

HL 64: Poster: Photovoltaics and Optics

Time: Wednesday 15:00–19:00

Location: P1C

HL 64.1 Wed 15:00 P1C

Chemical and electronic properties of Pt/In₂O₃ interfaces — ●JONAS MICHEL¹, THERESA BERTHOLD¹, STEFAN KRISCHOK¹, MARCEL HIMMERLICH¹, JULIUS ROMBACH², OLIVER BIERWAGEN², HOLGER VON WENCKSTERN³, and MARIUS GRUNDMANN³ — ¹Institut für Physik & Institut für Mikro- und Nanotechnologien MacroNano, Technische Universität Ilmenau, Germany — ²Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany — ³Universität Leipzig, Institut für Experimentelle Physik II, Leipzig, Germany

Indium oxide (In₂O₃), a transparent semiconducting oxide, is known to exhibit tunable electron transport characteristics, from semi-insulating to highly n-doped characteristics [1]. One important property of In₂O₃ is the existence of a surface electron accumulation layer which allows generation of ohmic contacts for devices, but hinders production of rectifying contacts. Recently it has been shown that sputtering from metal targets in a reactive oxygen atmosphere allows formation of Schottky contacts [2]. We have studied metallic Pt contacts deposited by different thin film methods as well as the influence of an In₂O₃ surface pretreatment by oxygen plasma in order to determine the relevant changes that influence the electron transport characteristics of the Pt/In₂O₃ interface and to identify the origin of Schottky barrier formation. For this purpose, photoelectron spectroscopy was applied to characterize the chemical composition of the semiconductor surface and the metal contacts as well as to determine the electronic barriers at the heterointerface. [1] O. Bierwagen, *Semicond. Sci. Technol.* 30 (2015), 024001; [2] H. v. Wenckstern et al., *APL Mater.* 2 (2014), 046104.

HL 64.2 Wed 15:00 P1C

Charge storage in β -FeSi₂ nanoparticles — ●FANGFEI LI¹, MARTIN GELLER¹, HANS ORTHNER², JENS THEIS¹, HARTMUT WIGGERS², and AXEL LORKE¹ — ¹Experimental Physics and CENIDE, University of Duisburg-Essen, Germany — ²Institute for Combustion and Gas Dynamics and CENIDE, University of Duisburg-Essen, Germany

Especially, for mobile electronics, rechargeable batteries or supercapacitors with high capacities and energy density are needed. Nanomaterials can fulfill this demand because of their large specific surface area, providing space for electrochemical reactions.

In our research, a capacitor with non-toxic, semiconducting β -FeSi₂ nanoparticles shows a relatively high capacity, which points towards a yet unexplored potential of β -FeSi₂ nanoparticles in energy storage technologies. The β -FeSi₂ capacitor does not require an electrolyte and operates under ambient conditions. However, its capacitance is quite sensitive to solvents in the gaseous atmosphere (i.e. water, acetone) and humidity. With increasing relative humidity, the capacitance increases exponentially. Compared to the bare electrodes without β -FeSi₂ nanoparticles, the β -FeSi₂ nanoparticles-coated samples exhibit an up to 3–4 orders of magnitude increased capacitance. Time-resolved current-voltage measurements show that for a short time after the charging pulse (seconds to minutes), the capacitance on average reaches 2.5 As/g at a charging voltage of 3V. Moreover, the devices are robust, show almost no degradation under ambient conditions, and can still be used after months of storage and repeated measurements.

HL 64.3 Wed 15:00 P1C

Optimizing Vertical Organic Field Effect Transistors — ●MARCO HÖPPNER, ALRUN GÜNTHER, MICHAEL SAWATZKI, and KARL LEO — Dresden Integrated Center for Applied Physics and Photonic Materials (IAPP), Dresden, Germany

Organic switchable resistors such as field effect transistors (OFETs) are important to realize future flexible electronic devices. In order to reach the needed switching speeds (e.g. for logic applications) and current densities (e.g. for display pixel driving) it is most important to overcome the low charge carrier mobilities and large channel lengths. In this sense, optimizing the geometry is a key element which is done by the novel approach of vertical organic field effect transistors (VOFETs). Here, the vertical channel length where the electric field driven charge carrier drift takes place can easily be scaled down into the sub 100 nm regime. However, a lateral charge diffusion component limits scooping the full potential of the short vertical channel length which is accessible in this device geometry. Here several approaches to surmount this difficulty are presented.

HL 64.4 Wed 15:00 P1C

Template-directed Nanoengineering for Promoted Solar Water Splitting — ●MIN ZHOU, YANG XU, LIYING LIANG, BENRONG HAI, and YONG LEI — Ilmenau University of Technology, Ilmenau 98693, Germany

Highly ordered nanostructures have attracted intensive attention in the field of solar water splitting due to their ordered nanoscale features, such as huge surface area, favorable transport properties and extended light absorption range from UV to visible light, etc. Template-directed fabrication is a facile and controllable approach to realize such nanoarchitectures. Having inherited the geometrical characteristics of the templates, the resulting water splitting cells demonstrate that the as-obtained nanoarchitectures benefit the photoelectrochemical reactions. For example, based on anodic aluminium oxide (AAO) templates, well-ordered CdTe/TiO₂ core/shell nanowire arrays show promoted photocurrent response to visible light. Au particle array together with ferroelectric materials was realized by a cost-effective nonlithographic route, resulting in enhanced water splitting performance through surface plasmon resonance and controllable charge transfer/transport. Overall, template-directed nanoengineering shows excellent promising to make progress in solar energy-related applications.

HL 64.5 Wed 15:00 P1C

Solution-producible solar cells with CuInS₂- and ZnO nanoparticles — ●HARALD REINHOLD, DOROTHEA SCHEUNEMANN, JÜRGEN PARISI, and HOLGER BÖRCHERT — University of Oldenburg, Department of Physics, Energy and Semiconductor Research Laboratory, 26111 Oldenburg

Solar cells with CuInS₂ nanocrystals are a nontoxic alternative to solar cells with Pb chalcogenides. On the other hand, CuInS₂ solar cells show a considerably lower power conversion efficiency. A main reason for this are insufficient transport properties originating from long organic ligands which are essential in the synthesis of CuInS₂ nanocrystals [1]. In order to raise the efficiency of our CuInS₂ solar cells, we exchanged the long organic ligands by short ionic ligands. After the exchange reaction, the nanoparticles were examined by FTIR spectroscopy and thermogravimetric analysis (TGA), which shows an exchange rate around 90%. Results on the ligand exchange and the impact on the performance of corresponding solar cells will be presented.

[1] D. Scheunemann et. al., Towards depleted heterojunction solar cells with CuInS₂ and ZnO nanocrystals, *Appl. Phys. Lett.*, 2013, 103, 133902.

HL 64.6 Wed 15:00 P1C

Empirical electronic structure correction for DFT-based calculations — ●HANH BUI^{1,2}, JENS HÜHNERT¹, ANASTASIA KARPULOVICH^{1,2}, PENG HAN¹, and GABRIEL BESTER^{1,2} — ¹Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, D-20146 Hamburg, Germany — ²The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, D-22761 Hamburg, Germany

While DFT is extremely successful in the prediction of ground state properties and is already used as a *data mining* tool to design materials with certain target properties it suffers from significant deficiencies in the prediction of the electronic structure. The hope to interpret Kohn-Sham eigenvalues as quasiparticle levels to predict, e.g., optical band gaps is far from fulfilled in most semiconductors. We offer a simple correction scheme based on a modification of the non-local part of norm-conserving pseudopotentials that allows for a quantitative use of the electronic structure in nanostructures. The method is implemented with the AEP [1,2] framework and demonstrated for various semiconductor nanostructures.

HL 64.7 Wed 15:00 P1C

Influence of long chain carboxylates as precursor on the performance of ZnO TFTs — ●CRISTIAN TELESU, JONAS KÖHLING, and VEIT WAGNER — Jacobs University Bremen, Campus Ring 1, 28759 Bremen, Germany

To produce ZnO TFTs with good morphological and electrical properties the need for very high deposition temperatures is the bottle neck for using bendable substrates like polyimides. Long chain carboxylates are known as ZnO precursors with low decomposition temperature. In this study ZnO films with thicknesses below 30 nm were deposited by

spray pyrolysis at various temperatures and varying the chain length of the carboxylates. In addition UV/ozone treatment was used to decompose remaining organic ligands and residues. The deposited ZnO films were systematically characterized by XPS, AFM, UV-VIS, FTIR and Raman measurements. Finally TFTs were fabricated and exhibit mobilities beyond $10 \text{ cm}^2/\text{Vs}$ for proper deposition conditions.

HL 64.8 Wed 15:00 P1C

Influence of long chain carboxylates as precursor on the performance of ZnO TFTs — ●JONAS KÖHLING and VEIT WAGNER — Jacobs University Bremen, Campus Ring 1, 28759 Bremen, Germany

To produce ZnO TFTs with good morphological and electrical properties the need for very high deposition temperatures is the bottle neck for using bendable substrates like polyimides. Long chain carboxylates are known as ZnO precursors with low decomposition temperature. In this study ZnO films with thicknesses below 30 nm were deposited by spray pyrolysis at various temperatures and varying the chain length of the carboxylates. In addition UV/ozone treatment was used to decompose remaining organic ligands and residues. The deposited ZnO films were systematically characterized by XPS, AFM, UV-VIS, and Raman measurements. Finally TFTs were fabricated and exhibit mobilities beyond $10 \text{ cm}^2/\text{Vs}$ for proper deposition conditions.

HL 64.9 Wed 15:00 P1C

MgZnO/ZnO quantum wells with distinct quantum-confined stark effect grown on a highly conductive ZnO:Al back contact layer — ●MAX KNEISS, GABRIELE BENNDORF, HOLGER VON WENCKSTERN, and MARIUS GRUNDMANN — Universität Leipzig, Institut für Experimentelle Physik II, Leipzig, Germany

Since stable p-type doping in ZnO has not been achieved until now [1], methods beyond traditional doping strategies have to be employed to realize high hole densities. One approach is the separation of photo-excited electrons and holes in the internal electric field of polar MgZnO/ZnO quantum wells (QWs) [2]. The effectiveness of the separation can be estimated by the ground state recombination energy and decay time of the QW emission and the internal field. To directly determine the latter, external field-dependent photoluminescence (PL) measurements can be used where a highly conductive back contact layer is needed. We have grown MgZnO/ZnO QWs on a degenerately doped ZnO:Al layer via pulsed laser deposition. Low temperature PL spectra showed a blue-shift of the QW emission with increasing excitation density indicating a quantum-confined stark effect resulting from the internal field. We modeled the temporal dynamics of the QW emission and determined ground state recombination energies and decay times of the QW excitons in dependence on the well width for symmetric QWs as well as the Mg-content in the upper MgZnO layer for QWs with asymmetric barriers. We further verified the internal field by field-dependent cw-PL spectroscopy. [1] Fan *et al.*, Prog. Mater. Sci. **58**, 874 (2013), [2] Stölzel *et al.*, Phys. Rev. B **88**, 045315 (2013)

HL 64.10 Wed 15:00 P1C

H₂S-sensing with ZnO NWs and the role of oxygen in the sensing mechanism — ●ANGELIKA KAISER, FLORIAN HUBER, SÖREN RIEGERT, MANFRED MADEL, and KLAUS THONKE — Institute of Quantum Matter / Semiconductor Physics Group, Ulm University

ZnO nanostructures are a promising candidate in the realization of a fast and portable H₂S-sensing device. However the lack of a reliable detection mechanism has hindered the development and manufacture of an effective sensor yet. General detection properties like selectivity, sensitivity and sensing recovery are still in need of further enhancement.

In our work we demonstrate the H₂S-sensing performance of two sets of differently grown ZnO nanowires. Besides conventionally grown ZnO nanowires, using gold as catalyst material on silicon, catalyst-free ZnO nanowires grown on sapphire are equally fabricated. We investigate oxygen as the crucial contributor in the H₂S-sensing mechanism. It is found that flushing the sensor device with different concentrations of oxygen reveals an additional increase in the H₂S-sensitivity and primarily a clear enhancement in the recovery property of the ZnO nanowires. Furthermore we characterize the temperature dependency of our sensor structure in regards of an overall optimal operating ambient.

HL 64.11 Wed 15:00 P1C

Is the oxygen vacancy in ZnO connected to the E3 deep level defect? — ●R. PICKENHAIN¹, M. SCHMIDT², H. VON WENCKSTERN¹, A. PÖPPL¹, G. BENNDORF¹, and M. GRUNDMANN¹ — ¹Universität

Leipzig, Fakultät für Physik und Geowissenschaften, Inst. für Exp. Physik II, Linnéstr. 5, 04103, Leipzig, Germany — ²Helmholtz-Centre for Environmental Research, Permoserstr. 15, 04318 Leipzig, Germany

The E3 defect is typically incorporated in bulk crystals and thin films of ZnO. We examined this defect in ZnO single crystals with deep level transient spectroscopy (DLTS), optical DLTS (ODLTS), electron paramagnetic resonance (EPR) and photoluminescence (PL). With DLTS- and ODLTS we demonstrate experimentally that the E3 level in ZnO can bind two electrons and exhibits negative U-property. The thermal activation energy of the defect is about 280 meV and corresponds to the emission of two electrons into the conduction band. The effective correlation energy of the negative U-defect was determined from the measured photo cross section $\sigma^o(h\nu)$ to be $U_{\text{cor}} \sim -1 \text{ eV}$. Temperature dependent EPR experiments suggest that the oxygen vacancy V_{O} is the microscopic origin of the E3 defect. Further we find with temperature dependent PL that the E3 defect has a radiative recombination for the transition $V_{\text{O}}^0 \Rightarrow V_{\text{O}}^+$ with a peak maximum energy of 2.09 eV. The comparatively low experimental value of 280 meV of the thermally activated $V_{\text{O}}^0 \Rightarrow V_{\text{O}}^{2+}$ transition should re-stimulate discussions on the contribution of the oxygen vacancy to the free electron density and on its role in the difficulty to obtain p-type ZnO.

HL 64.12 Wed 15:00 P1C

Optical Characterization of iron doped ZnO — ●SEBASTIAN BAUER¹, FLORIAN HUBER¹, BENJAMIN NEUSCHL¹, MATTHIAS SCHRECK², and KLAUS THONKE¹ — ¹Institute of Quantum Matter, Semiconductor Physics Group, University Ulm, Germany — ²Institute of Physics, University Augsburg, Germany

Typically Fe is deliberately incorporated into III-V- and II-VI-semiconductor materials for the realization of semi-insulating substrates which are needed for optoelectronic and electronic devices. However in ZnO iron on a Zn lattice site acts as a deep donor. Also the realization of ferromagnetic semiconductors for spintronics is a subject of interest.

In ZnO the influence of transition metals on magnetic, optical and electronic properties of the material are still subject to research. In this study we present results on the preparation of iron containing ZnO layers grown by chemical vapour deposition technique. Iron has been incorporated both during the growth of the sample itself and by ion implantation. Further optical and magneto-optical investigations on the photoluminescence band at 1.78 eV are presented. This band emerges for Fe³⁺ from the spin-forbidden electric-dipole transition from the excited state ⁴T₁(G) to the ground state ⁶A₁(S) transition. Additionally isotope and other effects leading to fine splittings are discussed.

HL 64.13 Wed 15:00 P1C

Nonlinear Optical Properties of SnS based Cluster Molecules — ●VANESSA DAHMEN¹, NILS W. ROSEMAN², JENS P. EUSSNER³, ANDREAS BEYER¹, KERSTIN VOLZ¹, STEPHAN W. KOCH¹, STEFANIE DEHNEN³, and SANGAM CHATTERJEE² — ¹Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, Renthof 5, 35032 Marburg, Germany — ²Institute of Experimental Physics I, Justus-Liebig-University Giessen, 35392 Giessen, Germany — ³Faculty of Chemistry and Materials Sciences Center, Philipps-Universität Marburg, Hans-Meerwein-Straße, 35043 Marburg, Germany

Supercontinuum sources are used in various scientific experiments and technical applications. Such sources provide broad spectra with well-defined beam parameters. The most common method of generation such supercontinua is by using tapered or photonic-crystal fibers. In this approach, self-phase modulation of the propagating light in the fiber leads to the generation of the supercontinuum. To achieve the field strength required for this process one has to use pulsed pump sources.

Here, we present a powder compound, composed of organyl-protected [Sn₄S₆] cluster molecules, which shows extreme nonlinear properties. This material enables the generation of a supercontinuum by pumping with a medium-power, commercial, continuous-wave laser diode. The distinct geometry and frustrated mesoscopic order of the tin sulfide-based cluster molecules is responsible for the nonlinear response. By studying the nonlinear properties we are getting closer to characterize and understand the material system.

HL 64.14 Wed 15:00 P1C

Determination of electronic trap states in polymer based diodes and their impact on the charge carrier mobility — ●MICHAEL BRETSCHNEIDER, ALEXANDER WAGENPFAHL, and CARSTEN DEIBEL — Institut für Physik, Technische Universität Chem-

nitz, 09126 Chemnitz, Germany

Aiming for more efficient organic electronic devices, one has to understand the limiting factors in terms of charge transport and recombination, which are often related to trap states. We characterise and quantify the energetic distribution of charge carrier traps of a PCDTBT diode by fractional thermally stimulated current measurements. We find that the density of occupied states shows an approximately Gaussian shape, which is often expected for disordered organic semiconductors. Time of flight measurements are used to determine the electron and hole mobility, respectively. We investigate the correlation of the charge carrier mobility with the trap distribution and discuss the impact on the device performance.

HL 64.15 Wed 15:00 P1C

Hole Transport in Low Donor Content Organic Solar Cells — ●DONATO SPOLTORE, ANDREAS HOFACKER, JOHANNES BENDUHN, SASCHA ULLBRICH, OLAF ZEIKA, SEBASTIAN SCHELLHAMMER, FRANK ORTMANN, and KOEN VANDEWAL — Dresden Integrated Center for Applied Physics and Photonic Materials, George-Bähr Str. 1, 01069 Dresden

Organic solar cells for which a small molecule electron donor is diluted in a fullerene matrix have a reduced density of donor-fullerene contacts, resulting in reduced free carrier recombination and increased open-circuit voltages. In such devices, the low donor concentration prevents the formation of pathways of directly adjacent hole transporting molecules. Despite this, high external quantum efficiencies in the strongly absorbing region of the fullerene can still be reached, suggesting an interesting hole transport mechanism. Here we perform a systematic study of the hole mobilities of 18 donor:C60 blends, where the donors are diluted at ~6 mol% and have varying frontier energy level offsets and relaxation energies. We find that hole mobilities are dominantly rendered by the relaxation energy of the donor allowing the formulation of an empirical law to estimate hole mobilities in low donor content organic solar cells. Surprisingly, the energy offset between the C60 matrix and the donor material shows no contribution indicating the formation of an effective hole transport level. The C60 matrix only adds by a constant contribution to the activation energy of the transport process.

HL 64.16 Wed 15:00 P1C

Solution processing of vertical organic field-effect transistors with TIPS-Pentacene — ●DAVID KNEPPE — Dresden Integrated Center for Applied Physics and Photonic Materials, Dresden, Germany

The interest in organic transistors has been growing rapidly in the past years due to their importance for the realization of future organic electronic devices such as flexible displays or logic applications. By using a novel device architecture with a short channel length and a high mobility organic semiconductor, key parameters like the maximum drain current as well as the switching frequency can be improved further. Therefore, vertical organic field-effect transistors (VOFETs) with vertical channel lengths in a regime of several nanometers are promising devices. Here, organic semiconductors with a high charge carrier mobility especially in the vertical direction are needed. However, vacuum deposition of several layers to produce these devices is rather expensive for later massive industrial fabrication. Here, first approaches in solution processing of VOFETs with the promising polycrystalline organic semiconductor TIPS-Pentacene are presented.

HL 64.17 Wed 15:00 P1C

Voltage dependent photoluminescence spectroscopy of dye-sensitized solar cells — ●NICO HOFEDITZ¹, INGO MEYENBURG¹, JANE FALGENHAUER², MELANIE RUDOLPH², NILS ROSEMAN¹, SANGAM CHATTERJEE³, DERCK SCHLETTWEIN², and WOLFRAM HEIMBRODT¹ — ¹Department of Physics, Philipps-University Marburg, Renthof 5, 35032 Marburg — ²Institute of Applied Physics, Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, 35392 Gießen — ³Institute of Experimental Physics I, Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, 35392 Gießen

Dye-sensitized solar cells with indoline dyes D149 and D131 and the squaraine dye SQ2 on mesoporous TiO₂ or ZnO have been prepared. The energy level alignment at the organic inorganic interface is important for an optimized electron transfer. We present a new method to determine the band offset. Photoluminescence spectra were recorded with varying applied voltages. Systematical analysis of the spectra shows a significant dependence of the photoluminescence intensity on the applied voltage as well as a small energy shift. The observed char-

acteristics are discussed as interface effects of the dye-semiconductor interface. Time resolved photoluminescence spectroscopy gives further insight into these processes.

HL 64.18 Wed 15:00 P1C

Reorganization and disorder effects of the charge transfer state in organic solar cells — ●CLEMENS GÖHLER and CARSTEN DEIBEL — Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany

The efficiency of organic solar cells is directly linked to their ability to dissociate light-induced excitons into separate charge carriers. By using a bulk-heterojunction (BHJ) with a mixture of donor and acceptor semiconductors, a charge-transfer (CT) state between the acceptor LUMO and donor HOMO is created. Due to its lower binding energy, the exciton dissociation increases via the CT state.

This found state is believed to be affected by both its reorganization energy and ensemble disorder effects. Therefore, we expect a complex temperature dependence of both the CT states' energy and line-broadening.

We use electrooptical spectroscopy with respect to absorption and emission of the CT state. By measuring the ensemble CT energy and linewidth while varying the cell-temperature over a broad range, we are able to unravel whether molecular reorganization energy or disorder have a stronger influence on the CT state of common polymer-fullerene BHJs.

HL 64.19 Wed 15:00 P1C

Diffuse Transmission and Reflection of Light Scattering Polymer Substrates for Organic Light-emitting Diodes — ●PEN YIAO ANG, GEORG MARKS, ABDALLA MAHMOUD, AXEL FISCHER, SIMONE LENK, and SEBASTIAN REINEKE — Dresden Integrated Center for Applied Physics and Photonic Materials (IAPP) and Institute for Applied Physics, TU Dresden

Organic light-emitting diodes (OLEDs) are gaining more attention as the next generation of light sources. Still, the cost-performance ratio is not comparable to inorganic LEDs. One solution is to further enhance the performance of OLEDs by improving the outcoupling efficiency. Light trapped in waveguided modes of the substrate can be outcoupled if scattering particles are added to the OLED structure. The property of a scattering film to redirect light correlates with the haze factor, depending on the wavelength. Ideally, light is scattered into a direction which does not suffer from total internal reflection in the substrate. However, light having the right direction might be scattered in a way that it is coupled into waveguided modes or even reflected. Hence, it cannot be generalized that a higher haze factor automatically leads to a better performance of the scattering film. Here, we compare different self-made scattering films based on thin polymer substrates with incorporated nano-particles. By measuring the scattering of an incident light ray into all directions (360°), we identify the amount of direct transmission, diffuse transmission as well as diffuse reflection. The gained insights are related to the efficiencies of OLEDs using our substrates in order to specify optimal scattering properties.

HL 64.20 Wed 15:00 P1C

Nongeminate Recombination in Organic Solar Cells — ●CHRISTOPHER WÖPKE, CHRISTOPH BAUMBACH, and CARSTEN DEIBEL — Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany

Despite ongoing efforts to improving the overall efficiency of organic solar cells, nongeminate recombination - the dominant performance limiting mechanism - is still not fully understood. Nongeminate recombination depends strongly on the solar cell morphology.

The aim of this study is to explore the relationship between recombination and the morphology of P3HT:PCBM bulk-heterojunction organic solar cells. In a first step the charge carrier concentrations and recombination rates of devices with systematically varied morphologies will be studied with the method of time-delayed collection field (TDCF). Analysing the TDCF transients an approximated mean charge carrier mobility will be extracted. We will present our progress in finding the relationship between the devices morphology and the parameters recombination rate, charge-carrier mobility and concentration.

HL 64.21 Wed 15:00 P1C

Charge carrier mobility in fullerene-blended squaraine thin films and the impact of correct layer thickness determination — ●MAJGOR MACK¹, MATTHIAS SCHULZ², ARNE LÜTZEN², and

MANUELA SCHIEK¹ — ¹Energy and Semiconductor Research Laboratory, Institute of Physics, University of Oldenburg, D-26111 Oldenburg, Germany — ²Kekulé Institute for Organic Chemistry and Biochemistry, University of Bonn, Gerhard-Domagk-Str. 1, D-53121 Bonn, Germany

Squaraine-based solar cells suffer from a low fill factor which leads to a small efficiency. A possible reason for this could be the built up of space charges due to imbalanced hole and electron mobility. To address this issue, the mobility is determined from I-V-measurements of single carrier devices, which follow the Mott-Gurney law for space-charge-limited current (SCLC). Under these circumstances the current has a quadratic dependence of the voltage and an inversely cubic dependence of the organic layer thickness. Thus, the determination of the layer thickness is important. Two methods for the thickness measurement are opposed: atomic force microscopy (AFM) as a tactile method and spectroscopic ellipsometry (SE) as contactless, optical method. Topographic AFM images across scratches in the organic film are evaluated with the software Gwyddion and compared to the result obtained by modeling and fitting of ellipsometric data with the software WVASE32.

HL 64.22 Wed 15:00 P1C

Influence of white light and voltage bias on EQE measurements for squaraine based solar cells with varying active layer parameters — ●OLIVER KOLLOGE¹, MATTHIAS SCHULZ², ARNE LÜTZEN², and MANUELA SCHIEK¹ — ¹Energy and Semiconductor Research Laboratory, Institute of Physics, University of Oldenburg, D-26111 Oldenburg, Germany — ²Kekulé Institute for Organic Chemistry and Biochemistry, University of Bonn, Gerhard-Domagk-Str.1, D-53121 Bonn, Germany

Anilino-Squaraines are stable dyes and are readily available via environmentally friendly condensation reactions. Organic solar cells whose active layer consists of a model squaraine donor blended with a fullerene acceptor are particularly interesting because they show absorption within the deep-red combined with a high Voc. However, these devices suffer from a low fill factor around 40%.

The purpose of this study is a deeper understanding of the performance of these organic solar cells via advanced EQE measurements. J-V-measurements show a linear dependence of Jsc and illumination intensity independent of the active layer thickness. However, white light biased EQE measurements suggest a sublinear intensity response which becomes more obvious for increasing active layer thickness. Furthermore, voltage-dependent EQE measurements hints to a saturation of photocurrent at higher reverse bias voltages.

HL 64.23 Wed 15:00 P1C

Optical Spectroscopy on Organic DNTT Crystals — ●BENJAMIN HEIDELMEIER¹, MARLEEN AXT², ANDREA KARTHÄUSER², GREGOR WITTE², and WOLFRAM HEIMBRODT¹ — ¹Experimental Semiconductor Physics, Department of Physics, Philipps-Universität Marburg, Germany — ²Molecular Solid State Physics, Department of Physics, Philipps-Universität Marburg, Germany

DNTT (dinaphtho[2,3-*b*:2',3'-*f*]thieno[3,2-*b*]thiophene) is a promising organic semiconductor for application in organic field effect transistors (OFET). It shows a higher charge carrier mobility in comparison to the common OFET material Pentacene while it is stable under ambient conditions. To improve the performance of OFETs it is important to study and understand the optoelectronic processes in such organic solids.

Here we report an optical characterization of DNTT single crystals that were grown by molecular beam deposition onto glass substrates coated with thin oil films. This yields platelet shaped single crystals with a typical diameter of 50 μm. Using photoluminescence, absorption and time resolved spectroscopy we investigated the optical properties of such crystals. In particular we measured the polarization dependence of absorption and photoluminescence with respect to the crystallographic axes. The transition dipole moment is oriented along the short molecular axis. We were able to reveal both Davydov components. Even the excitonic luminescence exhibits a strong linear polarization.

HL 64.24 Wed 15:00 P1C

Optical Spectroscopy on Organic Molecules and Organic-Inorganic Hybrid Structures for Photodynamic Therapy and Organic Solar Cells — ●LUISE ROST¹, INGO MEYENBURG¹, MARTIN LIEBOLD², JAN TINZ³, DERCK SCHLETTWEIN³, JÖRG SUNDERMEYER², and WOLFRAM HEIMBRODT¹ — ¹Philipps-Universität Marburg department of physics and material sciences center, Marburg — ²Philipps-

Universität Marburg department of chemistry, Marburg — ³Justus-Liebig-Universität, institute of applied physics, Gießen

In the last two decades organic dyes and organic semiconductors get increasing attention due to the high molecular variability and the resulting wide applicability. For example in promising light-activated cancer therapy (Photodynamic Therapy PDT), where near-infrared light absorbing molecules produce reactive oxygen species by energy transfer which leads to cell death. Another application are dye sensitized solar cells (Grätzel cells). Naphthalocyanine-derivatives were synthesized and tested for their suitability as photosensitizer in Photodynamic Therapy with optical spectroscopy. The newly synthesized four different metal-naphthalo-derivatives differ in axial and peripheral anchoring groups. The influence of different amount of nitrogen and tert-butyl or mesityl groups was tested. Different newly sensitized organic molecules (derivatives of Phthalocyanine) were characterized optically and tested for application in Grätzel cells. The impact of different substrates like titanium dioxide (TiO₂) and zinc oxide (ZnO) will be discussed. Time Resolved Photoluminescence was performed on this newly processed solar cells.

HL 64.25 Wed 15:00 P1C

Electric field controlled dopant distribution in P3HT Films — ●MARC-MICHAEL BARF^{1,2}, CHRISTIAN WILLIG^{1,2,3}, LARS MÜLLER^{1,2,3}, ROBERT LOVRINCIC^{1,2}, and WOLFGANG KOWALSKY^{1,2,3} — ¹IHF, TU Braunschweig — ²InnovationLab, Heidelberg — ³KIP, Heidelberg University

Doping of organic semiconductors has become a common method to improve the efficiency of devices like organic light emitting diodes, organic solar cells and more recently also organic field effect transistors. So far in most devices doping is used statically to increase the conductivity of certain regions and to create space charge layers at interfaces in order to enhance charge transport. Here, the drift of p-type dopants like 2,3,5,6-Tetrafluoro-7,7,8,8-tetracyanoquinodimethane (F4TCNQ) in films of Poly(3-hexylthiophene-2,5-diyl) (P3HT) is actively used to operate a device. We control the drift of the dopants in devices such as simple memristors and thereby switch those on and off by shifting highly conductive regions within the device. We explore this mechanism for possible application in an organic field effect transistor.

HL 64.26 Wed 15:00 P1C

Electroreflectance studies of Cu(In,Ga)(S,Se)₂ solar cell absorber and buffer layers — ●JASMIN SEEGER¹, OLIVER KIOWSKI², MICHAEL POWALLA^{2,3}, HEINZ KALT¹, and MICHAEL HETTERICH^{1,3} — ¹Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — ²Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70565 Stuttgart, Germany — ³Light Technology Institute (LTI), KIT, 76131 Karlsruhe, Germany

Cu(In,Ga)(S,Se)₂ (CIGS) is one of the most promising thin-film solar cell absorber materials with demonstrated conversion efficiencies of up to 22.6% [1]. However, the commonly used CdS buffer still poses a problem due to the absorption losses in this layer. Further research into alternative buffer layers with less parasitic absorption, which enable even higher efficiencies, is therefore required. For that purpose we employ electro-modulated reflectance (ER) spectroscopy to study the CIGS absorber and CIGS/buffer interface for different fabrication conditions as well as absorber compositions and buffer materials.

[1] P. Jackson, R. Wuerz, D. Hariskos, E. Lotter, W. Witte, and M. Powalla. *Effects of heavy alkali elements in Cu(In,Ga)Se₂ solar cells with efficiencies up to 22.6%*, Phys. Status Solidi RRL 10(8), 583-586, 2016.

HL 64.27 Wed 15:00 P1C

Co-evaporated CZTSe solar cells: influence of Cu deposition rate during precursor processing on the growth and device performance — LWITIKO MWAKYUSA^{1,4}, ●MARKUS NEUWIRTH¹, MAX REIMER¹, SIMON WOSKA¹, WILLI KOGLER², THOMAS SCHNABEL², ERIK AHLWEDE², BRYCE RICHARDS^{3,4}, HEINZ KALT¹, and MICHAEL HETTERICH^{1,3} — ¹Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — ²Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70565 Stuttgart, Germany — ³Light Technology Institute, KIT, 76131 Karlsruhe, Germany — ⁴Institute of Microstructure Technology, KIT, 76344 Karlsruhe, Germany

The performance of Cu₂ZnSnSe₄ (CZTSe) thin film solar cells is still

limited by a high open-circuit voltage deficit and low fill factor. To boost device performance it is crucial to improve grain size and quality, control the formation of defects and inhibit the formation of secondary phases. It is often assumed that a Cu–Se eutectic liquid-phase is beneficial for the growth of a high-quality CZTSe absorber layer. However, too much Cu may provoke the formation of Cu_{2-x}Se which can act as a shunt path in the solar cell thus deteriorating overall device performance. In this contribution we investigate solar cells with CZTSe absorbers fabricated using low-temperature co-evaporation and following high-temperature annealing in a Se atmosphere. The Cu concentration in the absorber is varied by changing the Cu deposition rate during precursor deposition. The finished devices are compared with respect to their performance in order to optimize growth conditions.

HL 64.28 Wed 15:00 P1C

Effects of selenium-to-sulphur ratio in $\text{Cu}_2\text{ZnSn}(\text{S},\text{Se})_4$ absorbers for thin-film solar cells — ●ELISABETH SEYDEL¹, MARKUS NEUWIRTH¹, MICHAEL WOLF¹, LWITIKO MWAKYUSA¹, THOMAS SCHNABEL², ERIK AHLWEDE², WILLI KOGLER², HEINZ KALT¹, and MICHAEL HETTERICH¹ — ¹Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — ²Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70565 Stuttgart, Germany

$\text{Cu}_2\text{ZnSn}(\text{S},\text{Se})_4$ is a promising material system for thin-film solar cells as a substantial supply of all constituents is available. Yet the band gap of the resulting absorber of a pure selenide CZTSe ($E_g = 1.0\text{ eV}$) or pure sulphide CZTS ($E_g = 1.5\text{ eV}$) solar cell is not optimal for AM 1.5 radiation. To achieve an optimal value of approximately $E_g = 1.3\text{ eV}$ our wet-chemically fabricated precursors are annealed in both selenium atmosphere and sulphur atmosphere. Hereby the ratio of Se and S and thus the band gap can be optimized to fit the solar spectrum best.

HL 64.29 Wed 15:00 P1C

Approaches for the incorporation of Ge into wet-chemically produced $\text{Cu}_2\text{ZnSn}(\text{S},\text{Se})_4$ solar cells — ●MICHAEL WOLF¹, MARKUS NEUWIRTH¹, ELISABETH SEYDEL¹, THOMAS SCHNABEL², ERIK AHLWEDE², WILLI KOGLER², HEINZ KALT¹, and MICHAEL HETTERICH¹ — ¹Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — ²Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70565 Stuttgart, Germany

$\text{Cu}_2\text{ZnSn}(\text{S},\text{Se})_4$ (CZTSSe) is a promising absorber material for thin film solar cells. As has been demonstrated, it can easily be doped with elements like germanium, lithium or sodium, leading to improvements in energy conversion efficiency. Germanium on the one hand is said to be a catalyst for CZTSSe grain growth when used in small amounts during annealing. On the other hand, its substitution of tin in CZTSSe increases the band gap enabling a better match to the solar spectrum and an enhanced open-circuit voltage. In this contribution we utilize two approaches to incorporate Ge into CZTSSe. First the influence of a thin doctor-bladed germanium oxide (GeOx) layer underneath and on top of the precursor on grain growth and solar cell parameters is studied. Furthermore, germanium sulfide (GeS) is used during the annealing process to tune the band gap.

HL 64.30 Wed 15:00 P1C

Absorber surface treatment and alternative buffer layers for $\text{Cu}_2\text{ZnSn}(\text{S},\text{Se})_4$ solar cells — ●MARKUS NEUWIRTH¹, ELISABETH SEYDEL¹, MICHAEL WOLF¹, LWITIKO MWAKYUSA¹, THOMAS SCHNABEL², ERIK AHLWEDE², HEINZ KALT¹, and MICHAEL HETTERICH¹ — ¹Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — ²Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70565 Stuttgart, Germany

Solar cells based on $\text{Cu}_2\text{ZnSn}(\text{S},\text{Se})_4$ (CZTSSe) are promising since they only comprise environmentally friendly and earth-abundant elements. However, they still struggle with low efficiencies, mainly related to a high open-circuit voltage deficit that could partially result from the presence of secondary phases in the absorber layer. These phases can be especially problematic at the absorber's surface where they influence the CZTSSe/CdS interface. Surface treatments like chemical etching can remove such parasitic phases and improve the interface quality. Alternative buffer layers like ZnSe may also improve the interface quality and modify the band alignment in the interface region. In this contribution we compare CZTSSe solar cells with alternative buffer layers and previous absorber surface treatments to solar cells

with chemical bath deposited CdS buffer layer.

HL 64.31 Wed 15:00 P1C

Open circuit voltage (VOC) in GaAs based quantum well solar cell by using III-V semiconducting materials: A Numerical Simulation Study — ●BHASKAR SINGH and DANIEL SCHAADT — Institute for Energy Research and Physical Technologies, Technische Universität Clausthal, Germany

The Sun provides an infinite source of green energy in the form of sun-light which can be directly converted into electricity. GaAs is a direct band-gap ($E_g=1.42\text{ eV}$) semiconducting material which is a very promising material for solar cell fabrication in space applications. To increase the current generation in pn homojunction devices, introducing quantum wells in the intrinsic region is an alternate concept while it allows for easy fabrication and reduces problems with lattice and current matching comparing to stacked solar cells but it triggers a significant reduction in open circuit voltage. In GaAs/GaAs based quantum well solar cell shows this kind of effect in the I-V characteristics. To elevate this problem, we introduce here AlGaAs in place of GaAs barrier layers in the intrinsic region. Numerical device simulations show a significant enhancement in the open circuit voltage of quantum well solar cell device.

Reference: 1X.H. Li, P.C. Li, D.Z. Hu, D.M. Schaad and E.T. Yu, J. Appl. Phys. 115, 044303 (2014)

HL 64.32 Wed 15:00 P1C

Time resolved photoluminescence of $\text{Cu}_2\text{ZnSn}(\text{S},\text{Se})_4$ solar cell absorbers with varying composition — MARIO LANG¹, TOBIAS RENZ¹, NIKLAS MATHES¹, MARKUS NEUWIRTH¹, THOMAS SCHNABEL², ●ANDRÉ SCHENDEL¹, HEINZ KALT¹, and MICHAEL HETTERICH^{1,3} — ¹Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — ²Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, 70565 Stuttgart, Germany — ³Light Technology Institute, KIT, 76131 Karlsruhe, Germany

$\text{Cu}_2\text{ZnSn}(\text{S},\text{Se})_4$ absorbers offer a huge potential for future thin-film solar cells. Up to now the low efficiency is predominantly caused by the low open circuit voltage V_{OC} compared to the theoretical possible V_{OC} . The reasons for the low open-circuit voltage are amongst others miscellaneous defects and secondary phases within the material. To suppress their formation absorber layers with off-stoichiometric Cu poor and Zn rich composition are used for highly efficient devices. In our contribution we analyze the effect of the composition on the radiative recombination by means of photoluminescence (PL) and especially time-resolved photoluminescence (TRPL).

HL 64.33 Wed 15:00 P1C

Structural and electronic characterization of crystalline silicon-aluminum oxide interfaces — ●HANNAH STOLZENBURG, ARNE AHRENS, and MICHAEL SEIBT — IV. Physikalisches Institut, Georg-August-Universität Göttingen, Germany

Aluminum oxide deposited on crystalline silicon is known for its high surface passivation capabilities. This surface passivation is attributed to a high negative fixed charge density of about $-4 \times 10^{12}\text{ cm}^{-2}$ [1] in the aluminum oxide layer close to the silicon-aluminum oxide interface. This makes aluminum oxide an interesting material to increase the efficiency of solar cells by passivation of surface states. Examples of applications are passivated emitter and rear cells (PERC) [2] and rear-emitter inversion layer solar cell [3], for which efficiencies of 20 % [2] and 18,1 % [3] have been reported, respectively.

In this work, we investigate aluminum oxide layers deposited by atomic layer deposition (ALD) for different processing conditions parameters, as e.g. post-deposition heat treatments, layer thickness, and the effect of UV irradiation. Transmission electron microscopy (TEM) imaging combined with electron energy loss spectroscopy (EELS) is used to study the structure and chemistry of the interface between crystalline silicon and aluminum oxide. Electronic characterization of surface states and oxide charges is done using deep-level-transient-spectroscopy (DLTS) and capacitance-voltage measurements.

[1] F.Werner and J. Schmidt Appl. Phys. Lett. Vol.104, 091604 (2014). [2] J. Schmidt et al., Prog. Photovol: Res. Appl. Vol. 16 461-466 (2008). [3] F. Werner et al., J. Appl. Phys. Vol. 115, 073702 (2014).

HL 64.34 Wed 15:00 P1C

Ultra-Thin Resonant Cavity Enhanced Amorphous Germanium Solar Cells on Zinc Oxide Honeycomb Structures —

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Hydrogenated amorphous germanium (a-Ge:H) has a high absorption coefficient and similar band gap to microcrystalline silicon ($\mu\text{c-Si:H}$). Recently, solar cells with ultra-thin ($<25\text{nm}$) a-Ge:H absorber films based on absorbing resonant cavities were developed in our group. Due to strong broadband absorption and good electrical quality they have the potential to replace thick ($>1\mu\text{m}$) standard $\mu\text{c-Si:H}$ cells. In order to further enhance their optical properties a-Ge:H solar cells are deposited on 3D $1\mu\text{m}$ -sized zinc oxide (ZnO) honeycomb structures, fabricated in a combined process of nanosphere lithography and electrochemical deposition. The honeycomb structure increases the volume of the overlying absorber layer making it possible for more light to be absorbed. We present external quantum efficiency (EQE) measurements which demonstrate the beneficial optical effects and the potential for a high short circuit current density. We also deduce an optimal fabrication procedure for the ZnO honeycomb structures with optimal geometry for the a-Ge:H absorber system.

HL 64.35 Wed 15:00 P1C

Cross-section electron beam induced voltage investigations of different p-n junctions — •TOBIAS WESTPHAL, PATRICK PERETZKI, and MICHAEL SEIBT — Georg-August-Universität Göttingen, IV. Physikalisches Institut, Göttingen

P-n heterojunctions consisting of the p-doped manganite $\text{Pr}_{1-x}\text{Ca}_x\text{MnO}_3$ (PCMO) and the n-doped titanite $\text{SrTi}_{1-y}\text{Nb}_y\text{O}_3$ (STNO), both perovskite-structured, have been investigated with Electron Beam Induced Current (EBIC) [1,2]. To further study the photovoltaic properties of this system, the Electron Beam Induced Voltage (EBIV) technique is used in this work. The standard form for EBIV models [3] predicts a behaviour logarithmic to the EBIC, which is useful for measuring the nanometer scale diffusion length of minority charge carriers in this system.

In this work a well-known silicon sample is used at first to understand the results of the EBIV technique. For this reason, both plan view and cross-section measurements are done by combining SEM-based EBIV with Focused Ion Beam preparation in dual beam instruments and comparing them to finite element based simulations. In a next step, the method is brought to PCMO/STNO interfaces.

[1] B. Iffland, P. Peretzki, B. Kressdorf, P. Saring, A. Kelling, M. Seibt and C. Jooss, Beilstein J. Nanotechnol. 2015, 6, 1467-1484

[2] P. Peretzki, B. Iffland, C. Jooss and M. Seibt, Phys. Status Solidi RRL. 2016

[3] H.-C. W. Huang, C. F. Aliotta, and P. S. Ho, Appl. Phys. Lett. 41, 54 (1982)

HL 64.36 Wed 15:00 P1C

Analysis and preparation of $\text{In}_2\text{S}_3:\text{V}$ intermediate band solar cells — •TANJA JAWINSKI^{1,2}, LEONARD WÄGELE¹, HOLGER VON WENCKSTERN², MARIUS GRUNDMANN², and ROLAND SCHEER¹ — ¹Martin-Luther-University Halle-Wittenberg, Institute of Physics, 06120 Halle, Germany — ²Universität Leipzig, Institut für Experimentelle Physik II, Leipzig, Germany

The maximum efficiency of a standard single junction solar cell is given by the Shockley Queisser limit of around 33%. To overcome this limit an intermediate band, which allows the absorption of photons with energies lower than the band gap E_g can be introduced. In addition, thermalization losses can be reduced since within intermediate band solar cells materials with higher E_g than that of conventional cells are used. According to theoretical calculations In_2S_3 doped with vanadium is a promising candidate for such intermediate band devices.

We grew intrinsic $\text{In}_2\text{S}_3:\text{V}$ on n -TCOs ZnO:Al and SnO:F by physical co-evaporation of the elements. $\text{In}_2\text{S}_3:\text{V}$ p - i - n solar cells are formed with ZnCo_2O_4 and NiO which are prepared by pulsed laser deposition. Current-voltage measurements in the dark reveal rectification of up to 4 orders of magnitude. Measurements under illumination as well as external quantum efficiency measurements provide a proof of principle, even though the short circuit current and the open circuit voltage need to be improved by optimizing the deposition parameters. For deeper understanding we compare solar cells with varying V-concentrations.

HL 64.37 Wed 15:00 P1C

Secondary phase investigation on kesterite materials using X-ray absorption spectroscopy — •KONRAD RITTER¹, SERGIO GIRALDO², GALINA GURIEVA³, LAURA ELISA VALLE RIOS³, GÖTZ

SCHUCK³, EDGARDO SAUCEDO², SUSAN SCHORR^{3,4}, and CLAUDIA S. SCHNOHR¹ — ¹Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — ²Catalonia Institute for Energy Research (IREC), Jardins de les Dones de Negre 1 08930, Sant Adrià de Besòs, Barcelona, Spain — ³Helmholtz-Zentrum Berlin für Materialien und Energie, Department Crystallography, Hahn-Meitner-Platz 1, 14109 Berlin, Germany — ⁴Institut für Geologische Wissenschaften, Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin, Germany

$\text{Cu}_2\text{ZnSnSe}_4$ based kesterites offers a wide range of promising absorber materials for photovoltaics, but the record efficiency has only reached 12.6% yet. One of the limiting factors seems to be the formation of secondary phases throughout the preparation process. Therefore we used X-ray absorption near edge structure spectroscopy for an element specific detection of secondary phases via linear combination fitting. Kesterite powder samples created by solid state reaction with varying compositions were studied, to better understand the phase formation depending on the initial material composition. Furthermore, kesterite solar cells with and without small amounts of Ge were studied for different stages of preparation. The presence of Ge greatly improves the device performance and a detailed phase analysis will help to understand the underlying absorber formation mechanisms.

HL 64.38 Wed 15:00 P1C

Composition - dependent atomic - scale structure of $\text{Cu}_2(\text{Zn,Fe})\text{SnS}_4$ — •CORA PREISS¹, KONRAD RITTER¹, PHILIPP SCHÖPPE¹, SUSAN SCHORR², and CLAUDIA S. SCHNOHR¹ — ¹Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — ²Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin und Institut für Geologische Wissenschaften, Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin, Germany

The chalcogenides $\text{Cu}_2\text{ZnSnS}_4$ (kesterite) and $\text{Cu}_2\text{FeSnS}_4$ (stannite) are interesting as potential photovoltaic absorbers and provide a promising alternative to other solar cell materials. They offer advantages like the availability of the elements and their non-toxicity but the record efficiencies are still well below the theoretical prediction. In order to further improve the efficiency, a detailed knowledge of the fundamental material properties is needed. $\text{Cu}_2\text{ZnSnS}_4$, $\text{Cu}_2\text{FeSnS}_4$, and their solid solutions with different Zn/(Zn+Fe) ratios were investigated with extended X-ray absorption fine structure spectroscopy. The absorption at the K-edge of Cu, Zn, Sn and Fe was measured and is analyzed to reveal the bond length of the Cu, Zn, Sn and Fe atoms to their nearest S neighbors thus directly providing the different anion displacements. These results lead to a detailed understanding of the correlation between crystal structure and local atomic arrangements of this material system and show their impact on important material properties like the band gap energy.

HL 64.39 Wed 15:00 P1C

Absolute distance semiconductor laser self-interferometry towards microscopy object position detection — •DANIEL HARTNAGEL, CHRISTOPH WEBER, and STEFAN BREUER — Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt, Germany

The precise knowledge of the location of a microscopic object under investigation in nonlinear confocal imaging microscopy is crucial for allowing a concise series of microscopic images. Non-contact high-precision measurement techniques involving triangulation or mechanical position sensing cannot immediately be employed due to the dimension restrictions in the microscopes sample holder. We study a compact semiconductor laser based concept for absolute distance interferometry that is expected to cope with the stringent requirements. An experiment involving a directly modulated commercial diode laser emitting at 1310 nm is presented where the absolute distance can be retrieved by the measured interference frequency and parameters. The results are then validated by spectro-temporal and time-domain analysis. The obtained results suggest paths towards future development and implementation of semiconductor laser based absolute distance interferometry concepts. Support by the Support Initiative Interdisciplinary Science (FiF) of the Technische Universität Darmstadt and the Adolf-Messer Foundation, Germany, is thankfully acknowledged.

HL 64.40 Wed 15:00 P1C

Optical feedback stabilization of a passively mode-locked multi quantum well semiconductor laser emitting at 1070 nm — •DOMINIK AUTH¹, CHRISTOPH WEBER¹, ANDREAS KLEHR²,

ANDREA KNIGGE², and STEFAN BREUER¹ — ¹Institute of Applied Physics, Applied Semiconductor Optics and Photonics, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt, Germany — ²Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

Passively mode-locked semiconductor lasers emitting at 1070 nm are compact photonic sources for multi-GHz repetition rates and for high-speed data transmission where excellent pulse train stability in time and amplitude are demanded. Timing and amplitude stability (AJ) investigations were performed recently in C. Weber et al., Internat. Conf. on Transparent Optical Networks 2016, We.P.30. In this contribution we study experimentally the influence of self-feedback by an external optical fiber cavity on the mode-locking dynamics of a multi-section narrow ridge quantum-well (QW) laser with an active InGaAs double QW embedded in GaAsP spacer layers. We focus on the timing and amplitude stability improvement by single optical feedback and quantify this improvement by radio-frequency domain, temporal and optical domain analysis in dependence on the feedback delay and feedback strength. The obtained results are compared to investigations performed on the pulse train stability of an InGaAs quantum dot laser emitting at 1250 nm.

HL 64.41 Wed 15:00 P1C

Pulse train stabilization of a passively mode-locked quantum dot laser emitting at 1250 nm subject to single and dual long fiber optical self-feedback — ●SEBASTIAN STUTZ¹, OLEG NIKIFOROV², CHRISTOPH WEBER¹, THOMAS WALTHER², and STEFAN BREUER¹ — ¹Institute of Applied Physics, Applied Semiconductor Optics and Photonics, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt, Germany — ²Institute of Applied Physics, Laser and Quantum Optics, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt, Germany

Passively mode-locked semiconductor lasers are compact photonic sources delivering a train of picosecond short optical pulses for optical clock distribution, high bit-rate optical time division multiplexing and compact microwave/millimeter-wave signal generation. The pulse train can exhibit considerable timing jitter and concepts to reduce timing and amplitude jitter are demanded. Recently the influence of dual optical feedback with fine-delay control and two short feedback cavities has been studied in Optics Express 24, 14301, 2016. Here, we study experimentally the influence of single cavity fiber feedback as well as dual cavity long fiber feedback on an InGaAs quantum dot semiconductor laser. We focus on the timing and amplitude stability as well as the pulse repetition rate control of an InGaAs quantum dot laser subject to self-feedback by long dual fiber delay cavities with fine-delay control. Simulation results by a simple time-domain model (L. Drzewietzki et al., Optics Express 21, 16142, 2013) allow to reproduce the experiments with good agreement.

HL 64.42 Wed 15:00 P1C

Passively mode-locked quantum dot laser emitting at 1250 nm operated in a low temperature environment — ●SEBASTIAN STUTZ, CHRISTOPH WEBER, and STEFAN BREUER BREUER — Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt, Germany

The pulse train stability and mode-locking (ML) properties of passively mode-locked InAs/InGaAs quantum dot semiconductor laser are studied experimentally. The laser consists of a multi-section cavity with a total cavity length of 8 mm and a 0.9 mm long absorber section length. Initial experimental investigations of a mode-locked GaAs quantum well laser at cryogenic temperatures have been performed by M. H. Kiang et al., Electron. Lett. 3, 880 in 1995 with a focus on radio-frequency linewidth study. Here, we expand these investigations towards a comprehensive study of the mode-locking dynamics under various operating temperatures. We then discuss the experimentally obtained dependencies of mode-locked pulse train stability and emission properties in the radio-frequency and spectral domain on laser biasing conditions and temperature down to -98 °C. The results suggest future perspectives on investigating the mode-locking at low temperatures.

HL 64.43 Wed 15:00 P1C

Development of AlGaInP-based electrically-pumped VECSELS emitting in the red spectral range — ●MONA STADLER, MATTHIAS PAUL, STEFAN HEPP, MICHAEL JETTER, and PETER MICHLER — Institut für Halbleitertechnik und Funktionelle Grenzflächen und Research Center SCoPE, Allmandring 3, 70569 Stuttgart, Germany

The electrically-pumped vertical external-cavity surface-emitting laser (EP-VECSEL) is a promising device to combine the advantages of electrically-pumped semiconductor lasers with them of optically pumped vertical-cavity surface-emitting lasers (VCSELs). Next to high and scalable output powers and good beam qualities of the VECSEL, offers the open cavity the use of intra-cavity elements for different applications, e.g. frequency stabilized emission or frequency-doubling. In electrical driven lasers the pumping scheme is simplified drastically, compared to optical pumped systems. Additionally, electrical pumping facilitates higher integration and further miniaturization and is therefore an important step towards compact laser sources. Regarding the chip design of the EP-VECSEL, it should be as easy as possible, keeping optical losses and Joule heating, which are unavoidable in doped layers, minimal. Therefore, a good thermal management, a suitable carrier distribution and a balance between the optical and electrical requirements have to be found. We present the first steps towards an electrically-pumped AlGaInP-based VECSEL emitting in the red spectral range regarding the chip design and its spectral and luminescence characteristics.

HL 64.44 Wed 15:00 P1C

Injection Locking of Spontaneous Emission Enhanced Microlaser — ●FELIX KRÜGER¹, ELISABETH SCHLOTTMANN¹, STEFFEN HOLZINGER¹, CHRISTIAN SCHNEIDER², SVEN HÖFLING², MARTIN KAMP², JANIK WOLTERS³, XAVIER PORTE¹, and STEPHAN REITZENSTEIN¹ — ¹Institut für Festkörperphysik, Technische Universität Berlin — ²Technische Physik, Universität Würzburg — ³present adress: Universität Basel, Switzerland

Micro- and nanolasers are of broad interest because of their size, modulation speed and low energy consumption. In recent years the nonlinear dynamics of such lasers are spotlighted in an interdisciplinary context at the crossroads of classical and quantum physics.

The experimental studies address the influence of the spontaneous emission factor β on the locking properties and on mode switching in bimodal microlasers. Our studies reveal, that for small mode-volume microlasers emission of thermal light is maintained at the solitary cavity mode while only the coherent part of emission locks to the external master laser [1].

Moreover, in bimodal micropillar lasers the master laser allows for a polarization dependent destabilization or stabilization of switching processes. We also discuss more complex injection schemes involving delayed optical feedback.

[1] E. Schlottmann, S. Holzinger et al., Phys. Rev. Applied 6, 044023 (2016)

HL 64.45 Wed 15:00 P1C

Emitter and absorber assembly for multiple self-dual operation and directional transparency — ●CHRISTIAN V. MORFONIOS¹, PANAYOTIS A. KALOZOUIMIS², GEORGIOS KODAXIS², FOTIOS K. DIAKONOS², and PETER SCHMELCHER^{1,3} — ¹Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — ²Department of Physics, University of Athens, 15771 Athens, Greece — ³Centre for Ultrafast Imaging, Universität Hamburg, 22761 Hamburg, Germany

We propose a recursive scheme for the design of scatterers acting simultaneously as emitters and absorbers, such as lasers and coherent perfect absorbers in optics, at multiple prescribed frequencies. The approach is based on the assembly of non-Hermitian emitter and absorber units into self-dual emitter-absorber trimers at different composition levels, exploiting the simple structure of the corresponding transfer matrices. In particular, lifting the restriction to parity-time-symmetric setups enables the realization of emitter and absorber action at distinct frequencies and provides flexibility in the choice of realistic parameters. We further show how the same assembled scatterers can be rearranged to produce unidirectional and bidirectional transparency at the selected frequencies. With the design procedure being generically applicable to wave scattering in single-channel settings, we demonstrate it with concrete examples of photonic multilayer setups.

HL 64.46 Wed 15:00 P1C

Inverted HEMT structure with electric field induced 2DEG — ●ISMAIL BÖLÜKBASI, JULIAN RITZMANN, ANDREAS D. WIECK, and ARNE LUDWIG — Ruhr-Universität Bochum, D-44780 Bochum, Germany

Two-dimensional-electron gases (2DEG) have interesting physical properties and allow studies in reduced dimensions. They can function as a host material for electrostatic qubit systems, like quantum dots.

These 2DEGs are mostly created in high-electron-mobility transistors with modulation doping.

However, there are deep donor levels, that hinder compatibility with photonic applications. Approaches like short-period-superlattice doping^[1] lead to unwanted gate hysteresis. All structures seem to be plagued by charge noise, probably arising from the dopands in the modulation doped region. To avoid the interference with the impurities, the 2DEG can alternatively be induced with an electric field.

An issue with these structures is to produce reliable ohmic contacts to the 2DEG without short-circuits to the inducing gate. Here we use an approach with alloyed ohmic contacts to a global backgate, inducing the 2DEG. The 2DEG is then contacted with non-alloyed epitaxial contacts.

[1] Umansky, V., et al. “MBE growth of ultra-low disorder 2DEG with mobility exceeding $35 \cdot 10^6 \text{cm}^2/\text{Vs}$.” *Journal of Crystal Growth* 311.7 (2009): 1658-1661.