

## HL 46: Organic Photovoltaics I

Time: Wednesday 10:15–13:30

Location: FOE Anorg

HL 46.1 Wed 10:15 FOE Anorg

**Charge transport and electron trapping in a donor/acceptor-type copolymer** — ●MARCEL SCHUBERT<sup>1</sup>, EDUARD PREIS<sup>2</sup>, ULLRICH SCHERF<sup>2</sup>, and DIETER NEHER<sup>1</sup> — <sup>1</sup>Universität Potsdam, Institut für Physik und Astronomie, 14476 Potsdam — <sup>2</sup>Bergische Universität Wuppertal, Makromolekulare Chemie, 42119 Wuppertal

Low bandgap polymers are the driving force of the ongoing increase in efficiency of organic solar cells (OSC). Most of them are so called donor/acceptor-type copolymers. The polymer PFTBTT was one of the first of this material class, specially design for use in OSC [1]. It has been successfully incorporated as donor material in combination with soluble fullerenes or as acceptor in all-polymer solar cells.

Here, we present a detailed study of the electron transport properties of PFTBTT. By making use of an ultra thin charge generation layer, we were able to (1) selectively address the charge transport of electrons, (2) perform time-of-flight measurements on samples with less than 200 nm thickness and (3) to combine the time-of-flight and Photo-CELIV technique to investigate charge carrier dynamics. Our measurements proof that PFTBTT is an ambipolar material with a high electron bulk mobility. Furthermore, detailed investigations of the charge carrier dynamics with time-delayed extraction fields revealed a power law-type relaxation of the free electron mobility over two orders in time. These results help to quantify relaxation phenomena reported recently for PFTBTT containing all-polymer solar cells [2].

[1] M. Svensson et al., Adv. Mater. 15, 988 (2003).

[2] C. R. McNeill et al., J. Appl. Phys. 106, 024507 (2009).

HL 46.2 Wed 10:30 FOE Anorg

**Investigation of Charge Transfer States in MDMO-PPV:PCBM Solar Cells** — ●JULIA KERN<sup>1</sup>, SEBASTIAN SCHWAB<sup>1</sup>, CARSTEN DEIBEL<sup>1</sup>, and VLADIMIR DYAKONOV<sup>1,2</sup> — <sup>1</sup>Experimental Physics VI, Faculty of Physics and Astronomy, Julius-Maximilians-University of Würzburg, Am Hubland, D- 97074 Würzburg — <sup>2</sup>Center for Applied Energy Research (ZAE Bayern e. V.), Am Hubland, D-97074 Würzburg

In recent years, so called charge transfer states (CTS), i.e. interfacial states generated at the donor-acceptor heterojunction in organic solar cells, have attracted a considerable amount of attention and their role in the processes of charge carrier dissociation and recombination has been discussed controversially. In this context, we investigated the photo- (PL) and electroluminescence (EL) originating from blends of MDMO-PPV and various fullerene derivatives. Upon blending donor and acceptor, a peak emerges at the lower energetic side of the pure material excitonic transitions which can be attributed to a CTS. Interestingly, a distinct red shift of this CTS emission is observed between the obtained EL and PL spectra. Furthermore, we studied the influence of temperature and voltage variations on the intensity and spectral shape of the CTS emission.

HL 46.3 Wed 10:45 FOE Anorg

**Structure-Property-Relations in PPE-PPV based Polymer Solar Cells** — ●CHRISTIAN KÄSTNER<sup>1</sup>, BURHAN MUHSIN<sup>1</sup>, ADAM GETACHEW<sup>2</sup>, CHRISTOPH ULBRICHT<sup>2</sup>, ÖZLEM USLUER<sup>2</sup>, DANIEL AYUK MBI EGBE<sup>2</sup>, and HARALD HOPPE<sup>1</sup> — <sup>1</sup>Institute of Physics, Ilmenau University of Technology, Ilmenau, Germany — <sup>2</sup>Linz Institute for Organic Solar Cells, Johannes Kepler University Linz, Austria

Abstract: Photophysical and photovoltaic properties of a series of anthracene-containing and ethylene-3,4-dioxythiophene (EDOT)-containing poly(p-phenylene-ethynylene)-alt-poly(p-phenylene-vinylene)s (PPE-PPV) copolymers with general constitutional units (Ph-C-tC-Anthr-C-tC-Ph-CH-dCH-Ph-CH-dCH)-*n* and (Ph-C-tC-EDOT-C-tC-Ph-CH-dCH-Ph-CH-dCH)-*n* have been studied. Mixed linear and branched alkoxy side chains were grafted to the backbone in order to tune the  $\pi$ - $\pi$ -stacking ability of the materials, which significantly affects their photovoltaic response when used as donor components in a bulk heterojunction construct together with PCBM as acceptor.

HL 46.4 Wed 11:00 FOE Anorg

**Morphological aspects of the exciton transport in molecular thin films** — ●A.K. TOPCZAK<sup>1</sup>, T. ROLLER<sup>2</sup>, and J. PFLAUM<sup>1,3</sup> — <sup>1</sup>Inst. Exp. Phys. VI, Würzburg University, 97074 Würzburg — <sup>2</sup>3rd

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The exciton diffusion length is a key criteria to optimized design of organic thin film photonic devices. This optimisation requires fundamental understanding and control of the excitonic transport. It has been proposed that exciton transport should depend on the extension of crystalline domains [1]. Therefore we performed photoluminescence-quenching measurements to compare the exciton diffusion length (EDL) of the three archetypical semiconductors Diindenoperylene (DIP), Sexithiophene ( $\alpha$ -6T) and tris-8-hydroxyquinolate-aluminum (Alq<sub>3</sub>) and to link this quantity to the polycrystalline structure. A correlation between the exciton transport and the crystalline morphology is demonstrated. Long-range ordered thin films of DIP and  $\alpha$ -6T show a high EDL. For these films the necessity of taking interference effects into account for a precise modeling became evident. In comparison, amorphous films of Alq<sub>3</sub> showed an EDL which is significantly smaller. We will elucidate the microscopic transport mechanisms and their respective energies by means of temperature dependent measurements. From our results, conclusions on the cell design of planar heterojunction thin film cells can be drawn. Financial support by the DFG (project PF385/4) is gratefully acknowledged. [1] D. Kurrle, J. Pflaum, Appl. Phys. Lett.92 (2008) 133306

HL 46.5 Wed 11:15 FOE Anorg

**Electronic Trap States in Methanofullerenes and their Influence on Organic Solar Cells** — ●JULIA SCHAFFERHANS<sup>1</sup>, CARSTEN DEIBEL<sup>1</sup>, and VLADIMIR DYAKONOV<sup>1,2</sup> — <sup>1</sup>Experimental Physics VI, Physical Institute, Julius-Maximilians University of Würzburg, Am Hubland, D-97074 Würzburg — <sup>2</sup>Bavarian Center for Applied Energy Research (ZAE Bayern e.V.), Am Hubland, D-97074 Würzburg, Germany

Methanofullerenes are the most commonly used electron acceptors in organic bulk heterojunction solar cells, due to their advantages that they can be easily processed from solution, possess a high electron affinity and form segregated phases in blends with common donor polymers.

Although trap states can have a significant impact on the performance of organic solar cells, as they can act as recombination centers, lower the mobility and disturb the internal field distribution, the traps in methanofullerenes have not been matter of research so far.

We investigated the trap states of three commonly used fullerene derivatives, namely PC<sub>61</sub>BM, PC<sub>71</sub>BM and bisPC<sub>61</sub>BM, by thermally stimulated current measurements. Each of the studied methanofullerenes exhibit a broad trap distribution, whereby the PC<sub>71</sub>BM and bisPC<sub>61</sub>BM reveal significantly deeper traps compared to PC<sub>61</sub>BM. These findings will be discussed with respect to the solar cell performance.

HL 46.6 Wed 11:30 FOE Anorg

**Luminescence imaging of polymer solar cells: visualization of progressing degradation** — MARCO SEELAND, ●ROLAND RÖSCH, and HARALD HOPPE — Institute of Physics, Ilmenau University of Technology, Ilmenau, Germany

We apply luminescence imaging as tool for the non-destructive visualization of degradation processes within bulk heterojunction polymer solar cells. The imaging technique is based on luminescence detection with a highly sensitive silicon-ccd camera and is able to visualize the with time advancing degradation patterns of polymer solar cells. The devices investigated have been aged under defined conditions and were characterized periodically with current-voltage-sweeps. This allows determining the time evolution of the photovoltaic parameters and - in combination with the luminescence images - understanding differences in the observed degradation behaviour. The versatile usability of the method is demonstrated in a correlation between local reduction of lateral luminescence and a fast decrease of the short-circuit-current due to the loss of active area. Differences in the degradation of photovoltaic parameters under varied aging conditions are discussed.

15 min. break

HL 46.7 Wed 12:00 FOE Anorg

**Quantitative Description of Electroluminescence Images of Polymer Solar Cells** — ●MARCO SEELAND, ROLAND RÖSCH, and

HARALD HOPPE — Institute of Physics, Ilmenau University of Technology, Ilmenau, Germany

We present a quantitative description of electroluminescence images obtained on organic solar cells, which is based on a device modeling employing a network of interconnected microdiodes. The equivalent circuit network model takes interface and bulk resistances as well as the sheet resistance of the transparent electrode into account. The application of this model allows direct calculation of the lateral current and voltage distribution as well as determination of internal resistances and the sheet resistance of the higher resistive electrode. Furthermore, we have extended the microdiode-model to also describe and predict current voltage characteristics for devices under illumination. Finally the local nature of this description enables important conclusions concerning the geometry dependent performance of thin film solar cells.

HL 46.8 Wed 12:15 FOE Anorg

**Investigation of Field-dependent Charge Carrier Generation and Recombination in Polymer Based Solar Cells by Transient Extraction Currents** — ●JULIANE KNIEPERT, JAMES BLAKESLEY, and DIETER NEHER — University of Potsdam, Germany

There is an ongoing discussion as to whether photoinduced charge transfer in P3HT:PCBM solar cells leads to fully separated electrons and holes, independent of an electric field, or Coulombically bound interfacial charge pairs. While recent studies by R.A. Marsh et al. with transient absorption spectroscopy gave clear evidence for the formation and field-induced dissociation of bound polaron pairs, measurements by I.A. Howard et al. were in favour of hot exciton dissociation. Here, we present the results of bias-dependent Time Delayed Collection Field (TDCF) measurements to access directly the density of free charge carriers in P3HT:PCBM blends coated from dichlorobenzene. Solvent annealing was applied to yield a phase-separated morphology and the corresponding solar cells exhibit high values for the external quantum efficiency and fill factor. Our setup allowed us to follow the generation and recombination of photogenerated charges with a so far unattained time resolution of 40 ns. Our experiments show that the number of collected carriers is independent of the applied bias during pulsed illumination implying that extractable carriers in P3HT:PCBM blends are not generated by the field-assisted separation of bound polaron pairs. In addition, our experiments support the view that bimolecular recombination of free carriers is strongly suppressed in phase-separated P3HT:PCBM blends.

HL 46.9 Wed 12:30 FOE Anorg

**Influence of phase separation on the recombination dynamics of trapped charges in disordered organic semiconductors** — ●JULIEN GORENFLOT<sup>1</sup>, MATTHIAS GUNZ<sup>1</sup>, ANDREAS KÄMPGEN<sup>1</sup>, JENS LOHRMANN<sup>1</sup>, CARSTEN DEIBEL<sup>1</sup>, and VLADIMIR DYAKONOV<sup>1,2</sup> — <sup>1</sup>Experimental Physics VI, Julius-Maximilians University, D-97074 Würzburg — <sup>2</sup>Bavarian Center for Applied Energy Research (ZAE Bayern), D-97074 Würzburg

Using a combination of steady-state and transient photoinduced absorption, we explore the recombination of polarons in pristine poly(3-hexylthiophene) (P3HT) as well as in its blend with [6,6]-phenyl-C<sub>61</sub> butyric acid methyl ester (PCBM). Interestingly those two systems behave very differently with a recombination order of two for pure P3HT which contrasts with the much higher apparent order in the blend. We explain those results in terms of trap induced delay in the blend where energetically trapped polarons can be unavailable for recombination due to phase separation. We determine the activation energy of the bimolecular recombination in pure P3HT. Our results show that the polaron recombination is caused in both neat polymer and blend by intermolecular rather than intramolecular charge transport.

HL 46.10 Wed 12:45 FOE Anorg

**Determination of the built-in voltage of BHJ solar cells by temperature dependent photocurrent measurements** — ●MARKUS MINGEBACH<sup>1</sup>, CARSTEN DEIBEL<sup>1</sup>, and VLADIMIR DYAKONOV<sup>1,2</sup> — <sup>1</sup>Experimental Physics VI, Physical Institute,

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Despite all progresses in the performance of organic BHJ solar cells (up to 8% power conversion efficiency) some very important properties such as the voltage dependent photocurrent or the built-in potential are not fully understood yet. We investigate poly(3-hexyl thiophene) (P3HT) : [6,6]-phenyl-C<sub>61</sub> butyric acid methyl ester (PCBM) solar cells by means of temperature dependent pulsed photocurrent measurements and impedance spectroscopy. We find a point of optimal symmetry (POS) that represents the case of quasi flat bands (QFB) in the bulk of the cell, which is lower than the built-in voltage. [1] This difference is due to band bending at the contacts, which is reduced at lower temperatures. Therefore we can identify the built-in voltage by measuring the POS (confirmed by temperature dependent current voltage measurements). This leads to the conclusion that the potential determined by Mott-Schottky analysis is not the built-in potential.

[1] M. Limpinsel, A. Wagenpfahl, M. Mingeback, C. Deibel and V. Dyakonov, Phys. Rev. B 81, 085203 (2010).

HL 46.11 Wed 13:00 FOE Anorg

**Charge Transport and Recombination Dynamics in Oxygen Exposed P3HT:PCBM Bulk Heterojunction Solar Cells** — ●ALEXANDER FOERTIG<sup>1</sup>, ANDREAS BAUMANN<sup>1</sup>, JULIA SCHAFFERHANS<sup>1</sup>, CARSTEN DEIBEL<sup>1</sup>, and VLADIMIR DYAKONOV<sup>1,2</sup> — <sup>1</sup>Experimental Physics VI, Physical Institute, Julius-Maximilians-University of Würzburg, Am Hubland, D-97074 Würzburg — <sup>2</sup>Bavarian Centre for Applied Energy Research (ZAE Bayern e.V.), Am Hubland, D-97074 Würzburg, Germany

The effect of synthetic air exposure on the charge transport and recombination dynamics in poly(3-hexyl thiophene)(P3HT):[6,6]-phenyl-C<sub>61</sub> butyric acid methyl ester (PCBM) bulk heterojunction solar cells was studied using the complementary measurement techniques of (photo-generated) charge carrier extraction by linearly increasing voltage (photo-CELIV) and transient photovoltage (TPV) and transient photocurrent (TPC). An additional extraction peak appeared in the photo-CELIV transient at larger extraction fields, which is assigned to a field dependent release of previously trapped charge carriers. The complementary techniques consistently revealed an increased charge carrier density and reduced recombination with exposure time to oxygen which we attribute to delayed release from oxygen induced traps and therefore reduced recombination.

HL 46.12 Wed 13:15 FOE Anorg

**Charge transport measurements by transient techniques and their detailed evaluation** — ●JENS LORRMANN<sup>1</sup>, DAVID VOCKE<sup>1</sup>, CARSTEN DEIBEL<sup>1</sup>, and VLADIMIR DYAKONOV<sup>1,2</sup> — <sup>1</sup>Experimental Physics VI, Physical Institute, Julius-Maximilian-University of Würzburg — <sup>2</sup>Bavarian Center for Applied Energy Research e.V. (ZAE Bayern e.V.), Würzburg

The charge carrier transport in pristine poly(3-hexyl thiophene-2,5-diyl) (P3HT) of different regioregularities and in blends with [6,6]-phenyl-C<sub>61</sub> butyric acid methyl ester (PCBM) was investigated by time-of-flight measurements (TOF). We investigate the field and temperature dependence of hole and electron mobilities down to temperatures of 130 K in order to understand the effects of the transport on the solar cell efficiency. The results from the TOF measurements are compared with the outcome of complementary methods like charge extraction by linearly increasing voltage (CELIV) and field effect transistor measurements. We calculate the disorder parameters from the temperature and field dependencies of the charge mobility using a Gaussian disorder transport formalism. Furthermore, we present the detail evaluation of TOF current transients with an improved method by Scott et al. [1], which provides explicit distributions of the transit times and the mobilities instead of discrete values.

[1] J.C. Scott, L.T. Pautmeier and L.B. Schein, *Mean mobilities of charge carriers in disordered media*, Phys. Rev. B 46:8603, 1992