## Experimental design

**Please check: are the following details reported in the manuscript?**

| 1. Dimensions |  |  |  |
|----------------|------------------------|------------------------|------------------------|
| Area of the tested solar cells | ☑ Yes | **Methods; Characterizations** |  |
| Method used to determine the device area | ☑ Yes | **Methods; Characterizations** |  |

| 2. Current-voltage characterization |  |  |  |
|-----------------------------------|------------------------|------------------------|------------------------|
| Current density-voltage (J-V) plots in both forward and backward direction | ☑ Yes | **Supplementary Information Figures 17, 23, & 24** |  |
| Voltage scan conditions | ☐ No | **Methods; Characterizations** |  |
| Test environment | ☑ Yes | **Methods; Characterizations** |  |
| Protocol for preconditioning of the device before its characterization | ☑ Yes | **Methods; Characterizations** |  |
| Stability of the J-V characteristic | ☑ Yes | **Supplementary Information Figure 18** |  |

| 3. Hysteresis or any other unusual behaviour |  |  |  |
|---------------------------------------------|------------------------|------------------------|------------------------|
| Description of the unusual behaviour observed during the characterization | ☑ Yes | **Minor hysteresis (Supplementary Information Figures 17, 23, & 24)** |  |
| Related experimental data | ☐ No | **No significant difference in PCE for forward and reverse scans** |  |

| 4. Efficiency |  |  |  |
|----------------|------------------------|------------------------|------------------------|
| External quantum efficiency (EQE) or incident photons to current efficiency (IPCE) | ☑ Yes | **Figure 5 & Supplementary Information Figure 17** |  |
| A comparison between the integrated response under the standard reference spectrum and the response measure under the simulator | ☐ No | **Figure 5 & Supplementary Information Figure 17** |  |
| For tandem solar cells, the bias illumination and bias voltage used for each subcell | ☐ No | **No tandem solar cells were evaluated.** |  |

| 5. Calibration |  |  |  |
|----------------|------------------------|------------------------|------------------------|
| Light source and reference cell or sensor used for the characterization | ☑ Yes | **Methods; Characterizations** |  |
| Confirmation that the reference cell was calibrated and certified | ☑ Yes | **Methods; Characterizations** |  |
Calculation of spectral mismatch between the reference cell and the devices under test

6. Mask/aperture
   Size of the mask/aperture used during testing
   Variation of the measured short-circuit current density with the mask/aperture area

7. Performance certification
   Identity of the independent certification laboratory that confirmed the photovoltaic performance
   A copy of any certificate(s)
   Provide in Supplementary Information

8. Statistics
   Number of solar cells tested
   Statistical analysis of the device performance

9. Long-term stability analysis
   Type of analysis, bias conditions and environmental conditions
   For instance: illumination type, temperature, atmosphere humidity, encapsulation method, preconditioning temperature

   ☑ Yes  The solarsimulators are 3A grade
   ☑ No

   ☑ Yes  Methods; Characterizations
   ☑ No

   ☑ Yes  They were already measured at the maximum aperture
   ☑ No

   ☑ Yes  Kanagawa Institute of Industrial Science and Technology (KISTEC), Japan
   ☑ No

   ☑ Yes  Supplementary Information Figure 26
   ☑ No

   ☑ Yes  Table 1 & Table 2
   ☑ No

   ☑ Yes  Table 1 & Table 2
   ☑ No

   ☑ Yes  Supplementary Information Figure 25
   ☑ No