CHEOPS	A 10x10 cm^2 module with an initial active area efficiency of 15% (12% stable)	Deliverable Number **D1.5**
Project Number **653296**		Version **1**

H2020-LCE-2015-1

CHEOPS – Production Technology to Achieve Low Cost and Highly Efficient Photovoltaic Perovskite Solar Cells

Deliverable D1.5

A 10x10 cm^2 module with an initial active area efficiency of 15% (12% stable)

WP1 – Perovskite single junction development

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Delivery date: 30 January 2018

Dissemination level: Public

Type: Demonstrator

The research leading to these results has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 653296

Revision History

Author Name, Partner short name	Description	Date
Fabio Matteocci and Aldo Di Carlo (CHOSE)	Draft deliverable	27.01.2018
Sylvain Nicolay, Soo Jin Moon, Arnaud Walter (CSEM)	Revision 1	29.01.2018
Fabio Matteocci and Aldo Di Carlo (CHOSE)	Final version	30.01.2018

Contents

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Acronyms

CHOSE	Università degli Studi di Roma Tor Vergata *(CHEOPS Beneficiary 4)*
CSEM	Centre Suisse d'Electronique et de Microtechnique *(CHEOPS Beneficiary 1)*
ETL	Electron Transport Layer
FF	Fill Factor
HTL	Hole Transport Layer
Jsc	Short Circuit Current
MAPI	Methyl-Ammonium-based Perovskite
MPPT	Maximum Power Point Tracking
PCE	Power Conversion Efficiency
PK	Perovskite
PV	Photovoltaics
Voc	Open Circuit Voltage
WP	Work Package

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Executive Summary

This deliverable is based on the development and characterization of perovskite (PK) solar modules on a substrate area of 10x10cm^2. In particular we report on the optimization of the mixed cation perovskite, in order to increase the photovoltaic performance with respect to methyl ammonium-based perovskite (MAPI). The main goals of the deliverable can be highlighted as following:

1. Improving the efficiency of planar-SnO_2 PK modules
2. Optimizing the PK deposition
3. Designing new layout for PK modules

Need for the Deliverable

The improvement of photovoltaic parameters on substrate areas equal to 10x10 cm^2 is a crucial requirement for the further development of the project and to achieve the final scaling-up objective of CHEOPS. To reach the deliverable which represents the state of art of the PV performance for PK modules, we performed different experiments in order to improve V_{OC} and FF of the PK modules. In particular, the design of an optimized layout for PK modules is one of the more important actions undertaken to reach the deliverable.

Objectives of the Deliverable

The main objective of this deliverable is the fabrication of PK modules with an initial active area efficiency of 15% on 10x10 cm^2 substrate and with a stabilized efficiency of 12%.

Outcomes

Firstly, we fabricated modules with planar SnO_2 Electron Transporting Layer (ETL) by varying the PK deposition and the layout. The planar architecture is based on SnO_2 processed at low temperature by spin-coating. The results show the performance of planar SnO_2-based modules which guarantee higher V_{oc} and FF values with respect to our standard architecture based on mesoscopic TiO_2 scaffold. The absorber layer was obtained by a mixed cation perovskite using the following precursors: PbI_2, $PbBr_2$, FAI, MABr, CsI. Furthermore DMF/DMSO mixture was used as a solvent of the PK solution.

In a first step, we fabricated modules with non-optimized layout formed on 10 cells with 7mm width. The results show an efficiency of 10.9% on as substrate area of 10x10cm^2. It can be seen that the main factors limiting the efficiency are both low FF and low J_{sc} values, equal to 58.8% and 16.7mA/cm^2, respectively. In order to improve these crucial parameters, two kinds of optimization steps were realized regarding the PK layer and the module layout. The light absorption of the PK layer was increased by varying the spin-coating program during the PK deposition. Furthermore, an optimized layout was designed in order to reduce the impact of the ohmic losses due to the FTO substrate.

The new layout is formed by 15 series connected cells with a cell width of 4.5mm. An optimized condition for P1-P2-P3 laser ablations was used to pattern the module. The results show an active area (47.2 cm^2) efficiency of 15% for a module fabricated with planar architecture on a SnO_2 ETL and substrate area of 10x10cm^2. Furthermore, a Maximum Power Point Tracking was used to assess the stabilized efficiency of the modules which results to be equal to 12% after 180s.

Next steps

Next steps comprise the reduction of the difference between IV measured PCE and MPPT measured stabilized PCE. This difference is mainly related to the hysteresis effect due to the unbalanced extraction properties of ETL/HTL layers. Proper optimization of ETL and HTL can reduce this effect. Additional efforts will be devoted to reduce the difference between substrate area and active area and, regarding the module fabrication, the optimization of ETL, PK and HTL layers deposition via the blade coating technique.

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1 Preliminary results on Planar PK modules

In this section, we report the preliminary results obtained for planar PK modules. The composition of the module stack is FTO/BL-SnO_2/$Cs_{0,06}(FA)_{0,78}(MA)_{0,14}Pb(I_{0,83}Br_{0,17})_3$/Spiro-OMeTAD/Au. Each layer has been optimized in terms of deposition parameters, annealing and thicknesses starting from the deposition parameters used for 1cm^2-cell and smaller PK modules. The triple cation perovskite was deposited by solvent quenching method by using chlorobenzene as anti-solvent. The spin coating program is 1000rpm 5s and 4000rpm 23s. Hereafter, all the results will be obtained by using the same deposition technique for SnO_2, PK and Spiro-OMeTAD (if not specified).

UV-vis spectrometer was used to measure the absorbance on four different spots of the device to check uniformity of the PK layer on area of 10x10 cm. The absorbance spectra of the PK layer on four different spots of the device are reported in Figure 1.

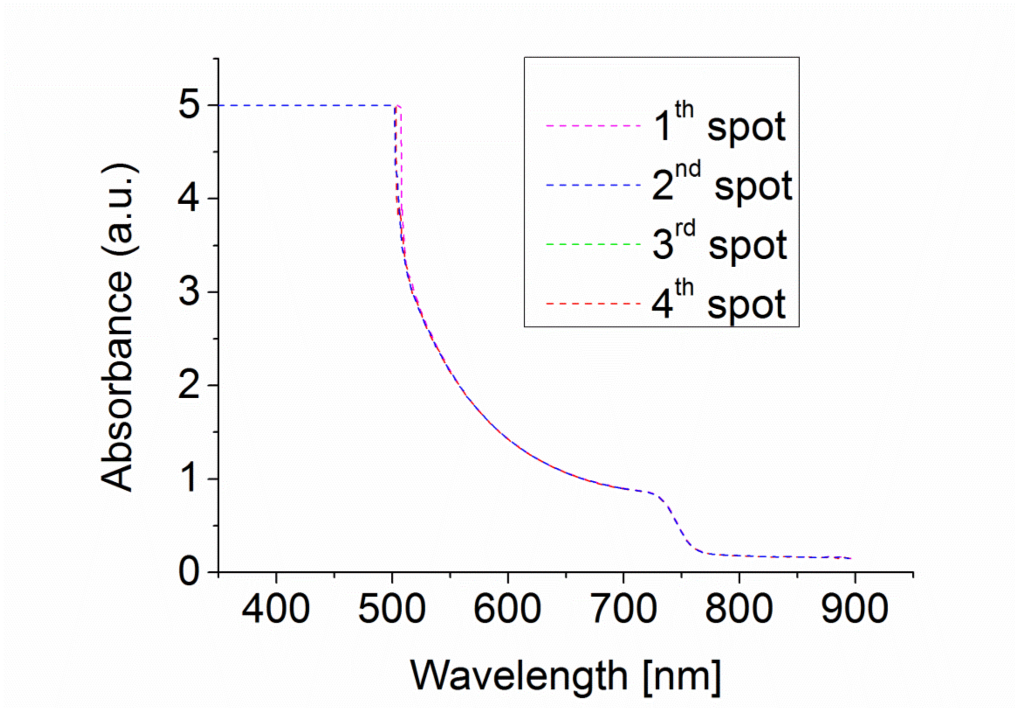

Figure 1. Absorbance spectra of the module in four different spots of the 10x10cm^2 sized device.

The absorbance spectra do not reveal any difference in terms of wavelength onset and signal intensity. This result demonstrates the feasibility of a uniform deposition of PK on the entire 10x10cm^2-sized substrate.

The layout of the module formed by 10 PK sub-cells with a width of 7mm and a length of 70mm is reported in Figure 2.

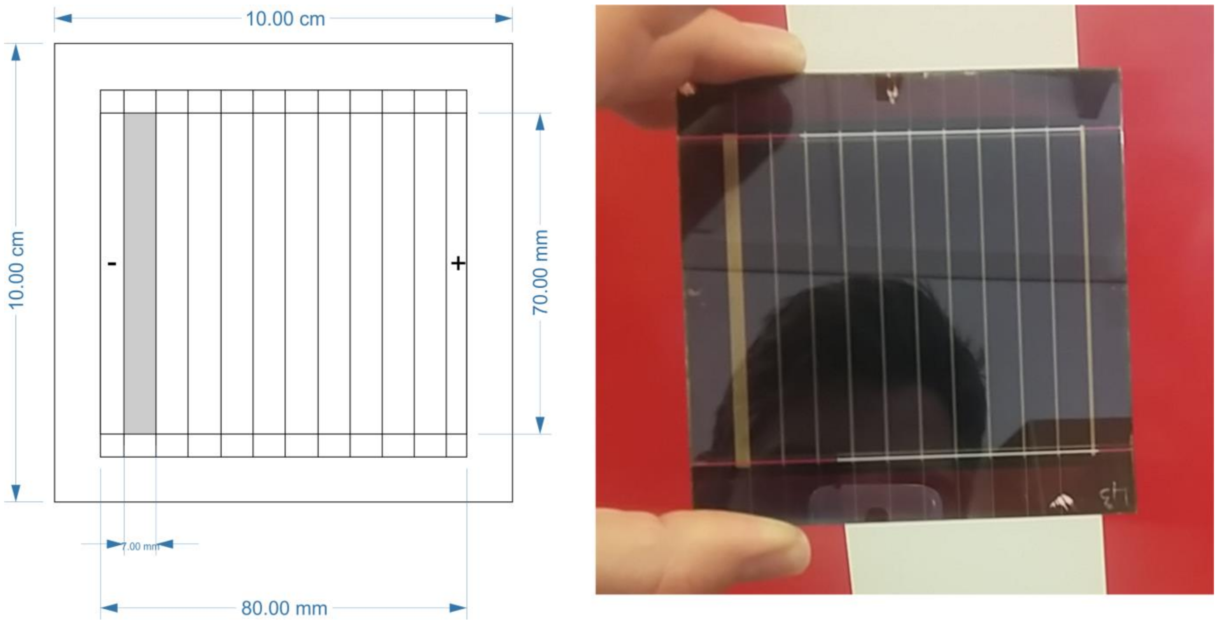

Figure 2. Layout of the PK module formed with 10 sub- cells. Each cell has a 7mm width and a 70mm length. The series interconnections are obtained by P1-P2-P3 laser ablation.

The module layout shows an active area of the single cell of 4.98cm^2 and a module active area of 49.8cm^2 with an aspect ratio (Active Area / Aperture Area) of 91%. The high AR is obtained by optimizing the P1-P2-P3 scribe lines by using laser assisted ablation.

The laser parameters have been optimized in order to remove the full stack of the device (BL-SnO_2/PK/Spiro-OMeTAD) in the P2 process. In Figure 3 we reported the image of the interconnection design of the module.

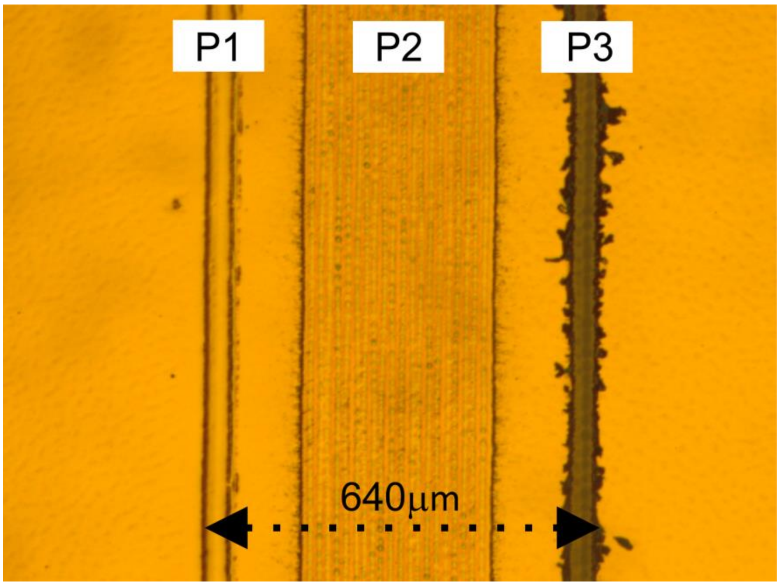

Figure 3. Image of the monolithic interconnection of the modules. The total dead area width was around 640µm.

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The module I-V curve under 1 sun illumination is reported in Figure 4. An efficiency of 10.9% was reached as the best result by using this module layout.

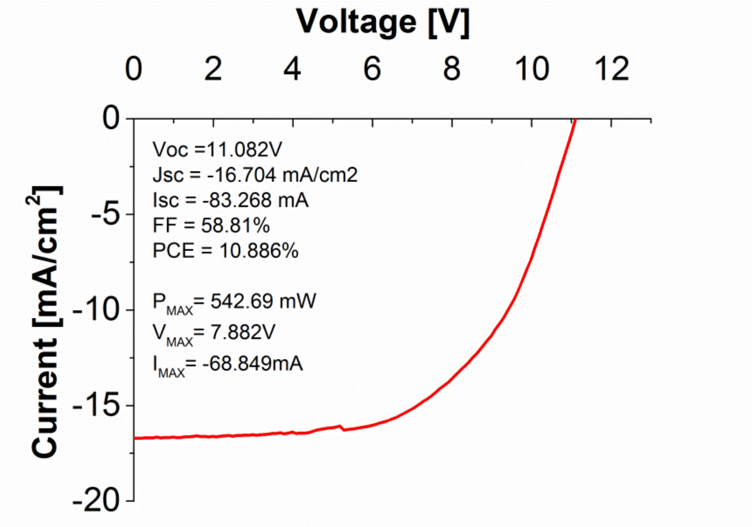

Figure 4. I-V curve for planar PK module with 7mm as cell width.

The result clearly shows a low current density of the module compared to 1cm^2-sized cell (for which the current was typically 19-20 mA/cm^2). The low photocurrent is mainly related to the insufficient light absorption of the perovskite layer. Although, the uniformity of the PK deposition is very promising, the low thickness of the PK layer could play a role on the charge generation. Furthermore, this module is also characterized by a low FF, which is mainly ascribed to high series resistances in the module coming mainly from un-optimized individual segment width.

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2 Results of optimized Planar PK modules

We explore alternative spin coating programs in order to increase the absorption of the perovskite layer without losses in uniformity of the PK layer. We found that by increasing the time of the first ramp at 1000rpm from 5s to 10s, the absorbance of the perovskite is remarkably increased thanks to a thicker deposited PK film. In Figure 5, we compared the absorbance spectra by varying the spin coating program. The results were deposited using the same concentration of precursors and solvents of the perovskite solution.

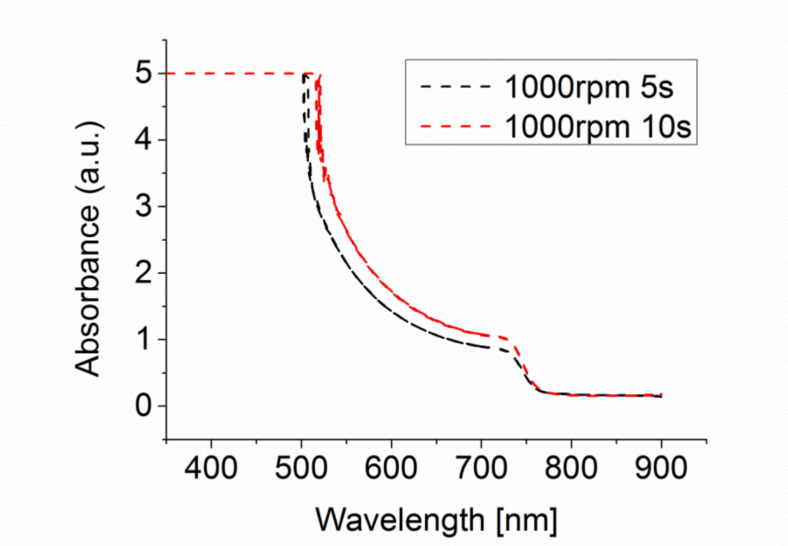

Figure 5. Comparison between absorbance spectra by varying the spin coating program.

The results showed an increase of the absorbance of the PK layer which can be related to an increase of the thickness. Then, we evaluated the optimized ramp at 1000rpm as main parameter to increase the current in our modules. In Figure 6, we compare the I-V curves of the modules by varying the spin coating program.

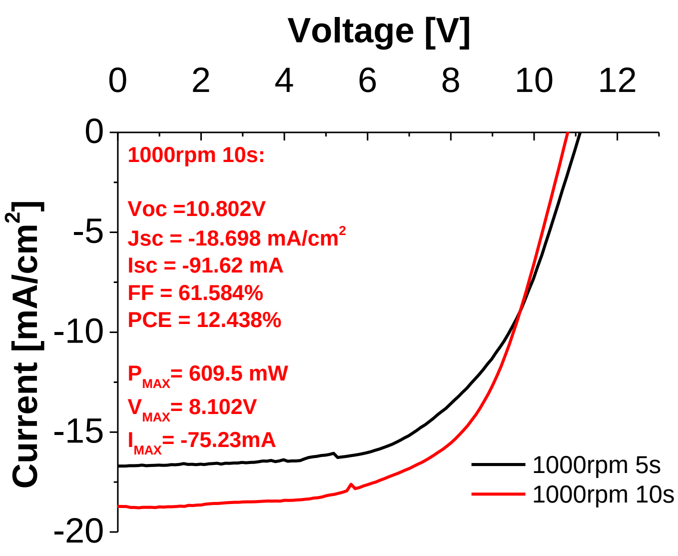

Figure 6. I-V curves of the modules by varying the spin coating program: 1000 rpm 5s (black curve) and 1000rpm 10s (red curve).

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As expected, the current density is remarkably increased due to an increase of the thickness of the PK layer passing from 16.7mA/cm^2 to 18.7mA/cm^2. The FF value is slightly increased passing from 58.8% to 61.6%. The efficiency with the optimized ramp is 12.5% on 49cm^2 as active area. Although, this result is at the state of art of planar PK module on this active area, it is too far from the deliverable goal of 15%.

In order to further improve the efficiency, we designed a new layout for the module with the same aperture area and interconnection design. The main differences are related to the cell width, which is now reduced to 4.5 mm, to the number of the cells, increased up to 15. The AR of the new module is slightly decreased from 91% to 88% but it remains still high compared to the results in literature. The active area of the constituent segments forming the module is 3.15 cm^2.

In Figure 7 the optimized layout is reported with 4.5 mm as cell width and 70 mm as cell length.

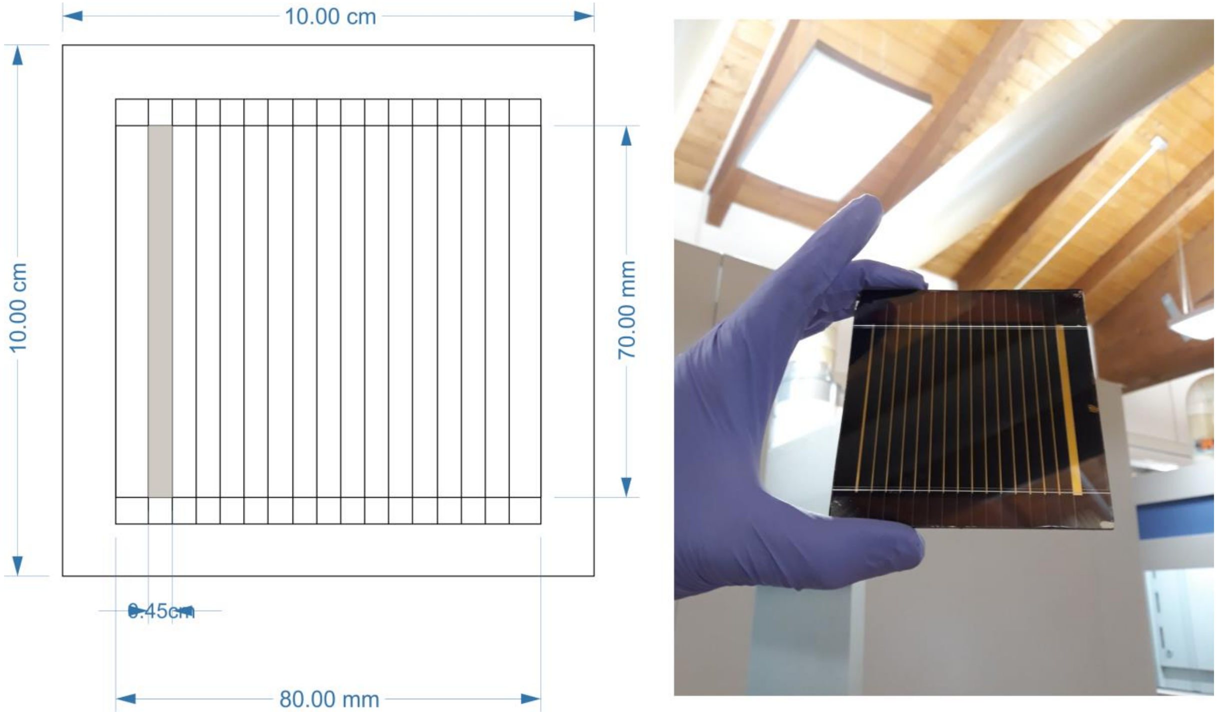

Figure 7. Optimized layout for planar PK modules with 4.5mm cell width and 15 cells.

In Figure 8 we report the I-V characteristic of the module by using the optimized ramp and layout.

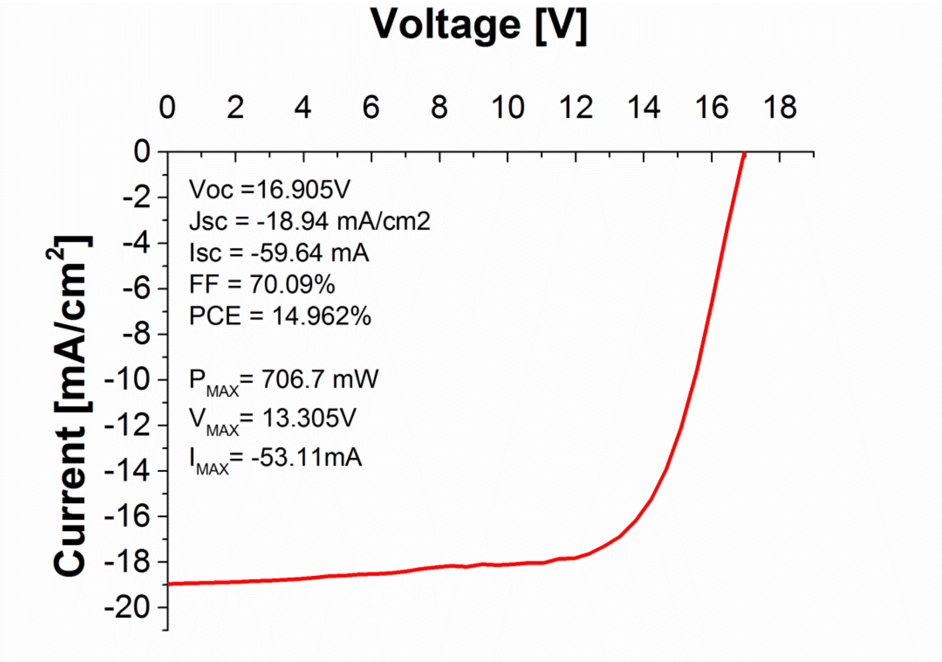

Figure 8. I-V characteristic of the optimized module.

The I-V results demonstrated outstanding photovoltaic performance showing the following I-V parameters: V_{oc}=16.9V, J_{sc}= 18.94mA/cm^2, FF= 70.09% and PCE=14.96%. The active area was 47.3cm^2 with an output power of 706.7mW. The optimized layout plays a crucial role to obtain the result needed for the deliverable with an impressive increase of fill factor value.

Furthermore, we performed MPPT measurement to evaluate the steady state efficiency of the developed device. The MPPT test was realized at 1 Sun by using a calibrated sun simulator class A for 300s of light soaking.

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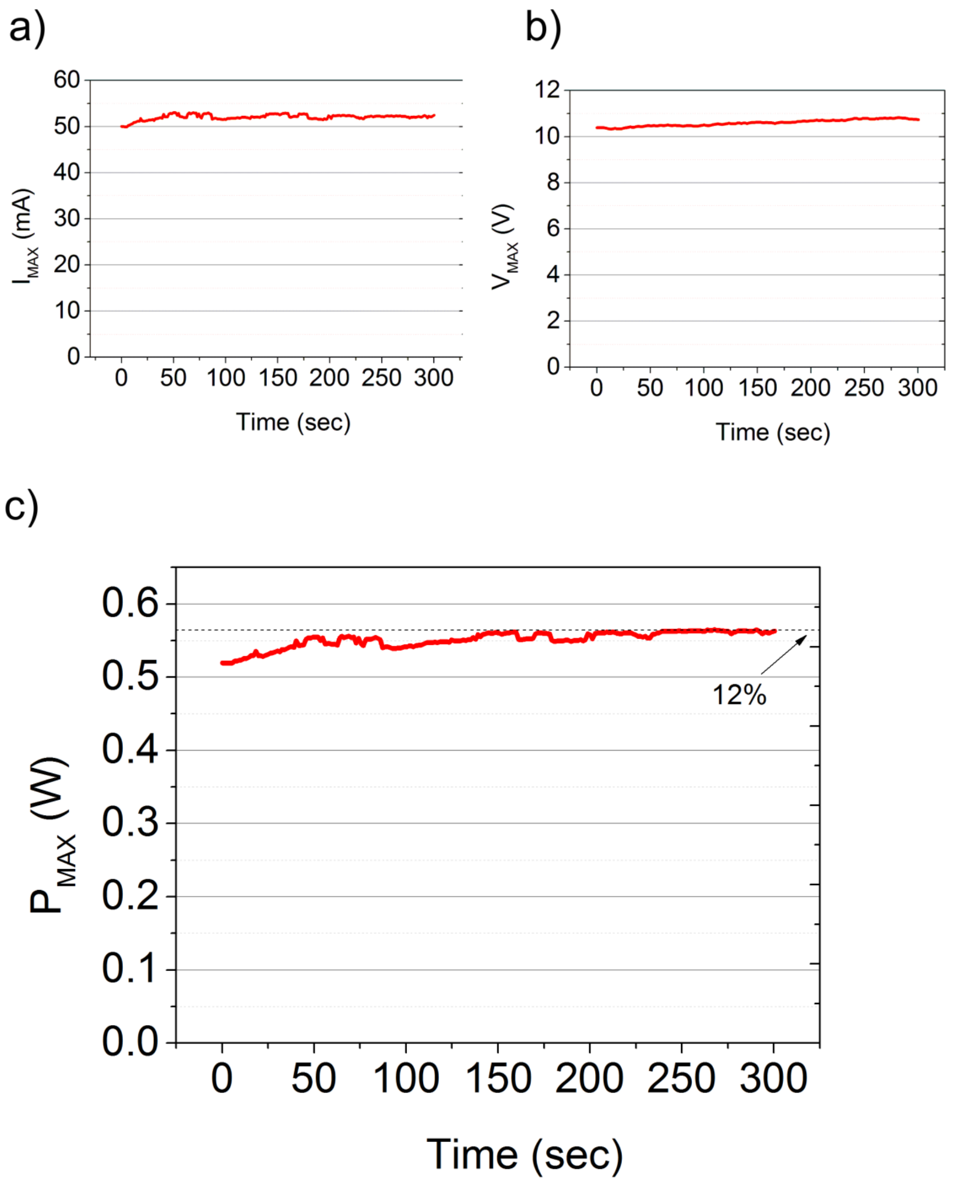

Figure 9. Results obtained for MPPT test long 300s: a) I_{MAX} profile, b)V_{MAX} profile, c) P_{MAX} profile.

It can be seen from Figure 9 that the MPPT P_{MAX} stabilized at 0.56 W, corresponding for an active area of 47.3 cm^2, to a steady state efficiency of 12%, the aim of the present deliverable.

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