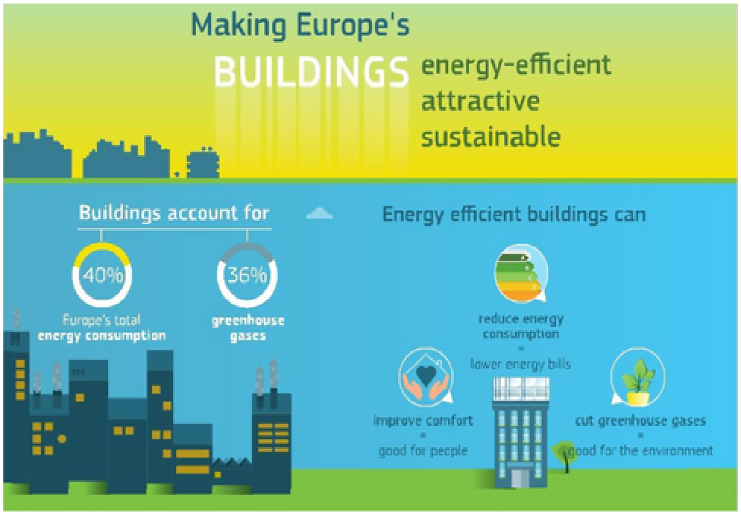
CITYSOLAR

ENERGY HARVESTING IN CITIES WITH
TRANSPARENT AND HIGHLY EFFICIENT WINDOW
INTEGRATED MULTI-JUNCTION SOLAR CELLS

Welcome to the fifth issue of CITYSOLAR Newsletter. You will find relevant information about the Project and its progress on developing innovative transparent and highly efficient window integrated multi-junction solar cells. In this issue we will share the final outcome of the project, show you some insights of the final review meeting in Brussels and recent publications and progresses in the relevant topics.
We hope you enjoy reading it and we invite you to share your thoughts through our social media at the following adresses:
twitter.com/CITYSOLAR_H2020
linkedin.com/company/citysolar-eu
facebook.com/CitysolarH2020



Final Review Meeting in Brussels

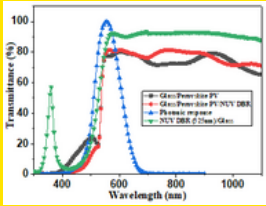
On June 6th and 7th 2024 the consortium met in Brussels at CNRS to discuss the final results of the CITYSOLAR project and presented the results to the project officer.
A small recap to the goals of CITYSOLAR:
We are developing highly transparent and highly efficient photovoltaics by combining the emerging PV technologies of perovskite and organic Photovoltaics. Both will be combined as a tandem device, where the perosvskite solar moduel is near-ultraviolet absorbing and the organic solar module near-infrared absorbing and so reach high transparencies in the visible spectra.
Within the consortium, there is a clearemphasis on research excellence with four renowned universities in the field (FAU, UNITOV,SDU and KAUST), two national research centres(CNR and CNRS-IPVF), two large companiesspecialized in the energy field and life cycleassessment (ENI, EDF) and a SMEs specialized infunctional materials (Brilliant Matters).

In the final review meeting we presented all the results of the different work packages and demonstrated our developed tandem devices. Due to flight restriction, just a small version of these devices was shown to Maider Machado, our project officer. Additionally we deeply discussed exploitation and dissemination after the success of the project. Please see details about the results on page #2. In the evening of the 6th we went for a social dinner to an italian restaurant.

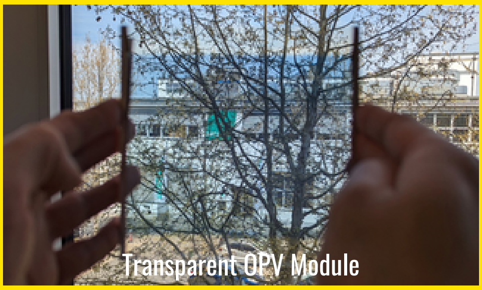
CITYSOLAR TANDEM SOLARMODULE

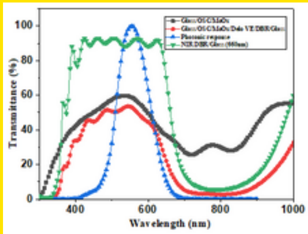
In the project we developed outstanding tandem solar modules, which will be descibed in the following section.

UNITOV developed NUV absorbing Perovskite modules with $FAPbBr_3$ with a planar NIP architecture and DMF-free perovskite ink. As a top electrode transparent ITO was used. With the additional selective NUV distributed bragg reflector from SDU, hero efficiences of 8.1 %, with an AVT of 70.7 % and a CRI of 60 could be achieved.

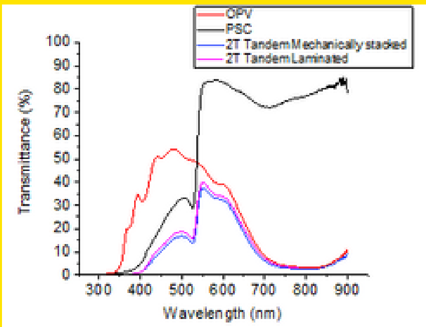


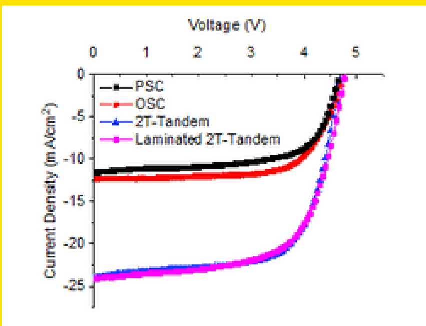
FAU developed NIR absorbing OPV modules with PM6 as donor and an IR absorbing NFA as acceptor. As transparent top elecotrde Silver Nanowires were used. The production process was completely in air, highly scalable and no toxic materials were used. With the addition of the NIR DBR from SDU, hero efficiencies of 7.3 %, with an AVT of 47 % and a CRI of 85 could be achieved.





Both modules were upscaled and the number of cells connected in series were adapated, that the Vmpp of both modules is matched. The modules, including the individual DBRs were laminated together and connected in parallel. With these highly optimized modules and the unique 2T connection methode the consortium could achieve efficiences of 12.3 %, an AVT of 30 % and CRI of 77.
In the end, SDU has built demonstrators with a window manufacturer, by connecting several of the 100 cm² active area modules together





EXAMPLES OF CITYSOLAR NETWORK EVENTS

HOPV - June 13th - 15th, 2024

The CITYSOLAR consortium was represented by Prof. Aldo di Carlo at the 16th Hybrid and Oragnic Photovoltaics conference, 13-15th 2024 in Valéncia (Spain). He discussed the key developments in the project. Additional Prof. Dr. Christoph Brabec (FAU) hold a presentation about Discovering molecules and processed with optimized performance for emerging PV Technologies

EMRS Spring - May 27th - 30th, 2024

Prof. Dr. Christoph Brabec (FAU) discussed with the audience in Strasbourg, about the Discovering of materials and processes for emerging photovoltaics

ESEMA 2024 - May 27th - 31st, 2024

The CITYSOLAR technology and results were discussed at the ESEMA conference / summer school at Proquerolles, France by Philip Schutz and Morten Madsen.

MATSUS 2024 - March 4th - 8th, 2024

Morten Madsen (SDU), Eswaran Jayaraman (SDU), Chun Yuen Ho (SDU), Robin Basu (FAU) were giving talks in Barcelona at the Matsus 2024

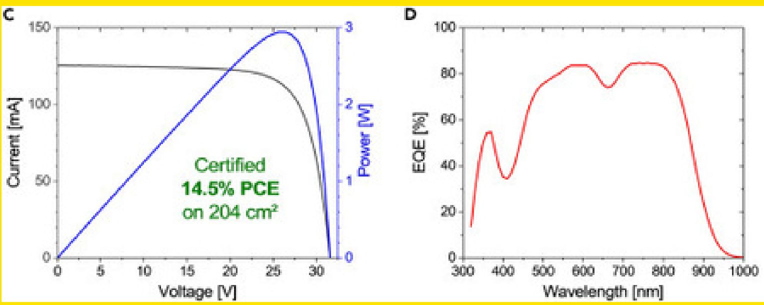
HIGHLIGHT PUBLICATIONS

LARGE-AREA ORGANIC PHOTOVOLTAIC MODULES WITH 14.5% CERTIFIED WORLD RECORD EFFICIENCY

FAU and FZJ reported an OPV module with 14.5% certified PCE, which constitutes a new world record for OPV modules with areas >200 cm^2. Besides the quantified inevitable losses due to ITO resistance and GFF, hardly any difference in PCE is observed, compared with the >5,000 times smaller reference cells. This achievement was enabled by different FEM simulations that, on the one hand, analyzed and optimized the blade coating process to obtain homogeneous films on large areas and, on the other hand, provided the perfect module layout to minimize electrical and geometrical losses.

This surpasses the previous record (13.1% PCE by Waystech) by 11%, relatively, and reduces the efficiency gap between OPV record cells and modules from 32% to 24%.1,12 Since this gap is found to be in the range of 10%–15% for all first- and second-generation PV technologies, this will also be a realistic target for emerging third-generation PV technologies, like OPVs, once they have reached their full performance potential.

Measurement	VOC (V)	ISC (Ma)	FF (%)	VMPP (V)	IMPP (mA)	PMPP (W)	PCE (%) total area	PCE (%) active area
In-house	31.5	124.1	76.0	26.0	114.2	2.97	14.55	15.08
Certified	31.6 ± 0.13	125.3 ± 1.7	74.6 ± 0.4	26.12	113.0	2.952 ± 0.043	14.46 ± 0.21	14.98 ± 0.22



https://doi.org/10.1016/j.joule.2024.02.016

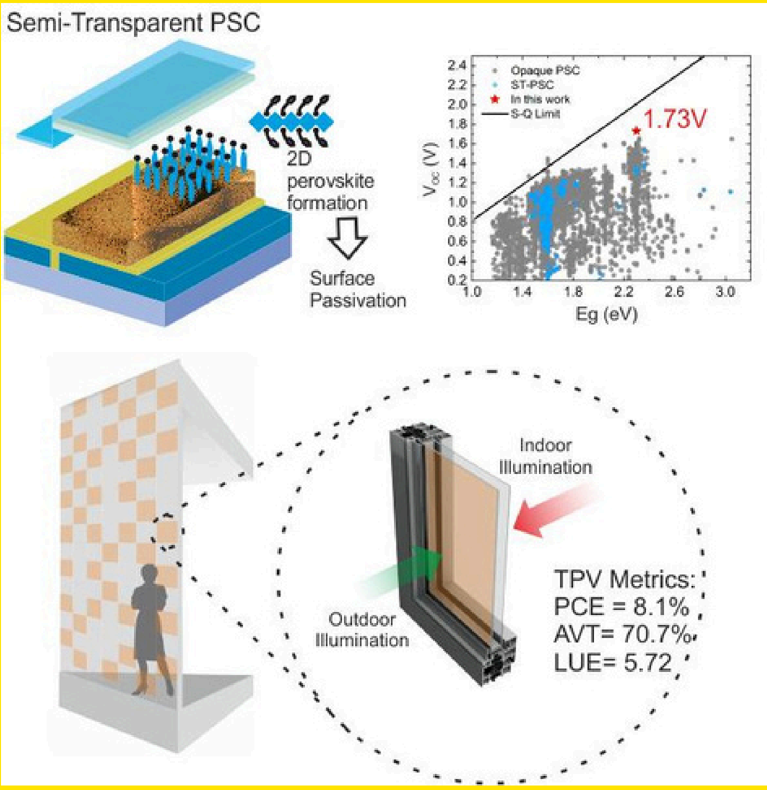
HIGHLIGHT PUBLICATIONS

LARGE-AREA PEROVSKITE SOLAR CELLS AND MODULES WITH 5.72 LIGHT UTILIZATION EFFICIENCY

UNITOV reported 1cm² Semi-Transparent PSCs with 8.1% tracked PCE and AVT equal to 70.7%, which represents the highest LUE reported so far for transparent PV being equal to 5.72. Two strategies were adopted to reach this milestone:

- the increase of the PCE using 2D passivation strategies on 3D-FAPbBr3 perovskite surface
- the increase of the AVT using ultra-thin perovkite absorber and light management tools such as Anti-Reflection Coatings

Thanks to the 2D passivation strategies, we achieve a record Voc of 1.73V using 2.3eV FAPbBr3 bandgap lowering the voltage loss for bromide perovskite to <0.6V. On the other hands Front and Rear ARCs were applied to minimize the impact of the reflections in the visible light spectrum. Furthermore, up-scaling process were performed on 20cm² modules with geometrical fill factor of 97.73% reaching a maximum PCE of 7.3%.



https://onlinelibrary.wiley.com/doi/full/10.1002/aenm.202400663

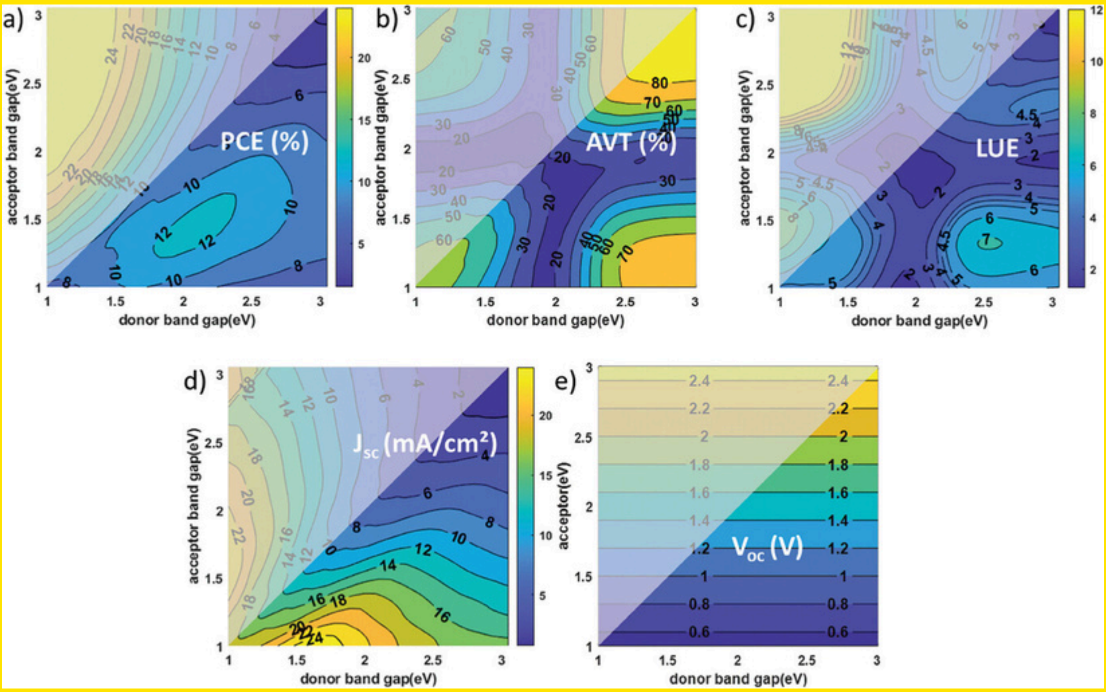
Guidelines for Material Design in Semitransparent Organic Solar Cells

FAU and FZJ have performed a study to determine the optimum performance of semitransparent organic solar cells based on the bandgaps of the donor and acceptor materials. The aim of the work is to provide a rationale and a guideline for selecting or designing appropriate donor and acceptor materials, rather than making exact predictions of the expected PCEs and AVTs. The model is based on the model by Scharber et al., incorporating actual absorbance spectra of commonly used materials for semitransparent cells that are adjusted in energy to accommodate variable bandgaps.

Independent of the particular assumptions that are made for material spectra, optical density etc., the results show that the maximum LUE is found for a minimum energy level offset, and in three different bandgap regions: firstly, for small donor and acceptor bandgaps of ≈1.3 eV, secondly for a small acceptor bandgap of ≈1.35 eV combined with a large donor bandgap of ≈2.5 eV, and thirdly for large donor and acceptor bandgaps of ≈2.9 and ≈2.3 eV, respectively. The comparison with literature data reveals that all high-performing semitransparent OSCs have been demonstrated with two different donors with bandgaps of 1.6 and 1.8 eV, and a variety of acceptors with bandgap values between 1.3 and 1.4 eV. The analysis shows that current record devices with respect to LUE do not employ materials with optimized bandgaps, and devices with more suitable bandgaps are not optimized with respect to photovoltaic performance.

The model can be easily adapted to other applications by replacing the weighting spectrum, for instance with the plant action spectrum, and thus making it suitable to assess the potential of a certain material for greenhouse applications. The result shows that, in this case we observe four maxima instead of three, with the highest performance to be expected at donor bandgaps of ≈2.0 eV and acceptor bandgaps of ≈1.3 eV.

Finally, FAU and FZJ analyze the availability of suitable molecules with a database search and find that all bandgap values are chemically feasible. They therefore encourage the community to synthesize both donors and acceptors with optimized absorption spectra and favorable transport properties to fully exploit the application potential of semitransparent OSCs.



https://doi.org/10.1002/adfm.202314116

Further Publications

Bilayer Layer-by-Layer Structures for Enhanced Efficiency and Stability of Organic Photovltiacs going beyond Bulk Heterojunction
T. Kumari, I. Vyalih, M. Á. L. Luna, H. Ahmed, M. Ahmad, R. Atajanov, E. Jayaraman, S. Manikandan, B. Paci, A. Di Carlo, J. W. Andreasen, V. Turkovic, and M. Madsen
https://doi.org/10.1016/j.xcrp.2024.102027

Uncovering the electronic state interplay at metal oxide electron transport layer/non-fullerene acceptor interfaces in stable organic photovoltaic devices
M. Ahmad, H. Cruguel, M. Ahmadpour, N. Vannucchi, N. M. Samie, C. Leuillet, A. Generalov, Z. Li, M. Madsen and N. Witkowski
https://doi.org/10.1021/acsami.3c11103

Single-Layer Carbon Nitride as an Efficient Metal-Free Organic Electron-Transport Material with a Tunable Work Function
Saboor A.; Stroyuk O.; Raievska O.; Liu C.; Hauch J.; Brabec C.J
https://doi.org/10.1016/j.nanoen.2021.106833

Electron-hole liquid formation in formamidinium lead bromide perovskite FAPbBr3
Ammirati G.; Catone D.; O'keeffe P.; Toschi F.; Turchini S.; Matteocci F.; Barichello J.; Di Carlo A.; Martelli F.
https://doi.org/10.1103/PhysRevB.108.195201

Unveiling the Electronic Band Structure and Temporal Dynamics of Excited Carriers in Formamidinium Lead Bromide Perovskite
Ammirati G.; Turchini S.; Toschi F.; O'Keeffe P.; Paladini A.; Martelli F.; Matteocci F.; Barichello J.; Moras P.; Sheverdyaeva P.M.; Milotti V.; Ory D.; Carlo A.D.; Catone D.
10.1002/adom.202302013

Charge Carrier Induced Structural Ordering And Disordering in Organic Mixed Ionic Electronic Conductors
Quill T.J.; LeCroy G.; Marks A.; Hesse S.A.; Thiburce Q.; McCulloch I.; Tassone C.J.; Takacs C.J.; Giovannitti A.; Salleo A.
https://doi.org/10.1002/adma.202310157

Semitransparent Organic Photovoltaic Devices: Interface/Bulk Properties and Stability Issues
Paci B.; Righi Riva F.; Generosi A.; Guaragno M.; Mangiacapre E.; Brutti S.; Wagner M.; Distler A.; Egelhaaf H.-J.
https://doi.org/10.3390/nano14030269

A 19% efficient and stable organic photovoltaic device enabled by a guest nonfullerene acceptor with fibril-like morphology
Chen H.; Jeong S.Y.; Tian J.; Zhang Y.; Naphade D.R.; Alsufyani M.; Zhang W.; Griggs S.; Hu H.; Barlow S.; Woo H.Y.; Marder S.R.; Anthopoulos T.D.; McCulloch I.; Lin Y.
https://doi.org/10.1039/D2EE03483B

Predicting layer thicknesses by numerical simulation for meniscus-guided coating of organic photovoltaics
Gumpert F.; Janßen A.; Brabec C.J.; Egelhaaf H.-J.; Lohbreier J.; Distler A
https://doi.org/10.1080/19942060.2023.2242455

Maximizing Performance and Stability of Organic Solar Cells at Low Driving Force for Charge Separation
Lüer L.; Wang R.; Liu C.; Dube H.; Heumüller T.; Hauch J.; Brabec C.J.
https://doi.org/10.1002/advs.202305948

Degradation and Self-Healing of FAPbBr3 Perovskite under Soft-X-Ray Irradiation
Milotti V.; Cacovich S.; Ceratti D.R.; Ory D.; Barichello J.; Matteocci F.; Di Carlo A.; Sheverdyaeva P.M.; Schulz P.; Moras P.
https://doi.org/10.1002/smtd.202300222

Polymer-acid-metal quasi-ohmic contact for stable perovskite solar cells beyond a 20,000-hour extrapolated lifetime
Luo J.; Liu B.; Yin H.; Zhou X.; Wu M.; Shi H.; Zhang J.; Elia J.; Zhang K.; Wu J.; Xie Z.; Liu C.; Yuan J.; Wan Z.; Heumueller T.; Lüer L.; Spiecker E.; Li N.; Jia C.; Brabec C.J.; Zhao Y.
https://doi.org/10.1038/s41467-024-46145-7

CITY SOLAR

ENERGY HARVESTING IN CITIES WITH TRANSPARENT AND HIGHLY EFFICIENT WINDOW INTEGRATED MULTI-JUNCTION SOLAR CELLS

CITYSOLAR

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