5th EUROREGIONAL WORKSHOP ON PHOTOVOLTAICS

20th – 21st June 2024

Tržaška cesta 25, Ljubljana, Slovenia

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BOOK OF ABSTRACTS

FE | UNIVERSITY OF LJUBLJANA Faculty of Electrical Engineering | LPVO

About this publication

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About the workshop

Photovoltaics has long been one of the rapidly advancing technologies, now establishing itself as a swiftly developing global energy source. We are witnessing the historically fastest adoption of a new energy source. Whether it will become the dominant energy source will be revealed in the coming years.


2nd workshop

The Euroregional workshop is intended to gather experts together with PhD students. It is organised as a forum of global R&D trends. You will get the chance to meet researchers from across the Europe, get to know their research projects and share the common issues and challenges.

The workshop consists of the following sessions:

1. **Perovskites and New Concepts**
2. **Perovskite-based Tandems**
3. **Modelling & Testing**
4. **PV System Performance**
5. **PV in the Energy Transition**

Program

Thursday, 20th June

9:30 – 10:00	***Registration***	
10:00 – 10:10	**Opening of the workshop** *Marko Topič*	
	PV in the Energy Transition, *Chair: Marko Topič*	
10:10 – 10:50 INVITED	Antonin Faes CSEM, EPFL, PV-Lab, Neuchâtel Switzerland	Vehicle Integrated Photovoltaics Systems
10:50 – 11:10	Marko Jankovec Univ. of Ljubljana, Fac. of. Elec. Eng., Ljubljana, Slovenia	Real-World Energy Yield and Range Extension of Vehicle-Integrated Photovoltaics in Diverse Driving Scenarios
11:10 – 11:30	Matevž Bokalič Univ. of Ljubljana, Fac. of. Elec. Eng., Ljubljana, Slovenia	A virtual energy community at University of Ljubljana
11:30 – 11:50	Matej Guštin Univ. of Ljubljana, Fac. of. Elec. Eng., Ljubljana, Slovenia	Solar power plant as a community common point
11:50 – 13:30	***Lunch break***	

13:30 – 15:00	***LPVO tour** (departure from the Registration desk)*	
	PV System Performance, *Chair:Kristijan Brecl*	
15:00 – 15:40 INVITED (on-line)	Julián Ascencio-Vásquez Univers, USA	Current and future trends in operational loss breakdown of PV systems
15:40 – 16:00	Jelena Joksimović Rudolfovo, Novo mesto, Slovenia	Recurrent Neural Networks for Energy Management Systems
16:00 – 16:20	Žiga Miklič Univ. of Ljubljana, Fac. of. Elec. Eng., Ljubljana, Slovenia	Performance Assessment and Optimization of Mid-Life (Si) Solar PV System
16:20 – 16:40	***Break***	
	Modelling, *Chair: Miha Kikelj*	
16:40 – 17:00	Marko Remec HZB, UL FE, Berlin, Germany	Challenges in Evaluating Perovskite Solar Cell Performance
17:00 – 17:20	Nikolina Pervan PCCL, Leoben, Austria	Enabling glass-free light weight PV modules via honeycomb structures
17:20 – 17:40	Špela Tomšič Univ. of Ljubljana, Fac. of. Elec. Eng., Ljubljana, Slovenia	Finite element method-based thermal modeling of solar cells and photovoltaic modules
19:00	***Dinner**, Location: Pod vrbo*	

Friday, 21st June

	Perovskites and New Concepts, *Chair: Marko Jošt*	
9:00 – 9:20	Martin Ledinsky FZU, Prague, Czech Republic	Universal Formation Mechanism of Halide Perovskite Thin Films
9:20 – 9:40	Scheler Florian HZB, Berlin, Germany	Heterogeneities in 1.68eV Wide-Bandgap Perovskite Solar Cells Trigger Degradation: Composition, Surface Treatments and Contact Design
9:40 – 10:00	Matija Pirc Univ. of Ljubljana, Fac. of. Elec. Eng., Ljubljana, Slovenia	Light Weight Numerical Model for Light Soaking Effect Prediction in Perovskite Solar Cells Under Low Light Conditions
10:00 – 10:20	Žan Ajdič Univ. of Ljubljana, Fac. of. Elec. Eng., Ljubljana, Slovenia	Long-term stability of FACs perovskite solar cells under different testing conditions
10:20 – 10:40	Fernando Solorio Soto Univ. of Ljubljana, Fac. of. Elec. Eng., Ljubljana, Slovenia	ZnO films as electronic transport layer for perovskite solar cells
10:40 – 11:10	***Coffee break***	
	Perovskite-based Tandems, *Chair: Marko Jošt*	
11:10 – 11:30	Stanko Tomić VIN, Belgrade, Serbia	Machine learning for current matched MJSC stack
11:30 – 11:50	Jure Pušnjak Univ. of Ljubljana, Fac. of. Elec. Eng., Ljubljana, Slovenia	Characterization of defects in NiO for implementation in perovskite/CIGS tandem solar cells
11:50 – 12:10	Miha Kikelj Univ. of Ljubljana, Fac. of. Elec. Eng., Ljubljana, Slovenia	3-Terminal Perovskite-Silicon Tandems: A Powerful Characterisation Device or a Mainstream Future Tandem Technology
12:10 – 12:30	***Break***	
	Testing, *Chair: Marko Jankovec*	
12:30 – 12:50	Laurent Calame Lumartix, Aubonne, Switzerland	Plasma lamp for aging
12:50 – 13:10	Kléber Nicolet EPFL, PV-Lab, Neuchâtel, Switzerland	Assessing the outdoor performance and reliability of commercial modules
13:10 – 13:30	Paul Rémondeau EPFL, PV-Lab, Neuchâtel, Switzerland	Monitoring Dashboard for PV modules
13:30 – 13:50	Kristijan Brecl Univ. of Ljubljana, Fac. of. Elec. Eng., Ljubljana, Slovenia	Back-side irradiance and bifacial PV module energy performance modelling

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ABSTRACTS

Thursday, 20th June 2024

Vehicle Integrated Photovoltaics Systems

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Abstract

Vehicle Integrated Photovoltaics (VIPV) interest is nowadays increasing due to recent surge in electricity price and the rise of electric vehicles sales over the past few years. In order to optimize the benefits of VIPV, integrated modules should be as light as possible and accommodate the roof curvature of a car.

The work includes all steps to integrate light curved PV modules into a vehicle from the glass-free design development, the mechanical integration including the curvature and the mechanical load test, and finally the electrical integration in the car with a specific focus on testing different MPPT-DC/DC systems dedicated for the VIPV application.

Keywords: Vehicle integrated PV modules and VIPV systems, MPPT-DC/DC system.

Real-World Energy Yield and Range Extension of Vehicle-Integrated Photovoltaics in Diverse Driving Scenarios

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Abstract

A rigid crystalline silicon photovoltaic (PV) module with a nominal peak power of 192.4 W, accompanied by four irradiance sensors (positioned horizontally and vertically to the left, right, and back), was mounted on an electric vehicle. Various driving scenarios were executed, and data were recorded for analysis. Over a two-month continuous monitoring period, primarily in the Central Slovenia region during late winter and early spring, daily energy generation by the PV module provided an additional driving range of up to 5 km per day, totaling 93 km over the entire period. Hypothetically, if all sides of the vehicle were covered with state-of-the-art PV modules, the driving range could extend to 471 km for the same period.

When compared to a fixed, optimally installed PV module at our outdoor monitoring site in Ljubljana, the mobile PV module exhibited an average performance ratio (PR) of 87%, while the fixed PV module achieved a PR of 83%. The energy yield varied significantly under different car usage scenarios, averaging 41% of the fixed PV module's energy yield. This study presents and evaluates various car use cases under diverse driving and parking conditions through real-world experiments and data collection. From these findings, the foundational specifications for a dedicated mobile vehicle-integrated photovoltaic (VIPV) monitoring system are identified.

A virtual energy community at University of Ljubljana

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Abstract

In the scope of the H2020 project AURORA, we aimed to establish a renewable energy community at University of Ljubljana, Faculty of Electrical Engineering. However, we encountered several legal and social barriers, therefore we invented a virtual approach.

With a virtual approach, we bypassed legal barriers while promoting awareness of energy consumption, carbon emissions, and climate change. We created The Student Energy Club to educate and connect students. To demonstrate and to educate about photovoltaics, we are installing a photovoltaic power plant (PV PP) on the remaining free roofs of the faculty. The Aurora Energy Tracker app developed within the project allows users to monitor and analyse their energy usage with the goal of encouraging behaviour changes to reduce consumption.

Although the virtual approach does not provide direct economic benefits to the participants, it effectively raises awareness and fosters sustainable behaviours among students. The focus on the younger generation will lead to significant long-term impacts on future energy decisions and climate outcomes.

Solar power plant as a community common point

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Abstract

Another project, another technical approach. Not any more. Photovoltaics reached a stage of development some time ago where there are no longer technical barriers to its unrestricted expansion. But there are still many non-technical barriers. They all have a common denominator - the human being, the resident user, if you like. In parallel with technical development, there must also be the assimilation of a new, or rather additional, source of energy into social consciousness.

How and with which social groups have we been working on raising awareness of the use of renewable energy sources, with a focus on photovoltaics? This is a more sociological approach to the introduction of new technologies.

Yes, this is another project (H2020) but this time with a sociological approach to technology. European project AURORA and the Student Energy Club at the University of Ljubljana - All around solar power plant.

Current and future trends in operational loss breakdown of PV systems

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Abstract

Photovoltaic (PV) systems projects are designed to operate for several decades and are supported by financial and warranty schemas that ensure project feasibility and profitability. However, during the operational years, many different issues like curtailment, soiling, snow, or DC issues can occur, impacting the stability of the PV project. The technological advancements in data collection, processing and analytics allow today asset managers to understand the actual performance issues better by offering explicit details about the operational losses and how to optimize performance. In this talk, technical details on how different operational losses can be quantified and disentangled from operational losses are presented. Real-world examples will be shown for this purpose.

Recurrent Neural Networks for Energy Management Systems: a case study

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Abstract

Hybrid energy systems, which integrate diverse energy sources including solar power plants, supercapacitors, UPS batteries, generators, hydrogen cells, and the grid, represent sophisticated yet highly promising approaches to enhancing energy efficiency, reducing operational costs, and supporting renewable and grid-independent initiatives. The inherent complexity of these systems necessitates energy management strategy (EMS) capable of judiciously allocating resources in line with demand forecasts.

A critical component of devising an effective task scheduling system within this framework is the ability to generate precise forecasts of energy production from renewable sources, solar power in this case. This paper showcases the deployment and comparative evaluation of two advanced deep learning models, Long Short-term Memory Recurrent Neural Networks (LSTMs) and Bidirectional Long Short-term Memory Networks (BiLSTMs) and our proposed Ensemble model, which averages the forecasts from LSTM and BiLSTM models, developed at our Laboratory for Energy Management (LabE). Our primary goal is to predict solar power output over a span of three days at 15-minute intervals.

Incorporating thirteen weather features, our findings reveal that the proposed models perform well in predicting energy production data, with the Ensemble predictions showing the best performance for 15-minute interval forecasts spanning three days.

Keywords: solar power, energy management, recurrent neural networks, LSTMs, BiLSTMs, deep learning

Performance Assessment and Optimization of Mid-Life (Si) Solar PV System

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Abstract

This study addresses the performance assessment and optimization of a mid-life Silicon (Si) solar photovoltaic (PV) system operating for 14 years at the Faculty of Electrical Engineering in Ljubljana. The solar power plant consists of two strings, each containing ten 230Wp solar modules, with a total peak power of 4.6 kW. We measured both solar generators' current-voltage (I-V) curves to evaluate the system's performance and degradation over time. Our findings indicate that string 1 has experienced a degradation of 18.8%, while string 2 has a degradation of 15.7%, resulting in an overall degradation of 17.3% for the entire power plant. Additionally, we plan to conduct flash scans on each module individually to gain detailed insights into their performance. The resulting data will be analyzed to detect patterns and anomalies, guiding the development of a new, optimized rewiring scheme. The aim is to enhance the energy yield of this long-running solar power plant, ensuring its continued efficiency and productivity. This optimization is crucial for extending the operational lifespan and maximizing the output of existing solar installations, thereby supporting more sustainable energy practices.

Challenges in Evaluating Perovskite Solar Cell Performance

Marko Remec[1,2], Mark Khenkin[2], Špela Tomšič[1], Florian Scheler[2], Quiterie Emery[2], Carolin Ulbrich[2], Marko Topič[1]

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Abstract:

Indoor ageing tests of perovskite solar cells (PSCs) show that stability of the devices can vary significantly between constant and cycled illumination [1]. Besides illumination cycles, outdoor testing introduces further complexity, presenting unique challenges in monitoring the device performance – not only due to the changing environmental conditions but also perovskite metastability. At our outdoor test location in Berlin, we monitored multiple different lab-scale PSCs at maximum power-point (MPP) condition. Some of the datasets are now more than two years long. Collected MPP data, together with environmental conditions, enables us to analyze the daily and long-term performance of PSCs under real-world conditions. As with indoor tests, PSCs exhibit greater variability in their outdoor behavior compared to silicon solar cells, which makes the assessment of irreversible degradation effects difficult. In particular, intermediate indoor characterization of outdoor devices can be largely affected by the history of the device, leading to erroneous conclusions if the experimental procedures are not carefully considered. We propose that accurate outdoor performance evaluation requires an energy yield model of the device. The comparison of outdoor measurements with the prediction of a validated model proved to be a valuable tool for the evaluation of long-term stability and short-term metastability [2].

[1] M. V. Khenkin *et al.*, “Light Cycling as a Key to Understanding the Outdoor Behaviour of Perovskite Solar Cells,” *Energy Environ. Sci.*, Dec. 2023, doi: 10.1039/D3EE03508E.

[2] M. Remec *et al.*, “From Sunrise to Sunset: Unraveling Metastability in Perovskite Solar Cells by Coupled Outdoor Testing and Energy Yield Modelling,” *Advanced Energy Materials*, vol. n/a, no. n/a, p. 2304452, doi: 10.1002/aenm.202304452.

Enabling glass-free light weight PV modules via honeycomb structures

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Abstract:

BIPV systems need to combine primary building envelope functionalities, (stiffness, wind and water tightness, roof and facade cladding) with the generation of solar electricity [1]. One major challenge for integration of PV into buildings is the weight of standard PV modules, that can reach up to 20 kg/m², with racking even 40 kg/m² [2,3]. Lighter PV modules would enable installation and allow easier integration into areas where standard modules could never be placed.

One approach for glass-free, lightweight PV modules is based on honeycomb sandwich materials used as the back of the PV modules. First iterations of this technology relied primarily on aluminum or Nomex honeycombs. In this work, the properties and suitability of mainly polymeric honeycomb structures is investigated. Suitability for use in PV modules is assessed on the basis of (i) characterization of thermal properties (melting behavior, thermal conductivity), (ii) dimensional stability (CTE), (iii) material compatibility and stability as well as water vapor permeability.

Particular attention is paid to the suitability of honeycomb structures with regard to their behavior during PV module lamination. In addition, the possibility of water condensation in the honeycomb structure and its possible adverse effect on the electrical insulation properties is evaluated.

Keywords: glass-free, light weight PV, BIPV, reliability, polymers

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2. Ferroni, F., Hopkirk, R.J. Energy Return on Energy Invested (ERoEI) for photovoltaic solar systems in regions of moderate insolation. Energy Policy 2016, 94, 336–344
3. Binkley, A. Solar Technology Reference Guide; NAIOP Research Foundation: Herndon, VA, USA, 2012

Finite element method-based thermal modeling of solar cells and photovoltaic modules

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Abstract:

For thermal modeling of PV devices, researchers frequently resort to empirical models, especially when studying the complete PV modules and solar panels due to a significant increase in the simulation domain compared to that of a single solar cell. These models can provide us with satisfactory accuracy in the calculated average temperature of the PV module when the empirical parameters are appropriately selected. However, their output information cannot give us insights into the actual temperature distribution within the module.

In this work, we will use utilize the COMSOL Multiphysics simulation tool to investigate the steady-state temperature profile in a conventional crystalline silicon solar cell and PV module. First, we will study the impact of the cell's front metallization grid and surface texturization. We will then expand our analysis to an entire PV module installed in an open-rack configuration, operating at its maximum power point. We will focus on studying the impact of various influencing parameters, such as the optical power density incident on a module, natural convection dependent on the module inclination angle, and forced convection induced by wind. After discerning the temperature distribution across the individual cells of the module, we will finally analyze the power loss associated with this temperature inhomogeneity.

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ABSTRACTS

Friday, 21st June 2024

Universal Formation Mechanism of Halide Perovskite Thin Films

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Abstract

With the insight of in-situ photoluminescence (PL) and GIWAXS measurements, we have studied the halide Perovskites MHP film formation from solution. Based on the results, we divided the MHPs growth into two stages. In short, we observe fast growth of MHPs grains from GIWAXS in the first stage, accompanied by proportional increase in PL signal. However, in the second stage the growth speed significantly decreases, and the PL signal is highly quenched. This observation means that once the grains start to connect the highly defective grain boundaries are formed. This leads to rapid decrease of the PL signal. Surprisingly, very similar observation was done by in-situ measurement of evaporated MHPs (Slovak Academy of Sciences) and films prepared by pizza oven deposition (EPFL). Preliminary results shows the same tendencies for pulsed laser deposited MPHs as well (University Twente).

Deeper understanding to this universal formation mechanism of MPHs thin films give us a unique opportunity to enhance its optoelectronic quality (VOC of the finalized cell). The precisely timed passivation process focused at the grain boundaries is the key to minimize defect densities. In-situ PL characterization is able to guide us through these processes, as will be documented on the very first results.

Keywords: Formation of halide perovskites, photoluminescence, GIWAXS, defects, grain boundaries

Heterogeneities in 1.68eV Wide-Bandgap Perovskite Solar Cells Trigger Degradation: Composition, Surface Treatments and Contact Design

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Abstract:

Solar cells based on crystalline silicon (c-Si) dominate the photovoltaic market, boasting efficiencies of up to 27.3%[1] and offering over 20-year warranties on stable power output. Perovskite-based solar cells have also achieved high efficiencies, reaching 26.1% in 2023[1]. However, their commercial breakthrough is hindered by stability issues, primarily attributed to high mobile ion densities present.[2] Wider bandgap perovskite absorbers, ideal for top cells in multijunction configurations and seen as promising for rapid market entry, use a mixture of bromide and iodide. This composition makes them particularly vulnerable to phase segregation caused by ion movement. In addition, mobile ions contribute to performance losses through impaired extraction and long-term degradation from permanent ion loss, both vertically and laterally[3]. Understanding degradation mechanisms and the role of ions is crucial for developing stable perovskite devices.
I present an overview of three studies examining the influence of heterogeneities on stability, with a focus on the role of ions. Our findings include:

Masking reduces edge effects occurring at laser scribes but accelerates degradation in other areas, indicating the negative impact of lateral ion migration.

Lateral heterogeneity in the perovskite absorber composition correlates with faster degradation.

Surface treatments with diammonium salts reduce the interfacial losses, but can induce strong surface band bending toward the conduction band in the perovskite layer, negatively impacting the stability.

We employ ion-sensitive techniques, such as fast hysteresis measurements, various optoelectronic characterization methods (including hyperspectral photoluminescence mapping), and photoelectron spectroscopy methods like ultraviolet photoelectron spectroscopy (UPS), to support these findings.

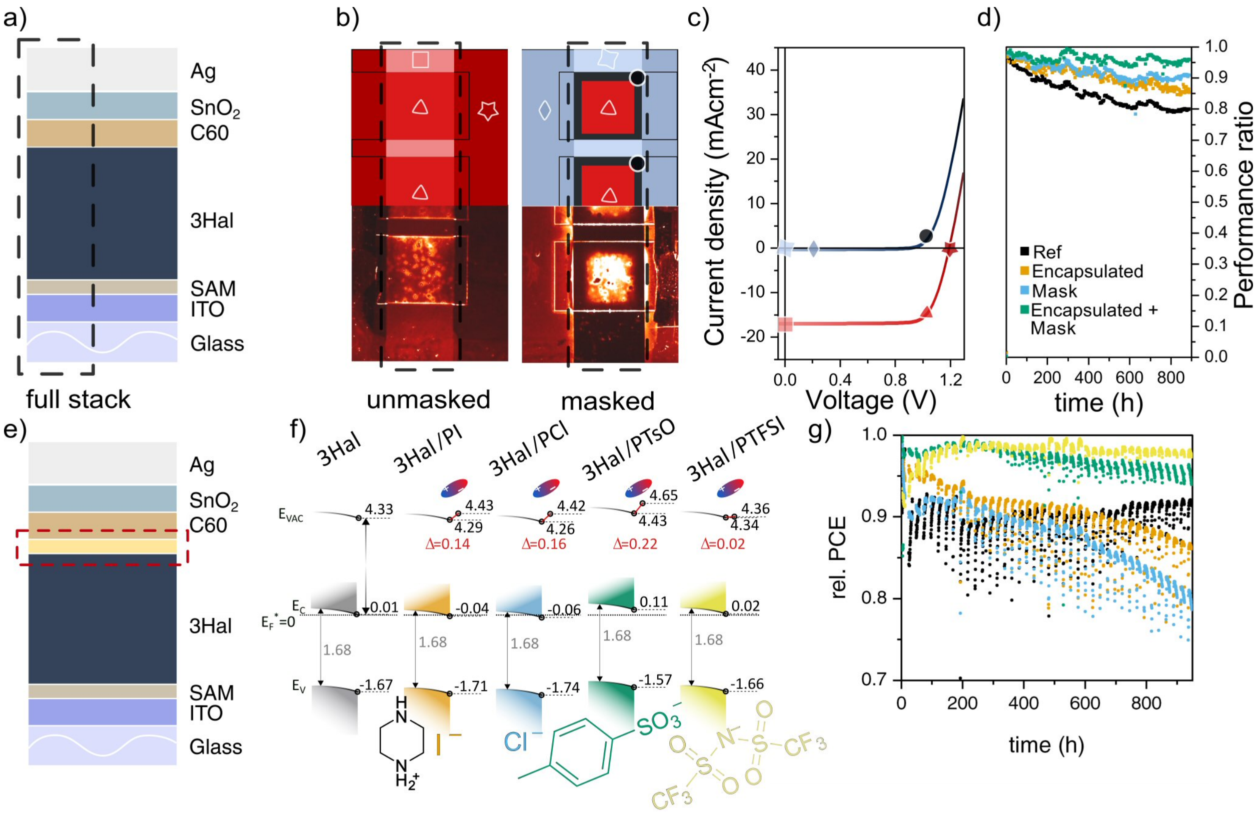

Figure 1: a) Layer stack of the solar cell devices used in the aging experiment in d); 3Hal referring to the triple halide perovskite composition $Cs_{0.22}FA_{0.78}Pb(Br_{0.17}I_{0.83})_3$+4% $MAPbCl_3$, SAM referring to the self-assembled monolayer Ph-4PACz. b) PL images (bottom) of masked (right) and unmasked devices (left); the scheme (top) shows the operating conditions in different areas of the solar cell during the aging experiment as indicated in the current voltage curve in c), with the 6 pixels operated under maximum power point (MPP). d) Performance ratio over 900h for (un)masked devices with and without additional 30nm Al_2O_3 encapsulation. e) Layer stack of solar cells used in the aging experiment g).Compared to a), an additional layer of the molecular salts Piperazinium – iodide (PI), chloride (PCl), tosylate (PTsO) and bistriflimide (PTFSI). f) band structure of Reference compared to treated perovskite films. g) stability of treated devices under ISOS-L1 cycled (25°C, N_2); the colors refer to the molecules shown in f).

[1] *Best Research-Cell Efficiency Chart*, https://www.nrel.gov/pv/cell-efficiency.html.

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Light Weight Numerical Model for Light Soaking Effect Prediction in Perovskite Solar Cells Under Low Light Conditions

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Abstract:

Perovskite solar cells (PSC) are fast approaching commercialization [1] with one of the more promising niches for this technology being indoor photovoltaics (IPV) [2]. One of the remaining challenges is the light soaking effect (LSE), which decreases the PSCs power conversion efficiency as well as makes it difficult to predict their performance. Much effort has been focused on understanding and modelling the underlying processes, but so far, we lack easy to use models of the LSE, that could be used to predict the current state of the LSE based on the time evolution of irradiance. Using the data collected by our long-term indoor monitoring experiment [3], [4], one-diode model parameters of one PSC have been extracted for a time period of one month, resulting in over 700 sets of parameters. All the parameters have been examined for direct correlations with irradiance and where possible these correlations were used for calculating their values. Saturation current of the one-diode model exhibits the strongest dependence on irradiance history. Therefore, a numerical model for predicting its value has been developed. The model is formulated like a discrete linear time-invariant (LTI) system which calculates each new predicted value for each new irradiance input value using a simple difference equation, while the non-linear relations between physical quantities are accounted for before the input is fed into the LTI system. The model tuned on two days of data demonstrated much better prediction ability of open circuit voltage for the rest of the month than it is possible based on static one-diode model parameters.

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Long-term stability of FACs perovskite solar cells under different testing conditions

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Abstract

Perovskite solar cells are a relatively new technology with great potential, as their efficiency is already comparable to that of a classic silicon solar cell. However, in order to reach the market, the long-term stability has to exceed at least 20 years, which is currently still not the case.

In this contribution we focus on the long-term stability of our typical FACs PSCs in a p-i-n configuration. By using Al_2O_3 as a capping layer, we were able to significantly improve the long-term stability under both continuous illumination and cyclic illumination. Further tests will show the performance under different test conditions, such as different temperatures and illumination intensities.

ZnO films as electronic transport layer for perovskite solar cells

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Abstract

Perovskite solar cells (PSC) possess attractive qualities that could compete with or complement well-established photovoltaic (PV) technologies. However, there is still plenty to achieve high efficiencies and long-term stability of PSC. A suitable electronic transport layer (ETL) may contribute to achieving such characteristics. Although C_{60}, SnO_2, and TiO_2 are common materials, little attention has been paid to ZnO.[1-2] In this work, we explore the deposition parameters of ZnO films as ETL in inverted planar perovskite solar cells. Films were deposited by atomic layer deposition (ALD) in combination with thermally evaporated C_{60} films. The overall cell performance was compared to reference cells incorporating SnO_2 as ETL by analyzing the long-term stability, power conversion efficiency (PCE), and other PV performance parameters.

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Machine learning for current matched MJSC stack

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Abstract:

The proper design of the multi-junction solar cell (MJSC) requires the optimisation search through the vast parameter space, with parameters for the proper operation quite often being constrained, like the current matching throughout the whole cell. Due to high complexity number of MJSC device parameters might be huge, which makes it a demanding task for the most of the optimising strategies based on gradient algorithm. One way to overcome those difficulties is to employ the paradigm of macnine learing and the global optimisation algorithms based on the stochastic search. We present the procedure for the design of MJSC based on the heuristic method, the genetic algorithm, taking into account physical parameters of the solar cell as well as various relevant radiative and non-radiative losses. In the presented model, the number of optimising parameters is 5 M+1 for a series constrained M-junctions solar cell. Diffusion dark current, radiative and Auger recombination's are taken into account with actual ASTM G173-03 Global tilted solar spectra, while the absorption properties of individual surrounding SCs were calculated using the multi band Hamiltonian and DFT using the modern hybrid or meta GGA exchange correlation functionals, including the effect of the spin orbit interaction and splitting.. We will predict the efficiencies in case when all losses are taken into account and with only radiative recombination, respectively.

Characterization of defects in NiO for implementation in perovskite/CIGS tandem solar cells

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Abstract:

Both perovskite and CIGS solar cells are part of the thin-film technology. The technology allows smaller thicknesses of cells – several µm instead of several hundred µm. Thin-film solar cells have lower carbon footprint per kWh produced. This and tuneable optical and electrical properties of both materials are the reasons for perovskite/CIGS tandem to be considered one of the more promising candidates for next generation high efficiency solar cells.

Tunnelling is an important charge carrier transport mechanism in the recombination junction of such cells One of the most important tunnelling mechanisms is trap assisted tunnelling. Here the charge carriers travel between materials via recombination in the defects of materials and at the interface. We used SPV measurements to determine certain characteristics of the defect states in the NiO and at the NiO/ITO interface. The results have then been used in simulations using Sentaurus TCAD simulating tool by Synopsys, where the analysis has been performed. The simulated results have been compared to the measurements of the junction to validate the results.

3-Terminal Perovskite-Silicon Tandems: A Powerful Characterisation Device or a Mainstream Future Tandem Technology

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Abstract:

It has been demonstrated time and time again, that 2-terminal (2T) perovskite-silicon tandems exhibit the potential to drive the efficiency increase of silicon based photovoltaic (PV) modules. The main open question, however, remain the tandems' long-term stability and whether the stability could be related to the sub cell current mismatch due to daily spectral variations. In our contribution we strive to answer parts of the question by using and monitoring IBC-based 3-terminal (3T) perovskite silicon tandem devices, which allow us to keep an identical material stack while keeping the possibility of probing individual sub cells of laminated devices. 3T tandems allow us to monitor identical devices, keeping the tandem at its maximum power point (MPP) in a 2T configuration or in the individual sub cell MPPs in the 3T configuration. We subjected 12 25cm^2 to outdoor monitoring, out of which 9 showed significant visual degradation. After degradation an additional contact allowed us to perform detailed characterisation of each individual sub cell of the tandem, confirming degradation modes which would otherwise be a mere guess, if the devices we characterised in the 2T configuration. Combining the detailed measurements and optical simulations we were able to confirm that degradation was mostly due to delamination at the C60/SnO_2 interface.

Plasma lamp for aging

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Abstract

Workshop Overview: Material Aging & UV Light Significance

This workshop delves into the significance of UV light in material aging, particularly for testing photovoltaic panels. We compare various solar simulator light sources including xenon lamps, metal halide lamps, LEDs, and plasma lamps, focusing on their light intensity, UV quality and durability, as well as operational costs.

Highlight on Plasma Lamps:

Among the evaluated sources, plasma lamps excel by simulating full sunlight without filters, offering over 20,000 hours of operation without spectral shifts or loss of wavelength emissions. They consistently provide a balanced mix of UVA and UVB light, crucial for accurate aging tests.

Conclusion:

Plasma lamps surpass the rigorous endurance and stabilization standards required by IEC 61215, proving to be superior for material testing in solar simulators. Their robust performance and longevity make them a preferred choice for assessing the durability of solar panel materials under UV exposure.

Assessing the outdoor performance and reliability of commercial modules

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Abstract:

As part of the Horizon Europe Pilatus project about rebuilding made-in-Europe photovoltaic production, the EPFL PV-Lab has been benchmarking commercially available solar modules. Our site is equipped with a complete PV monitoring system and weather station. Module-level monitoring is ensured using a LPVO-MS2X16+PID system from the University of Ljubljana, with individual maximum power point tracking and high accuracy sequential I-V curve scanning, with measurements taken every 180 seconds. In addition, backside temperature sensors can be added for module-level temperature monitoring. For meteorological data, the site is equipped with three high-accuracy Kipp&Zonen pyranometers measuring the global horizontal (GHI), global diffuse (DHI) and plane-of-array (GTI or POA, tilted 15° to match module tilt) irradiances. All the solar modules were characterised indoors before and after between 8 months and 4 years of outdoor exposure. This study presents methods for filtering and analysing the outdoor monitoring data in the aim of extracting module degradation and compares them with changes of indoor measurement.

Keyword:

Outdoor monitoring, Degradation of PV modules

Monitoring Dashboard for PV modules

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Abstract:

The photovoltaics field is undergoing rapid evolution, with new module architectures emerging annually. It is therefore necessary to monitor these new module technologies in order to validate their performance in outdoor applications. Nevertheless, monitoring a large number of modules simultaneously can be challenging because it requires the verification of the functionality of all equipment and sensors and the generation of meaningful comparisons between modules. In collaboration with the Laboratory of Photovoltaics and Optoelectronics (LPVO) of the University of Ljubljana, we are developing a monitoring dashboard with the objective of extending the LPVO outdoor monitoring system for PV modules. In addition to the existing features developed by the LPVO, several new features were developed. These included a feature to compare several modules simultaneously, equipment, modules and sensors health check table and an automated PDF report generator. To preserve the data privacy of the modules, the dashboard now enables administrators to give access to a restricted list of module data to each user. Thanks to this functionality, the dashboard can now be used by external companies. The dashboard will be applied to the monitoring of matrix shingling PV panels and systems in the frame of the Horizon Europe SPHINX project.

Keywords: Monitoring, Dashboard, PV Modules and Systems

Back-side irradiance and bifacial PV module energy performance modelling

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Abstract

In recent years, the bifacial crystalline silicon solar cells have gained the majority of the PV market. Bifacial PV modules are not used only in open-rack PV systems or systems specially constructed to benefit from the bifaciality (i.e. vertical module position in east-west orientations) but also on roofs. Many systems do not integrate irradiance measurements on the back side thus it is very important to properly model the back irradiance.

Here we are presenting new back-side irradiance and performance rating models for bifacial PV modules. The new energy performance model is based on separation of horizontal global and diffuse irradiance, plane-of-array irradiance, and back irradiance. We split the power calculation into three different parts, related to the proportion of the plane-of-array direct, diffuse irradiance, and back irradiance. For the back irradiance we developed a new empirical approach.

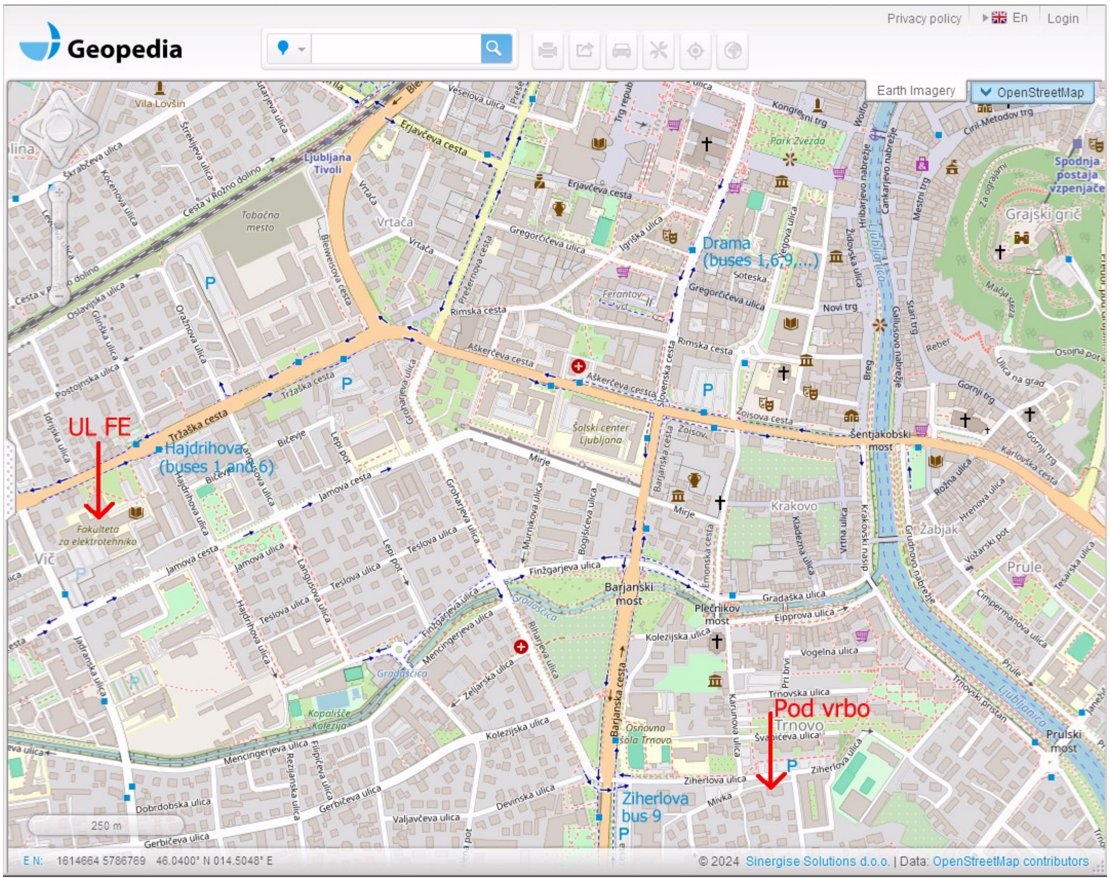
The accuracy of the models is verified on PV modules with cells of different crystalline silicon technologies (Top-Con, IBC, SHJ, PERC) monitored at three locations in Slovenia, Switzerland and Spain. With the new bifacial performance rating model, we were able to achieve an RMS error in the annual average performance ratio of about 1%.

Free WiFi connection

SSID: **FE-Guest**
User name: **euroreg-pv**
Password: **5050**

Workshop dinner

Thursday dinner will be in restaurant Pod vrbo (literally *under the willow tree*).
Address: Ziherlova ulica 36 (Trnovo), Time: 19:00
Transport:
- by walking: Due to close distance (1.4 km) we recommend walking. Go to the street south of the Faculty (Jamova cesta, parallel with Tržaška road), turn left in the direction of center. At fourth crossing (about 500 m) turn right to Groharjeva street (ulica). Follow it to the end (600 m) where it turns left to Barjanska road (cesta). When you cross the road, you are on Ziherlova street. After 280 m the restaurant is on the right.
- by public transport: At the crossing with Barjanska road there is station Ziherlova, served by bus 9, which runs through center and main bus/railway station. You can switch with many other buses incl. 1 and 6 at Drama (two stations away).



Google Maps location