Enhancing Measurement Protocols for Perovskite Photovoltaic Devices: Insights from the VIPERLAB Project

VIPERLAB
FULLY CONNECTED VIRTUAL AND PHYSICAL PEROVSKITE PHOTOVOLTAICS LAB

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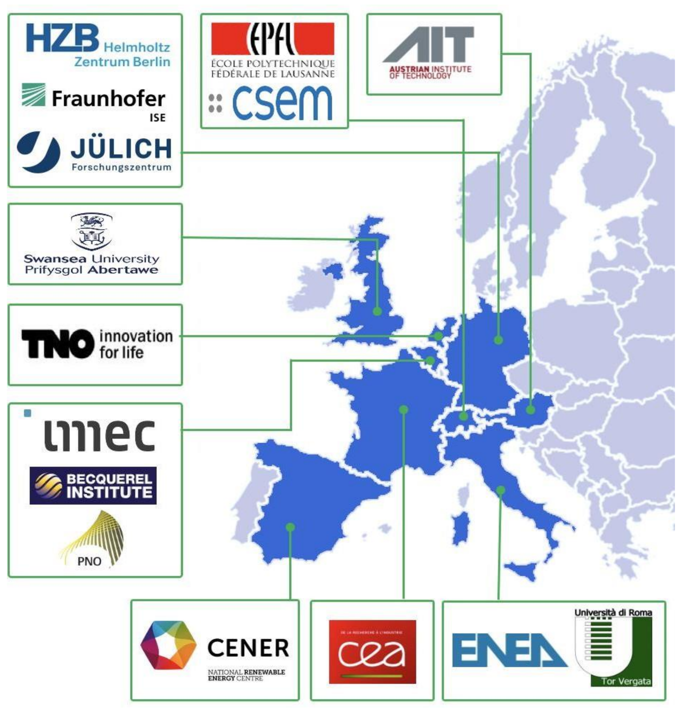
Poster Number 2CV.3.46

EU PVSEC

H2020-VIPERLAB project:



Main goal of the project:
Stimulate, through facilitated and coordinated transnational and virtual access to the best EU perovskite infrastructures and the use of advanced data mining approaches, the starting EU perovskite comunity to work together on the research and development of the perovskite PV technology development in Europe.

Challenge addressed by this work:
The perovskite devices present some measurement challenges that are currently not properly addressed by the existing standard procedures. In order to pave the way for the successful development of this innovative technology, a common approach to measurement protocols should be established

Our objective :

This work describes the outcomes of the three Round Robins performed during the EU project VIPERLAB for the electrical performance assessment of perovskite photovoltaic (PV) technology.

PROCEDURES

SINGLE JUNCTION SOLAR DEVICES

Procedures used for IV measurement: 3 different protocols		
PROCEDURE 1	Reverse scan (5 times) Forward scan (3 times) MPP tracking (2 minutes) Reverse and forward scan (1 time)	Voltage range: from (-0.4 to -0,1) V to (1,2 to 1.4) V for single junction From -0,1 V to (1,9 to 2) V for tandem Steps: (10 – 50) mV Delay time: 20 ms Scan speed: (17 to 200) mV/s Others: Cell in Voc condition between single measurement points or continuous voltage sweep
PROCEDURE 2	Reverse and forward scan (2 - 3 times) MPP fixed voltage Or MPP Tracking (60 s 180 s) Reverse and forward scan (1 times)	
PROCEDURE 3	Reverse and forward scan (2 times) MPP Tracking or MPP fixed voltage (180 s) Reverse and forward scan (1 times)	Voltage sweeps ranges from -0.2 V to 1.2 V, Delay time of 20 ms. Scan speed: 50-100 mV/s.

Procedures used for SR/EQE measurement

Wavelength ranges from 300 nm to 850 nm, chopper frequency: 25 Hz, temperature: 25 °C, no preconditioning, no bias light, step 10 nm.

TANDEM SOLAR DEVICES

Procedures used for IV measurement: 3 different protocols			
PROCEDURE 4	1 sun illumination	MPP Tracking (60 s) MPP Tracking (120 s) Reverse and forward scan slow (1 time) Reverse and forward scan fast (1 time)	Slow voltage sweeps ranges from -0.2 V to 2.2 V, Swept time of 60 s. Delay time: 10 ms. Fast voltage sweeps ranges from -1.5 V to 2.2 V, Swept time of 3 s. Delay time: 1 ms.
	IR illumination	Reverse scan slow (1 time)	
	Blue illumination	Reverse scan slow (1 time)	
	Dark	Reverse scan slow (1 time)	
PROCEDURE 5	1 sun illumination	Reverse and forward scan slow (1 time) MPP fixed voltage (60 s) Reverse and forward scan slow (1 time) MPP fixed voltage (180 s) Reverse and forward scan slow (1 time) Reverse and forward scan fast (1 time)	Slow voltage sweeps ranges from -0.2 V to 2.2 V, Swept time of 60 s. Delay time: 10 ms. Fast voltage sweeps ranges from -1.5 V to 2.2 V, Swept time of 3 s. Delay time: 1 ms.
	IR illumination	Reverse and forward scan slow (1 time)	
	Blue illumination	Reverse and forward scan slow (1 time)	
	Dark	Reverse and forward scan slow (1 time)	
PROCEDURE 6	1 sun illumination	Reverse and forward scan fast (1 time) Reverse and forward scan fast (1 time) Reverse and forward scan fast (1 time) Reverse and forward scan fast (1 time) Reverse and forward scan slow (1 time) MPP fixed voltage (180 s) Reverse and forward scan slow (1 time) Reverse and forward scan slow (1 time) Reverse and forward scan fast (1 time) Reverse and forward scan fast (1 time)	Slow voltage sweep ranges from -0.2 V to 2.2 V, Swept time of 60 s. Delay time: 50 ms Step: 20 mV. Integration time: 450 ms. Fast voltage sweeps ranges from -0.2 V to 2.2 V, Swept time of 4.8 s. Delay time: 20 ms Step: 20 mV. Integration time: 20 ms.
	IR illumination	Reverse scan slow (1 time)	
	Blue illumination	Reverse scan slow (1 time)	
	Dark	Reverse scan slow (1 time)	

Procedures used for SR/EQE measurement

Wavelength ranges from 300 nm to 1200 nm, chopper frequency: 25 Hz, temperature: 25 °C, no preconditioning,, step 10 nm. Bias light and voltage bias according with IEC 60904-8-1

CONFIGURATION

	1st ROUND ROBIN	2nd ROUND ROBIN	3rd ROUND ROBIN
Solar cell Architectures	• Flexible PSK **single junction**, with p-i-n structure, IO + barrier film vacuum lamination • Semitransparent PSK **single junction**, with p-i-n structure, box sealed in glovebox • Rigid PSK **single junction**, with p-i-n structure, PO + barrier film lamination • Rigid PSK **single junction**, with p-i-n structure, cavity glass using epoxy glue lamination • **Tandem** Si/PSK 2T, with p-i-in structure, box sealed in glovebox	• PSK **single junction**, with p-i-n structure, glass/glass encapsulation	• **Tandem** Si/PSK 2T, with p-i-in structure, glass/glass encapsulation
Round Robin configuration	**Binomials:** two laboratories that apply the same protocol within each pair. Different protocols for each binomial: each pair of laboratories uses a different protocol. So, while the two laboratories in each pair use the same protocol, the protocols vary between pairs.	**Star-shaped**: the central laboratory measures the devices and distributes them among the labs which apply the same protocol and bring them back to the central laboratory which performs a second measurement of the samples.	
Measurement	IV Curve	IV Curve and spectral response	

MAIN FINDINGS

- **Degradation** of the samples affected the measurements, even to the meta-stability effects occurring during preconditioning.
- The spectral distribution of the light source also affected the results, being more critical on tandem devices. For single junction cells this effect can be minimized by using a **spectral mismatch correction** but for tandem cells that is not enough, and a **multi-lamp sun simulator** is needed.
- Positioning of the **measurement mask** is also important to avoid differences. The reflections of the measurement table for semi-transparent solar cells may cause deviations in the determination of J_{sc} .
- Fill Factor is mainly affected by the **connecting system** between the cell terminals and the electronic load.
- Finally, *Voc* is affected by the sample **temperature**, so it is also important to use a temperature probe in order to correct the electrical parameters to STC.
- **Encapsulated** single junction perovskite solar cells delivered with **substrate holders, wires, and masks** reduced the sources of uncertainty in the measurements performed in the different measurement laboratories in these two aspects: aperture area and connection procedure
- The protocol used to determine performance consisting of nine steps (procedure 2, single junction), showed no significant variation or trend in the main electrical parameters at the different steps.
- During the initial measurements, increasing the delay time from 20 ms to 50 ms did not lead to a reduction in hysteresis, with the lowest hysteresis observed in the second reverse and forward scan.
- Discrepancies have been detected in short circuit current that could be related to differences in irradiance among labs: mask positioning, irradiance adjustment, spectral distribution…
- Differences are smaller for those cells which seem to be stable.
- Comparing measurements before and after their shipment to the measuring labs, the short circuit current has been heavily influenced by the measurements. Open circuit voltage has been also slightly influenced. The mean value for the fill factor seems to be stable (although silver paste had to be added to some of the substrates), but there are several samples in which the FF is different between labs. As a result, maximum power is affected by the measurements.

RECOMMENDATIONS

- It is difficult to extract clear information from the Round Robins if the PV devices suffer degradation during measurement or even shipment so the use of the most stable devices possible to prevent variations in the electrical parameters of the samples is advisable. Furthermore, the reduction, as much as possible, of the waiting period in the laboratories is also beneficial.
- Provide a sample holder with samples or encapsulated cells with wires for consistent contacting procedures. To minimize problems with electrical connections, it is recommended to put silver paste on the deposited electrodes to avoid damaging them with the contact tips and to reduce contact resistance.
- Perform also the measurement of the EQE of the samples; otherwise apply a spectral mismatch correction using the data from the manufacturer. In case tandem cells are included in the round robin, ensure that the spectral distribution is appropriate, minimizing the current mismatch between the junctions.
- It would be desirable to exchange a reference cell, ideally a filtered silicon cell, to ensure that all laboratories operate with the correct irradiance settings.
- Temperature control and monitoring of the samples to correct the data to STC is needed.
- The use of larger cells in the Round Robin would decrease the differences due to the positioning of the measurement masks.
- A briefer protocol to determine performance could be sufficient to extract electrical parameters of perovskite solar cells. Further work should be undertaken to check it in different types of perovskite cells.
- Ideally, circular Round Robins would be preferable, where the same cells are measured by all the laboratories

Acknowledgements

H2020 –VIPERLAB is receiving funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 101006715. Special thanks to the VIPERLAB project and Associated partners for their continued support in developing technology and promoting knowledge exchange within the Solar Perovskite Community.