

## Solar Cells Reporting Summary

Nature Research 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: are the following details reported in the manuscript?

##### 1. Dimensions

- Area of the tested solar cells  Yes  No Clearly stated in Characterization of PV devices in Methods
- Method used to determine the device area  Yes  No Clearly stated in Characterization of PV devices in Methods

##### 2. Current-voltage characterization

- Current density-voltage (J-V) plots in both forward and backward direction  Yes  No Clearly stated in Characterization of PV devices in Methods
- Voltage scan conditions  Yes  No Clearly stated in Characterization of PV devices in Methods  
*For instance: scan direction, speed, dwell times*
- Test environment  Yes  No All cells measured in nitrogen glovebox and it's clearly stated in Characterization of PV devices in Methods  
*For instance: characterization temperature, in air or in glove box*
- Protocol for preconditioning of the device before its characterization  Yes  No The devices were tested without any preconditions.
- Stability of the J-V characteristic  Yes  No Stated in manuscript and Stabilized Power Output plotted in figure 3  
*Verified with time evolution of the maximum power point or with the photocurrent at maximum power point; see ref. 7 for details.*

##### 3. Hysteresis or any other unusual behaviour

- Description of the unusual behaviour observed during the characterization  Yes  No It can be found in description of Fig.3. (Paragraph 7)
- Related experimental data  Yes  No See Fig.3 and Extended data Fig. 4. Parameters were presented in Tables

##### 4. Efficiency

- External quantum efficiency (EQE) or incident photons to current efficiency (IPCE)  Yes  No EQE provided in Figure 2.
- A comparison between the integrated response under the standard reference spectrum and the response measure under the simulator  Yes  No While not expressed directly in the manuscript, the integrated EQE is 97% of the measured Jsc.
- For tandem solar cells, the bias illumination and bias voltage used for each subcell  Yes  No No tandem cells presented in this work

##### 5. Calibration

- Light source and reference cell or sensor used for the characterization  Yes  No It can be found in Characterization of PV devices in Methods
- Confirmation that the reference cell was calibrated and certified  Yes  No It can be found in Characterization of PV devices in Methods

Calculation of spectral mismatch between the reference cell and the devices under test	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	The spectral mismatch was calculated (0.9923) and It can be found in Characterization of PV devices in Methods.
6. Mask/aperture		
Size of the mask/aperture used during testing	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	All devices have active area of 0.11 cm <sup>2</sup> but are masked with an aperture to 0.059 cm <sup>2</sup> . Clearly stated in Characterization of PV devices in Methods
Variation of the measured short-circuit current density with the mask/aperture area	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	An aperture/mask was always applied during measurement
7. Performance certification		
Identity of the independent certification laboratory that confirmed the photovoltaic performance	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	No solar cell efficiency world record is claimed in this work. Our group's cells have been certified in past to verify our measurements are in line with accredited laboratories
A copy of any certificate(s) <i>Provide in Supplementary Information</i>	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	No solar cell efficiency world record is claimed in this work.
8. Statistics		
Number of solar cells tested	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	See Extended Data Fig.5
Statistical analysis of the device performance	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	See Extended Data Fig.5
9. Long-term stability analysis		
Type of analysis, bias conditions and environmental conditions <i>For instance: illumination type, temperature, atmosphere humidity, encapsulation method, preconditioning temperature</i>	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	Long term stability has been performed in various ways and is stated clearly in the Extended Data