Pulsed Photocurrent Measurements in Bulk Heterojunction Solar Cells — **MARKUS MINGEBACH, MORITZ LIMPSINER, ALEXANDER WAGENPAHL, ALEXANDER GOLDSMANN, CARSTEN DIEBEL, and VLADIMIR DYAKONOV** — Experimental Physics VI, Physical Institute, Julius-Maximilians-University of Würzburg, Am Hubland, D-97074 Würzburg — **Centre of Applied Energy Research (ZAE Bayern e. V.), Am Hubland, D-97074 Würzburg**

The performance of organic bulk heterojunction solar cells greatly improved during the last years up to a power conversion efficiency of more than 6%. Nevertheless very important properties like the voltage dependent photocurrent are not fully understood yet. We investigate the photocurrent in poly(3-hexyl thioiphene) (P3HT): [6,6]-phenyl-C_{61} butyric acid methyl ester (PCBM) solar cells by applying a pulsed measurement technique (proposed by Ooi et al.) and also find a point of optimal symmetry (POS) at 0.52-0.64 V. In contrast to Ooi we identify this voltage not as the built-in voltage, but as the case of flat bands in the bulk of the cell (confirmed by macroscopic simulations). [1] To explain the voltage dependent photocurrent, we apply a combination of Onsager–Braun (polaron pair dissociation) and Sokel–Hughes (charge carrier extraction) theory in conjunction with the POS. In addition we observe and investigate a voltage independent offset of the photocurrent, which is crucial for optimizing the device performance. [1] M. Limpinsel, A. Wagenpfahl, M. Mingebach, C. Diebel and V. Dyakonov, Investigation of the photocurrent in bulk heterojunction Solar Cells, submitted (2009).

Analytical analysis of the CELIV theory — **JENS LORHMANN, BERKELE HOMA BADAZA, CARSTEN DIEBEL, OLLE INGANSS, and VLADIMIR DYAKONOV** — Experimental Physics VI, Physical Institute, Julius-Maximilians-University of Würzburg — **Biomolecular and Organic Electronics, IFM, Linköping University, Sweden — ZAE Bayern, Div. Functional Materials for Energy Technology, Würzburg**

Charge extraction by linearly increasing voltage (CELIV) has attracted much interest in organic semiconductor research, due to its feature of measuring charge carrier mobility and density directly and simultaneously. Up to now the theoretical description of this method has been solved for a low mobility approximation only, because the general solution was impeded by a Ricatti type first order differential equation. In this contribution we present the analytical solution for this Ricatti equation, thus completing the analytical framework of the CELIV method. We compare it with the approximated theory and show that especially for standard organic solar cell materials the low mobility approximation is hardly valid. The evaluation of photo-CELIV measurements on poly(3-hexyl thioiphene-2,5-diyl):[6,6]-phenyl-C_{61} butyric acid methyl ester solar cells can then be performed by the analytical solution of the charge carrier transients. Surprisingly the fit results are only in a good agreement with the experimental currents, if two extraction currents are taken into account – the origin of which we will discuss. Furthermore we present a new equation for mobility evaluation from numerical analysis within our framework, which can be applied over the entire experimental range.

Oxygen Induced Degradation of P3HT:PCBM Solar Cells — **JULIA SCHAEFFERHANS, STEFAN NEUGEBAUER, ANDREAS BAUMANN, ALEXANDER WAGENPAHL, CARSTEN DIEBEL, and VLADIMIR DYAKONOV** — Experimental Physics VI, Faculty of Physics and Astronomy, Julius-Maximilians-University of Würzburg, Am Hubland, 97074 Würzburg, Germany

Power conversion efficiencies of 6% for organic solar cells have already been achieved, with growing tendency. A critical issue yet to be addressed are the factors influencing the device lifetime. To gain a detailed understanding of the device stability, the underlying degradation mechanisms and their impact on the solar cell performance is an important prerequisite for lifetime enhancement. We investigated the oxygen induced degradation of state of the art (PCE > 3%) P3HT:PCBM (poly(3-hexylthiophene):[6,6]-phenyl C_{61} butyric acid methyl ester) solar cells in the dark as well as under simultaneous illumination. Current–Voltage measurements are supplemented by Thermally Stimulated Current (TSC) and Charge Extraction by Linearly Increasing Voltage (CELIV) measurements. In the case of dark degradation the influence of oxygen results in a decrease of the short circuit current (Isc), whereas degradation under bias light leads to a decrease of all solar cell parameters. With the aid of a macroscopic simulation we demonstrate that the origin of the loss in Isc is oxygen doping, which we confirmed by CELIV measurements. In addition, TSC and CELIV measurements revealed an increase of deeper traps and a slight decrease of the mobility due to oxygen.

Polaron Recombination Dynamics in Bulk Heterojunction Solar Cells — **ANDREAS BAUMANN, ALEXANDER WAGENPAHL, CARSTEN DIEBEL, and VLADIMIR DYAKONOV** — Experimental Physics VI, Physical Institute, Julius-Maximilians-University of Würzburg, Am Hubland, D-97074 Würzburg — **Centre of Applied Energy Research (ZAE Bayern e. V.), Am Hubland, D-97074 Würzburg**

Organic solar cells with more than 6% power conversion efficiency were recently shown, coming closer to commercialization. For further improvements, a better understanding of the loss mechanisms inside the solar cell are needed, such as the recombination of photo-generated charge carriers. We applied the experimental technique of charge extraction by linearly increasing voltage (Photo-CELIV) to investigate the recombination dynamics in poly(3-hexylthiophene) (P3HT): [6,6]-phenyl-C_{61} butyric acid methyl ester (PCBM) bulk heterojunction solar cells. It was found experimentally, that the dominating polaron loss mechanism in P3HT:PCBM solar cells is of Langevin type, but reduced by a factor in the range of 0.1 in pristine samples to 0.01 in annealed ones [1]. We propose a model taking the charge carriers profile inside the active layer into account, which describes the origin of the observed reduced Langevin recombination [2]. [1] C. Diebel, A. Baumann, V. Dyakonov, APL 93, 252104 (2008) [2] C. Diebel, A. Wagenpfahl, V. Dyakonov, PRB 80, 075203 (2009)

Relation of open circuit voltage to charge carrier concentration in organic bulk heterojunction solar cells — **DANIEL RAUCH, ALEXANDER WAGENPAHL, CARSTEN DIEBEL, and VLADIMIR DYAKONOV** — Bavarian Centre for Applied Energy Research e.V. (ZAE Bayern), D-97074 Würzburg — **Julius-Maximilians-University of Würzburg, Institute of Physics, Experimental Physics VI, D-97074 Würzburg**

A deeper understanding of the open circuit voltage $V_{oc}$ in bulk heterojunction solar cells is crucial for further performance enhancements. In order to investigate $V_{oc}$, we measured temperature dependent current–voltage characteristics of poly(3-hexylthiophene):[6,6]-phenyl C_{61} butyric acid methyl ester (P3HT:PCBM) solar cells (pristine and annealed) at various light intensities. With charge extraction measurements under the same conditions we could determine the corresponding charge carrier densities $n$ in the operating device. Extrapolating $V_{oc}$ to $T=0K$ gives a constant value for all intensities indicating the effective bandgap of the donor–acceptor system. Fitting the data with $V_{oc}$ models [1,2] showed excellent agreement with only one free parameter, the effective density of states. From our analysis, we gain insights into the recombination mechanisms limiting $V_{oc}$.

Charge Carrier Concentration and Temperature Dependent Recombination in Polymer-Fullerene Solar Cells — **ALEXANDER FORRITIC, ANDREAS BAUMANN, DANIEL RAUCH, THEMIO GEBEIICH, VLADIMIR DYAKONOV, and CARSTEN DIEBEL** — Experimental Physics VI, Physical Institute, Julius-Maximilians-University of Würzburg, Am Hubland, D-97074 Würzburg — **Centre for Applied Energy Research (ZAE Bayern e. V.), Am Hubland, D-97074 Würzburg, Germany**

We performed temperature dependent transient photovoltage and photocurrent measurements on poly(3-hexyl thiophene):[6,6]-phenyl-C_{61} butyric acid methyl ester bulk heterojunction solar cells. Thus we determined small perturbation carrier lifetime and charge carrier densities under operating conditions. We found a strongly charge car-
carrier concentration and temperature dependent Langevin recombination prefactor. The observed recombination mechanism is discussed in terms of a bimolecular loss and compared with charge carrier extraction by linearly increasing voltage (photo-CELIV) measurements done on the same blend system. The observed charge carrier dynamics, following an apparent order larger than two, are explained by dynamic trapping of charges in the tail states of the Gaussian density of states.

Charge Carrier Generation Yield in Organic Solar Cells using a C80 Derivative as Acceptor — Moritz Liedtke1,2, Andreas Sperlich2, Hannes Kraus2, Andreas Baumann2, Carsten Deibel2, Vladimir Dyakonov1,2, and Claudia Cardona3 —

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Organic solar cells (OSC) with C70 and C80 fullerenes show a higher open circuit voltage (Voc) than the standard [6,6]-phenyl-C[61]-butyric acid methyl ester (PCBM):poly-3-hexylthiophene (P3HT) bulkheterojunction cells. Devices containing the trimetallic nitride endohedral fullerene Lu3:N@C80 showed a Voc of 910mV compared to 600mV with C60-PCBM. Still the overall efficiency of these cells remain below the performance of our C60-PCBM:P3HT reference cells. We address the origin of the lower efficiency by means of optical, magnetic and current measurement techniques. In samples containing Lu3:N@C80 we found photoluminescence quenching 3.2 times weaker, triplet yield higher and short-cut current about 2mA/cm² lower than in cells with C60-PCBM as acceptor. We conclude that less efficient charge carrier generation in the Lu3:N@C80:P3HT bulkheterojunction system is the reason for the lower photocurrent.