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Efficiency, Long-Term Stability and Low Environmental Impact
(Acronym: LAPERITIVO)



LAPERITIVO – Report

Deliverable D1.1 – Report on the homogeneity and
manufacturability of the perovskite films

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About LAPERITIVO

In recent years, organometal halide perovskite-based photovoltaics (PV) have attracted great interest for their high-power conversion efficiency at low manufacturing cost. Presently, East Asia especially China and North America are rapidly ramping up towards mass production of perovskite PV. More efforts are urgently needed for perovskite PV upscaling in Europe. LAPERITIVO focuses on the development of large-area stable perovskite solar modules, using processes with high manufacturability. Efficiency targets are 22% and 20% for 900 cm² opaque and semi-transparent (with >95% bifaciality) modules, respectively. Key research activities include the deposition of high-quality perovskite films as well as contacting layers over large substrate area using industrially viable techniques. Indoor and outdoor field tests, in line with International Electrotechnical Commission (IEC) standards, will be performed to monitor module reliability. Safety, circularity, and sustainability will be assessed to demonstrate products with minimized environmental impact. The developed semi-transparent modules will be applied to perovskite/silicon four-terminal tandem modules and also to Agrivoltaics. Design of perovskite PV pilot line of 200 MW and production capacity of 5 GW in Europe will also be explored. The well-balanced consortium consists of 20 complementary partners including 8 European leading research institutes/universities (IMEC, UNITOV, EMPA, Fraunhofer ISE, IPVF, CNRS, CSEM, Hellenic Mediterranean University), 1 African research institute (Green Energy Park, Morocco), 5 small and medium-sized enterprises (Becquerel Institute, Becquerel Institute France, Becquerel Institute Spain, Dyenamo, TSE Troller, SmartGreenScans, BeDimensional), and 6 big companies (Pilkington Technology Management Limited (PTML), Singulus Technologies, Voltec Solar, Engie, TotalEnergies, EDF). In this way, the project aims to establish the pathway to open the era of manufacturing perovskite-based next-generation PV products in Europe.

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Abbreviations and acronyms list

Abbreviation	Meaning	Abbreviation	Meaning
PV	Photovoltaic	MPA-CPA	((2-(4-(bis(4-methoxyphenyl)amino)phenyl)-1-cyanovinyl)phosphonic acid)
SAM	Self-Assembled Monolayer	PCBM	[6,6] phenyl-C61-butyrac acid methyl ester
ETL	Electron Transport Layers	BCP	Bathocuproine
HTL	Hole Transport Layer	TEACl	2-Thiopheneethylammonium chloride
FF	Fill Factor	NiOx	Nickel Oxide
Jsc	Short-Circuit Current Density	ITO	Indium tin oxide
V _{oc}	Open-Circuit Voltage	LiF	Lithium Fluoride
PCE	Power Conversion Efficiency	C60	Fullerene
MPPT	Maximum power point tracking	Cu	Copper
GFF	Geometric Fill Factor	PbI ₂	Lead Iodide
PL	Photoluminescence	CsI	Cesium Iodide
SEM	Scanning Electron Microscope	FAI	Formamidinium Iodide
WFT	Wet Film Thicknesses	MAI	Methylammonium Iodide
PSCs	Perovskite Solar Cells	MAcL	Methylammonium Chloride
TCO	Transparent Conductive Oxide	EDAI	Ethylenediammonium Iodide
FWHM	Full Width at Half Maximum	SBLC	S-benzyl-L-cysteine
XRD	X-ray diffraction	MeO-2PACz	[2-(3,6-dimethoxy-9H-carbazol-9-yl)ethyl]phosphonic acid
ARC	Antireflection Coating	SnO ₂	Tin Oxide
ALD	Atomic Layer Deposition	EDS	Energy Dispersive X-ray Spectroscopy
KPFM	Kelvin-Probe Force Microscopy	QFLS	Quasi-Fermi Level Splitting
¹ H-NMR	Proton nuclear magnetic resonance	XPS	X-ray Photoelectron Spectroscopy

Executive Summary

The **LAPERITIVO** project aims to deliver high-quality, large-scale and industry-compatible perovskite photovoltaic modules. To achieve the project targets on device performances (namely PCE above 22% for 900 cm² opaque modules; PCE above 20% for 900 cm² semi-transparent modules with a faciality above 95 %), focus needs to be put on the homogeneity of the perovskite layer while transferring or optimizing processes on industry standard technologies. This work proposes an overview of the optimisations developed by each partner of the WP1 “*High-performance perovskite solar cells and mini-modules*” and the work resulting from their collaboration.

To achieve high performance devices, crystallization dynamic and homogeneity of the perovskite film are paramount. Multiple partners achieved increased PCE (and other PSC metrics) through different methods of controlled crystallization, some examples being: **IMEC** achieving small upscale loss (~4.1 %) through the addition and optimization of an additive to their perovskite inks for blade and slot die coating; **Fraunhofer ISE** improving large area homogeneity through the careful tuning of their gas quenching setup and solvent composition; **IPVF/EDF** developing vacuum quenching protocols to allow for open air large area deposition; or through the in-depth exploration of evaporated CsI-PBI to FAI ratios at **EMPA**.

Additionally, a lot of care was dedicated to the engineering of the interface between perovskite and hole transport layer (HTL) to allow either better wettability or improved charge injection. **Fraunhofer ISE** investigated the impact of various SAMs on the wettability and device performances of their baseline perovskite solar cells (PSC). **IPVF** introduced a washing step to improve wettability and consequently overall manufacturing yield. Moreover, they screened passivation molecules as alternative to self-assembled monolayer (SAM). **EMPA** demonstrated high homogeneity of their evaporated devices through the evaporation of SAMs, as proved by detailed XRD mapping.

A specific n-type passivation was proposed by **IPVF** for open air processed perovskite to limit nonradiative traps, resulting in improved photoluminescence (PL) mapping and power conversion efficiency (PCE) gain of ~2.5 % absolute.

Finally, **IMEC** and **UNITOV** proposed a dual interface approach consisting of applying similar component to both HTL and electron transport layer (ETL) sides of the perovskite to achieve better crystallinity (**IMEC**) or improve performance and homogeneity as demonstrated by **UNITOV**.