CHARACTERIZATION AND DEGRADATION OF PEROVSKITE MINI-MODULES

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ABSTRACT: With their exceptional optoelectronic properties, compatibility with low-cost and large-scale fabrication methods, organic-inorganic hybrid metal halide perovskites are poised to revolutionize the next generation of photovoltaics. The leap forward in the power conversion efficiency (PCE) enabled by lead halide perovskites is unprecedented, with PCEs emerging from 3.8% in its first study to a current certified value of 25.5% in single-junction and 29.52% in perovskite-silicon tandem devices [1-3]. The main challenge for the successful commercialization of perovskite solar cells is to achieve high stability at the module level. The commercially available solar modules undergo a series of characterization procedures that analyze their properties and ensure their quality. However, these procedures and protocols cannot unambiguously be applied to perovskite solar modules (PSM). To this end, more advanced characterization methods are needed to understand the degradation mechanisms in the PSM. In this context, optical and electrical measurement methods are effectively employed in quality control and development support and are essential characterization tools in industry and research.

KEYWORDS: Perovskite, Optical and electrical characterization, Degradation

1 INTRODUCTION

In the proposed work, we employed optical and electrical characterization methods to understand the degradation of perovskite mini-modules. Optical techniques such us electroluminescence (EL), photoluminescence (PL), and dark lock-in thermography (DLIT) are non-destructive measurement techniques and provide high-resolution images showing a two-dimensional distribution of the characteristic features of PV cells and allowing the investigation of cracks, defects, shunts, and stacking faults in the cells [4]. Furthermore, electrical measurements like current-voltage (IV) characteristics and external quantum efficiency (EQE) can provide information on the power output and other device parameters, which could be used to identify the possible degradation route.

2 EXPERIMENTS

A - double cation-double halide perovskite active layer with the composition $\mathbf{Cs_{0.18}FA_{0.82}PbI_{2.82}Br_{0.18}}$ was used. To make large-area devices, so called mini-modules were produced by laser scribing, to generate 7 sub-cells connected in series. To prevent penetration of metallic particles of the top electrode into the soft perovskite layer, ITO (indium-tin-oxide) was used. ITO was also selected as a top electrode to obtain semi-transparent modules. The module stack was as follows: glass/ITO/Hole transport layer (HTL)/550nm 2C Perovskite with bandgap of 1.6 eV/Electron transport layer (ETL)/ITO/glass. Fig.1 depicts the structure of the perovskite sub-cell and Fig. 2 illustrates the cross-section of the mini-module. Fig.3 shows two images of the front and back side of one perovskite mini-module (substrate size: 3cm x 3cm and module size: 2cm x 2cm). 4 perovskite mini-modules ("S9", "S10", "S11" and "S12") were produced and characterized by applying DLIT-, EL- and PL methods alongside IV and EQE measurements. The results are presented in section 3.

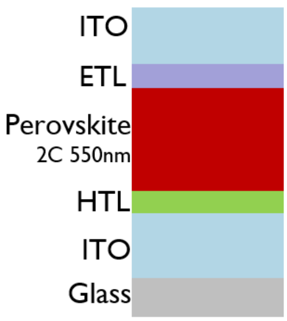


FIG.1 PIN-structure of each sub-cell.

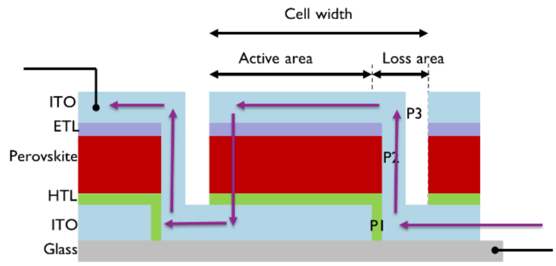


FIG.2 Cross-section of the mini-module.

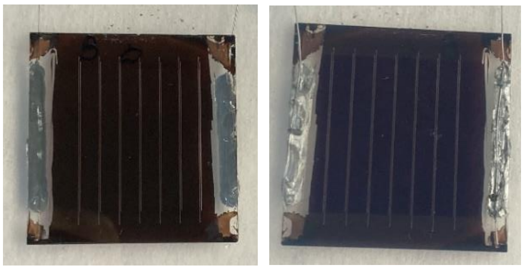


FIG.3 Perovskite mini-module: Front side (left), Back side (right).

3 RESULTS

3.1 Mini-module "S9"

Fig.4 shows the EL images (front side and back side) of mini-module "S9". All cells are active. The IV measurement results of mini-module "S9" are presented in Table 1, while the EQE measurement results are shown in Fig.5.

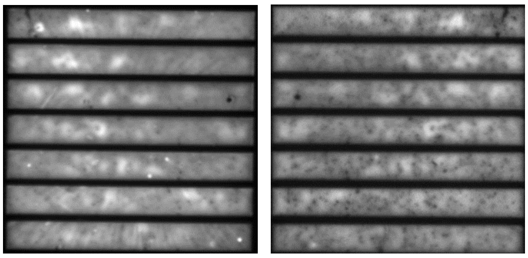


FIG.4 Perovskite mini-module "S9": Front side (left) and back side (right).

Table 1:
IV-measurement results of the mini-module "S9"

I_{SC} [mA]	V_{OC} [V]	FF [%]	P_{MPP} [mW]	Jsc [mA/cm²]
10.26	7.789	42.91	34.29	13.10

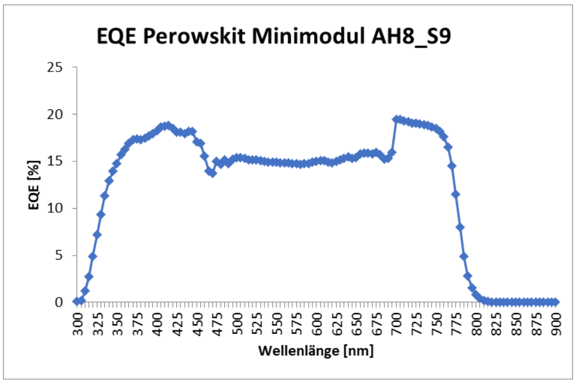


FIG.5 EQE of the perovskite mini-module "S9"

3.2 Mini-module "S10"

Fig.6 shows the EL images of mini-module "S10" with two inactive cells. The IV measurement results of minimodule "S10" are listed in Table 2. The EQE measurement results are shown in Fig.7.

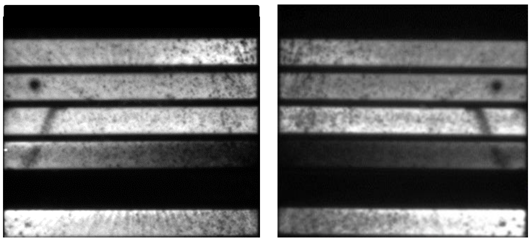


FIG.6 Perovskite mini-module "S10": Front side (left) and back side (right).

Table 2:
IV-measurement results of the mini-module "S10"

I_{SC} [mA]	V_{OC} [V]	FF [%]	P_{MPP} [mW]	Jsc [mA/cm²]
10.56	6.106	39.70	25.59	13.48

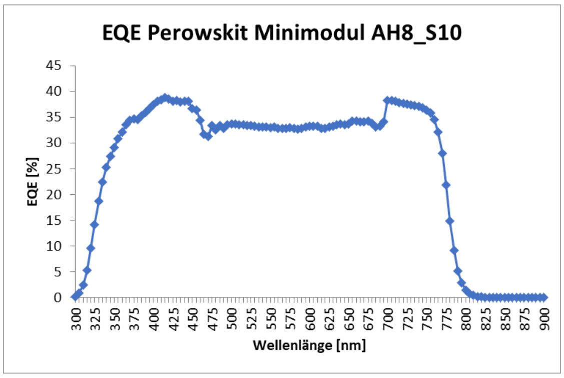


FIG.7 EQE of the perovskite mini-module "S10"

3.2.1 DLIT-measurements

DLIT measurements were carried out on the selected mini modules. However, it soon became evident that these measurements put a great strain on the modules, with the possibility to induce degradation, interrupt electrical contact or even re-establish broken contacts.

In the case of the mini-module "S10", it can be clearly seen in the EL image (see Fig.8), that an interrupted contact was reactivated, after the DLIT measurement performed on 10/2021 was carried out. After DLIT measurement there was only one inactive subcell instead of two.

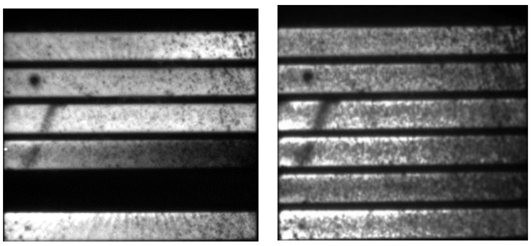


FIG.8 Mini-module "S10" before (left) and after (right) DLIT- measurement

The IV measurement results also showed a significant increase in performance after the DLIT measurement was performed (see Table 3).

Table 3: IV-measurement results of the mini-module “S10”, before and after DLIT measurement (10/21).

Mini-Modul	I_{SC} [mA]	V_{OC} [V]	FF [%]	P_{MPP} [mW]	Jsc [mA/cm²]
S10	10.56	6.106	39.70	25.59	13.48
S10 DLIT	10.39	6.756	39.81	27.94	13.27

However, there was already a drop in the measurement performed on 11/2021 and a subsequent return to the initial values.

3.3 Mini-module “S11”

Fig.9 shows the EL recordings of the minimodule "S11" with three inactive cells. The IV measurement results of the minimodule "S11" are presented in Table 4. The EQE measurement results are depicted in Fig.10.

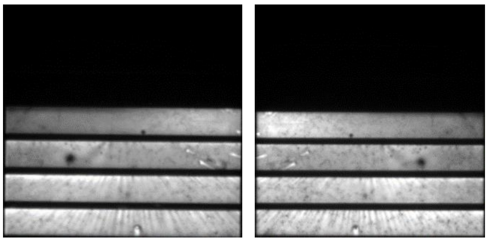


FIG.9 Perovskite mini-module “S11”: Front side (left) and back side (right).

Table 4:
IV-measurement results of the mini-module “S11”

I_{SC} [mA]	V_{OC} [V]	FF [%]	P_{MPP} [mW]	Jsc [mA/cm²]
10.37	5.260	37.60	20.50	13.24

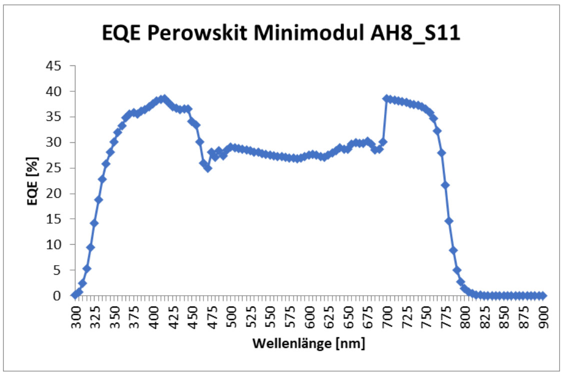


FIG.10 EQE of the perovskite mini-module “S11”

3.4 Mini-module “S12”

Fig.11 shows the EL images of the minimodule "S12" with two inactive cells.

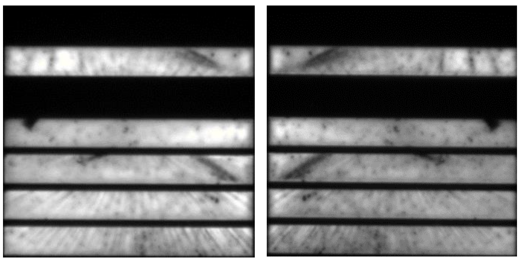


FIG.11 Perovskite mini-module “S12”: Front side (left) and back side (right).

The IV measurement results of the minimodule "S12" are listed in Table 5. The EQE measurement results are shown in Fig.12.

Table 5:
IV-measurement results of the mini-module “S12”

I_{SC} [mA]	V_{OC} [V]	FF [%]	P_{MPP} [mW]	Jsc [mA/cm²]
10.44	6.993	40.60	29.64	13.33

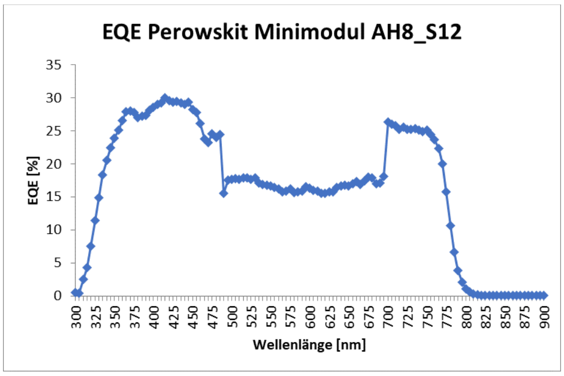
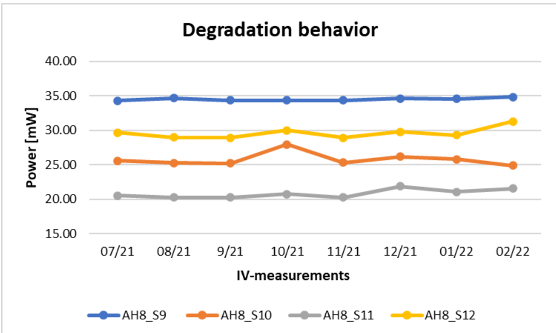


FIG.12 EQE of the perovskite mini-module “S12”

3.5 Aging behavior of the perovskite mini-modules S9, S10, S11 and S12

For the perovskite mini-modules, IV measurements as well as EL measurements were performed regularly from **July 2021 (07/21) to February 2022 (02/22)** to determine the **aging behavior** of the mini-modules. The modules were stored in the dark between the measurements. As can be seen in **Fig.13**, the mini-modules behaved in a very stable manner over the selected period.



	AH8_S9	AH8_S10	AH8_S11	AH8_S12
7/21	34.29	25.59	20.50	29.64
8/21	34.68	25.24	20.25	28.96
9/21	34.33	25.20	20.23	28.93
10/21	34.31	27.94	20.75	30.00
11/21	34.35	25.30	20.25	28.88
12/21	34.61	26.18	21.84	29.75
1/22	34.53	25.78	21.08	29.26
2/22	34.81	24.89	21.56	31.27

FIG.13 Aging behavior of the perovskite mini-modules

Only in the case of mini-module “S10” a significant increase in power was detectable in 10/2021 (after a DLIT measurement was carried out). However, already in November 2021 there was a decrease in power and a return to the initial values.

4 CONCLUSIONS

First defects and shunts were identified by EL, PL and DLIT measurements. The EQE measurements gave very high values for perovskite cells (e.g. about 90%, cell size:0.13cm^2, see Fig.12), but still too low values for perovskite mini modules (Fig.5).

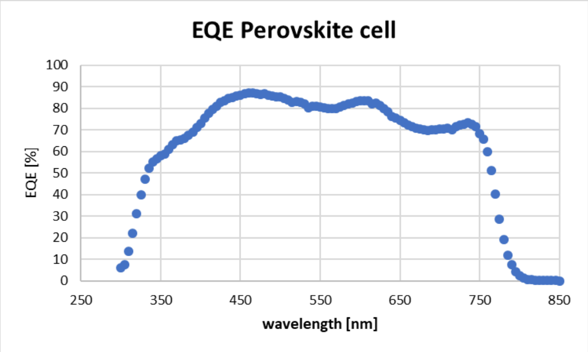


FIG.12 EQE of a perovskite cell

Further indoor tests and outdoor tests of differently structured perovskite samples and perovskite tandem cells have to be performed in order to identify more defects and thus be able to improve the perovskite cell and module structure. The aging behavior of the perovskite mini-modules will also be further analyzed. In addition, measurement protocols for indoor and outdoor tests of perovskites will be established.

5 REFERENCES

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http://www.foss.ucy.ac.cy/degradationlab/