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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	Area of the tested solar cells is 0.1225 cm2 defined by optical microscope (Olympus BX51). *Explain why this information is not reported/not relevant.*
Method used to determine the device area	☒ Yes ☐ No	Device area is determined by a mask of 0.092 cm2. *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	We tested current density-voltage (J-V) plots in both forward and backward direction
Voltage scan conditions	☒ Yes ☐ No	In forward direction, the voltage was scanned from 2.22 V to -0.2 V. In reverse direction, the voltage was scanned from -0.2 V to 2.22 V. The voltage step and delay time were 20 mV and 1 ms, respectively. Relative information is provided in method section. *Explain why this information is not reported/not relevant.*
Test environment	☒ Yes ☐ No	Devices were characterized at room temperature in In N_2-filled glove box. *Explain why this information is not reported/not relevant.*
Protocol for preconditioning of the device before its characterization	☐ Yes ☒ No	No preconditioning protocol. *Explain why this information is not reported/not relevant.*
Stability of the J-V characteristic	☒ Yes ☐ No	Relative information is provided in text. *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	Hysteresis is small and the related data is included in the manuscript. *Explain why this information is not reported/not relevant.*
Related experimental data	☐ Yes ☒ No	*Provide a description of the related experimental data.* We didn't find the unusual behaviour.

4. Efficiency

External quantum efficiency (EQE) or incident photons to current efficiency (IPCE)	☒ Yes ☐ No	The data is included in the manuscript. We show the EQE measurement details in the Methods section. *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 data is included in the manuscript. We show the EQE measurement details in the Methods section. *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	The device is tandem solar cell. The bias illumination obtained by 450-nm short-wave-pass filters and 800-nm long-wave-pass filters were used for the measurements of the rear subcells and front subcells, together with the corresponding applied bias voltage.

5. Calibration

Light source and reference cell or sensor used for the characterization	☒ Yes ☐ No	Relative information is provided in method section. *Explain why this information is not reported/not relevant.*
Confirmation that the reference cell was calibrated and certified	☒ Yes ☐ No	Relative information is provided in method section. *Explain why this information is not reported/not relevant.*
Calculation of spectral mismatch between the reference cell and the devices under test	☒ Yes ☐ No	Relative information is provided in method section. *Explain why this information is not reported/not relevant.*

6. Mask/aperture

Size of the mask/aperture used during testing	☒ Yes ☐ No	Device area is determined by a mask with area of 0.0918 cm2. *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 variation is within 0.3% *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	The photovoltaic performance of our devices was confirmed by National Photovoltaic Industry Measurement and Testing Center. *Explain why this information is not reported/not relevant.*
A copy of any certificate(s)	☒ Yes ☐ No	A copy is provided in Supplementary Information. *Explain why this information is not reported/not relevant.*

8. Statistics

Number of solar cells tested	☒ Yes ☐ No	The average PCE of the single-junction solar cells is obtained from more than 20 independent devices. *Explain why this information is not reported/not relevant.*
Statistical analysis of the device performance	☒ Yes ☐ No	We have given statistical data of device performance. *Explain why this information is not reported/not relevant.*

9. Long-term stability analysis

Type of analysis, bias conditions and environmental conditions	☒ Yes ☐ No	For the stability tests, all the device were encapsulated. The operational stability measurement was performed under a LED that was adjusted to 1 sun in ambient atmosphere. *Explain why this information is not reported/not relevant.*