inorganic Perovskites are recently under strong focus for their tremendous rise in efficiency up to 21%. However, it is not fully understood why this class of material shows such a high performance. Capacitance spectroscopy is a powerful method to investigate defects which give rise to recombination processes and therefore influence the solar cell output.

By performing capacitance-voltage and admittance measurements on mixed perovskite $\{Cs/FA/MA\}PbI_{(3-x)}Br_x$ solar cells and metal-insulator-semiconductor(MIS) devices we are able to get information not only about defects but other important material properties such as the dielectric constant, charge carrier type and concentration. The data supports the previous theory of slight n-type to intrinsic behaviour. Further on, evidence for a deep defect level is found.

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Origin and Location of Trap States in Perovskite Films — ●TOBIAS SEEWALD¹, CAROLA EBENHOCH¹, PHILIPP EHRENREICH¹, REBECCA MILOT², SUSANNE BIRKHOFF¹, LAURA HERZ², and LUKAS SCHMIDT-MENDE¹ — ¹Department of Physics, University of Konstanz, POB M 680, Konstanz 78457, Germany — ²University of Oxford, Clarendon Laboratory, Parks Road, Oxford OX1 3PU, UK

Lead halide perovskites have experienced tremendous research interest within the last years. High power conversion efficiencies in combination with the ability of crystal formation during a solution casting process make this material class very attractive for photovoltaic application. For efficient charge carrier generation, it is essential to minimize non-radiative recombination that can be initiated by energetic trap states. For this purpose, we have studied polycrystalline methylammonium lead iodide perovskite films with varying crystal sizes. Morphology and crystallinity have been modified by means of methylamine gas induced defect healing. Time-resolved photoluminescence as well as pump-probe spectroscopy have been applied in order to relate trap state distribution with crystal sizes and grain boundaries. In this study we can demonstrate the importance of large crystal grains, which al-

low for high carrier mobilities and reduced non-radiative losses that are crucial for efficient solar cell devices.

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Vacuum chamber for in-operando grazing-incidence X-ray scattering experiments on novel thin-film solar cells — ●BERNHARD KALIS, JOHANNES SCHLIPF und PETER MÜLLER-BUSCHBAUM — TU München, Physik-Department, LS Funktionelle Materialien, James-Franck-Str. 1, 85748 Garching

In the past few years hybrid perovskite solar cells have reached power conversion efficiencies of about 20%. Alternatively, organic and other types of hybrid solar cells offer potentially cheap energy supply. The photovoltaic performance of these novel solar cell materials seems to be directly linked to the morphology of the solar cell film. To understand these connections between structural changes of the absorber material due to the influences of temperature and humidity in addition to the aging of the solar cell we use the grazing-incidence small and wide angle X-ray scattering (GISAXS/GIWAXS) method during operation [1]. To fulfil and control all these environmental influences, a newly designed vacuum chamber comes to action that consists of several modules to provide multi-functionality. This Chamber has also the ability to be pre calibrated in order to minimize the expenditure of time during a beam time at a synchrotron such as the ELETTRA in Trieste, Italy or the DESY in Hamburg, Germany.

[1] C. J. Schaffer, C. M. Palumbiny, M. A. Niedermeier, C. Jendrzewski, G. Santoro, S. V. Roth, P. Müller-Buschbaum, *Advanced Functional Materials* 2013, 25, 6760.

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Spectroscopic investigation of trap states related to loss mechanisms in hybrid perovskite solar cells — ●SEBASTIAN REICHERT, FABIAN MEIER, ALEXANDER WAGENPFAHL, and CARSTEN DEIBEL — Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany

Due to excellent electrical and optical properties of perovskite films for solar cell applications the pace of improvement related to power conversion efficiency and morphological optimisation has been unprecedented. The efficiency of methyl ammonium lead iodide (MAPI) solar cells is limited by the loss of charge carriers which is occurring within the active layer. Choosing a suitable model for those recombination mechanisms is still difficult, also due to the influence of the neighbouring transport or contact layers. We present photoluminescence transients of various MAPI thin films and compare these measurements to theoretical predictions by the charge carrier continuity equation for different recombination models. Depending on the processing conditions, the results indicate recombination assisted by tail states. The energetic trap distribution is quantified by thermally stimulated current measurements. We discuss the dominant recombination process in the examined MAPI films.