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IPVF's Scientific Day - June, 30, 2022

Program IV - WP.5: Reliability Testing

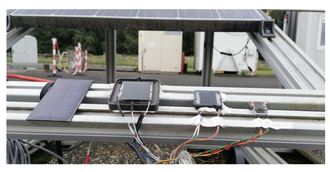
Perovskite in Real Environment

Analysis of Outdoor Results

Context & Objectives : Anes S. internship

→ Behavior on real environment is required for future PK technology industrialization

→ IPVF-SIRTA collaboration: Assess the PK behavior & degradation on outdoor conditions



27/07/2021 - Beginning of collaboration

Samples
- ✓ Semi-T large modules
- ✓ T sensor inside PK

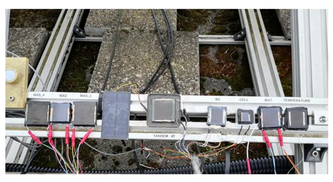
Objectives
- ✓ Compare Semi-T & Opaque
- ✓ Explore the T behavior

12/04/2021

19/10/2021

Samples
- ✓ Tandem PK/Si
- ✓ Mini-module PK

Objectives
- ✓ Initiate outdoor behavior
- ✓ Study large PK module



Samples
- ✓ Mini-module PK
- ✓ Large substrate PK

Objectives
- ✓ Explore better encapsulation process
- ✓ Compare 2D & 3D perovskite

➢ **Solve unorganized data: Weather, Electrical**

➢ **Analysis and understanding of PSC behavior on complex environment**

Developed Functionalities

→ Data treatments & cleaning

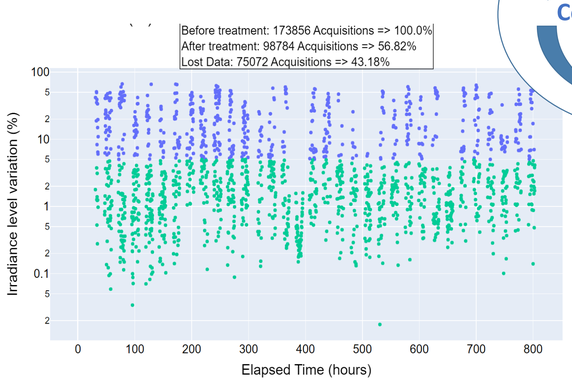
→ Combine weather & electrical data

→ Add new data to the old ones

→ Sample data visualization

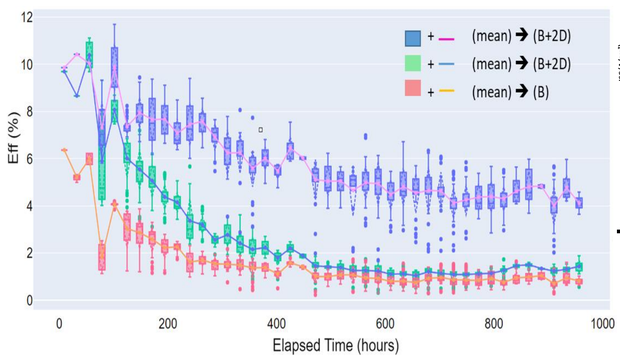
→ Analysis on electrical parameters

Complementary

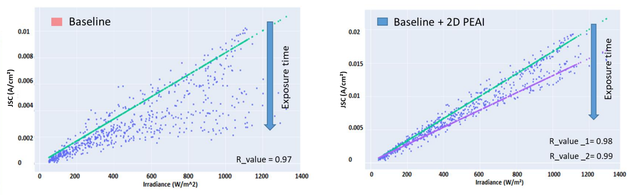


Case study : 2D & Baseline Comparison

Efficiency variation as function of exposure time



Linear regression for J_{SC} as function of Irradiance



Baseline: With degradation → J_{SC} becomes logarithmic with irradiance.

2D layer : With degradation → J_{SC} linear with irradiance.

→ Discrepancy on degradation rate for same architecture

→ 2D architecture present better stability → T_{80}=280h

1D V_{OC} model for temperature & irradiance variation

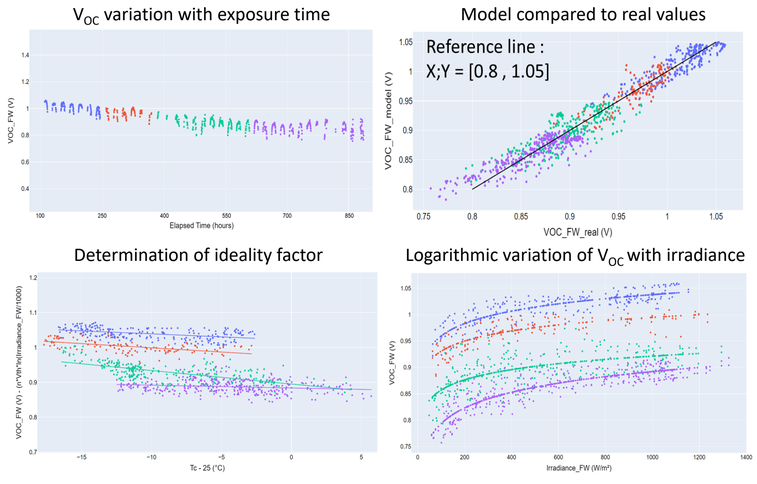
$$V_{OC}(X,T) = V_{OC}nV_{th}\ln(X) + \beta_{V_{OC}}(T_C - T_0)$$

n : ideality factor $\beta_{V_{OC}}$: temperature coefficient

X: Irradiance (Suns)

→ Model applied for region < 5% degradation

→ Good agreement model with SIRTA



Temperature coefficient & ideality factor determination

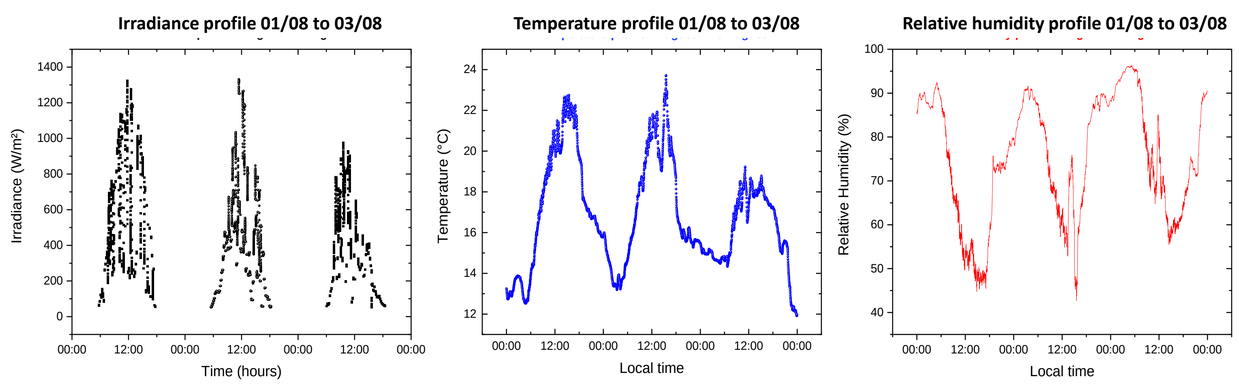
Date	V_{OC} T° Coeff, $\beta_{V_{OC}}$ (mV/°C)	Ideality Factor, n
2022-04-17 ➔ 2022-04-23	-1.7	1.54
2022-04-24 ➔ 2022-04-29	-2.4	1.64
2022-04-30 ➔ 2022-05-10	-3.8	1.47
2022-05-11 ➔ 2022-05-23	-0.8	1.44

Reproduce Outdoor at IPVF

Context & Objectives : Clara B. internship

→ Outdoor environment is complex to understand the PK degradation mechanisms

→ Simulate outdoor conditions in a climatic chamber and analyze the stress factors effects

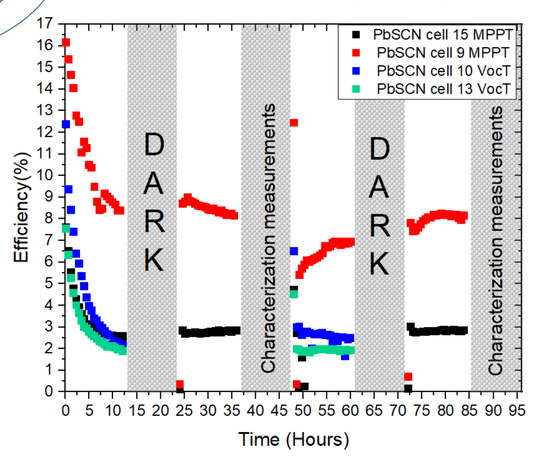


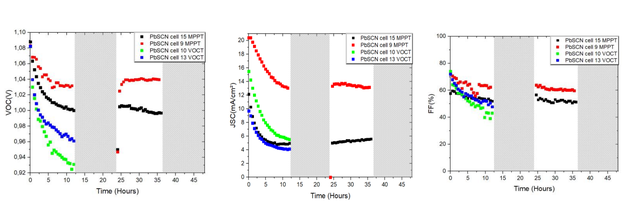
➢ **Develop a methodology to reproduce outdoor environment**

➢ **Address the question: Is the PSC outdoor behavior predictable ?**

Case study : Light Cycling Effect

Long-term light cycling : 12 hours light -12 hours dark





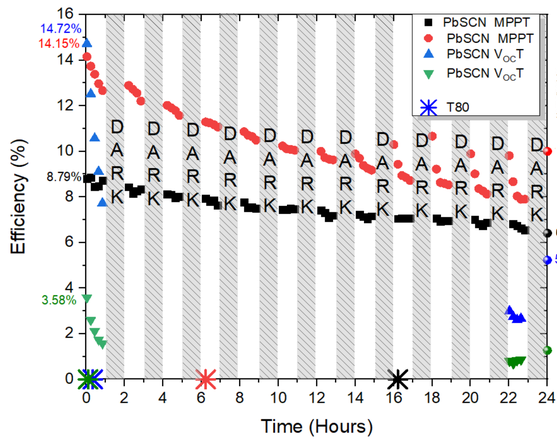
→ Exponential degradation observed during the first 12h

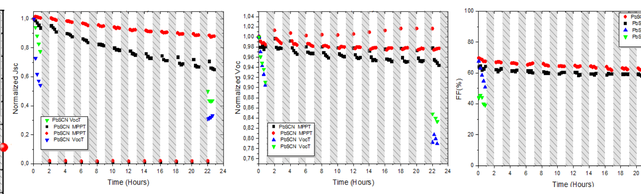
→ Slightly recovery observed after the dark cycle

→ Samples subjected to V_{OC} present higher degradation than MPPT

→ Effect of V_{OC} tracking mainly on V_{OC} and J_{SC}

Short-term light cycling : 1 hours light -1 hours dark



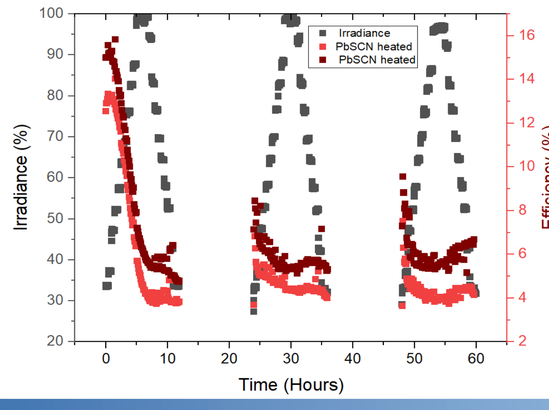


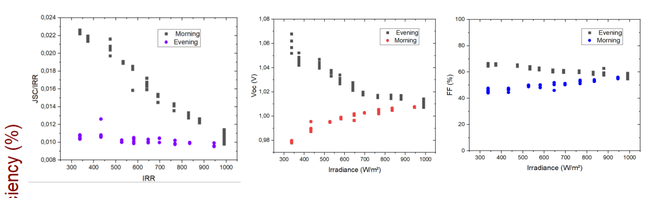
→ Samples subjected to V_{OC} present higher degradation than MPPT - confirms previous results

→ Non-negligeable recovery observed after all dark cycles

→ Recovery is more visible when cycling is performed during exponential degradation

Variable irradiance light cycling : diurnal variation





→ Exponential degradation at the beginning of the test

→ High recovery observed after dark cycle

→ Slight decrease in efficiency at high irradiance due to temperature increase

1 M. V. Khenkin et al., « Consensus statement for stability assessment and reporting for perovskite photovoltaics based on ISOS procedures » Nat. Energy, vol. 5, janv. 2020,

2 E. Velilla, « Outdoor performance of perovskite solar technology: Silicon comparison and competitive advantages at different irradiances », Sol. Energy Mater. Sol. mars 2019

3 M. Jošt et al., « Perovskite Solar Cells go Outdoors: Field Testing and Temperature Effects on Energy Yield », Adv. Energy Mater.,juill. 2020

4 H. Köbler et al., « The challenge of designing accelerated indoor tests to predict the outdoor lifetime of perovskite solar cells ». 2 février 2022.

Conclusion & Perspectives

- ✓ **Great achievements with the SIRTA team on measuring PK technology in outdoor environment**
- ✓ **The data processing, visualization and analysis program is functional and efficient**
- ✓ **1D model allows rapid V_{OC} analysis in terms of temperature, irradiation and degradation**
- ✓ **Severe degradation observed in the case of cells under V_{OC} than under MPPT : ongoing deployment**
- ✓ **Recovery depends on LC interval : higher values obtained for LC during exponential decrease**
- ❑ **Implement GU interface, conduct combined temperature, RH and light cycling variation**