

Measuring spectral responsivity in tandem PV devices

As tandem PV moves closer to commercial production, testing needs to keep pace. With different cells responding to different parts of the spectrum, accurately measuring performance means taking a more flexible approach. Multi-channel LED simulation could offer a simpler way to characterise individual devices and assess current matching, without the complexity of traditional spectral response testing.

Solar technology is moving into its next phase, with multi-junction devices, particularly silicon-perovskite tandems, edging closer to commercial production. Silicon remains the workhorse of the global solar industry, but tandem cells could capture more energy by combining materials that respond to different parts of the solar spectrum.

That also makes them more demanding to test. Unlike a conventional silicon cell, a tandem device's performance depends not just on how much light reaches it, but on which wavelengths are present. Understanding that spectral response is therefore becoming an increasingly important part of measuring how these devices perform.

The importance of current matching in multi-junction devices

The power output of multi-junction PV devices is strongly linked to the current generated by each sub-cell. Because the sub-cells are typically connected in series, the junction producing the lowest current limits the current of the entire device. Achieving an appropriate current balance between the junctions is therefore important.

The optimum balance depends on the application and on trade-offs involving factors such as stability, degradation and materials. It also depends on the irradiation spectrum because each junction absorbs light over different wavelength ranges¹.

One reason silicon-perovskite tandems can exceed the efficiency of silicon single-junction devices is that the perovskite junction converts shorter-wavelength light more efficiently, while the silicon junction absorbs longer wavelengths.

The solar spectrum varies with season, latitude, atmospheric conditions, air mass and humidity. Tandem devices operating outdoors therefore move in and out of current balance,

with either the silicon or perovskite sub-cell becoming current limiting. Because these conditions are difficult to reproduce consistently, laboratory measurements commonly establish defined current-matching conditions.

IEC 60904-1-1² addresses current-voltage measurement of multi-junction PV devices and the need to account for spectral conditions. Field performance can still differ from laboratory results depending on the operating environment.

In practice, individual device designs may require their own spectral settings. This differs from conventional solar simulator operation focused mainly on spectral match class and can add setup time for each module type. Direct sunlight or a sun-like source may simplify testing for devices tuned to AM1.5G, but it does not in itself ensure current matching³.

Conventional spectral response characterisation challenges

Characterising a PV device involves not only IV curve measurement under current-matched conditions but also measurement of spectral response, because current balance cannot be assessed without knowing the device's spectral responsivity. The same response curve is also used for energy-yield assessments under varying spectra.

Differential spectral response (DSR) has long been an established method for determining the spectral response of cells and modules, but it requires dedicated equipment.

A classic DSR setup uses two light sources: a bias light source with high irradiance to establish the device operating point and a second, low-irradiance monochromatic source to generate a wavelength-dependent perturbation. Switching the monochromatic light on and off adds a square-wave signal to the bias current. By varying the

monochromatic wavelength from 300 nm to 1,200 nm and measuring the square-wave contribution using lock-in detection, the spectral responsivity can be determined⁴.

The method is highly accurate, but the measurement setup can become increasingly complex for tandem devices. As these technologies move towards volume production, laboratories and manufacturers need characterisation approaches that combine precision with practical operation.

The role of tuneable LED-based solar simulation

Multi-channel LED light sources provide a high degree of spectral flexibility because individual wavelength bands can be adjusted independently. For tandem devices, this allows the illumination spectrum to be adapted to create current-matching conditions between sub-cells by increasing or reducing selected spectral regions.

As absorber materials, bandgap combinations and device designs diversify, characterisation systems must accommodate device-specific spectral requirements.

MBJ Solutions has developed LED-based metrology systems for this purpose. According to the company, MBJ Sunlike Lab uses 32 LED types across 300 nm to 1,200 nm and provides close to full spectral coverage, allowing the illumination spectrum to be tailored for multi-junction PV module measurements.

UV exposure is another consideration for tandem devices. Some indoor lifetime tests do not reproduce the shorter-wavelength UV present outdoors, even though deep-UV exposure can contribute to degradation mechanisms⁵.

MBJ states that Sunlike Lab can provide steady-state illumination down to 300 nm, allowing this part of the AM1.5G spectrum to be included in controlled testing.

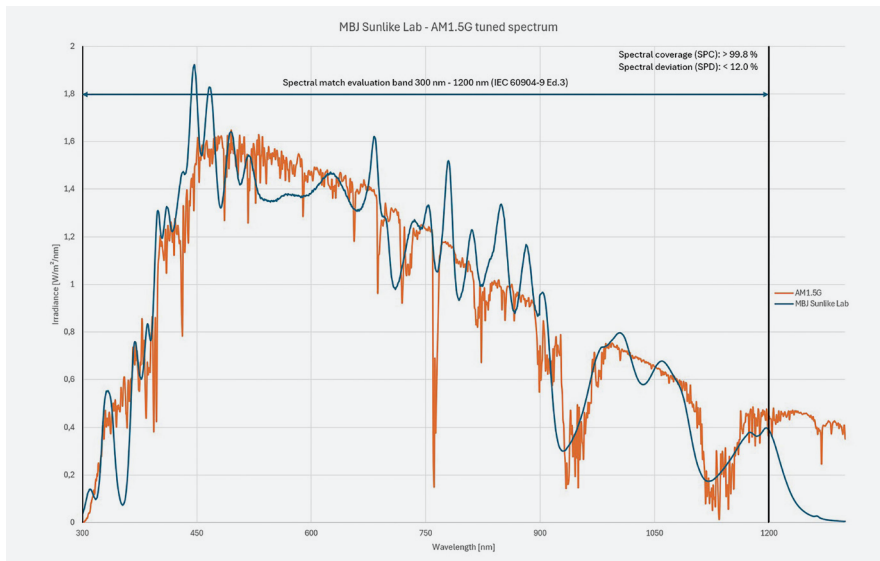


Figure 1: Class A++ spectrum of MBJ Sunlike Lab compared with the AM1.5G solar spectrum using 32 LED types. Each LED channel can be increased to 130% or reduced as required

Moving beyond IV measurements: the multi-spectrum approach

Spectral tuning is important for current-voltage characterisation, but IV measurements alone do not provide a complete picture of tandem device behaviour. Spectral responsivity is also needed to establish the conditions for a well-characterised IV measurement.

Advanced LED systems also open an alternative route to conventional DSR

measurement. Hinken et al.⁶ propose a method using an LED light source with multiple independently controlled wavelength bands. Rather than relying on a separate monochromatic scanning source, the system generates a sequence of spectrally distinct illumination conditions. The multi-spectrum method therefore replaces monochromatic scanning with a series of controlled spectra produced by the same light source. In principle, this reduces the need for the separate bias and monochromatic sources

used in a conventional DSR arrangement while retaining controlled spectral variation.

For each illumination condition, the selected spectrum is measured with a calibrated spectroradiometer and the short-circuit current of the multi-junction PV device is measured with an IV tracer. Each measurement can then be expressed mathematically as an integral relationship between the unknown spectral response function and the known irradiance distribution, resulting in the measured short-circuit current.

The measurements can be used to build a system of linear equations. With a sufficient number of diverse spectra, an exact or overdetermined system can be established and solved to derive the spectral response curve of the PV device.

Hinken et al.⁶ developed and tested this approach and reported precision comparable with classic DSR measurements of the same devices. Tandem-ready LED systems can implement this type of procedure where their spectral channels are independently controllable.

With 32 LED types, MBJ Sunlike Lab provides a large number of spectral combinations for this purpose. A broader set of independently adjustable wavelength bands increases the range of distinct illumination conditions available for building and solving the equation system.



Figure 2: MBJ Sunlike Lab configured for flash and continuous light operation

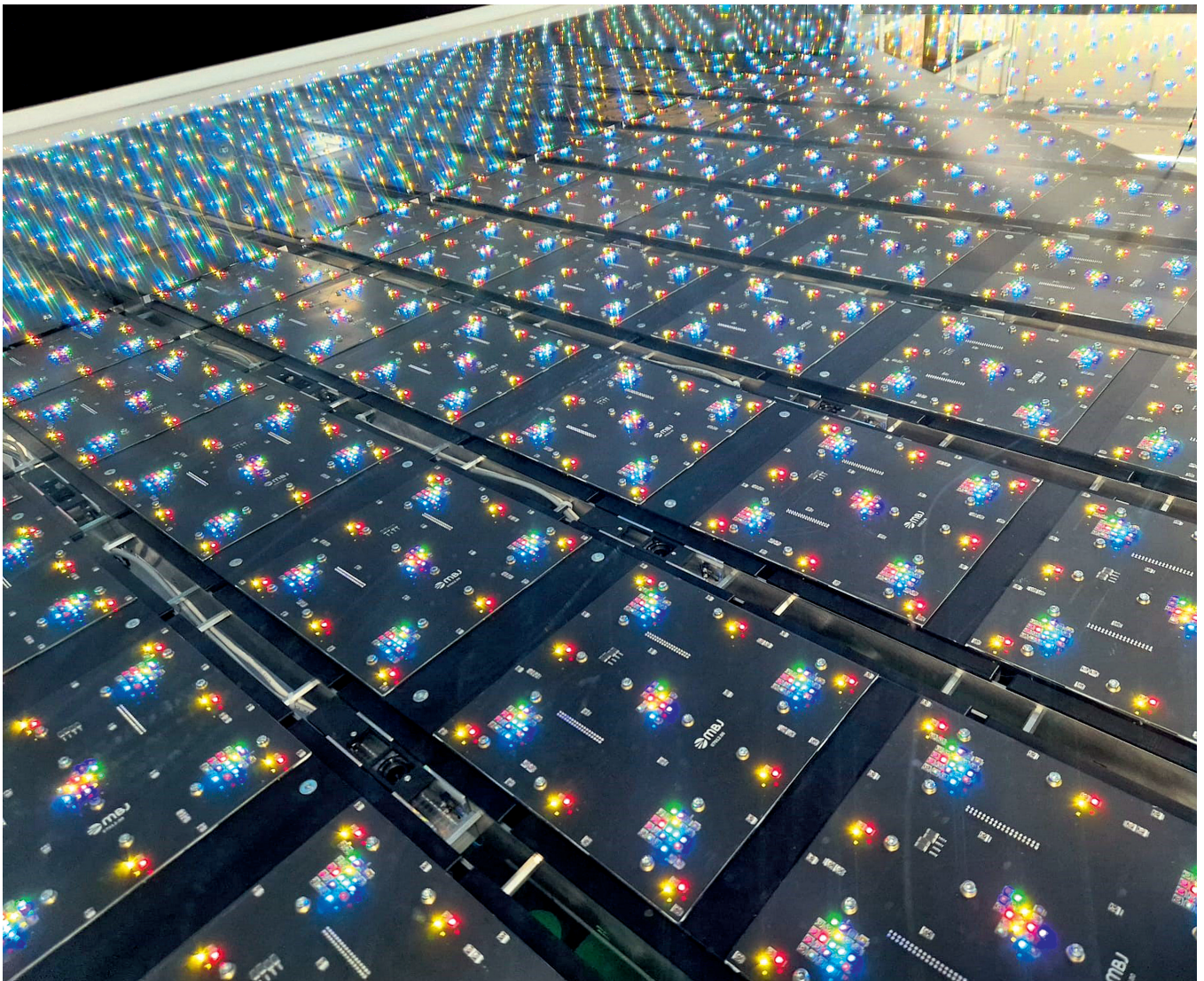


Figure 3: MBJ LED light source with 32 individually controllable LED types

Conclusion

Growing interest in tandem photovoltaics is changing measurement requirements across laboratories and manufacturing. Tandem devices are more complex to characterise than single-junction devices because current-voltage performance and spectral responsivity depend on the interaction between the device and the illumination spectrum.

Manufacturers need practical, repeatable methods for development and quality assurance, while certification laboratories need to adapt their measurement systems to emerging tandem requirements without adding unnecessary complexity.

Multi-channel LED illumination provides one route to meeting these requirements by combining adjustable spectra with existing IV measurement capability. The multi-spectrum method described by Hinken et al. suggests that spectral responsivity can be derived without conventional monochromatic DSR scanning, provided accuracy and traceability are maintained.

For tandem PV, such approaches could reduce measurement complexity while retaining device-specific spectral control. As tandem technologies move towards commercial production, adaptable spectral characterisation is becoming an increasingly important part of reliable PV module assessment.

References

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² IEC 60904-1-1:2017, Photovoltaic devices - Part 1-1: Measurement of current-voltage characteristics of multi-junction photovoltaic (PV) devices, International Electrotechnical Commission (IEC), Geneva, 2017.

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