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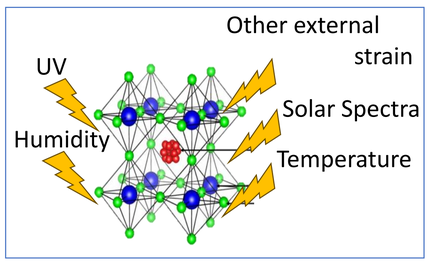
SIRTA Scientific Day June 24th, 2025

ICARE, Performances & Reliability

Performance Metastability of Perovskite Solar Devices

Perovskite Solar devices

- Perovskite (PK) solar devices presents a huge opportunity to boost the power conversion efficiency more than what the industry proposes now with silicon modules by conceptualizing PK-Si tandem solar device.
- PK is very sensitive to most of the environmental factors that induce extrinsic and intrinsic degradation. The main goal of this study is to identify the behavior of PK when exposed to different kinds of environments.

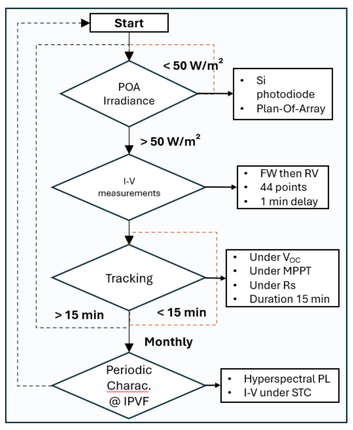


Perovskite Solar devices in Outdoor

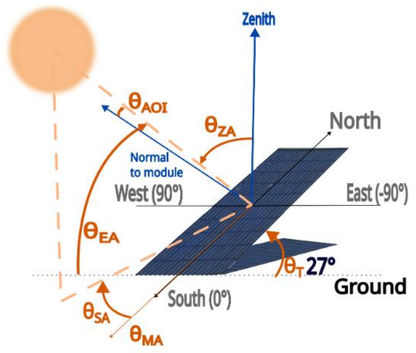
Outdoor aging platform at Ecole Polytechnique meteorological observatory (SIRTA) can preform various outdoor aging protocols. Results are synchronized to the climatic data of SIRTA

IPVF Outdoor testbench at SIRTA

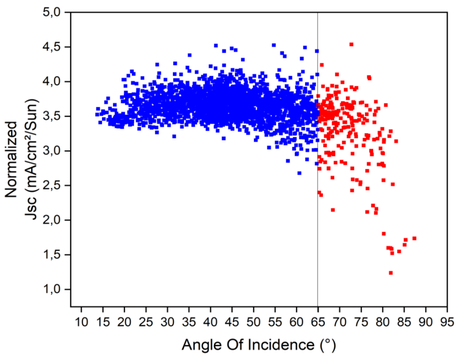
Outdoor measurement procedure



- Data affected by irradiance fluctuations greater than 5% from the initial value are excluded.

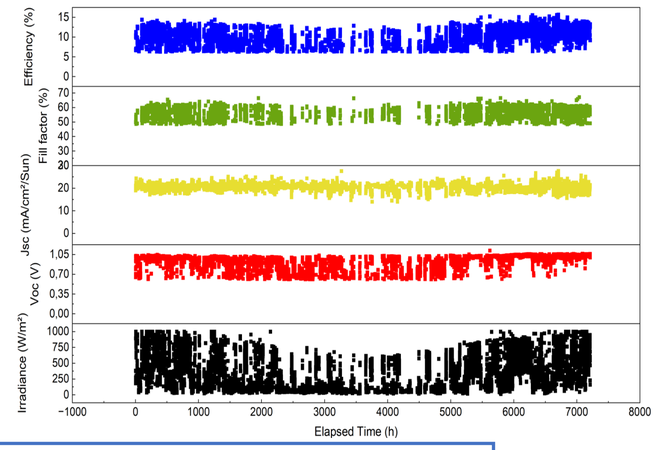


The Angle Of Incidence (AOI) is the angle between the solar beam radiation on a surface and the normal to that surface.

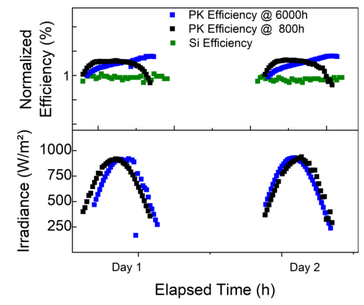


If the AOI is high the absorbed sunlight beam is low, thus a low current will be produced. Data with AOI > 65° are not taken in consideration

Evolution of electrical performances with time for an outdoor aging perovskite



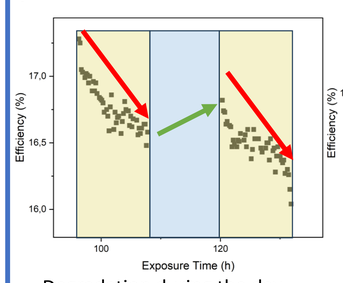
Diurnal behavior of different PV technologies



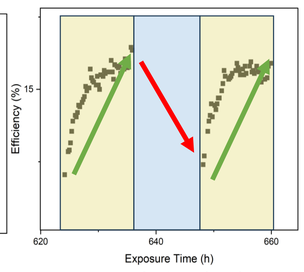
Compared to silicon, perovskite diurnal behavior varies through day and day night cycle, this is commonly called metastability.

Metastable behavior: Qualification & Quantification

Metastable behavior refers to temporary changes in the performance and stability of perovskite solar cells due to structural or property variations under daily sunlight exposure.



Degradation during the day, recovery during the night.



Recovery during the day, degradation during the night.

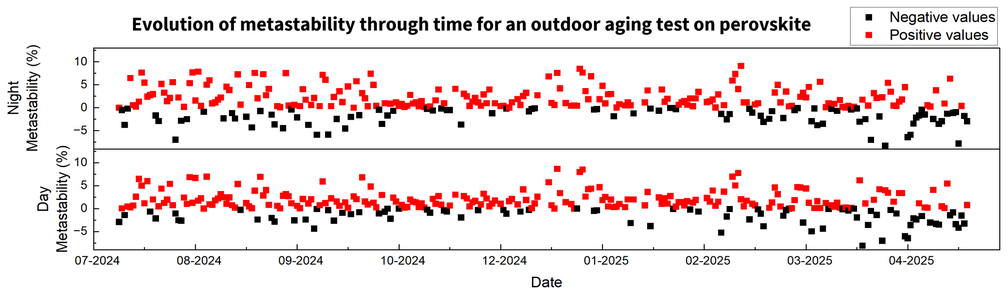
Two key parameters are introduced to quantify the metastability:

- DM: Day Metastability
- NM: Night Metastability

$$\mathrm{DM} = \frac{PCE_{Morning,day\ i} - PCE_{Evening,day\ i}}{PCE_{Morning,day\ i}}$$

$$NM = \frac{PCE_{Morning,day\ i+1} - PCE_{Evening,day\ i}}{PCE_{Morning,day\ i+1}}$$

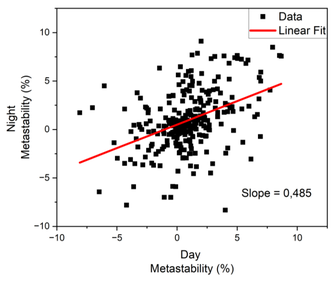
Evolution of metastability through time for an outdoor aging test on perovskite



If DM > 0, **degradation** during the **day**
If DM < 0, **recovery** during the **day**

If NM > 0, **recovery** during the **night**
If NM < 0, **degradation** during the **night**

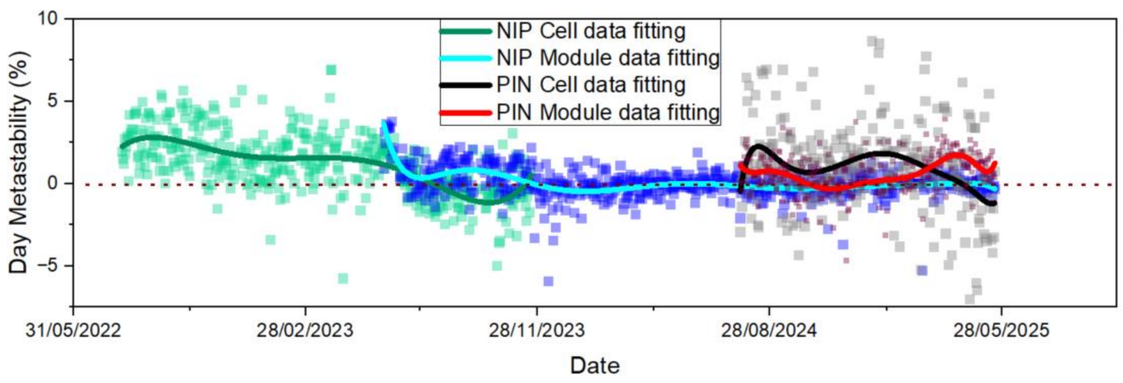
Evolution of NM VS DM



The DM and NM tend to follow the same evolution, but with different kinetics.

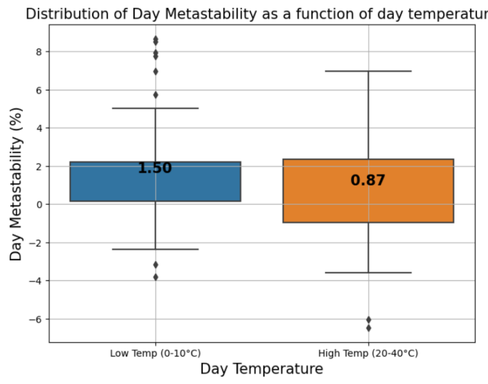
Results

Evolution of DM through time for different outdoor aging test different perovskite

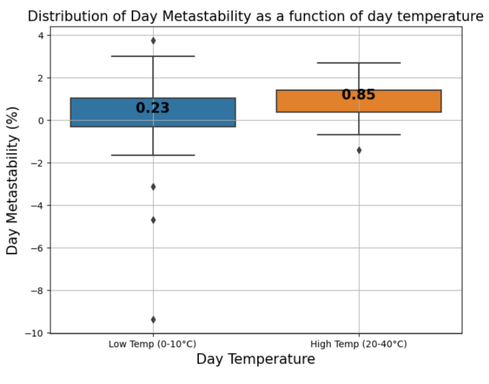


The polynomial fit clearly shows that the metastable behavior follows a cyclic evolution over time, oscillating between degradation and recovery. The metastable behaviour varies regarding the environment, device architecture and configuration and preconditioning.

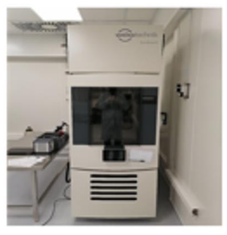
The correlation with temperature is unclear in outdoor data, as many factors interfere with the results.



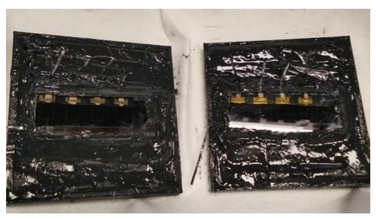
PIN Cell



PIN Mini-Module



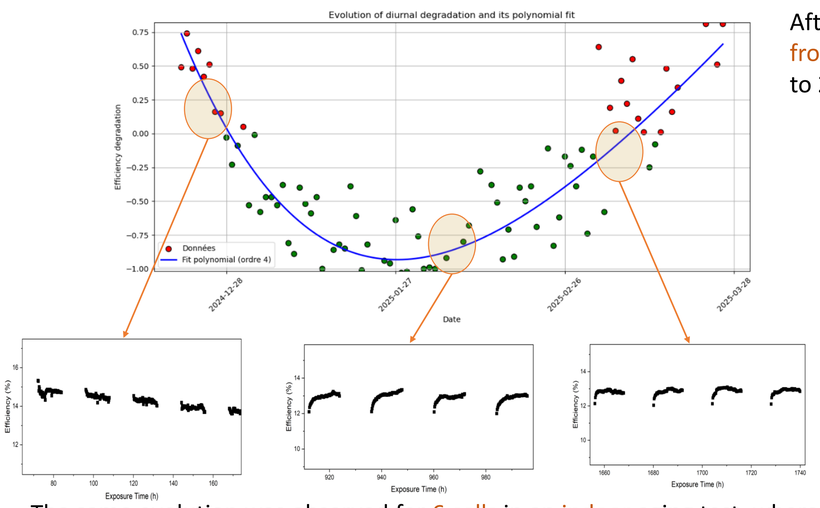
Climate chamber
Variable Temperature & Relative Humidity & Intensity



A light cycling test is launched in a climatic chambre "SunEvent" with the following parameters:

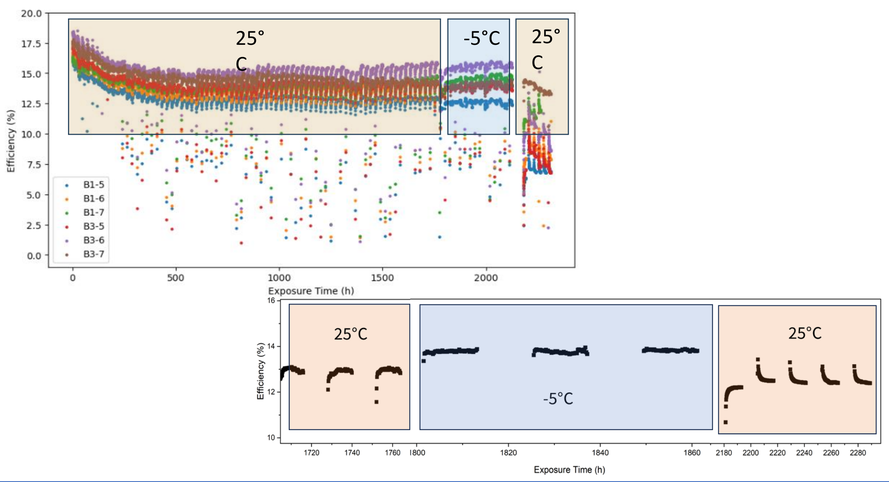
- 12h-12h light dark cycling
- Irradiance calibrated at 1 Sun before testing
- Temperature is controlled at 25°C for both light and dark
- Humidity is set at the minimum of 30%
- Aging under Maximum Power Point (MPPT)

Two multicell, each consisting of 4 cells per substrate. Encapsulated in a glass-glass configuration. An additional over-encapsulation is applied to ensure protection against humidity infiltration.



The same evolution was observed for 6 cells in an indoor aging test, where the metastable behavior oscillates between light-induced degradation and light-induced recovery.

After lowering the temperature from 25 °C to -5 °C, the metastable behavior was frozen, and the diurnal response became stable. Once the temperature was raised back to 25 °C, the metastable behavior reappeared, accompanied by significant degradation.



Conclusion & Perspectives

- Metastable behavior is observed across different architectures and device sizes, with varying intensities and behaviors.
- Metastability appears to evolve in a cyclic manner, oscillating between degradation and recovery, with a tendency to stabilize over time.
- Indoor testing shows that by fixing the light-dark cycle ratio, metastability is more pronounced for PIN architecture, and very low temperature freezes the performances metastability.

- A more in-depth analysis of outdoor data is needed to assess the impact of each environmental parameter on metastability.
- Further sophisticated indoor testing with varying light-dark cycle ratios and temperatures is required to isolate the effects of these parameters.
- An advances Optoelectronic characterization (EL/PL) needs to be done to understand this behavior.