Breaking the Boundaries of Perovskite Solar Cell Testing: A Practical Examination of the All-In-One Pico® LED Solar Simulator for Indoor and Outdoor Characterization

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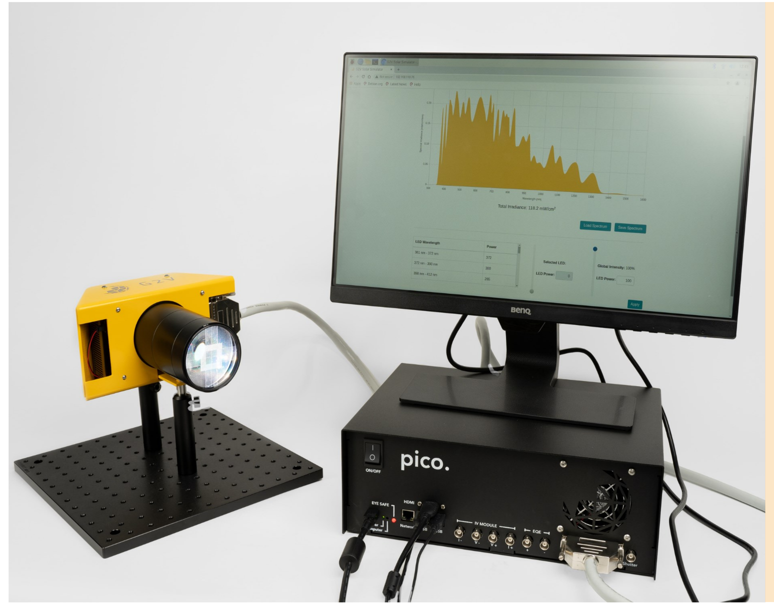
Motivation

As solar cells continue to be deployed in varied applications, the traditional solar simulator with its single air mass spectrum is becoming insufficient to keep up with increasingly complex testing needs.

Next generation LED solar simulators like the Pico unlock new levels of solar cell characterization thanks to their software-based output tuneability. This means that it is possible to adjust the output to match the needs of an experiment rather than adjusting the experiment to match the light source.

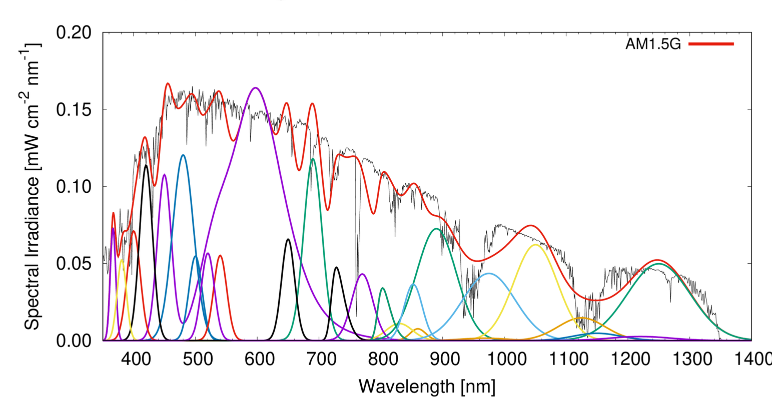
This work highlights how the Pico simulator can be used to characterize a perovskite sample under many realistic light conditions.

Experimentation Using the Pico LED Solar Simulator



- The Pico features multiple independent LED channels that can be adjusted to produce arbitrary spectra in a range of up to 350 nm to 1500 nm. In this work, spectral recipes inspired by AM0, AM1.5G, 5000 K CFL bulb, and 5000 K LED light profiles were created.
- The photovoltaic performance of a thin-film perovskite sample cell (active area of 0.64 cm²) from Solaronix was evaluated under each light profile in temperature controlled conditions (25 °C).
- Initial IV tests were carried out with the Pico's IV module to find the measurement parameters for the sample. Afterward, a 2460 Keithley SMU running a python script was used for IV sampling automation. The response of the perovskite cell was also characterized using the Pico's EQE and One-Click Sun day-night cycling features.

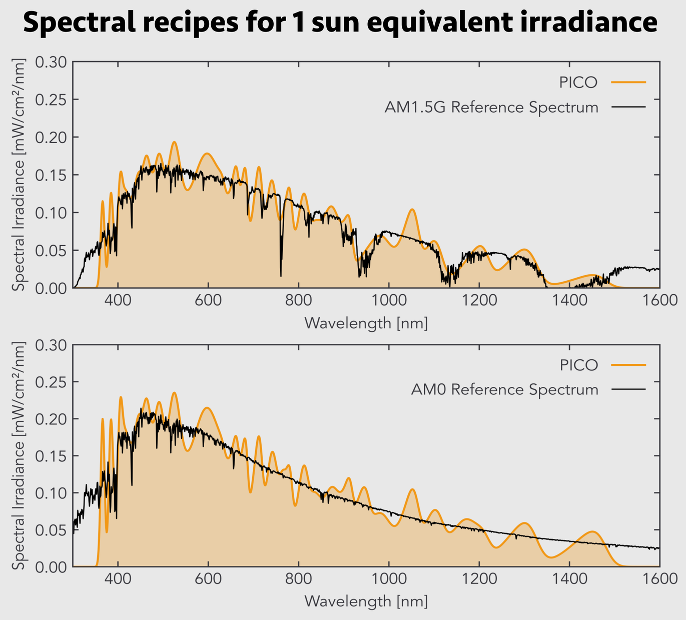
Example of an AM1.5 recipe created by adjusting individual LED channels



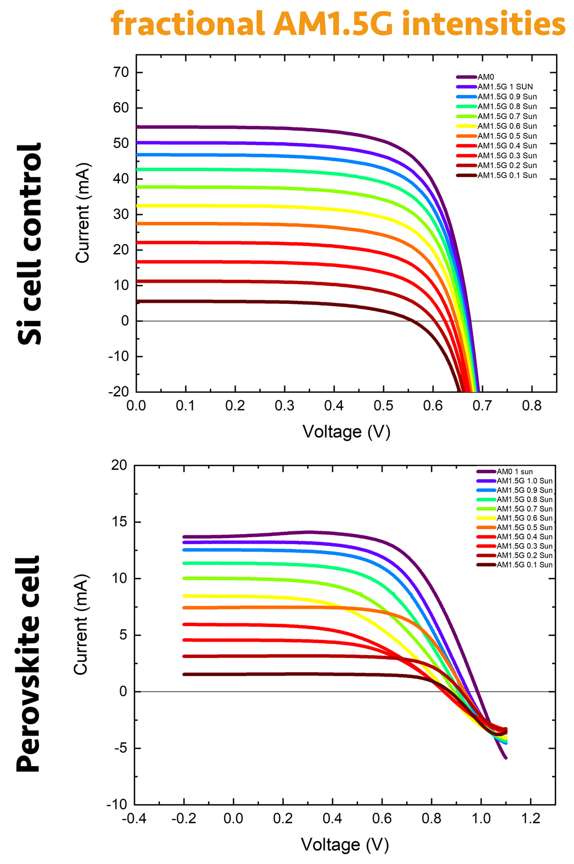
AM0 and AM1.5G Characterization

To illustrate the power of LEDs for outdoor characterization, AM0 and AM1.5G recipes were made and tested using a silicon control cell and the perovskite sample.

Spectral recipes for 1 sun equivalent irradiance



IV curves for AM0 and fractional AM1.5G intensities

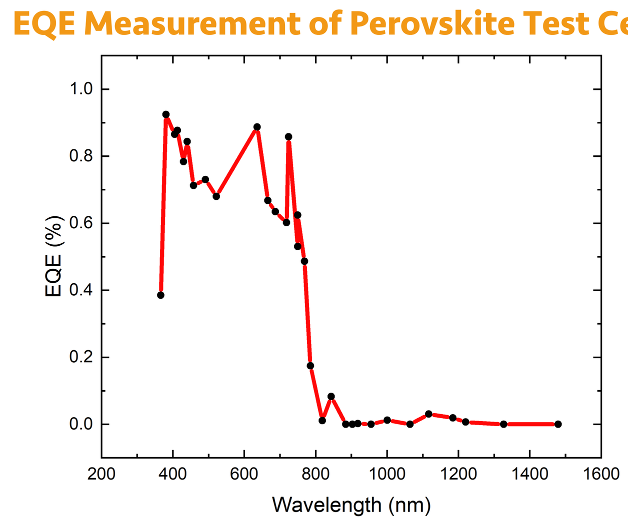


A linear relationship between I_{sc} and light intensity was observed in the IV plots of the Si control cell. In contrast, the perovskite sample showed saturation effects at higher intensities and an unexpected spike in power at 0.5 and 0.2 suns.

From the EQE measurement, it is observed that this cell's bandwidth is limited to a rough range of 350 to 800 nm. LED simulators allow users to minimize spectral mismatch [1] for different solar chemistries, so future work will explore additional optimization of these lower intensity spectral recipes specifically for this perovskite cell.

On another hand, the curved IV cut off and inconsistent performance during testing suggests chemical instability effects are present in the perovskite cell that require an analysis beyond the scope of this work.

EQE Measurement of Perovskite Test Cell



The perovskite cell's bandgap was estimated by

$$E_g = \frac{hc}{\lambda} = \frac{1240 \text{ eV nm}}{800 \text{ nm}} = 1.6 \text{ eV}$$

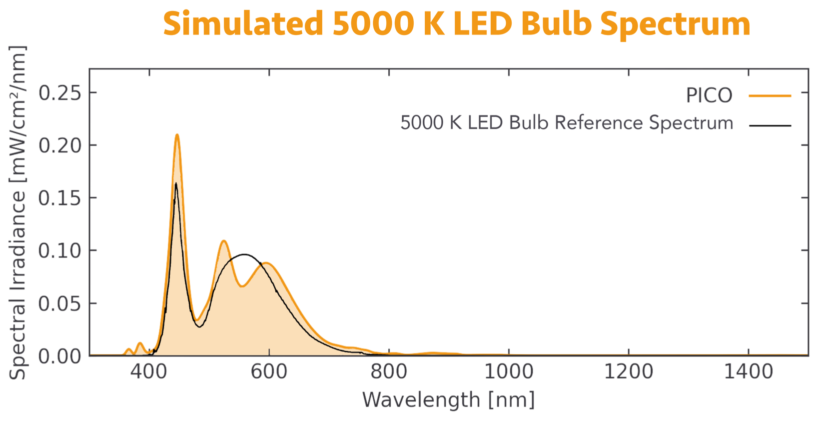
From this data it is possible to propose a refined test spectrum where short infrared channels could be turned off to reduce thermal strain on the device without impacting power conversion efficiency.

Using a stable control is helpful in separating the performance of the solar simulator from the performance of the main device under test.

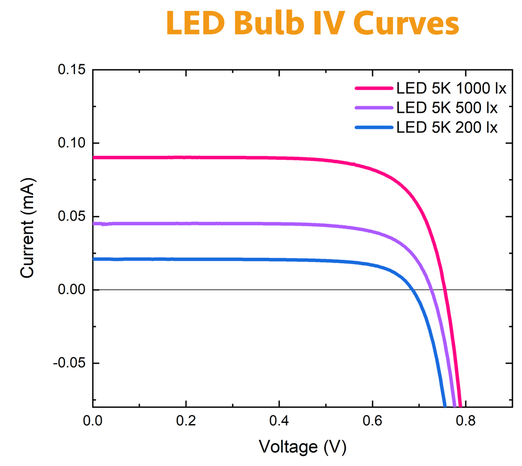
Spectral tuneability without external filters or mechanical parts is a paradigm shift in solar simulator instrumentation. The **Pico** addresses the two sides of solar cell research by providing the **ability to probe the underlying mechanisms** of the active semiconductor material and **qualification of the device** for deployment in a variety of outdoor conditions. This information arms researchers with first level data to guide additional characterizations and optimizations.

Indoor Light Characterization

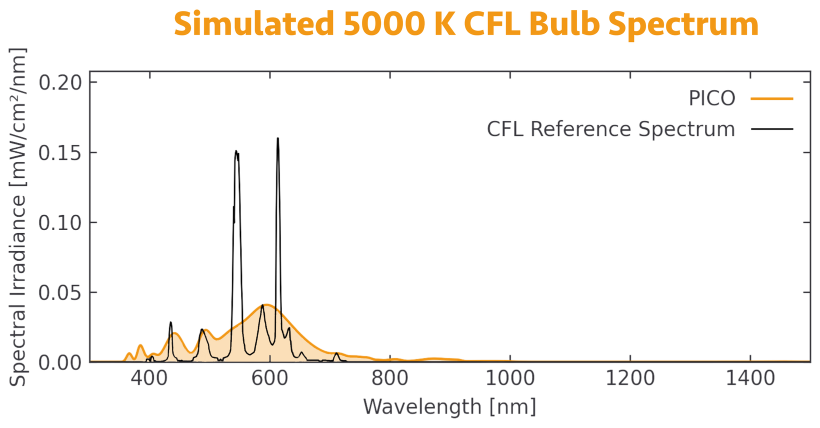
Simulated 5000 K LED Bulb Spectrum



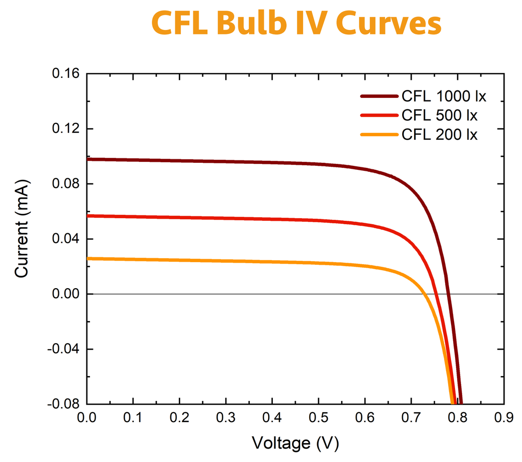
LED Bulb IV Curves



Simulated 5000 K CFL Bulb Spectrum



CFL Bulb IV Curves



With the rise of solar cell-integrated IoT devices, there is growing need to evaluate the photovoltaic performance of these devices under controlled indoor conditions. A new IEC standard [2] outlines target light profiles for indoor solar cell testing. Inspired in this standard, spectral recipes were made by adjusting the Pico channels to match CFL and LED bulb outputs. IV curves were measured for the test perovskite cell under 1000 lx, 500 lx, and 200 lx conditions. The Pico's ability to mimic arbitrary light sources means that parallel (outdoor or indoor) lines of solar cell research can be pursued using the same instrument.

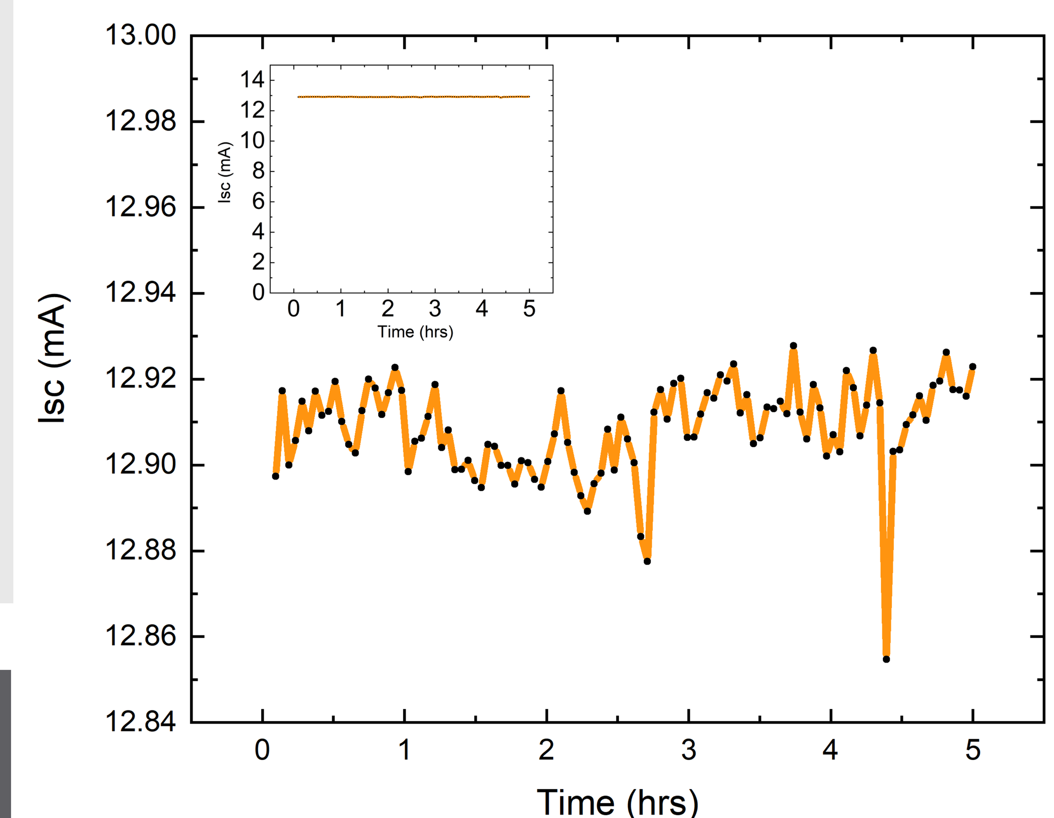
Long-Term Stability Testing

While short-term IV testing of the perovskite cell showed instability issues, further analysis of the general performance stability was carried out by performing a long-term exposure test. Here, the sample was irradiated for 5 continuous hours under AM1.5G 1 sun light while maintaining a cell temperature of 25 °C.

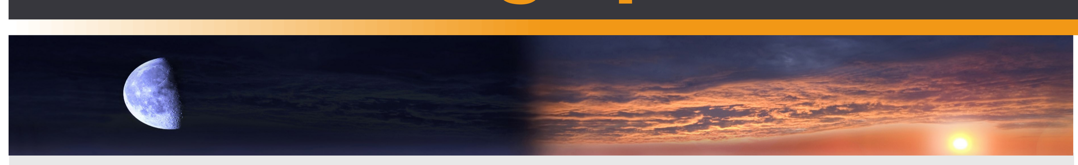
While instantaneous fluctuations in performance of the perovskite sample were still observed, the device appeared to be more stable under prolonged illumination conditions.

A key advantage of LED simulators is their stability, enabling continuous long-term stability testing without the need to constantly replace or recalibrate the lamp.

Long-term stability of Perovskite Test



Geographic and Seasonal Sunlight Simulation Characterization

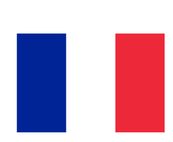


Although long-term irradiation of solar cells under AM1.5G 1 sun light is one way of evaluating their extended performance, the dynamic nature of sunlight (changing in air mass spectrum and intensity over time) means that such tests measure cell lifetime rather than true 'in-the-field' behavior.

Using the Pico's One-Click-Sun feature, we measured the response of the perovskite test cell under a simulated 30-hour day-night cycle within a total duration of 15 minutes. Geographic coordinates were chosen to simulate sunlight in Aix-les-Bains, France, although the test was performed at G2V Optics headquarters in Edmonton, Canada.

The Pico's One-Click-Sun feature allows for dynamic spectral and intensity modulation of the output to simulate sunlight in a target location at a specified date.

Simulated Sunlight Test Specially for JPH 2024!



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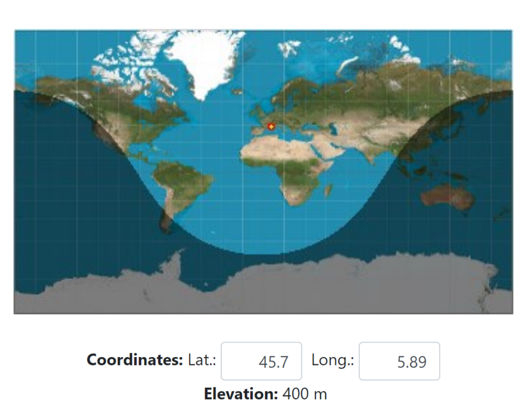
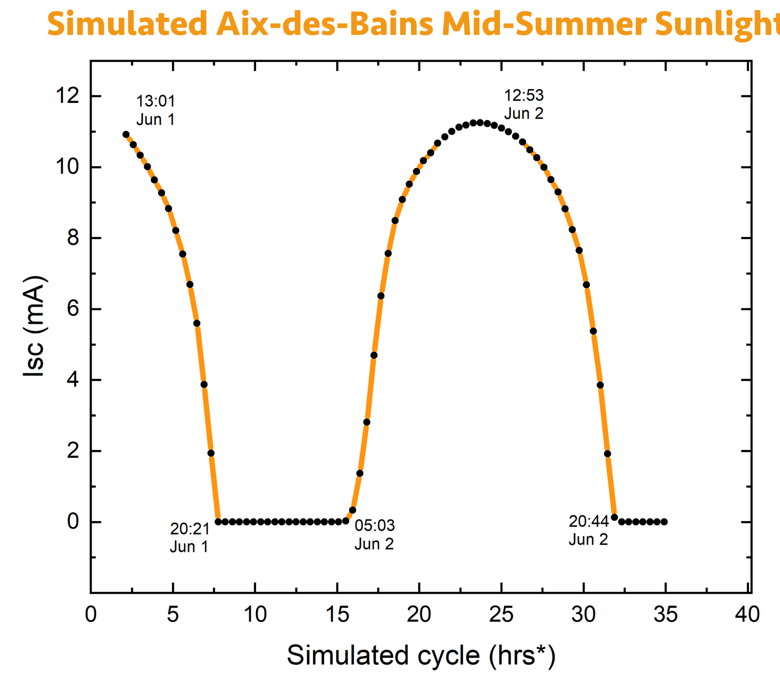
Journées Perovskites Halogénées



Photovoltaic Response of Perovskite Test Cell to Simulated Aix-des-Bains Mid-Summer Sunlight



* A 100x speed multiplier was applied, actual experiment run time was 15 minutes.

Conclusions

- LED solar simulators like the Pico elevate research efficiency by combining the functionality of multiple instruments (Light Source, SMU, EQE) into a compact platform that allows for integrated solar cell characterization.
- In this work, we illustrated the potential of the Pico's channel tuneability to elucidate the behavior of a perovskite test cell under various realistic conditions.

References

[1] ASTM. (2012). E973-10: Standard Test Method for Determination of the Spectral Mismatch Parameter Between a Photovoltaic Device and a Photovoltaic Reference Cell. C, 21–23

[2] International Electrotechnical Commission. (2023). Technical Specification: Nanomanufacturing - Part 7-2 Nano-enabled Photovoltaics, Device evaluation method for indoor light.