Conference Proceedings

10th International Conference on Next Generation Solar Energy (NGSE10)

Date and Venue

December 9-10, 2025, EnCN building in Fürtherstraße 250, Nuremberg, Germany

Organizers

Karen Forberich (Helmholtz Institute Erlangen-Nürnberg for Renewable Energy, Germany)

Osbel Almora (Universitat Rovira i Virgili, Spain)

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Sponsors:

Editors: *Osbel Almora, Karen Forberich, Luigi A. Castriotta, Christoph J. Brabec*

Speaker presentations

Thomas Kirchartz (Forschungszentrum Jülich, Germany), "Photodoping, Ideality Factors, and Power-Law Decays in Halide Perovskite Films"

Alexander Eberst (Forschungszentrum Jülich, Germany), "Silicon Heterojunction Solar Cells – From Single Junction to Bottom Cell Applications"

Erkan Aydin (LMU München, Germany), "Interfaces at Work: Enhancing Perovskite Solar Cells for Both Terrestrial and Space Environments

Ulrich W. Paetzold (Karlsruhe Institute of Technology, Germany), "Augmenting In Situ Monitoring of Perovskite Thin-Film Formation Using Deep Learning"

Pascal Friederich (Karlsruhe Institute of Technology, Germany), "Machine Learning for Design and Autonomous Discovery of Photovoltaic Materials"

Alessandro Troisi (University of Liverpool, UK), "Digital Discovery for Organic Electronics: from Molecules to Polymers"

Evelyne Knapp (ZHAW School of Engineering, Switzerland), "ML-Driven Analysis and Modelling of Perovskite Lab Cells and Modules"

Iacopo Benesperi (Newcastle university, UK), "Diffuse Light to Structured Information with High Efficiency Indoor Photovoltaics"

Jenny Nelson (Imperial College, UK), "The Impact of Molecular Properties on Charge Pair Generation in Organic Semiconductors"

Feng Gao (Linköping University), "Bright organic semiconductors for efficient organic solar cells"

Harald Ade (North Carolina State University, US), "Slot-die coating flexible modules on Ag-nanowire -coated substrates"

Frédéric Lacquai (LMU München, Germany), "Non-fullerene Acceptor Organic Solar Cells – Photophysics and Device"

Jie Min (Wuhan University, China), "High-speed preparation of OPV active layers and their devices"

Eva Unger (Helmholtz-Zentrum Berlin, Germany), "Recent progress in sheet-to-sheet coated flexible and transparent perovskite modules"

Jan Anton Koster (University of Groningen, Netherlands), "Perovskite solar cells: what can we learn from numerical modelling"

Philippe Holzhey (Helmholtz-Zentrum Berlin, Germany) "Elucidating the Role of Dimethylammonium for Stable Mixed Halide Perovskite Solar Cells"

Francesco Vanin (City University of Hong Kong), "Organic-Inorganic Halide Perovskite Materials and their Photovoltaic Applications: Chemical Strategies for Enhanced Stability and Performance"

Emerging PV workshop

Luigi Angelo Castriotta (University of Rome Tor Vergata, Italy), "Flexible photovoltaic devices"

Christian Sprau (Karlsruhe Institute of Technology, Germany), "Transparent photovoltaic devices"

Antonio Riquelme (IFW Dresden, Germany), "Operational photovoltaic stability"

Poster Presentations

Andreas J. Bornschlegl et al., "An Automated Workflow to Discover the Structure–Stability Relations for Radiation Hard Molecular Semiconductors"

Kerstin Märkle et al., "Morphological investigation of the photoactive layer in semitransparent organic solar cells"

Yanxue Wang et al., "Hybrid Learning Enables Reproducible >24% Efficiency in Autonomously Fabricated Perovskites Solar Cells"

Gangadhar Banappanavar et al., "A Dilute-Heterojunction Strategy for Probing Charge Generation in Organic Photovoltaics"

Sebastian Coen et al., "Silver nanowire composite electrodes for semitransparent organic solar cells"

Babar Mondal et al., "Interface Engineering for High-Performance Fully Printed Wide-Bandgap Perovskite Solar Cells with Carbon Electrodes"

Firouzeh Ebadi et al., "Temperature-Dependent Study of *EQE*, V_{oc}, and Luminescence in $Cs_2AgBiBr_6$ Solar Cells"

Tabea Krucker et al., "The Influence of SAMs on the Performance and Stability of Perovskite Solar Cells"

Lisa Reiland et al., "Non-halogenated volatile solid additives for efficient organic solar cells"

Yunan Chen et al., "Transparent Filler: Enhancing LUE in thick-film Semitransparent Organic Solar Cells"

Olive Zbinden et al., "Conditional Autoencoder for Parameter Estimation and *J-V* Curve Simulation of Perovskite Solar Cells"

Fransien Elhorst et al., "Determining the Ion Mobility and Ion Density of Perovskite Solar Cells with Impedance Spectroscopy" (Adv. Energy Materials' **POSTER AWARD**)

An Automated Workflow to Discover the Structure–Stability Relations for Radiation Hard Molecular Semiconductors

Andreas J. Bornschlegl,[1,*,‡] Patrick Duchstein,[2] Jianchang Wu,[1,3] Juan S. Rocha-Ortiz,[1,3] Mauricio Caicedo-Reina,[4] Alejandro Ortiz,[4,5] Braulio Insuasty,[4,5] Dirk Zahn,[2] Larry Lüer,[1,3,*] Christoph J. Brabec,[1,3,*]

Abstract

Emerging photovoltaics for outer space applications are one of the many examples where radiation hard molecular semiconductors are essential. However, due to a lack of general design principles, their resilience against extra-terrestrial high-energy radiation cannot be currently predicted. In this work, the discovery of radiation hard materials is accelerated by combining high-throughput, lab automation and machine learning. This way, a large material library of more than 130 organic hole transport materials is automatically processed, degraded, and measured. The materials are degraded under ultraviolet-C (UVC) light in a nitrogen atmosphere, serving as the conditions for electromagnetic radiation hardness tests. A parameter closely related to the differential quantum yield for photodegradation is extracted from the evolution of the UV–visible (UV–vis) spectra over time and used as a stability target. Following this procedure, a stability ranking spanning over 3 orders of magnitude was obtained. Using Gaussian Process Regression based on predictors derived from structural fingerprints, structure–stability relations for UVC stable materials were identified: fused aromatic ring clusters are beneficial, whereas thiophene, methoxy and vinylene groups are detrimental. The established predictive model quantifies the effect of specific molecular features on UVC stability, allowing chemists to consider UVC stability in their molecular design strategy.

Acknowledgements

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Morphological investigation of the photoactive layer in semitransparent organic solar cells

Kerstin Märkle,[1,‡] Yunan Chen,[1] Sebastian Coen,[1] Erich Müller,[2] Yolita M. Eggeler,[2] Christian Sprau,[1,*]

Abstract

The narrow absorption range of organic semiconductors enables high semitransparency of organic solar cells (OSCs) in the visible spectrum. Typically, the active layer of OSCs consists of an interpenetrating network of donor and acceptor materials known as a bulk heterojunction. The effective separation of carriers at the interfaces between the donor and acceptor materials and their subsequent transport to the electrodes is crucial for device performance. Therefore, the size and distribution of the material phases, as well as their controlled manipulation during processing, are essential to achieve a high power conversion efficiency. As in large-scale fabrication, thicker films would be beneficial for defect-free deposition, we incorporate transparent fillers such as polystyrene into the photoactive layer to increase its thickness. However, this additional component has a significant impact on the morphology.

This work focuses on the morphological study of the photoactive layer in semitransparent OSCs by electron microscopy and atomic force microscopy. Although PTQ10 and BTP-FTh exhibit a high miscibility in BHJs without filler materials, PeakForce Kelvin Probe Force Microscopy measurements reveal a "mountain" structure caused by the additional filler material. The higher contact potential difference (CPD) of the "mountains" indicates a higher amount of BTP-FTh compared to the "valleys". Complementary Low-Energy Scanning Transmission Electron Microscopy shows that donor-acceptor and donor-filler mixtures form highly miscible layers, while acceptor-filler layers tend to show agglomerations. Overall, the study of the morphology (e.g., see the below figure) provides key insights into the phase formation of the bulk hetero junction (BHJ) with incorporated filler material and highlight crucial parameters for the optimization.

Acknowledgements

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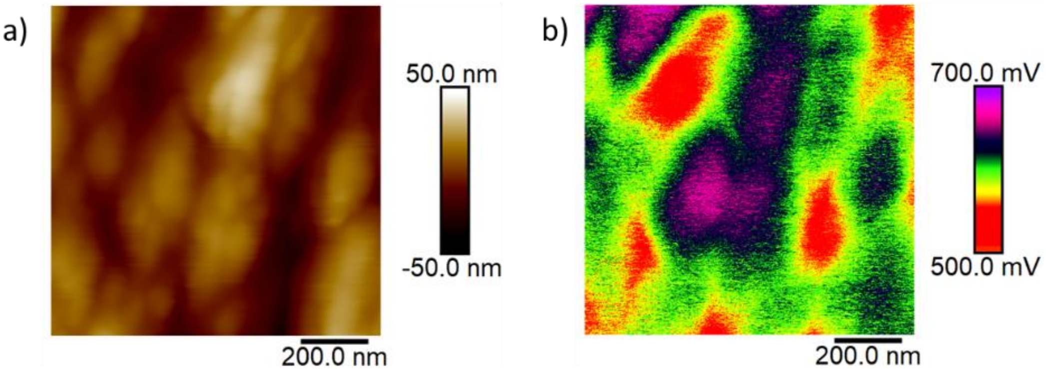

Figure: a) Topography and b) measured CPD of a BHJ with high amounts of a transparent insulator.

Hybrid Learning Enables Reproducible >24% Efficiency in Autonomously Fabricated Perovskites Solar Cells

Yanxue Wang,[1, ‡,] Sinuhé Perea-Puente,[2,] Ian Marius Peters,[1,*]

Abstract

Achieving high-performance perovskite solar cells (PSCs) with satisfactory reproducibility remains a major challenge due to their intrinsic susceptibility to processing variations and environmental fluctuations. To address this challenge, this study introduces an autonomous optimization framework that integrates hybrid machine learning and high-throughput experimentation with modified gradient ascent methods to optimize fabrication processes and minimize experimental variances.

The framework successfully maps the complex, non-linear interdependencies between fabrication parameters and reveals the critical decoupling of photovoltaic metrics. Optimization across seven rounds and 144 parameter sets results in pronounced power conversion efficiency (PCE) and reproducibility enhancement on the platform.

The optimized procedure delivers champion devices achieving PCEs exceeding 24%, surpassing the experience manual operator performance (20.6% PCE, CV >25%) and reducing the coefficient of variation (CV) to below 4.7%, with improvements consistently validated across independent trials. This work offers a practical strategy for improving PSC performance and reproducibility, while laying a foundation for scalable manufacturing and accelerated materials development.

Acknowledgements

This project was co-funded by the European Union through the European Research Council (ERC) under the C2C-PV project (Grant No. 101088359) and the Helmholtz Association under the innovation platform “Solar TAP” (Az: 714-62150-3/1 (2023)).

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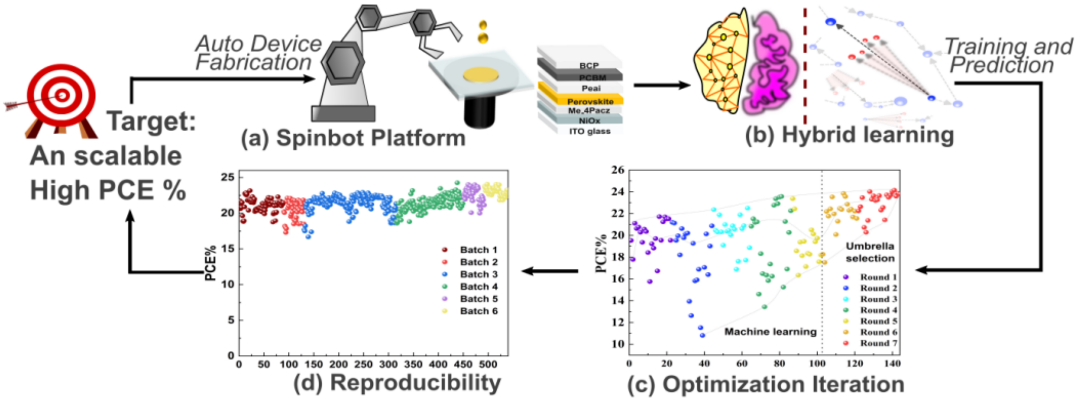

Figure: Optimization framework for PSCs fabrication.

A Dilute-Heterojunction Strategy for Probing Charge Generation in Organic Photovoltaics

Gangadhar Banappanavar,[1,] ‡, Nakul Jain,[1,] Feng Gao,[1,*]

Abstract

Recent advances in non-fullerene acceptors (NFAs) have enabled organic photovoltaics (OPVs) to surpass 20% power-conversion efficiency. Despite this progress, the microscopic mechanisms governing efficient charge generation remain incompletely understood, largely due to the complex and highly intermixed morphology of bulk heterojunction (BHJ) blends. Such structural heterogeneity makes it difficult to disentangle key processes such as exciton dissociation, charge-transfer (CT) state formation, and free-charge generation.

To overcome these limitations, this study [1,2] employs dilute donor/acceptor model systems, which provide a significantly simplified and well-controlled morphology. These systems allow direct probing of charge-generation pathways by minimizing phase-separation and reducing structural ambiguity compared to conventional BHJs. Preliminary measurements across multiple NFA/donor systems reveal that charge-generation efficiency strongly depends on the interplay between film morphology, energetic offsets, and the donor/acceptor doping ratio (see figure below).

Additionally, aggregation-driven charge generation is examined in selected NFA blends to evaluate how molecular packing influences early-time photophysics. These results highlight the importance of understanding morphology-dependent and aggregation-induced charge-generation mechanisms in simplified NFA architectures, offering new insights that can guide the rational design of next-generation high-efficiency OPV materials.

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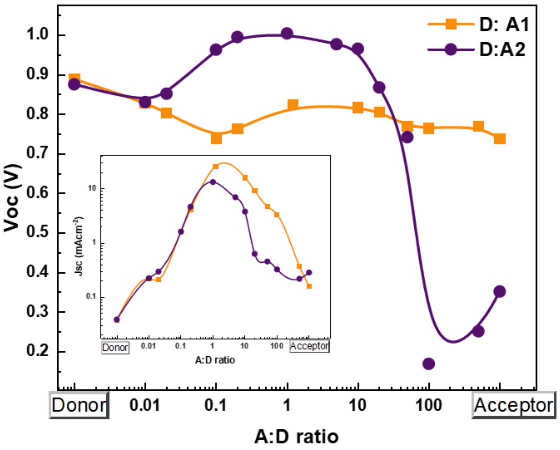

Figure: The open-circuit voltage (V_{oc}) and short-circuit current density (J_{sc}, inset) for the dilute heterojunction OPV for the two NFA systems with the polymer donor.

Silver nanowire composite electrodes for semitransparent organic solar cells

Sebastian Coen,[1, ‡] Yunan Chen,[1] Kerstin Märkle,[1] Christian Sprau,[1,*]

Abstract

Semitransparent organic photovoltaics (OPV) are emerging as a key technology for agrivoltaic systems, as they can transmit light within the photosynthetically active radiation (PAR) range due to their wavelength-selective absorption properties. Their light weight, non-toxicity, and mechanical flexibility also make them well suited to agricultural applications, such as in greenhouses and foil tunnels.[1] However, large-area, low-cost production of such modules is currently hindered by the need to produce highly transparent and conductive liquid-processed electrodes, which could replace the expensive and technically challenging indium-tin oxide (ITO) sputtering and silver evaporation processes [2].

Here, we present a fully blade-coated silver nanowire (AgNW) electrode that meets the electrical and optical requirements of semitransparent OPV, and which can be adapted directly to large-area, roll-to-roll coating processes. The electrode consists of a composite of AgNWs and organic conductive polymers, fabricated via multiple coating steps. It fulfils the requirements of sheet resistance of under 10 Ωsq^{-1} and optical transmittance of over 80% in the spectrum relevant for agrivoltaics (370–740 nm). Based on this electrode, we have developed blade-coated, halogenated-solvent-free organic solar cells with an ITO/ZnO/PTQ10:BTP-FTh/electrode architecture, which have exceptional fill factors and an LUE_{APT} of 3.5%.

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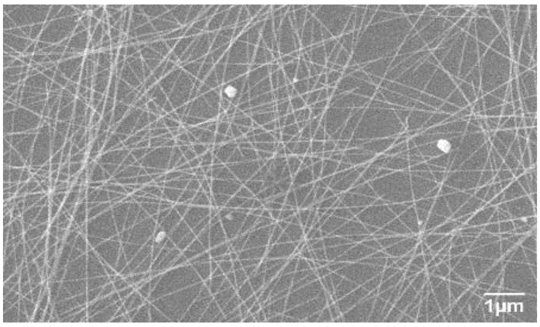

Figure: Scanning electron microscopy (SEM) image of a silver nanowire electrode.

Interface Engineering for High-Performance Fully Printed Wide-Bandgap Perovskite Solar Cells with Carbon Electrodes

Babar Mondal,[1] Shudi Qiu,[1] Michael Wagner,[1] Andreas Distler,[1] Christoph J. Brabec,[1,2,3,*]

Abstract

Fully printed wide-bandgap (WBG) perovskite solar cells are promising for semi-transparent Building-Integrated Photovoltaics, tandem top cells, and low-temperature indoor photovoltaics (PV), but their performance is hindered by high non-radiative recombination from interface defects and band alignment mismatch between charge transporting layers and the active halide layer, causing open circuit voltage (V_{oc}) losses > 400 mV. To address this, we implement an interface-engineered design featuring bilayer electron transporting layers (ETLs), hole transporting layers (HTLs), and triethylamine hydrochloride (TEAHCl) modified SnO_2, which improves film uniformity, enhances conductivity, and suppresses interfacial recombination. This integrated approach achieves a low VOC deficit (< 200 mV) and high efficiencies of 16.51% on glass and 14.10% on flexible substrates.

In this work, TEAHCl incorporation was found to enhance SnO_2 film uniformity, delivering higher transmittance and conductivity. It also boosts perovskite crystallinity and absorption. Collectively, these improvements achieve efficiencies of 16.51% (glass) and 14.10% (flexible) with a lower V_{OC} deficit, highlighting strong practical potential in practical applications.

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Temperature-Dependent Study of *EQE*, V_{oc}, and Luminescence in $Cs_2AgBiBr_6$ Solar Cells

Firouzeh Ebadi,[1] Kazem Meraji,[1,‡] Miguel A. Torre Cachafeiro,[1] Florian Wolf,[2] Maximillian T. Sirtl,[2] Thomas Bein,[2] Wolfgang Tress,[1]

Abstract

Halide double perovskites (HDP) constitute a distinct subclass of perovskites in which the single B-site metal cation is substituted by two different metal species, resulting in the general composition $A_2BB'X_6$. In this work, we investigate the optoelectronic behaviour of HDP solar cells under realistic operating conditions. Temperature-dependent spectral response measurements reveal a strongly varying Urbach energy. We also correlate photocurrent collection efficiency with photoluminescence quenching as a function of applied voltage and temperature.

Additionally, by measuring photoluminescence spectra and open-circuit voltage under both above-gap and sub-gap excitation and combining all this information, we suggest charge separation and recombination pathways in the device performance (se figure below).

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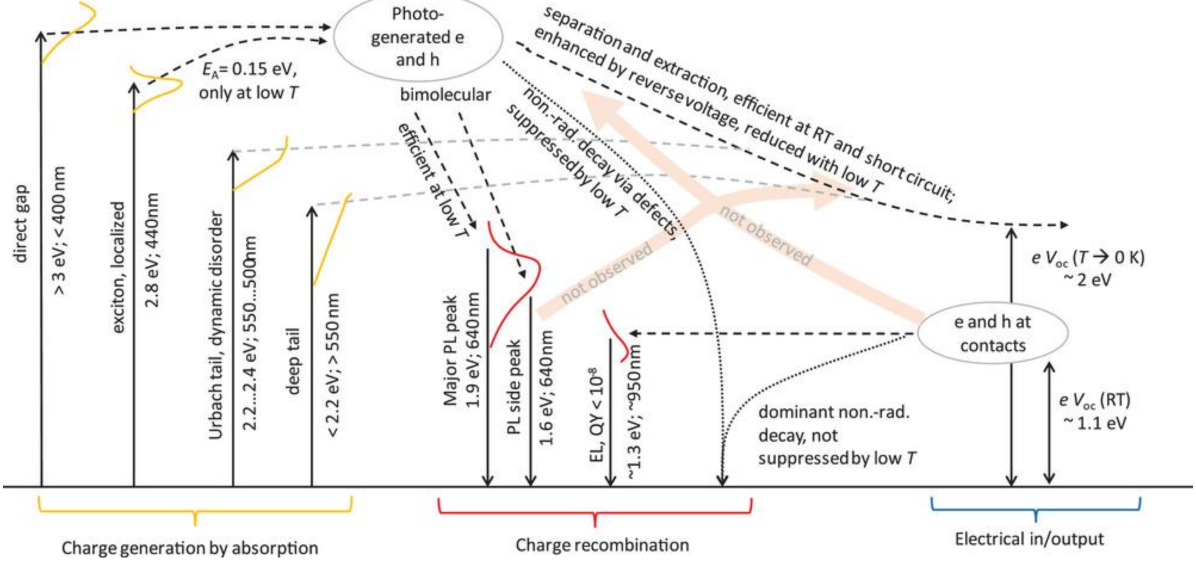

Figure: Optoelectrical processes occurring in $Cs_2AgBiBr_6$ perovskite solar cell. Reproduced with permission from Ebadi et al. [1], under a Creative Commons Attribution 4.0 International license.

Non-halogenated volatile solid additives for efficient organic solar cells

Lisa Reiland,[1,2 ‡,] David Garcia-Romero,[1,] Lorenzo Di Mario,[1,] Masbah Hakim,[2,] Francesco Modena,[1,] Mordechai Kot,[1,] Gabor Ersek,[1,] Francesco Simone Ruggeri,[2,] Giuseppe Portale,[1] Maria Antonietta Loi,[1,*]

Abstract

Additives can improve the performance and stability of organic solar cells (OSCs) through optimised active layer (AL) morphology. The main advantage of volatile solid additives (VSAs) compared to solvent additives is their pronounced volatility allowing for a complete removal by simple post-treatments such as thermal annealing. Halogenated VSAs resulting in very efficient devices have been studied in detail [1]. However, there is no evidence that halogenation is essential for high device performance and thus more environmentally friendly alternatives namely non-halogenated VSAs could represent viable alternatives [2].

Herein, two novel non-halogenated VSAs 1,4-diacetylbenzene (DAB) and terephthalaldehyde (TPA) (see figure below) effectively improve the power conversion efficiency (PCE) to 18.0% and 17.5%, respectively. This is a large improvement when compared to the reference binary OSC achieving a PCE of 16.9%. Furthermore, both novel VSAs improve the OSCs' stability. After >165 days of storage, the best device treated by TPA still maintains ~95% of its initial PCE compared to the reference keeping ~89% of its initial PCE. To elucidate the working mechanisms we combined photoluminescence, X-ray scattering and nanoscale imaging techniques, allowing us to investigate the synergistic effects of the VSAs and the annealing temperature. These findings demonstrate the broad prospects of non-halogenated VSAs in the fabrication of highly efficient organic semiconductors.

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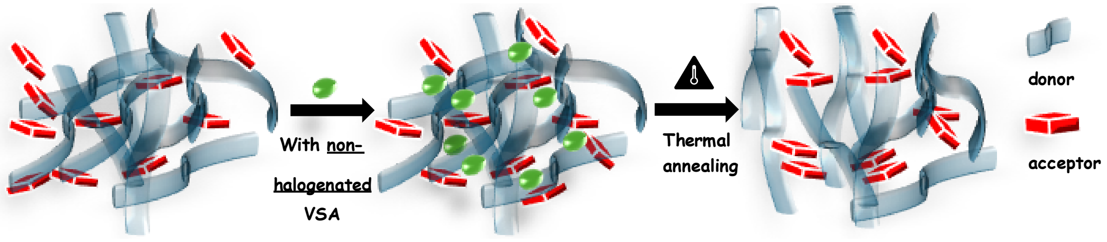

Figure: Schematic of the AL morphology reorganization upon the use of a non-halogenated VSA

The Influence of SAMs on the Performance and Stability of Perovskite Solar Cells

Tabea Krucker,[1, 2, ‡, *] Christophe Ballif,[2,3] Aïcha Hessler-Wyser,[2] Sandra Jenatsch,[4] Davide Moia,[4] Mostafa Othman,[2] Christian Wolff,[2] and Beat Ruhstaller,[1, 4]

Abstract

Self-assembled monolayers (SAMs) are promising candidates to replace conventional hole-transport layers (HTLs) in perovskite solar cells (PSCs). However, the fundamental mechanisms by which SAMs influence perovskite crystal growth and device stability remain insufficiently understood. In this work, we investigate two SAMs, Me-4PACz and F-4PACz, that differ in their functional groups. Although perovskite films exhibit improved wetting on F-4PACz, the resulting devices show a reduced fill factor (FF).

To elucidate the origin of this behaviour, we examine the perovskite crystal structure on both SAMs using Kelvin probe force microscopy (KPFM), atomic force microscopy (AFM), X-ray diffraction (XRD), grazing-incidence wide-angle X-ray scattering (GIWAXS), scanning electron microscopy (SEM) and photoluminescence (PL) mapping. Furthermore, we assess charge-transport properties across the two SAMs and their corresponding device stacks using ultraviolet photoelectron spectroscopy (UPS), transient surface photovoltage (trSPV) and time-resolved photoluminescence (trPL).

This study provides deeper insight into how SAMs govern interfacial energetics, perovskite growth and ultimately the performance and stability of PSCs.

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Transparent Filler: Enhancing LUE in thick-film Semitransparent Organic Solar Cells

Yunan Chen,[1, ‡] Sebastian Coen,[1] Kerstin Märkle,[1] Christian Sprau,[1,*]

Abstract

Organic solar cells (OSCs) have attracted significant interest due to their low cost, flexibility, solution processability and semitransparency. In particular, semitransparent OSCs are promising for building-integrated and agricultural applications. However, up-scaling production requires a thicker photoactive layer to minimize defects, which typically compromises the transparency and sometimes even the power conversion efficiency (PCE), thereby leading to a reduction in light utilization efficiency (LUE).

To address this challenge, we introduced PS as transparent filler into blade-coated PTQ10 based solar cells to increase the thickness and transparency, as illustrated in the figure below. We investigated the influence of different content of PS on device performance and found that the addition of PS into the photoactive layer induces phase separation and the degree of phase separation increases with the increasing PS amount, resulting in a reduced device performance. Nevertheless, incorporating PS enhances the transparency of the OSC and shifts the optimal PCE towards larger active layer thickness, achieving an improvement of the LUE of thick-film semitransparent OSCs. Finally, with silver nanowires blade-coated as the transparent top electrode, a LUE above 2.4% was achieved with a 200 nm thick PTQ10 based photoactive layer. Our work demonstrates that transparent fillers are a viable approach to facilitate future scalable fabrication of high-performance semitransparent OSCs.

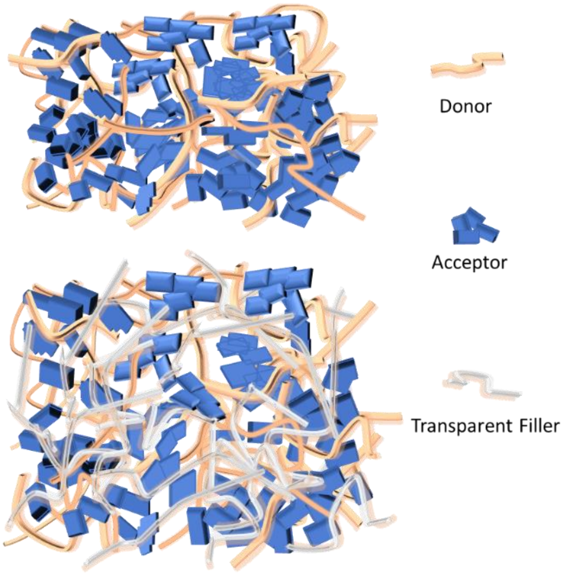

Figure: Schematic illustration for Transparent Filler concept.

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Conditional Autoencoder for Parameter Estimation and Current-Voltage Curve Simulation of Perovskite Solar Cells

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Abstract

Within only a decade the power conversion efficiency of perovskite solar cells (PSCs) has increased by almost a factor of two, exceeding 26%. Easy and cheap production, together with many favourable physical properties, PSCs receive a lot of attention from the scientific community. But there are still several challenges that have to be overcome, such as improvements in device efficiency and stability. Improvements are often based on trial and error, expending time and resources without any guarantee of success. Furthermore, PSCs are still not fully understood, because their architecture is complex, and some processes cannot be measured directly. This makes it challenging to identify sources of under-performance or degradation of a device. To push the technology of PSCs to the next level, it is crucial to gain a deeper understanding of their behaviour.

We employ conditional auto-encoder to estimate device parameters like Surface recombination velocity, bulk lifetimes, carrier mobility, ionic mobility, ionic density and mobility of electron transport layer from various scan rates of current-voltage curve (JV curve).

References

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Determining the Ion Mobility and Ion Density of Perovskite Solar Cells with Impedance Spectroscopy

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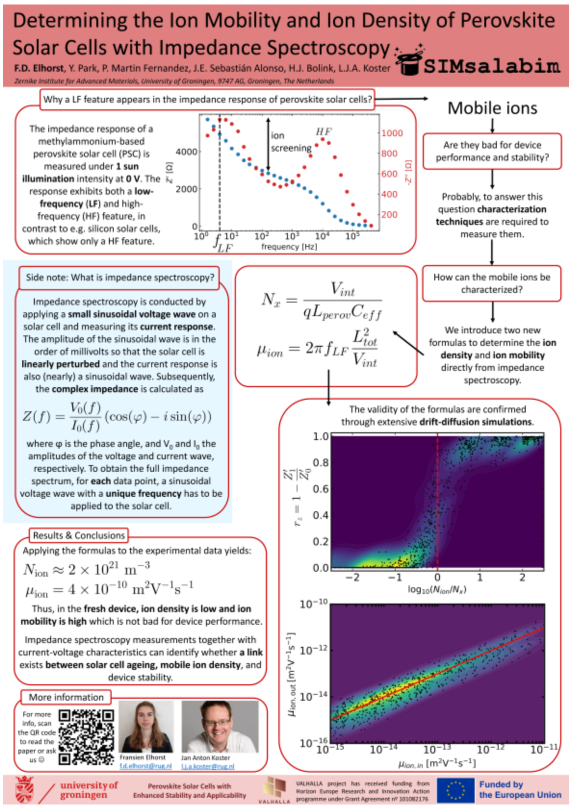
Abstract

Mobile ions in metal halide perovskites are found to degrade perovskite solar cells (PSCs). Therefore, characterizing their density and mobility is crucial for improving the long-term performance of PSCs. A common method to characterize PSCs is impedance spectroscopy.

In the literature, the low-frequency (LF) feature of the PSC impedance response is related to ion dynamics and the high-frequency feature to electronic processes. Yet, why these features can vary over orders magnitude in terms of frequency and impedance is unclear.

In this work (see figure below), we identify the specific ion dynamics that drive the LF feature.[1] We derive two separate analytical expressions that directly relate the frequency and magnitude of the LF feature to the ion density and ion mobility, respectively. The validity of both analytical expressions is confirmed through extensive drift-diffusion simulations, varying over 35 parameters.



Determining the Ion Mobility and Ion Density of Perovskite Solar Cells with Impedance Spectroscopy

F.D. Elhorst, Y. Park, P. Martin Fernandez, J.E. Sebastián Alonso, H.J. Bolink, L.J.A. Koster

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Why a LF feature appears in the impedance response of perovskite solar cells?

The impedance response of a methylammonium-based perovskite solar cell (PSC) is measured under **1 sun illumination** intensity at **0 V**. The response exhibits both a **low-frequency** (**LF**) and high-frequency (HF) feature, in contrast to e.g. silicon solar cells, which show only a HF feature.

Mobile ions

Are they bad for device performance and stability?

Probably, to answer this question **characterization techniques** are required to measure them.

How can the mobile ions be characterized?

We introduce two new formulas to determine the **ion density** and **ion mobility** directly from impedance spectroscopy.

$$N_x = \frac{V_{int}}{qL_{perov}C_{eff}}$$

$$\mu_{ion} = 2\pi f_{LF}\frac{L_{tot}^2}{V_{int}}$$

Side note: What is impedance spectroscopy?

Impedance spectroscopy is conducted by applying a **small sinusoidal voltage wave** on a solar cell and measuring its **current response**. The amplitude of the sinusoidal wave is in the order of millivolts so that the solar cell is **linearly perturbed** and the current response is also (nearly) a sinusoidal wave. Subsequently, the **complex impedance** is calculated as

$$Z(f) = \frac{V_0(f)}{I_0(f)}(\cos(\varphi) - i\sin(\varphi))$$

where φ is the phase angle, and V_0 and I_0 the amplitudes of the voltage and current wave, respectively. To obtain the full impedance spectrum, for **each** data point, a sinusoidal voltage wave with a **unique frequency** has to be applied to the solar cell.

The validity of the formulas are confirmed through extensive **drift-diffusion simulations**.

Results & Conclusions

Applying the formulas to the experimental data yields:

$$N_{\text{ion}} \approx 2 \times 10^{21}\ \text{m}^{-3}$$

$$\mu_{\text{ion}} = 4 \times 10^{-10}\ \text{m}^2\text{V}^{-1}\text{s}^{-1}$$

Thus, in the **fresh device, ion density is low and ion mobility is high** which is not bad for device performance.

Impedance spectroscopy measurements together with current-voltage characteristics can identify whether **a link** exists **between solar cell ageing, mobile ion density**, and device stability.

More information

For more info, scan the QR code to read the paper or ask us ☺

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Perovskite Solar Cells with Enhanced Stability and Applicability

VALHALLA

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Funded by the European Union

Figure: *Poster at NGSE10.*

Alternative formulas from the literature are also tested, but are found to be suboptimal. After the validation, we experimentally determine the ion density and mobility of a methylammonium lead iodide PSC. They are 3.0 × 10^{21} m^{-3} and 4 × 10^{-10} m^2 V^{-1} s^{-1}, respectively.

This new method, which depends on the low-frequency feature of the impedance spectrum, facilitates the precise and straightforward determination of the ion density and ion mobility in PSCs.

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