

Solar Cells Reporting Summary

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► 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

The active area of small size solar cells is 0.16 cm², and the aperture area of perovskite solar modules is 22.08 cm². The certificated module area is 12.83 cm².

Explain why this information is not reported/not relevant.

Method used to determine the device area

☒ Yes
☐ No

A 0.16 cm² metal shadow mask was used to define the active area of small devices. And the aperture area of solar module is determined by P4 lines. Corresponding descriptions can be found in the Methods and Supplementary Fig. S62.

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

The J-V curves were collected from reverse scans unless otherwise stated. The J-V curves for hysteresis study were collected from both reverse and forward scans.

Voltage scan conditions

☒ Yes
☐ No

The J-V characteristics of small devices were measured from 1.2 V to -0.1 V with a dwell time of 10 ms voltage step of ~0.014 V. 100 data points were collected for each J-V curve. The J-V characteristics of modules were measured with a scan range from 9.6 V to -0.1 V with a dwell time of 10 ms and voltage step of 0.1 V. 90 data points were collected for each J-V curve.

Explain why this information is not reported/not relevant.

Test environment

☒ Yes
☐ No

All the tests were performed in a dry room with a relative humidity below 30% and temperature below 20 °C. Corresponding descriptions can be found in the Methods.

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.

No preconditioning is needed.

Stability of the J-V characteristic

☒ Yes
☐ No

The steady-state power output can be found in Fig. S59. The power output of small size cell at a fixed bias (corresponding to maximum power point) was tracked (Fig. 5e, f, Fig. S59, and S66).

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

Provide a description of hysteresis or any other unusual behaviour observed during the characterization.

The devices showed negligible J-V hysteresis.

Related experimental data

☒ Yes
☐ No

J-V curves from forward and reverse scans are provided in Fig. 5d, Fig. S58, S59, S63, S65 and Table S9, S10.

Explain why this information is not reported/not relevant.

4. Efficiency

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

☒ Yes
☐ No

The EQE of small size device is shown in Fig. S60.

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	The integrated current densities from the EQE spectra match well with the Jsc extracted from the J-V curves. Corresponding descriptions can be found in the device performance discussion section. <i>Explain why this information is not reported/not relevant.</i>
For tandem solar cells, the bias illumination and bias voltage used for each subcell	☐ Yes ☒ No	<i>Provide a description of the measurement conditions.</i> No tandem solar cell was fabricated.
5. Calibration		
Light source and reference cell or sensor used for the characterization	☒ Yes ☐ No	The solar simulator is calibrated using a KG-3 mono-silicon cell. <i>Explain why this information is not reported/not relevant.</i>
Confirmation that the reference cell was calibrated and certified	☒ Yes ☐ No	The KG-3 mono-silicon cell was calibrated and certified. <i>Explain why this information is not reported/not relevant.</i>
Calculation of spectral mismatch between the reference cell and the devices under test	☐ Yes ☒ No	<i>Provide a value of the spectral mismatch and/or a description of how it has been taken into account in the measurements.</i> No spectral mismatch calculations were performed.
6. Mask/aperture		
Size of the mask/aperture used during testing	☒ Yes ☐ No	A 0.16 cm ² metal shadow mask was used to define the active area of small devices. The aperture area of solar module is 22.08 cm ² . Corresponding descriptions can be found in the Methods. <i>Explain why this information is not reported/not relevant.</i>
Variation of the measured short-circuit current density with the mask/aperture area	☐ Yes ☒ No	<i>Report the difference in the short-circuit current density values measured with the mask and aperture area.</i> This is not the aim of this study.
7. Performance certification		
Identity of the independent certification laboratory that confirmed the photovoltaic performance	☒ Yes ☐ No	Shanghai Institute of Microsystem and Information Technology (SIMIT, China) <i>Explain why this information is not reported/not relevant.</i>
A copy of any certificate(s)	☒ Yes ☐ No	The certification report is provided in Fig. 63. <i>Explain why this information is not reported/not relevant.</i>
8. Statistics		
Number of solar cells tested	☒ Yes ☐ No	At least 15 devices for each conditions of control and target were used for statistical analysis. 15 modules were fabricated for statistics analysis. <i>Explain why this information is not reported/not relevant.</i>
Statistical analysis of the device performance	☒ Yes ☐ No	Corresponding descriptions can be found in the Fig. S50, S61 and Table S10. <i>Explain why this information is not reported/not relevant.</i>
9. Long-term stability analysis		
Type of analysis, bias conditions and environmental conditions	☒ Yes ☐ No	Corresponding descriptions can be found in the Methods. <i>Explain why this information is not reported/not relevant.</i>

