

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.

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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 0.14 cm² and 1.1 cm² for small and large-area devices respectively, as described in the Methods.
Explain why this information is not reported/not relevant.
- Method used to determine the device area Yes No A black metal mask with an area of 0.09 cm² and 1 cm² are used to define the active area of small cell and large-area cell, respectively.
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 manuscript provides current density-voltage (J-V) plots in both forward and backward direction (Fig. 3a-3d).
- Voltage scan conditions Yes No Voltage scan conditions are reported in the manuscript and described in the Methods (Characterization of the solar cells).
Explain why this information is not reported/not relevant.
- Test environment Yes No The current-voltage characteristics are obtained under ambient temperature and air conditions, as reported in the Methods (Characterization of the solar cells).
Explain why this information is not reported/not relevant.
- Protocol for preconditioning of the device before its characterization Yes No Current-voltage characteristics were recorded in accordance with the procedure reported in the manuscript and in the Methods. No specific protocol for preconditioning was applied.
Explain why this information is not reported/not relevant.
- Stability of the J-V characteristic Yes No Maximum power point tracking and damp-heat stability tests were conducted, as reported in the manuscript (Fig. 3g and 3h).
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 Very low hysteresis was observed upon altering the scan direction is reported in the manuscript (Fig. 3a-3d).
Explain why this information is not reported/not relevant.
- Related experimental data Yes No The manuscript provides current density-voltage (J-V) plots in both forward and backward direction with related experimental data provided in the manuscript (Fig. 3a-3d).
Explain why this information is not reported/not relevant.

4. Efficiency

- External quantum efficiency (EQE) or incident photons to current efficiency (IPCE) Yes No IPCE spectra were recorded, as reported in Fig. 3f.
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	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<p>The integrated Jsc from IPCE spectra is consistent with the Jsc from JV measurements, as detailed in the manuscript (Fig. 3b and Fig. 3f).</p> <p><i>Explain why this information is not reported/not relevant.</i></p>
For tandem solar cells, the bias illumination and bias voltage used for each subcell	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	<p><i>Provide a description of the measurement conditions.</i></p> <p>Not applicable as no tandem solar cells are reported in this work.</p>
5. Calibration		
Light source and reference cell or sensor used for the characterization	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<p>The current density-voltage (J-V) characteristics of the devices were measured in ambient air (the relative humidity was 40-50%) by an AM 1.5G solar simulator equipped with 450 W Xenon lamp (Newport, 2612A) and a Keithley 2400 source meter. Light intensity was adjusted to AM 1.5G one sun (100 mW/cm²) with a NIM calibrated standard Si solar cell, as detailed in the Methods (Characterization of the solar cells).</p> <p><i>Explain why this information is not reported/not relevant.</i></p>
Confirmation that the reference cell was calibrated and certified	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<p>The Si reference cell was calibrated and certified by Newport Corporation PV Lab, Bozeman, MT, USA, as detailed in the Methods.</p> <p><i>Explain why this information is not reported/not relevant.</i></p>
Calculation of spectral mismatch between the reference cell and the devices under test	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<p>The spectral mismatch between our simulator and the AM 1.5 solar source was insignificant as the integrated current densities estimated from the IPCE spectra were in good agreement with the values obtained from the current density-voltage (J-V) curves as detailed in the manuscript. Spectra mismatch factor of 1 was used.</p> <p><i>Explain why this information is not reported/not relevant.</i></p>
6. Mask/aperture		
Size of the mask/aperture used during testing	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<p>All measurements were conducted using a non-reflective metal mask with an aperture area of 0.09 cm² for small cells and 1 cm² for large scale cells to cover part of the active area of the device and avoid stray light capturing by our device, as detailed in the Methods (Characterization of the solar cells).</p> <p><i>Explain why this information is not reported/not relevant.</i></p>
Variation of the measured short-circuit current density with the mask/aperture area	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	<p><i>Report the difference in the short-circuit current density values measured with the mask and aperture area.</i></p> <p>We haven't measured the cells with apertures of different sizes.</p>
7. Performance certification		
Identity of the independent certification laboratory that confirmed the photovoltaic performance	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<p>The photovoltaic performance of our devices were certified by Shanghai Institute of Microsystem and Information Technology (SIMIT), Chinese Academy of Sciences.</p> <p><i>Explain why this information is not reported/not relevant.</i></p>
A copy of any certificate(s)	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<p>Fig. S25.</p> <p><i>Explain why this information is not reported/not relevant.</i></p>
8. Statistics		
Number of solar cells tested	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<p>At least 15 devices for each condition were tested, as reported (Fig. 3e).</p> <p><i>Explain why this information is not reported/not relevant.</i></p>
Statistical analysis of the device performance	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<p>Histograms of efficiency for the devices are reported (Fig. 3e).</p> <p><i>Explain why this information is not reported/not relevant.</i></p>
9. Long-term stability analysis		
Type of analysis, bias conditions and environmental conditions	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<p>The long-term stability analysis is detailed in the manuscript with respect to the type of analysis, illumination, bias, and environmental conditions (involving temperature and atmosphere humidity), as well as the exclusion of encapsulation, which is detailed in the manuscript (Fig. 3g and 3h).</p> <p><i>Explain why this information is not reported/not relevant.</i></p>

