

Solar Cells Reporting Summary

Nature Portfolio wishes to improve the reproducibility of the work that we publish. This form is intended for publication with all accepted papers reporting the characterization of photovoltaic devices and provides structure for consistency and transparency in reporting. Some list items might not apply to an individual manuscript, but all fields must be completed for clarity.

For further information on Nature Research policies, including our [data availability policy](#), see [Authors & Referees](#).

► Experimental design

Please check the following details are reported in the manuscript, and provide a brief description or explanation where applicable.

1. Dimensions

Area of the tested solar cells

☒ Yes
☐ No

Provided in this device characterization and effective area is 0.0867 cm².

Explain why this information is not reported/not relevant.

Method used to determine the device area

☒ Yes
☐ No

A metal aperture masks was used during the J-V measurements.

Explain why this information is not reported/not relevant.

2. Current-voltage characterization

Current density-voltage (J-V) plots in both forward and backward direction

☒ Yes
☐ No

Supplementary Fig. 34.

Voltage scan conditions

☒ Yes
☐ No

Provided in this device characterization.

Explain why this information is not reported/not relevant.

Test environment

☒ Yes
☐ No

Provided in this device characterization.

Explain why this information is not reported/not relevant.

Protocol for preconditioning of the device before its characterization

☐ Yes
☒ No

Provide a description of the protocol.

There is no preconditioning before the device is tested.

Stability of the J-V characteristic

☒ Yes
☐ No

Fig. 4h. Supplementary Fig. 43.

Explain why this information is not reported/not relevant.

3. Hysteresis or any other unusual behaviour

Description of the unusual behaviour observed during the characterization

☒ Yes
☐ No

The device shows negligible hysteresis.

Explain why this information is not reported/not relevant.

Related experimental data

☒ Yes
☐ No

J-V curves under reverse and forward scans were provided in Supplementary Fig.34 .

Explain why this information is not reported/not relevant.

4. Efficiency

External quantum efficiency (EQE) or incident photons to current efficiency (IPCE)

☒ Yes
☐ No

EQE spectra was provided in Supplementary Fig. 38.

Explain why this information is not reported/not relevant.

A comparison between the integrated response under the standard reference spectrum and the response measure under the simulator

☒ Yes
☐ No

Basically consistent

Explain why this information is not reported/not relevant.

For tandem solar cells, the bias illumination and bias voltage used for each subcell	☒ Yes ☐ No	Provided in this methods. Explain why this information is not reported/not relevant.
5. Calibration		
Light source and reference cell or sensor used for the characterization	☒ Yes ☐ No	Provided in this device characterization Explain why this information is not reported/not relevant.
Confirmation that the reference cell was calibrated and certified	☒ Yes ☐ No	Provided in this device characterization Explain why this information is not reported/not relevant.
Calculation of spectral mismatch between the reference cell and the devices under test	☐ Yes ☒ No	Provide a value of the spectral mismatch and/or a description of how it has been taken into account in the measurements. The spectrum used for measurement matched well with the reference CIGS cell, so no calculations were made.
6. Mask/aperture		
Size of the mask/aperture used during testing	☒ Yes ☐ No	The area of the test mask is 0.0867 cm ² . Explain why this information is not reported/not relevant.
Variation of the measured short-circuit current density with the mask/aperture area	☒ Yes ☐ No	The area of each device is fixed, and the difference is negligible. Explain why this information is not reported/not relevant.
7. Performance certification		
Identity of the independent certification laboratory that confirmed the photovoltaic performance	☒ Yes ☐ No	National Measurement and Test Centre for Photovoltaic Industry 福建 Institute of Metrology and Science Explain why this information is not reported/not relevant.
A copy of any certificate(s)	☒ Yes ☐ No	Supplementary Fig. 40, and 41. Explain why this information is not reported/not relevant.
8. Statistics		
Number of solar cells tested	☒ Yes ☐ No	Stated in the manuscript. Explain why this information is not reported/not relevant.
Statistical analysis of the device performance	☒ Yes ☐ No	Supplementary Fig. 23. Explain why this information is not reported/not relevant.
9. Long-term stability analysis		
Type of analysis, bias conditions and environmental conditions	☒ Yes ☐ No	Fig. 5, Supplementary Fig 43. Explain why this information is not reported/not relevant.