

## 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 In our lab, the area of the solar cells tested is 0.04 cm<sup>2</sup> (Methods section: J-V and EQE measurements)

*Explain why this information is not reported/not relevant.*

Method used to determine the device area  Yes  No In our lab, the area of the solar cells tested is defined by a non-reflective metal mask with an aperture area of 0.04 cm<sup>2</sup> for regular.

*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 backward scans were performed on the cell (supplementary Fig.17)

Voltage scan conditions  Yes  No For the cells tested in our lab, the scan was performed in the range from -0.1 to 0.9V, with a scan step of 0.01V and delay time of 10ms

*Explain why this information is not reported/not relevant.*

Test environment  Yes  No For the cells tested in our lab, the cells were unencapsulated and the measurements were performed in an N<sub>2</sub>-filled glove box at room temperature

*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.

For the cells tested in our lab, no preconditioning was applied.

Stability of the J-V characteristic  Yes  No In our lab, stabilized power output tracking was performed to confirm the stability of J-V characteristics (Fig.4g)

*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 minor hysteresis was observed for devices herein

*Explain why this information is not reported/not relevant.*

Related experimental data  Yes  No Forward and backward scans were performed on the cell (supplementary Fig.17)

*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 measurement was carried out by the QE-R system (Enlitech) with an NREL-calibrated Si solar cell with an infrared cutoff filter (KG-5), as shown in Fig.4d

*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 values of the integrated current from EQE and the short-circuit current from J-V curve measured under AM 1.5G solar simulator are matched well

*Explain why this information is not reported/not relevant.*

For tandem solar cells, the bias illumination and bias voltage used for each subcell	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	<div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px; margin-bottom: 2px;"><i>Provide a description of the measurement conditions.</i></div> <div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px;">We do not report tandem solar cells in this work.</div>
<b>5. Calibration</b>		
Light source and reference cell or sensor used for the characterization	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px; margin-bottom: 2px;">In our lab, the cells were measured under AM 1.5G(100 mW cm<sup>-2</sup>) irradiation using an EnliTech, AAA solar simulator. The light intensity was calibrated using an NREL-calibrated Si solar cell with an infrared cutoff filter (KG-5) (Methods section: J-V and EQE measurements)</div> <div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px;"><i>Explain why this information is not reported/not relevant.</i></div>
Confirmation that the reference cell was calibrated and certified	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px; margin-bottom: 2px;">The solar simulator in our lab is equipped with a silicon solar cell (with a KG-5 filter) (Methods section: J-V and EQE measurements)</div> <div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px;"><i>Explain why this information is not reported/not relevant.</i></div>
Calculation of spectral mismatch between the reference cell and the devices under test	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px; margin-bottom: 2px;">In our lab, the light spectrum used for measurements matches well with the reference silicon cell, and we did not calculate the spectral mismatch between the reference cell and the tested devices</div> <div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px;"><i>Explain why this information is not reported/not relevant.</i></div>
<b>6. Mask/aperture</b>		
Size of the mask/aperture used during testing	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px; margin-bottom: 2px;">For the cells tested in our lab, the mask/aperture area is 0.04 cm<sup>2</sup>. (Methods section: J-V and EQE measurements)</div> <div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px;"><i>Explain why this information is not reported/not relevant.</i></div>
Variation of the measured short-circuit current density with the mask/aperture area	<input type="checkbox"/> Yes <input checked="" type="checkbox"/> No	<div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px; margin-bottom: 2px;"><i>Report the difference in the short-circuit current density values measured with the mask and aperture area.</i></div> <div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px;">For the cells tested in our lab, all cell were measured using one identical mask.</div>
<b>7. Performance certification</b>		
Identity of the independent certification laboratory that confirmed the photovoltaic performance	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px; margin-bottom: 2px;">Certified PCE of 10.57% for the nip-type TPSC first time from Shanghai Institute of Microsystem and Information Technology (an independent PV calibration laboratory)</div> <div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px;"><i>Explain why this information is not reported/not relevant.</i></div>
A copy of any certificate(s)	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px; margin-bottom: 2px;">We have provided the certified efficiency in Supplementary Fig.17</div> <div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px;"><i>Explain why this information is not reported/not relevant.</i></div>
<b>8. Statistics</b>		
Number of solar cells tested	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px; margin-bottom: 2px;">The data from 24 cells were statistically analyzed. The information is provided in supplementray Fig. 23</div> <div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px;"><i>Explain why this information is not reported/not relevant.</i></div>
Statistical analysis of the device performance	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px; margin-bottom: 2px;">The information is provided in supplementray Fig. 23</div> <div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px;"><i>Explain why this information is not reported/not relevant.</i></div>
<b>9. Long-term stability analysis</b>		
Type of analysis, bias conditions and environmental conditions	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No	<div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px; margin-bottom: 2px;">the long-term stability of the nip-type TPSCs with Sn(S0.92Se0.08)<sub>2</sub> ETLs was examined under ambient conditions. the nip-type TPSC with the Sn(S0.92Se0.08)<sub>2</sub> ETL still retains over 95% of its initial efficiency after 1632 h, which is of particular interest for practical applications.</div> <div style="border: 1px solid #ccc; border-radius: 5px; padding: 2px;"><i>Explain why this information is not reported/not relevant.</i></div>

