D8.1 - 1. Demonstrators characterization transnational access provision interim report

WP8: TA4 – Access to demonstrator characterization and validation

The EMERGE project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement Nº 101008701

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List of abbreviations

2D – Two-dimensional
3D –Three-dimensional
AFM – Atomic force microscopy
CEZAMAT –Centre for Advanced Materials and Technologies
DFT – Density functional theory
EIS – Electrochemical impedance spectroscopy
EU – European Union
FIB – Focused Ion Beam
FLAPEP – Flexible, large-area, printed electronics and photonics
FTIR – Fourier transform infrared spectrometry
FZJ – Forschungszentrum Jülich
GO – Graphene oxide
HMU – Hellenic Mediterranean University
IV – Current-voltage
JOR – Joanneum Research Forschungsgesellschaft mbH
LEH – Light energy harvesting
MCL – Materials Center Leoben
NIR – Near-infrared
RISE – Research institutes of Sweden
RTO – Research & Technology Organization
SEM – Scanning electron microscopy
SME – Small-medium enterprise
TA – Transnational access activity
TEM – Transmission Electron Microscope
TUD – Technische Universität Dresden
UNOVA - UNINOVA - Instituto de Desenvolvimento de Novas Tecnologias
UV – Ultraviolet
VIS – Visible
WP – Workpackage
WUT – Warsaw University of Technology
XPS – X-ray photoelectron spectroscopy

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CONTENTS

The EMERGE project has received funding from the European Union's Horizon 2020 research and Innovation programme under grant agreement Nº 101008701

List of Tables

The EMERGE project has received funding from the European Union's Horizon 2020 research and Innovation programme under grant agreement Nº 101008701

1. Executive Summary

Deliverable **D8.1 "1. Demonstrators characterization transnational access provision interim report"(M23)** falls within the scope of workpackage WP8 (transnational access TA4 - test and validation of prototypes and demonstrators), which aims to provide external users with access to a diverse range of technology infrastructure essential for testing, quality assessment, and reliability evaluation of FLAPEP (flexible, large area, printed electronics and photonics) related materials and devices. This report focuses on two specific installations that play a crucial role in advancing FLAPEP technology:

- Devices validation & standardization: This installation addresses a key obstacle in the widespread adoption of FLAPEP technology - the standardization of evaluation methods for FLAPEP components. Performance and stability tests of products will be performed under industrial protocols in simulated and real conditions. Various tests are performed, including device and display characterization, piezoelectric/ ferroelectric characterization, analysis of applicability in electronics/ biomedical engineering, characterization of layers and coatings, evaluation of cross-correlation between structural properties and functionalities of nanomaterials, and thorough analysis of all production steps with fast defect identification.
- Device metrology: This installation focuses on the precise characterization of developed structures and integrated systems, including their electrical and mechanical properties evaluation, and to provide properties verification during all development steps needed for improved product quality.

Together, these installations under WP8 provide essential resources for researchers and innovators in the FLAPEP domain, offering access to cutting-edge technology infrastructure for comprehensive testing, standardization, and precise characterization of materials and devices. This interim report serves as a foundation for forthcoming deliverables, where specific case studies and their outcomes will be thoroughly investigated.

2. Overview of services on demonstrator characterization and validation

This report is dedicated to the activities under WP8, which focus on streamlining access to two installations crucial for standardizing methods and characterization techniques to

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assess the quality of printed components/systems. The subsequent sub-sections provide a concise description of the tools offered by each EMERGE WP8 partner for demonstrator characterization and validation.

2.1. MCL

MCL (Materials Center Leoben Forschung GmbH) offers state-of-the-art ultraviolet-visible (UV-VIS) confocal Raman facilities coupled with dielectric/ ferroelectric measurement capabilities. MCL has a variety of advanced characterization modes combined with chemical and structural analyses on the microscale using Raman spectroscopy: gas-tight chamber for concurrent temperature (-196°C-600°C), electric field (up to 300 V, 4-point probe setup) and gas atmosphere analysis; polarised light analysis for texture studies, stroboscopic mode to study dynamical properties as a function of applied alternating current electric field and time. The instrumentation comprises UV (355 nm) and visible (532 nm, 785 nm) solid-state lasers with automated power reductions to avoid sample damage. These are coupled with high-end spectrometers and filters enabling measurements down to ~10 cm-1. The spectrometer has a vertical and lateral spatial resolution of ~10 nm and ~25 nm, respectively. The equipment is especially suitable for the study of polymers, inks/pastes, semiconductor films, dielectric and piezoelectric films, ceramic films, (ferroic) plastic crystals, and related composites. The MCL uses ad-hoc developed density functional theory (DFT) routines for the interpretation of Raman spectra. These methods involve the reproduction of Raman spectra starting from simulated molecular structures, and thus enable the quantification of stoichiometry, phases, stress, and the detection of defects. Mesoscopic stress fields can be also determined by coupling with Finite Element Methods, also developed in-house. Up to four among scientists and technicians are involved with characterization facilities, plus two scientists are dedicated to data interpretation using DFT methods.

2.2. UNOVA

UNOVA (Uninova - *Instituto Desenvolvimento de Novas Tecnologias*) is focused on the development and application of methods for high resolution inspection of materials systems. UNOVA offers a comprehensive suite of equipment for demonstrator characterization and validation, allowing for in-depth analysis and assessment of printed components/systems.

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The advanced tools available include scanning electron microscopy (SEM, with attached focused ion beam (FIB) and scanning transmission electron microscope), X-ray diffraction, dfferential scanning calorimetry-thermogravimetry, ellipsometry, Raman spectroscopy, Fourier Transform Infrared spectrometry (FTIR), optical and fluorescence microscopy, dynamic light scattering, confocal laser scanning, viscometry, profilometry, atomic force microscopy (AFM), ultraviolet-visible-near-infrared (UV-VIS-NIR) spectrometry, potentiostat, luminescence spectrometry, X-ray photoelectron spectroscopy (XPS), photo-response and quantum efficiency measurements, current-voltage (IV) measurements (with temperature control and testing under vacuum conditions), four-point-probe, contact angle measurement, and Hall effect analysis. Besides, a bench of electronic tests for products and systems validation on foils (semiconductor device and circuit characterization system; coupled temperature and illumination setup; parameter extraction tool; ageing and bias stress set up). This extensive range of advanced instrumentation empowers researchers to perform precise and accurate characterizations, contributing significantly to the validation and advancement of printed components and systems.

2.3. HMU

HMU provides access to equipment for the fabrication and characterization of perovskite and solar cells and modules. Key equipment assembled include: Extensive analytical facilities for the characterization of compounds, morphology and optical properties. An open-air characterization laboratory, which includes standardized performance testing of solar cells and modules according to ISOS protocols and dedicated weather station. Dedicated all-in-one optoelectronics platform with the following capabilities: Photo-CELIV, impedance spectroscopy, transient-photovoltage/current, MPPT tracker, Transient EL spectroscopy, thermal resolved analysis, and photoluminescence spectroscopy.

2.4. WUT – CEZAMAT laboratory

CEZAMAT (Centre for Advanced Materials and Technologies) is a laboratory equipped with leading technologies of FLAPEP: inkjet printing, aerosol jet printing, screen printing. CEZAMAT deals in the production of new, functional materials, assembly of electronic components, and material testing. CEZAMAT as a part of the WUT (Warsaw University of Technology) is able to provide different validation methods like shock chamber or climate

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chamber to analyse the aging process. Furthermore, CEZAMAT is currently equipped with parylene coating system for homogeneous and transparent encapsulation processes. Different measuring tools (precise Keithley multimeters, nano-weight for loss of weight calculation etc.) enable to validate the production effect and estimate products lifetime. CEZAMAT technical building comprises several types of laboratories: semiconductor cleanrooms (ISO 4-7), biotechnological cleanrooms and classic high laboratories of increased cleanliness. Combine cleanroom area is above 4000 m2 and total area of laboratories is almost 20,000 m^2. CEZAMAT offers the access to high resolution field-emission SEM "Hitachi SEM SU8230" with cryo system "PP3010TCRYO System" and high-resolution SEM "Carl Zeiss Auriga 60" with optical microscope “Carl Zeiss Axio”. Over the standard metrology equipment, WUT offers spectroscopic ellipsometer "UVISEL2-NIR" and even the industrial computer tomography Metrotom 800 from Zeiss, and different measuring tools like scratch tester, IV measurement tool, 4-probe measurement, etc.

2.5. JOR

JOR (Joanneum Research Forschungsgesellschaft mbH) provides access to nanometrology techniques such as AFM/ Kelvin probe force microscopy/ piezoelectric force microscopy (Oxford Instruments Jupiter XR), SEM (RAITH eLine, JEOL/JSM-IT 100), three-dimensional (3D)-profiling (Keyence confocal laser microscopy and Tektak), cross-cut preparation by Kryo-Ultramicrotomy (Boeckeler / PowerTome XL RMC Products) and XPS (Omicron Nanotechnology/UHV-surface-analysis system) for surface chemical characterization. In addition, piezoelectric characterization equipment including piezometer (Piezotest PiezoMeter System 200) and JOR’s home-built heavy stamp setup + Dewesoft Sirius DAQ + Keithley as well as a customary built equipment for manual and an automatic polling station are available. Access is also available for electrical characterization equipment like impedance spectroscopy (HIOKI LCR meter, Alfa system Novocontrol technologies) or 4-point probing for sheet resistance measurements (JANDEL Universal Probe Station). Furthermore, rheological characterization instruments like a Brookfield rheometer for ink development are accessible. Finally, access to optical characterization equipment like UV-VIS-NIR spectroscopy (Perkin Elmer Lambda 900 UV/VIS/NIR spectrometer), variable angle spectroscopic ellipsometry (J.A.Woollam Inc./Ellipsometer VASE) and FTIR (Bruker/Tensor27) can be offered.

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2.6. TUD

TUD (Technische Universität Dresden) offers a wide range of device characterization tools including IV analysis, parameter analysis, current-voltage measurement w/o illumination for solar cell characterization, UV-VIS absorption measurements and ellipsometry, external quantum efficiency extraction, and grazing-incidence wide-angle X-ray diffraction.

2.7. RISE

RISE (Research institutes of Sweden) provides state-of-the-art facilities for test and validation of printed organic devices based on ionic and electronic conductors; IV-measurement system for two, three and four terminal devices, electrochemical impedance spectroscopy (EIS), battery testing equipment, four probe measurement system, controlled climate chambers, vector network analyser, confocal Raman microscopy; and respective data analysis expertise.

RISE is offering electrostatic discharge protected area with range of advanced equipment for electrical characterization of materials, components, devices, and circuits using wide range of electrical characterization equipment. Different techniques such as, IV, pulsed IV, EIS, capacitance-voltage, polarization-electric field and dielectric breakdown, can be applied for evaluation of capacitive, semiconducting, resistive, ferroelectric, dielectric, and conducting materials and devices.

Following is list of different characterization equipment offered at RISE labs:

- HP 4155B and Keithley 4200A-SCS Semiconductor Parameter Analyzer;
- Keithley 2600B Series Source Meters (2602B, 2612B);
- Radiant Ferroelectric Tester;
- HP 4285A Precision LCR Meter (75 kHz – 30 MHz), and Hameg HM8118 Programmable LCR Bridge;
- HP E4407B ESA-E Spectrum Analyzer (9 kHz – 26.5 GHz);
- Oscilloscopes (Keysight), and Multimeters (Fluke);
- Waveform generators (HP and Keysight), and DC power supplies;
- Manual probe stations (Wentworth Laboratories, etc.);
- Probe manipulators/micropositioners (Picoprobe, Cascade Microtech DPP-105);
- 4-point probe electrical resistivity measurement system (Ossila);
- Mechanical peel testing equipment (Mark-10) with a ESM303 test stand;

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- Anton-Paar Rheometer for inks characterization;
- Measurement set up and tools for electrochemical characterization are available materials lab;
- Controlled Climate chambers: Vötsch VCL 4006 and the Vötsch LabEvent C/64/40/3 climate chambers can be operated at temperatures between –40 to 180 °C and humidities between 10 to 95%RH;
- Customizable measurement setups for the characterization of electrochromic displays (ECD). Setup composed of: X-probe (Inventables) with a stepper motor for semi-automated characterization;
- Recently Confocal Raman Microscope (WITec alpha300 RAS) equipped with three excitation lasers: 532 nm, 785 nm and 1064 nm has been added into offered techniques by RISE partner laboratory. This technique allows to identify various chemical components (polymers, oxides, etc.) and map their distribution spread across an area or across the coating thickness in confocal regime.

3. Overview of user-projects on demonstrator characterization and validation

The following section offers a comprehensive analysis of the project proposals concerning demonstrator characterization and validation.

3.1. Overview of submitted projects

During the reporting period, from July 2022 to May 2023, a total of four open calls were organized, resulting in an impressive submission of 63 projects. The collaborative efforts of 11 European partners have brought together a vibrant community of 85 participants from 26 nationalities. This multicultural and multidisciplinary approach has fuelled invaluable knowledge exchange and fostered a dynamic environment within the EMERGE project.

Several effective means have been identified for attracting our target audience, with word of mouth (37.7%), direct contact with access provider (27.1%), conferences (14.1%), and social media (14.1%), and proving to be particularly successful strategies in engaging the user community. The website (6%) has shown to be least effective means in terms of engagement. This insight highlights the importance of investing in the improvement of

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EMERGE's online presence and user experience, as doing so is likely to yield better results. By enhancing our website and making it more user-friendly and engaging, we can better connect with our target audience and increase our overall impact.

The strong interest and involvement of research institutions in the European Union (EU) is evident, with 43 projects submitted by participants working in institutes located in EU countries. Equally remarkable is the fruitful contribution of 20 projects from industry, start-ups, and small-medium enterprises (SMEs), ensuring that the projects developed under EMERGE are both relevant and applicable in real-world contexts.

One of the key highlights of the project is the exceptional quality and relevance of the submitted proposals. An impressive 88% of the 34 projects submitted during the first three open calls have been approved for further development. Currently, the projects submitted during the fourth call are undergoing evaluation, promising additional exciting outcomes.

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Table 1 shows a detailed analysis of the user-projects, which received a total of 33 submissions from 47 participants, with 38.2% being female contributors, all seeking access to demonstrator characterization and validation transnational access within the EMERGE institutions associated with WP8. Most of the projects are affiliated with university institutions and research & technology organizations (RTOs, 20 projects) and 13 projects are from SMEs, start-ups and industry. Additionally, it is noteworthy that 26 projects were submitted by participants working within EU, demonstrating regional interest in our facilities. Word of mouth and direct contact with the access provider have shown to be the most effective means of EMERGE propaganda to attract these participants. Over the course of the 4 open calls, 7 projects have been successfully completed, 3 were rejected, 1 was cancelled, 3 are scheduled, and 2 are currently pending scheduling. Additionally, 17 projects from the 4th Call are currently under evaluation.

The EMERGE project has received funding from the European Union's Horizon 2020 research and Innovation programme under grant agreement Nº 101008701

Table 1- Projects requesting access to demonstrator characterization and validation tools.

Projects	User's gender/ nationality	Institute	Selected installations	Selected institution	Host institution/ status of project
1st Call – 3650: Bio-OLED: Bio-based organic light-emitting diodes	Male/ Italy	Start-up, Germany	TA3. Vacuum assisted deposition TA4. Device metrology & characterization	TUD	**Rejected**
1st Call – 3652: Graphene-based electrically conductive coatings	Male/ Italy Female/ Italy	Industry, Italy	TA4. Validation and standardization TA2.Chemical & physical techniques	HMU	HMU **Completed**
1st Call – 3664: Integration of dielectric light harvesting nanostructures in perovskite solar modules	Female/ Russia	University, Russia	TA4. Device metrology & characterization TA2. Chemical & physical techniques	HMU	**Rejected**
1st Call – 3665: Correlation between steady-state and transient electro-optical tests on photovoltaic devices	Male, Netherlands	University/ Italy	TA4. Device metrology & characterization	HMU	HMU **Completed**
2nd Call – 3824: Bio-OLED: Bio-based organic light-emitting diodes	Male/ Italy	Start-up, Germany	TA3. Industrial printing TA3. Vacuum assisted deposition TA4. Device metrology & characterization	TUD UNOVA	**Not scheduled**
2nd Call – 3829: Uniformity in visual appearance of individual cells in laminated OPV devices	Male/ Austria	SME, Sweden	TA1. Modelling & simulation TA4. Device metrology & characterization	JOR	JOR **Completed**
2nd Call – 3845: Resist-free e-beam lithography for robust nanophotonic and flexible electronic devices in harsh environments	Male/ Greece Female/ Greece	RTO, Switzerland	TA3. Functional two-dimensional (2D) & 3D printing TA4. Device metrology & characterization	HMU	HMU **Completed**
2nd Call – 3846: Effect of Electrochromic Pixel Size on Temperature and Humidity Performance	Female/ Norway Male/ India	Industry, Germany	TA3. Device Preparation(1) TA4. Device metrology & characterization TA4. Validation and standardization	RISE	RISE **Completed**

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2nd Call – 3857: Smart end effectors for next generation sustainable industry robotics	Male/ Greece	University, Denmark	TA3. Device Preparation(1) TA4. Device metrology & characterization	HMU	**Rejected**
2nd Call – 3858: Piezoelectric Chitosan for the development of sustainable wearable sensing devices	Female/ Italy	University, Italy	TA4. Device metrology & characterization	JOR	JOR **Completed**
3rd Call – 3992: Improving Color Matching between Active and Non-Active Areas of Electrochromic Displays	Female/ Norway	Industry, Germany	TA3. Device Preparation(1) TA4. Device metrology & characterization TA4. Validation and standardization	RISE	RISE **Scheduled to June 2023**
3rd Call – 4008: Exploiting UV nanoimprinting for introducing micro-structured burst valves in a self-powered microfluidic device for precise liquid volume metering	Male/ Belgium	University, Belgium	TA3. Nanoimprinting & laser patterning TA4. Device metrology & characterization	JOR	JOR **Scheduled to July 2023**
3rd Call – 4009: Screen printing and paste preparation based on Al 1%Si powder for flexible, wearable, self-powered sensor used as human respiration detector	Male/ Serbia Male/ Serbia	RTO, Serbia	TA2. Chemical & physical techniques TA3. Industrial printing TA4. Validation and standardization	WUT	WUT **Scheduled to June 2023**
3rd Call – 4075: Hybrid organic-inorganic transparent UV photodetector	Male/ Italy Male/ Italy	University, Italy	TA3. Vacuum assisted deposition TA4. Device metrology & characterization	TUD	**Not scheduled**
3rd Call – 4076: Manufacturing and Characterization of Flexible Thermoelectric Modules	Male/ Iran	SME, Denmark	TA3. Device Preparation(1) TA4. Device metrology & characterization	RISE	**Canceled**
3rd Call – 4077: FIB lamella preparation on photovoltaic cells for TEM observations	Female/ Germany	RTO, Germany	TA2. Materials characterization TA4.Device metrology & characterization	UNOVA	UNOVA **Completed**
4th Call – 4625: Mass production of NFC tags printed on paper with additive techniques and at least 2 years lifetime, easy to recycle	Male/ Spain Male/ Spain	SME, Spain	TA3. Industrial printing TA4. Validation and standardization	RISE FZJ (Forschungszentrum Jülich)	**Under evaluation**

The EMERGE project has received funding from the European Union's Horizon 2020 research and Innovation programme under grant agreement Nº 101008701

4th Call – 4682: Interface engineering in perovskite solar cells based on 2D materials	Female/ China Female/ China	University, United Kingdom	TA2. Materials characterization TA3. Device Preparation(1) TA4. Device metrology & characterization	HMU	**Under evaluation**
4th Call – 4776: Investigation on Processability of Inkjet Printed E-beam Resists	Male/ Netherlands Male/ Netherlands	University, Netherlands	TA4. Device metrology & characterization TA3. Functional 2D & 3D printing	JOR	**Under evaluation**
4th Call – 5320: Photonic sintering of reverse offset printed structures	Male/ Finland Male/ Finland	RTO, Finland	TA3. Functional 2D & 3D printing TA4. Device metrology & characterization	RISE	**Under evaluation**
4th Call – 5549: Fabrication and electrical characterization on two-dimensional (2D) polymers-based flexible organic electronics	Male/ China	RTO, Germany	TA2. Chemical & physical techniques TA4. Device metrology & characterization	UNOVA	**Under evaluation**
4th Call – 5682: Evaluation of scalability of 2D printing of magneto-rheological and magneto-electrical composites	Male/ Czech Republic Male/ Spain	RTO, Spain	TA3. Functional 2D & 3D printing TA4. Device metrology & characterization	RISE	**Under evaluation**
4th Call – 5684: Printing of electrochemical (bio)sensors using aerosol jet printing techniques	Male/ Italy	University, Italy	TA3. Functional 2D & 3D printing TA4. Device metrology & characterization	RISE	**Under evaluation**
4th Call – 5809: Real-time automated conductivity inspection	Female/ Canada Male/ Unites States	SME, Canada	TA4. Validation and standardization TA4. Device metrology & characterization	FZJ	**Under evaluation**
4th Call – 5810: Evaluation of different gold inks printed by inkjet	Germany	RTO, Germany	TA2. Materials characterization TA3. Device Preparation(1) TA4. Device metrology & characterization	RISE	**Under evaluation**
4th Call – 5812: Smart end effectors for next generation sustainable industrial robotic applications	Male/ Greece	University, Denmark	TA2. Materials characterization TA3. Device Preparation(1)	HMU	**Under evaluation**

The EMERGE project has received funding from the European Union's Horizon 2020 research and Innovation programme under grant agreement Nº 101008701

			TA4. Device metrology & characterization		
4th Call – 5813: Characterization of enhanced electrochemical sensors	Female/ Denmark	SME, Denmark	TA3. Functional 2D & 3D printing TA4. Device metrology & characterization	RISE	**Under evaluation**
4th Call – 5815: Functional Ink-Jet Printing of Wireless Energy Systems	Male, Latvia Male, Latvia Female, Latvia Male, Latvia	RTO, Latvia	TA3. Device Preparation(1) TA4. Device metrology & characterization	RISE	**Under evaluation**
4th Call – 5821: Comparison of Material Properties of Electrochemically Printed Structures against Screen and Inkjet printed Structure	Female/ Latvia Female/ India	SME, Australia	TA3. Functional 2D & 3D printing TA4. Device metrology & characterization	RISE	**Under evaluation**
4th Call – 5824: Thin film carbon nanotubes and membranes-based sensors development and characterization to enhance sensors sensitivity and selectivity	Female/ Italy Female/ Dominican Republic	University, Italy	TA4. Device metrology & characterization TA2. Materials characterization	TUD	**Under evaluation**
4th Call – 5825: Characterization of solution processable nanomaterials for transistor and memristor-based biosensors applications	Female/ Italy Male/ Italy	University, Italy	TA2. Materials characterization TA4. Device metrology & characterization	JOR	**Under evaluation**
4th Call – 5827: Manufacturing and Characterization of Flexible Thermoelectric Modules and associated electronics through printing techniques	Male/ Iran	SME, Denmark	TA3. Device Preparation(1) TA4. Device metrology & characterization	RISE	**Under evaluation**
4th Call – 5830: Printed Flexible Organic Light-Emitting Diodes for Bio-Medical Applications	Male/ India Male/ India	University, India	TA3. Device Preparation(1) TA4. Device metrology & characterization	RISE	**Under evaluation**

(1) Non-official installation

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3.2. Overview of completed projects

In this section, additional details on the concluded user-projects are provided below, including main objectives, relevant results and expected/ achieved outcomes.

Project 3652: Graphene-based electrically conductive coatings (HMU)

- Objectives: The objective of this project is to validate the feasibility of low-temperature curable graphene-based pastes/inks with thermoplastic binding agents as replacements for metal electrodes in solar cells, particularly perovskite solar cells. Additionally, the project aims to validate low-temperature laminable graphene-based electrically conductive adhesives for solvent-free processes.
- Results: The project successfully processed various graphene-based pastes into films for testing as electrodes in carbon-based solar cells. These carbon pastes were formulated in different solvents, with a focus on alcoholic mixtures, to ensure compatibility with the underlying perovskite and charge-transporting layers. The thickness and conductivity of the resulting graphene-based electrodes were thoroughly evaluated by systematically varying the deposition parameters and techniques. Additionally, the project achieved the fabrication of laminable graphene-based electrodes, which were applied to solar cells using a bench-top laminator at temperatures below 120 °C to maintain compatibility with the perovskite solar cell structure.
- Potential difficulties of the experiments: The project faced challenges due to time constraints and encountered difficulties with screen-printing. Specifically, the use of excessively high mesh count for screen printing resulted in the clogging of frames during the graphene paste processing.
- Potential use after the project: This research project has achieved a significant scientific impact by providing a robust understanding of the design of graphene-based pastes and laminable graphene-based carbon electrodes for perovskite solar cells. Through this work, cost-effective carbon-based perovskite solar cells with efficiency levels approaching those achieved with noble metal-based electrodes have been developed. The valuable outcomes obtained from this project hold the potential for scientific publication. The parties involved in this research endeavour will continue to advance the development of carbon-based perovskite solar cells, exploring additional

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graphene paste formulations and laminable graphene-based electrodes, building upon the knowledge gained from this study.

Project 3665: Correlation between steady-state and transient electro-optical tests on photovoltaic devices (HMU)

- Objectives: The objective is to establish correlations between steady-state and small-high perturbation dynamic tests. The analysis aims to investigate charge carrier recombination dynamics by quantifying and correlating internal and external quantum efficiency, recombination dynamics, and radiative emission detection. As samples are not produced in-house, external assistance is sought to conduct the required tests for evaluating the samples.
- Results: Various substrates were utilized, and specific test samples were prepared by HMU, offering them to the users. Transient tests, such as transient photo-voltage and transient photo-current, provided essential information on charge carrier lifetime and densities, directly impacting device efficiency through improved charge collection. As a result of the project's insights, HMU will prepare new samples aligned with these findings to drive further advancements in the field.
- Potential difficulties of the experiments: The project required access to additional probes for gate bias, presenting a technical obstacle. Furthermore, time constraints hindered the realization of capacitance measurements.
- Potential use after the project: The project greatly enhanced testing protocols for memristor and transistor-based devices, advancing participants understanding.

Project 3829: Uniformity in visual appearance of individual cells in laminated OPV device (JOR)

- Objectives: In this project, an approach should be developed to use extrinsic measures to reduce the visual differences between cells in an organic solar cell and inhomogeneities on the active area by means of diffusive surfaces and patterns, exploiting also optical effects on a microscopic level but keeping the output power as high as possible. Subsequently, the approach should be validated both theoretically and experimentally. Only approaches that can potentially be scaled up to a cost-effective roll-to-roll production will be considered.

The EMERGE project has received funding from the European Union's Horizon 2020 research and Innovation programme under grant agreement Nº 101008701

- Results: The main achievements of the theoretical and experimental work were the knowledge that it is possible to change the reflection spectrum of the light energy harvesting (LEH) module by inserting a colored foil between the cells and the backsheet. This gives the possibility to change the visual appearance of the LEH modules without losing efficiency. In addition, it is possible to reduce the angle-dependent inhomogeneities with a colored front foil that has high transmission values. This leads to less efficiency losses when using such a front foil.
- Potential difficulties of the experiments: This project faced challenges due to limited time and technical issues. One of the main technical problems is related to colour sheets placed between the module and the backsheet. While this method reduces inhomogeneities and maintains the efficiency of the LEH modules, certain viewing angles may still reveal noticeable inhomogeneities. To overcome this, finding or producing the ideal foil with matching spectra becomes essential.
- Potential use after the project: improvement of the company's products.

Project 3845: Resist-free e-beam lithography for robust nanophotonic and flexible electronic devices in harsh environments (HMU)

- Objectives: The objective of this project is to enhance the mechanical properties of flexible photonic and electronic devices. Through the application of nanopatterns, we aim to engineer materials' failure and control crack formation. By upscaling methods, we will produce standard electrodes of printable inks on flexible substrates. Subsequently, resist-free e-beam lithography and high-resolution large-scale UV laser ablation will be employed to pattern functional nanoscale thick electrodes, creating mechanical robust nanopatterns that prevent device failure under strain.
- Results: In this project electrodes made from various materials were successfully deposited onto flexible substrates. These materials include electrochemically exfoliated graphene and graphene oxide (GO) on polyethylene, as well as silver nanowires/exfoliated graphene and PEDOT/PSS/GO on standard polyimide (kapton tape). Diverse printing mechanisms tailored to the specific requirements of each sample size were explored.
- Potential difficulties of the experiments: No difficulties of the experiment were identified during the course of the project.

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- Potential use after the project: This project holds the potential to make significant advancements in the field of nanophotonics and nanoelectronics by delivering a robust methodology for nanoscale thick flexible electronic and photonic devices, by exploring explore the novel e-beam treating technique on standard printable electronics, while investigating large-scale UV laser ablation to induce patterns. The establishment of experimental recipes and protocols to enhance the mechanics of these devices will address the issue of mechanical aging and cracking caused by applied stresses and temperature variations. This could lead to longer lifetimes of energy devices, resulting in substantial cost reductions. The anticipated future publications on resist-free e-beam lithography for mechanically robust flexible electrodes and large-scale patterns for boosting the mechanics of thin electrodes through high-resolution UV ablation. This opens up a new research direction for patterning of different energy materials to improve their nanomechanics. The next attempt will be to pattern transition metal dichalcogenides.

Project 3846: Effect of Electrochromic Pixel Size on Temperature and Humidity Performance (RISE)

- Objectives: The project aimed to investigate the impact of pixel size on the behaviour of large area electrochromic devices under various environmental conditions (temperature and humidity). Specifically, the study focused on evaluating switching speed and visual propagation fonts in large area displays, where the absence of underlying conducting electrodes necessitated reliance on the low sheet resistance of the chromogenic film. The project involved printing and characterizing the displays after subjecting them to a range of temperatures from -40°C to 80°C in a climate chamber to analyze their optical performance.
- Results: The project achieved significant milestones within the first 2-3 days, successfully printing and converting the test structures. The yield was excellent, enabling the use of all printed displays for testing, even those with the smallest dimensions (e.g., a 7-segment display with 1 cm in height). Regarding the characterization elements, a well-considered decision was made to conduct a more thorough characterization at fewer temperatures (0, 20, 40, and 80 ºC). For the larger displays (1 x 5 cm, 1-segment), voltage vs. time plots were collected for 6 switch

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cycles, measuring at 4 different contacts in the display, with 3 replicas. The data revealed a distinct potential drop across the working area from the position of the electrical contact, aligned with the visual propagation front recorded in video. Regarding the smaller displays (1 and 2 cm^2, 7-segment), video footage was gathered over the range of temperatures to monitor switching speed and bi-stability.

- Potential difficulties of the experiments: The printing and conversion of the devices took most of the time in the project. This limited the time the resources that could be used for the characterization.
- Potential use after the project: The EMERGE project has made a significant scientific impact by providing key data points that correlate switching speed and propagation fronts of various display sizes at different temperatures. This critical data is instrumental in designing electronics and driving circuits for activating displays. Furthermore, the project has expanded the knowledge base by exploring propagation fronts in devices without underlying conducting electrodes in a 2-electrode configuration, filling a gap in the limited body of existing research. The collection of essential preliminary data sets through this project has laid the foundation for continued investigations and data collection using the devices produced during EMERGE.

Project 3858: Piezoelectric Chitosan for the development of sustainable wearable sensing devices (JOR)

- Objectives: The project aimed to investigate the performance of thin and flexible devices made from a biocompatible and biodegradable biopolymer, chitosan, for pressure sensing applications. The focus was on characterizing their piezoelectric behaviour in response to different loads, frequencies, temperatures, and impedance. By utilizing chitosan as a biodegradable piezoelectric material, the goal was to develop sustainable sensors that can replace conventional synthetic materials with high environmental impact. Another objective was to assess the printability of a piezoelectric chitosan-based ink for additive manufacturing processes. This evaluation involved determining the viscosity of the Chitosan solution used to fabricate the devices. The aim was to replace the time-consuming solvent-casting

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technique previously employed for chitosan fabrication with a more efficient and scalable approach.

- Results: The project's main achievements include significant findings from impedance spectroscopy, indicating a distinct frequency dependence compared to benchmark piezoelectric polymers. This behaviour necessitates further investigation of the data to understand its implications, which may be attributed to impurities or residual solvent affecting the results. In addition, various excitations of piezo devices were conducted, demonstrating their responsiveness to force load. Short impacts showed a favourable agreement between chitosan and benchmark materials, but under slow and continuous loading conditions, chitosan's response was undetectable, requiring further analysis. Viscosity measurements revealed complex behaviour of the ink, exhibiting frequency-dependent shear thinning at room temperature. The viscosity remained stable after two hours, making it promising for inkjet printing processes. Temperature-dependent measurements indicated a decrease in viscosity, necessitating further efforts to lower the ink's viscosity for suitable inkjet printing applications.
- Potential difficulties of the experiments: Impedance spectroscopy measurements proved to be unstable possibly due to the presence of solvents or impurities in the samples. Additionally, it was not possible to detect the piezoelectric response of the devices under slow and continuous loading conditions.
- Potential use after the project: The outcomes open up possibilities for future EMERGE proposals to further investigate the piezoelectric behaviour of the devices and to explore the application of chitosan ink in inkjet printing processes.

Project 4077: FIB lamella preparation on photovoltaic cells for TEM observations (UNINOVA)

- Objectives: The main output of this work is the production of the transmission electron microscopy (TEM) lamellas of electronic devices based on metal oxide nanomaterials with pristine conditions without introducing artifacts. This will allow the complete structural characterization of lead-halide perovskite solar cells at a nanoscale level. Moreover, it will be possible to improve the procedure of the TEM lamella preparation using Focused ion beam (FIB) and spread the knowledge among the EMERGE

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researchers. For that, a Kleindiek manipulator needs to be mounted and be in proper operations conditions, and the lift-out procedure needs to be learned. This knowledge can be easily adapted to other electronic devices.

- Results: During of the project execution, the Kleindiek manipulator was properly mounted and could be used on FIB and SEM analysis to achieve TEM lamellas without inducing defects or sample damage. Furthermore, the sample preparation to reach atomic resolution was improved, and the lift-out was trained.
- Potential difficulties of the experiments: FIB beam was not aligned at the instrument, therefore the milling process was much more complicated than expected.
- Potential use after the project: The use of Kleindiek manipulator on FIB and SEM analysis allows future users to properly characterize nanodevices, including for inspection of defects at the atomic level.

3.3. User feedbacks

Overall, the feedback from participants reflects a combination of positive and negative experiences. While some participants appreciated various aspects of EMERGE, others highlighted concerns regarding administrative inefficiencies and website usability, as detailed below:

- **Project 3652:** Overall, the experience and experiment were satisfactory for both participnats. They found the logistic support and the application process, including the website, guidelines, and evaluation procedures, to be satisfactory as well.
- **Project 3829:** The participant rated all aspects as excellent, except for the helpfulness of the website and guidelines.
- **Project 3845:** Both participants rated all aspects as excellent. They provided a suggestion to include relevant expertise of the hosting group on the EMERGE website, such as previously published work.
- **Project 3846:** The participant expressed dissatisfaction with the support received before access, citing a heavy administrative burden that was not clearly communicated during the application process. Due to unpreparedness in the EMERGE pre-access process, the project had to be cancelled last minute and rescheduled, leading to wasted time and resources. The helpfulness of the EMERGE website and guidelines were also rated as unsatisfactory. Despite these issues, the

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participant mentioned that if EMERGE can resolve their administrative problems, it could be a fantastic opportunity for researchers to access state-of-the-art facilities.

- **Project 3858:** The participant rated the support received before access as satisfactory, and pointed out issues with communication between various parties involved, resulting in late bookings and increased costs.
- **Project 4077:** The user reported that all support received before, during and after her access was excellent. That also included the logistic, administrative, scientific and technical support.

It is worth noting that many of these issues have been recently addressed by streamlining the booking process through a travel agency and enhancing the website's content with systematic updates and improvements. These measures aim to enhance the user experience and make EMERGE more user-friendly and appealing to researchers.

4. Final Remarks & Outlook

To facilitate the implementation of additional projects alongside those already completed, we are intensifying our marketing efforts with individual partners. This will involve direct advertising during meetings with potential partners, providing them with a comprehensive overview of the project and the opportunities it offers for external collaboration.

Moreover, we aim to enhance our project's visibility by increasing advertisement across various platforms. By reaching a wider audience, we can attract more potential partners and foster meaningful collaborations.

Through these proactive marketing initiatives, we seek to foster stronger partnerships and create a fertile ground for the successful realization of future projects, ultimately advancing our goals and creating impactful outcomes.

For all projects performed until now, the partners expect to have follow-up projects for more detailed analysis and characterization. Moreover, MCL will initiate a promotion campaign starting to actively acquire more TA-projects.

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