Integrated testing solutions for next-generation solar modules

MBJ Solutions GmbH has introduced a new hardware and software platform for sun simulators, designed to enhance the efficiency and precision of photovoltaic (PV) module testing. This article examines the evolving requirements for next-generation solar modules and reviews technical solutions that support ongoing research in photovoltaics.

As solar technology advances rapidly, laboratory software plays a central role in supporting research and development. Accurately evaluating solar module performance requires the integration of various measurement and inspection methods.

Among these, electroluminescence analysis at different wavelengths is a key application. This phenomenon, occurring in semiconductor materials like silicon diodes or solar cells, reveals details about the internal structure and defects. In tandem cells, imaging each sub-cell at distinct wavelengths is essential for mapping charge carrier lifetime across different layers. For instance, significant differences in electroluminescence intensity patterns between top and bottom cells are often observed, typically resulting from localized defects in perovskite layers.

Simulating sunlight with adjustable spectra and intensity is another critical laboratory process. Photovoltaic devices must be evaluated under conditions that resemble real-world environments, but they also need to perform reliably across a range of spectral inputs. This allows researchers to test modules under different current-limiting regimes and better understand their behavior.

Current-voltage (I-V) analysis remains essential for solar cell characterization. A dark I-V curve shows how a cell behaves without illumination, while the illuminated curve reveals its performance under specific light spectra. This evaluation provides key parameters such as short-circuit current, open-circuit voltage and peak power output.

Previously, different instruments were needed for each measurement, such as systems to determine thermal coefficients, capture electroluminescence images and provide consistent illumination. This extended testing duration and introduced variability between procedures. Such inconsistencies pose a risk, particularly with modules that exhibit metastable behavior and change characteristics when exposed to light or electrical current. In these cases, maintaining strict control over all measurement variables is critical.

In addition, operators were often required to run tests manually or develop custom scripts for limited automation. Managing complex procedures across multiple samples like this introduced the potential for errors. To improve reliability, full automation of test sequences has become essential.

To address these challenges, a new platform incorporates the key measurement functions into a single system. Researchers can now define complex workflows using a graphical interface that allows drag-and-drop sequencing of individual steps. This simplifies setup and enhances consistency.

Perovskite technology and its potential

Perovskite solar cells offer great promise, especially in tandem configurations where their properties complement those of traditional silicon cells. This multi-layered approach improves light absorption and can boost overall efficiency.

Beyond the potential for higher power output from the same area, perovskite technology may also reduce production costs due to more affordable materials. However, several critical challenges must be addressed before widespread adoption is feasible.

Long-term stability remains a primary concern. These materials must maintain performance under standard operating conditions, yet many degrade over time. In parallel, scalable production techniques that deliver consistent quality are still under development. These barriers must be overcome before perovskite modules can contribute meaningfully to global solar capacity.

Characterization complexities in perovskite cells

Perovskite devices introduce specific challenges when it comes to performance evaluation. These materials exhibit metastability, meaning their properties can temporarily shift due to light exposure, electrical fields or environmental changes[1]. This impacts I-V measurements and can lead to misleading performance data if not accounted for correctly.

Ionic movement within the cell, such as halide ions and lead vacancies, under electrical stress alters internal fields, affecting charge transport and recombination. This dynamic behavior leads to inconsistencies in measurement.

A common issue is hysteresis, where the current output varies depending on the direction of the voltage sweep. This makes it difficult to determine accurate values for key performance indicators like short-circuit current, open-circuit voltage, fill factor and conversion efficiency.

Additionally, exposure to light alters carrier concentrations through a process known as photodoping, which may skew test results. Cells can also exhibit improved performance over time under illumination, a phenomenon known as light soaking. If stabilization is not reached beforehand, these effects can distort measurements.

Careful control of testing conditions is therefore crucial. Procedures such as preconditioning with light soaking help bring the device to a stable state before evaluation[2]. Without this step, transient effects caused by changing voltage or light can alter results significantly.

System capabilities

To support advanced research, three system designs are available for laboratory use, all operated through a unified software platform.

The Sun Simulator Lab is a core solution featuring 15 LED types that achieve 94.5% spectral coverage and a spectral deviation of 35.5%. A flash duration of up to 200 milliseconds supports the testing of all current solar technologies. Tandem perovskite modules can be evaluated using multiple flashes with constant voltage during each pulse, allowing high-fidelity I-V measurement.

The Steady State Sun Simulator is optimized for cell and mini-module testing. With 22 LED types, it reaches 98% spectral coverage and a deviation of 24.2%. It offers steady illumination and allows combined use of different spectra for soaking and measurement within a single test recipe.

The Sunlike Lab, the most advanced model, includes 32 LED types, full 100% spectral coverage and a spectral deviation of only 11.9%. A built-in temperature chamber enables testing under thermal stress and the evaluation of temperature coefficients for various electrical properties.

Functional highlights for research workflows

These systems offer a broad range of features tailored to the demands of photovoltaic R&D. Maximum power point tracking helps identify optimal operating conditions. Extended I-V measurement routines allow for slow voltage sweeps and both forward and reverse directions, reducing hysteresis effects.

Electroluminescence imaging is available at multiple wavelengths, using cameras with automatic filter switching to capture detailed views of both the top and bottom cells.

Dark I-V measurements provide insight into recombination behavior and long-term degradation. Temperature control between 15°C and 75°C supports investigations into thermal sensitivity and module durability.

Compact system footprints ensure easy integration into existing lab setups. The adjustable LED spectrum can be precisely tuned, an advantage particularly important for testing tandem modules.

Optional dual-spectrometer integration allows real-time monitoring of light output during both steady and flash modes. Diode testing ensures bypass components function properly and can reveal critical circuit issues.

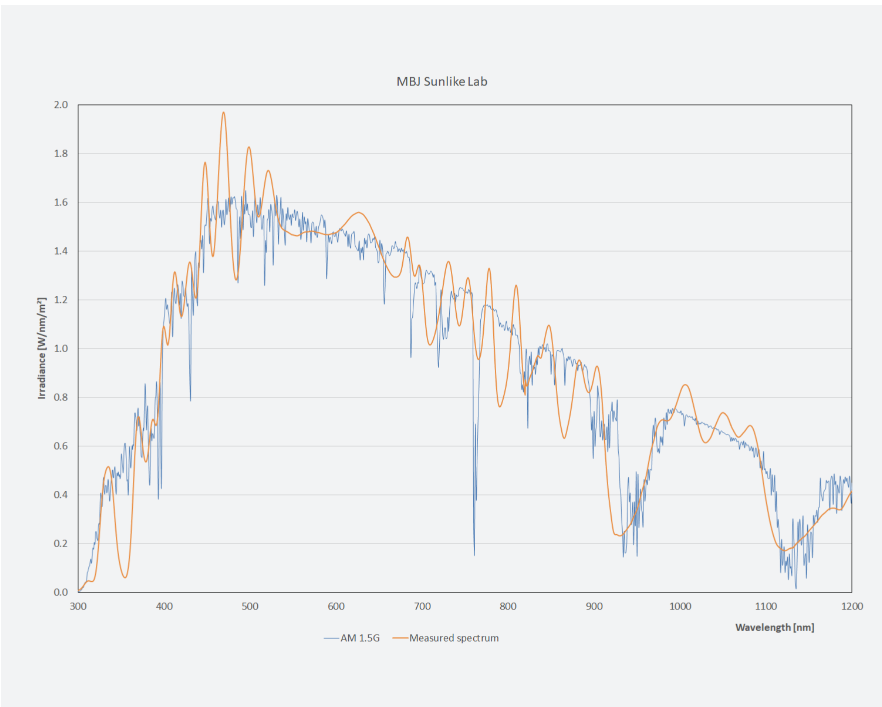
A graphical software interface allows users to build custom measurement sequences without programming skills. These can be saved as reusable recipes for consistent test execution.

Data handling and experimental tracking

Effective data management is another strength. Each measurement is stored with time and module ID, making it easy to locate data sets such as electroluminescence images before and after environmental stress tests.

Results can be exported in multiple formats, including Excel and PDF, with charts and visual summaries for reporting. Integration with central databases enables tracking of long-term trends and module performance history.

Together, these features streamline testing workflows, support accurate data capture and promote repeatable research conditions.



Conclusion

The combination of advanced hardware and intuitive software provides researchers with an efficient and reliable platform for solar module evaluation. These systems support precise control over complex measurement processes and reduce the risk of error in high-throughput testing environments. By meeting the evolving needs of photovoltaic research, this integrated platform accelerates the development of next-generation solar technologies.

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References

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