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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	Small-area cells had an active area of 0.04 cm2. Perovskite solar modules had an active area of 65 cm2. *Explain why this information is not reported/not relevant.*
Method used to determine the device area	☒ Yes ☐ No	Small-cell areas were defined by black metal aperture masks. Module active areas were defined by the laser-scribed module layout. *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	Forward and reverse J–V scans were provided over voltage windows extending from -0.1 V to slightly above the Voc of each device group and back to -0.1V.
Voltage scan conditions	☒ Yes ☐ No	Scan rate:0.2V/s Step size:0.02V Delay:50 ms *Explain why this information is not reported/not relevant.*
Test environment	☒ Yes ☐ No	J–V measurements were performed in a nitrogen-filled glovebox under simulated AM 1.5G illumination. *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 was used in this work.
Stability of the J-V characteristic	☒ Yes ☐ No	Device stability was evaluated under dark-storage, continuous MPP-tracking and open-circuit ageing conditions. *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	Minor hysteresis was observed for devices herein. *Explain why this information is not reported/not relevant.*
Related experimental data	☒ Yes ☐ No	J-V curves under reverse and forward scans were provided. *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 curves were provided. *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 Jsc values from EQE were consistent with the Jsc values from J-V measurements. *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

Provide a description of the measurement conditions.

Not applicable; single -junction inverted perovskite architecture.

5. Calibration

Light source and reference cell or sensor used for the characterization

☒ Yes
☐ No

Using a Keithley 2400 sourcemeter under 1 sun irradiation from an AM 1.5G solar simulator (SS-F5, Enlitech). The illumination intensity was calibrated to 100 mW/cm2 using a certified Si reference cell.

Explain why this information is not reported/not relevant.

Confirmation that the reference cell was calibrated and certified

☒ Yes
☐ No

The Si reference cell used to calibrate the solar simulator was calibrated and certified. It was used to set the AM 1.5G illumination intensity to 100 mW/cm2 before J–V measurements.

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.

Spectral mismatch was not explicitly calculated. The solar simulator was calibrated using a certified Si reference cell, and EQE-integrated Jsc values were compared with J–V-derived Jsc values to verify consistency.

6. Mask/aperture

Size of the mask/aperture used during testing

☒ Yes
☐ No

A black metal aperture mask of 0.04 cm2 was used for small-area cells. The module active area was 65 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

Report the difference in the short-circuit current density values measured with the mask and aperture area.

Not measured. All small-area devices were measured using the same 0.04 cm2 black metal aperture mask to avoid area-dependent variation.

7. Performance certification

Identity of the independent certification laboratory that confirmed the photovoltaic performance

☒ Yes
☐ No

The champion small-area device was certified by the South China National Center of Metrology, accredited to ISO/IEC 17025:2017. TÜVNORD certification report for a 65 cm2 PSC module with electrodeposited SAMs, tested in accordance with IEC 61215-2:2021.

Explain why this information is not reported/not relevant.

A copy of any certificate(s)

☒ Yes
☐ No

Supplementary Figures 45 and 59.

Explain why this information is not reported/not relevant.

8. Statistics

Number of solar cells tested

☒ Yes
☐ No

For J–V performance statistics, 10 cells were tested for each device group. For stability measurements, 5 cells were tested for each condition unless otherwise stated.

Explain why this information is not reported/not relevant.

Statistical analysis of the device performance

☒ Yes
☐ No

Device performance statistics are shown as distributions for 10 cells per group. Stability data shown as distributions for 5 cells per group. Stability data are reported as mean ± s.d. from five devices per condition.

Explain why this information is not reported/not relevant.

9. Long-term stability analysis

Type of analysis, bias conditions and environmental conditions

☒ Yes
☐ No

Long-term stability was evaluated under three conditions. Dark-storage ageing was performed at 85 °C and 50% relative humidity with light off. Operational stability was measured by continuous MPP tracking at 65 °C under one-sun-equivalent illumination in a nitrogen-filled glovebox. Accelerated open-circuit ageing was also performed at 65 °C under one-sun-equivalent illumination. Device temperature was monitored using a thermocouple attached to a dummy device placed adjacent to the tested cells.

Explain why this information is not reported/not relevant.