

Electronic Supplementary Information for:

**In-situ one step growth of amorphous Tin oxide electron
transport layers for High-Performance perovskite solar cells**

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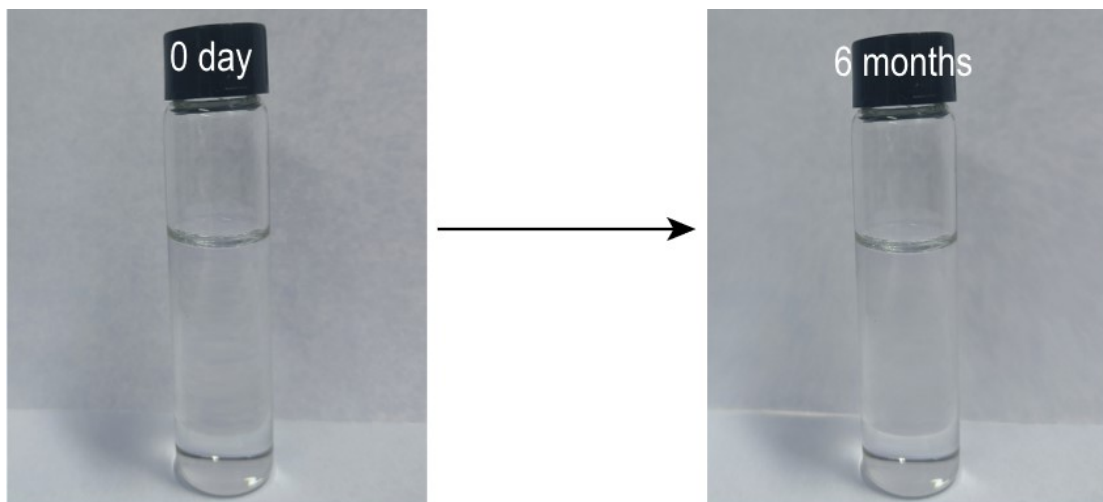


Figure S1. Digital photos of SnCl_2/DMF precursor solution before and after six months of storage at room temperature.

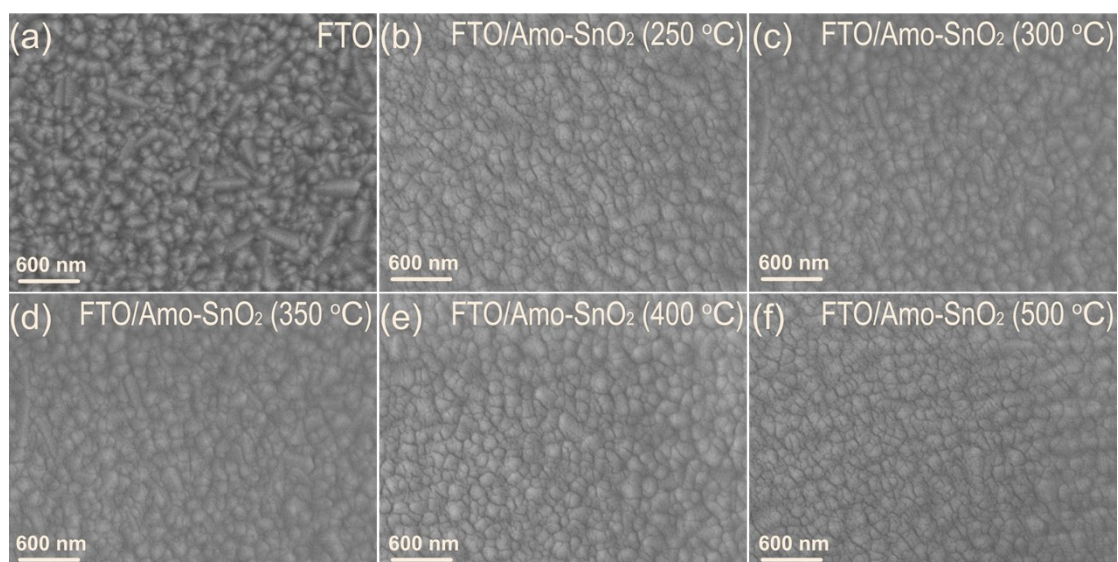


Figure S2. SEM images of Amo-SnO_2 films covered onto FTO substrate with post annealing at different temperatures: (a) FTO, (b) 250 °C, (c) 300 °C, (d) 350 °C, (e) 400 °C and (f) 500 °C.

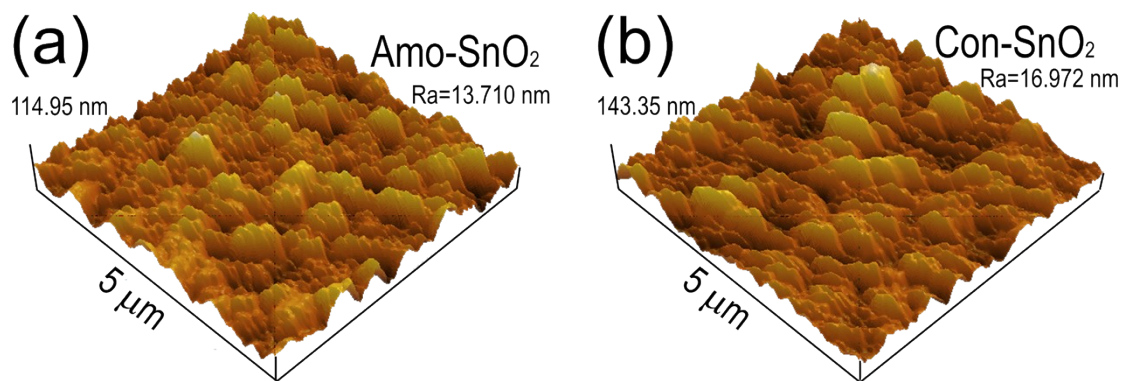


Figure S3. AFM images of Amo-SnO₂ and Con-SnO₂ films with scanning range of 5×5 μm.

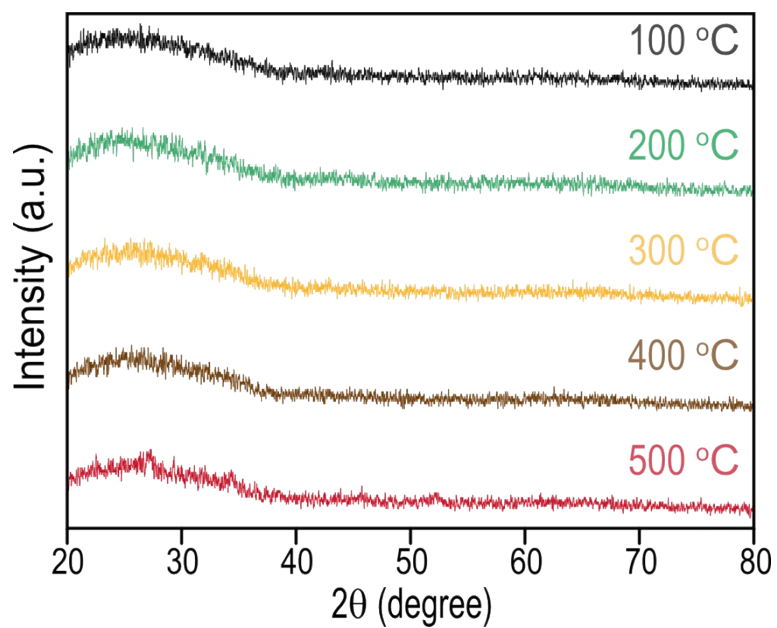


Figure S4. XRD patterns of Amo-SnO₂ films covered onto glass substrate with different annealing temperatures.

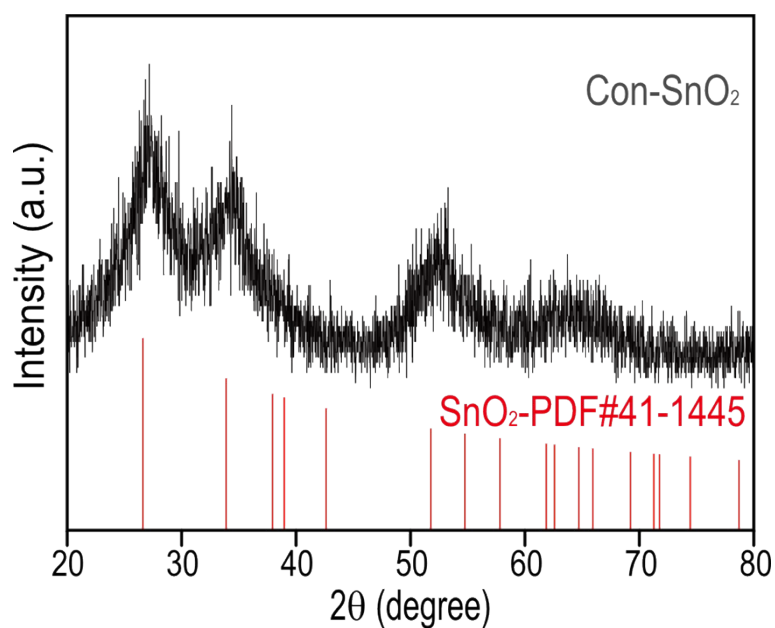


Figure S5. XRD pattern of Con-SnO₂ films covered onto glass substrate.

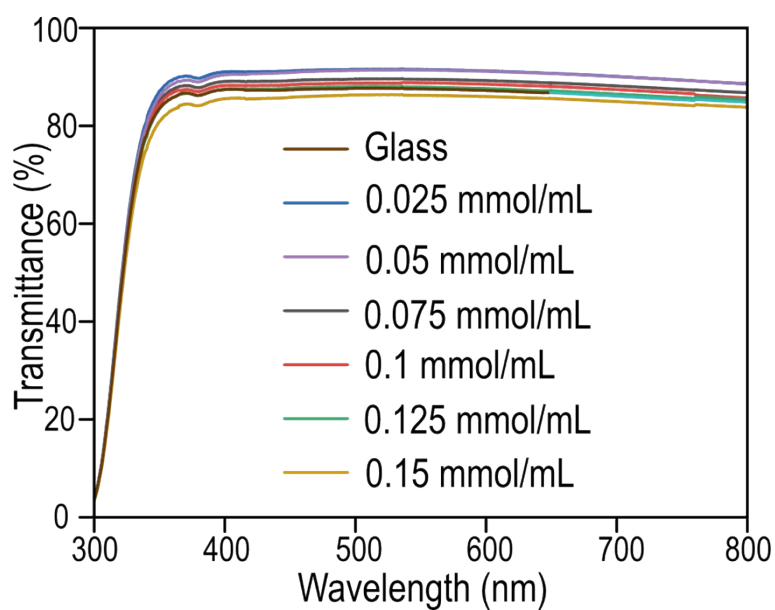


Figure S6. Optical transmittance of SnO₂ films covered onto glass substrate prepared with different concentrations of SnCl₂/DMF solution.

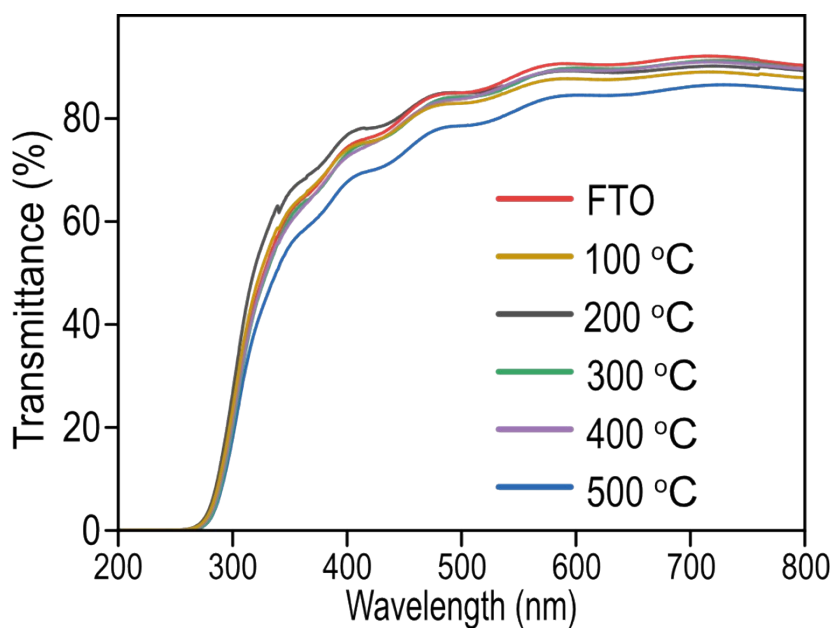


Figure S7. Optical transmittance of AmO-SnO₂ films annealed at different temperatures.

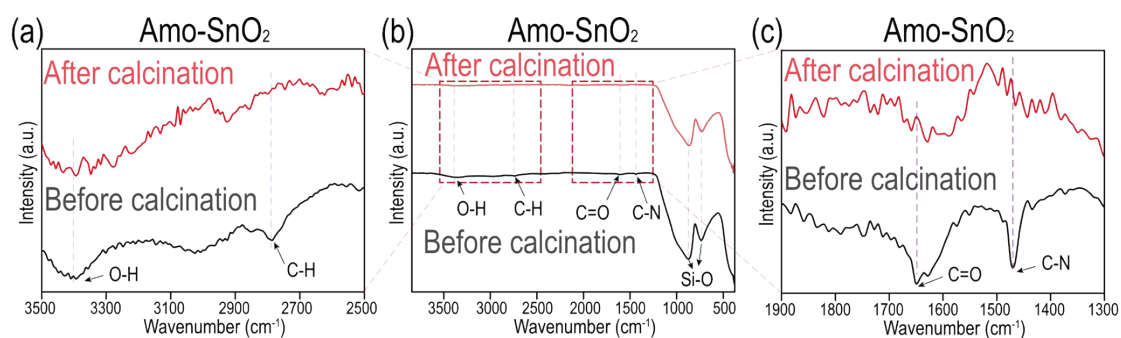


Figure S8. FTIR spectra of AmO-SnO₂ film before and after calcination. (a) Magnified pattern (wavenumber: 2500-3500 cm⁻¹), (b) Full spectra (wavenumber: 400-4000 cm⁻¹) and (c) Amplified pattern (wavenumber: 1300-1900 cm⁻¹).

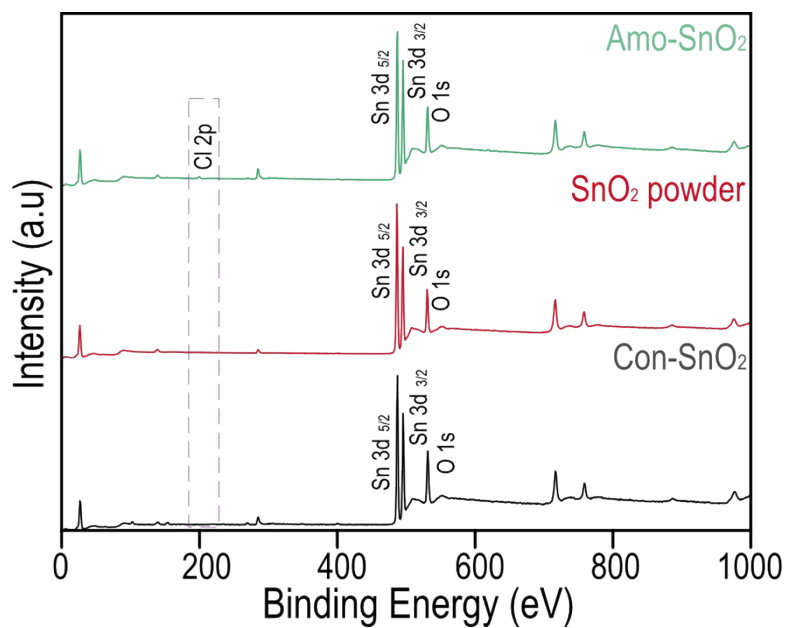


Figure S9. XPS full spectra of Amo-SnO₂ film, SnO₂ powder and Con-SnO₂ film.

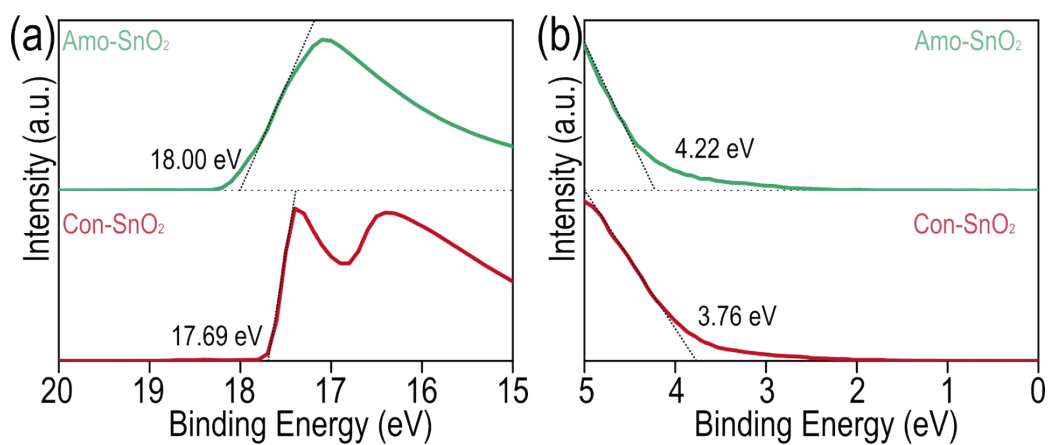


Figure S10. UPS spectra of Amo-SnO₂ film and Con-SnO₂ film. (a) E_{cutoff} edge. (b) E_{onset} range.

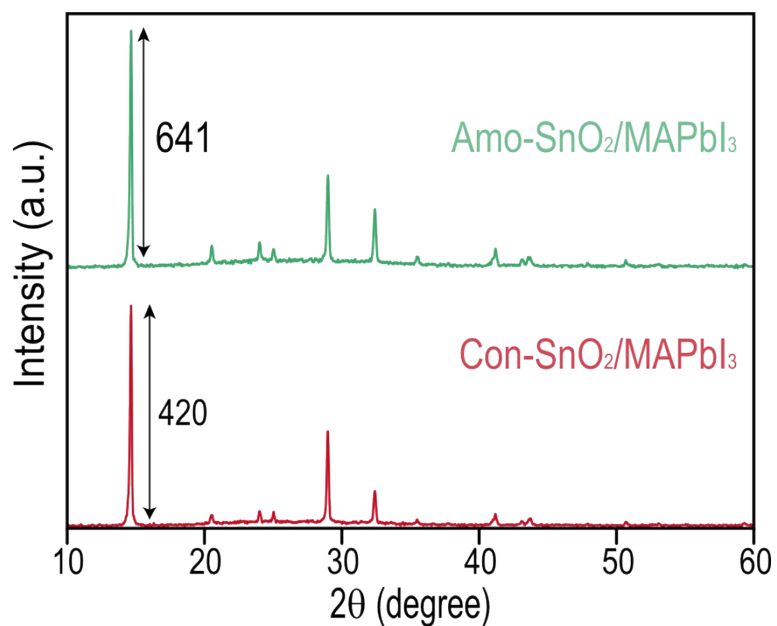


Figure S11. XRD patterns of MAPbI₃ thin films separately coated onto Amo-SnO₂ and Con-SnO₂ ETL annealed at 200 °C, respectively.

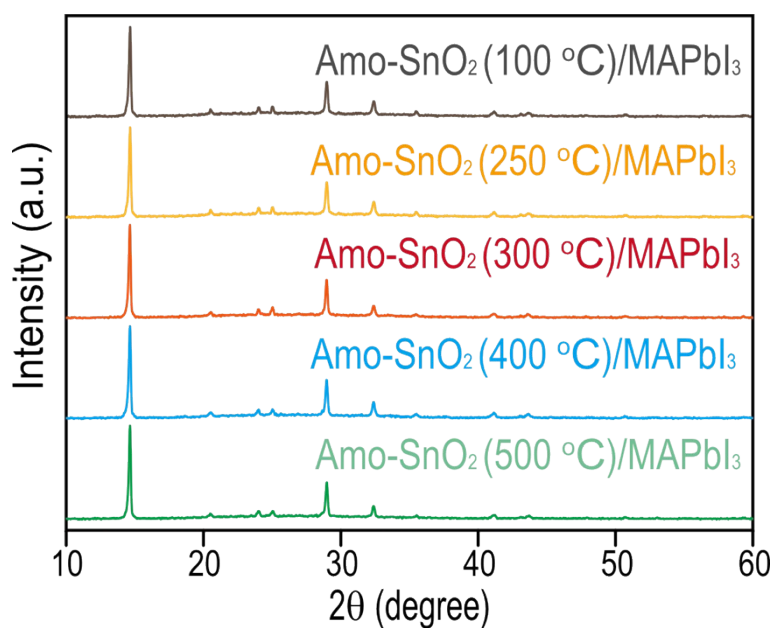


Figure S12. XRD patterns of MAPbI₃ films separately coated onto Amo-SnO₂ ETL annealed at different temperatures.

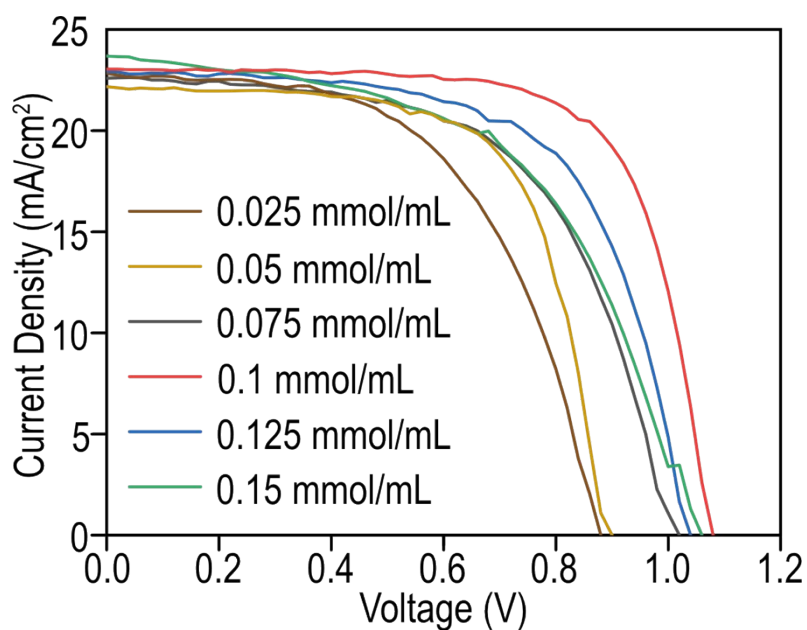


Figure S13. Reverse scan of $J-V$ curves of PSCs in which Amo-SnO_2 films are prepared using different concentrations of SnCl_2/DMF solution.

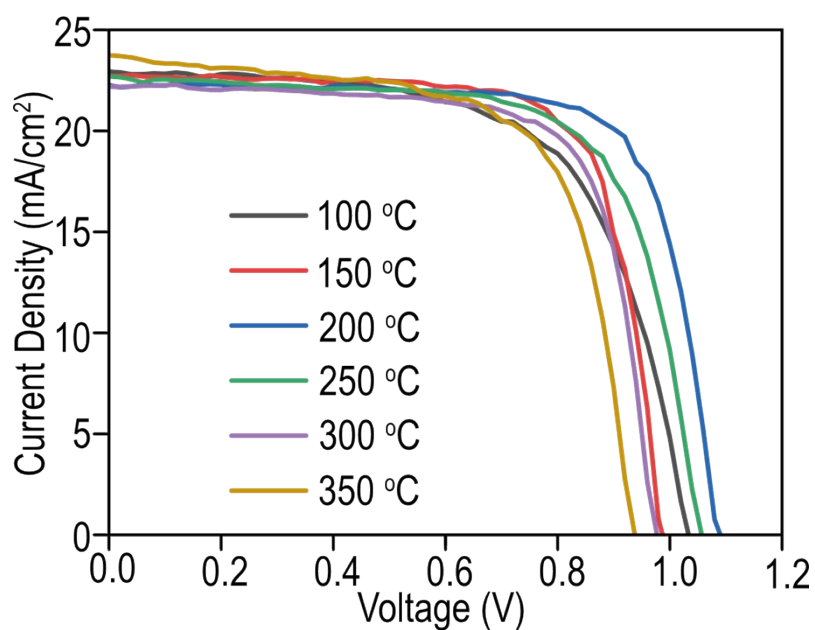


Figure S14. Reverse scan of $J-V$ curves of PSCs in which Amo-SnO_2 films are prepared by different annealing temperatures.

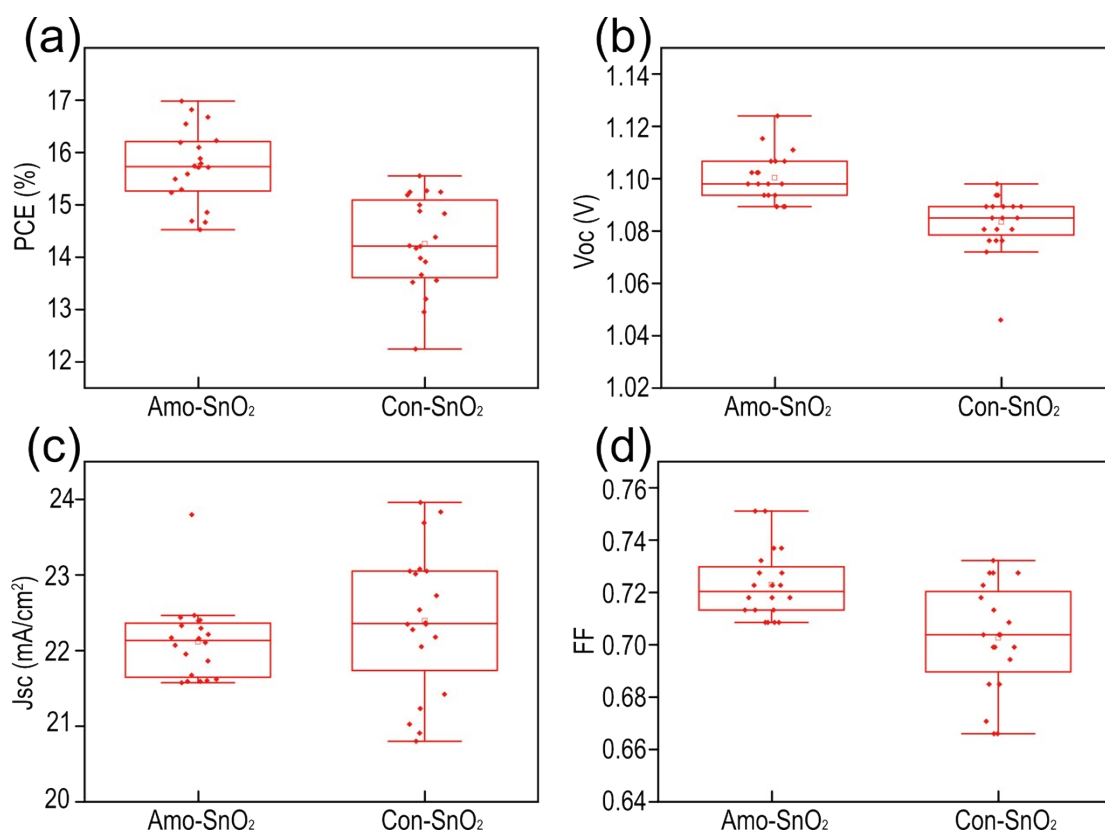


Figure S15. Statistical comparison of J-V parameters with reverse scan of PSCs between Amo-SnO₂ and Con-SnO₂ as ETL for 20 samples.

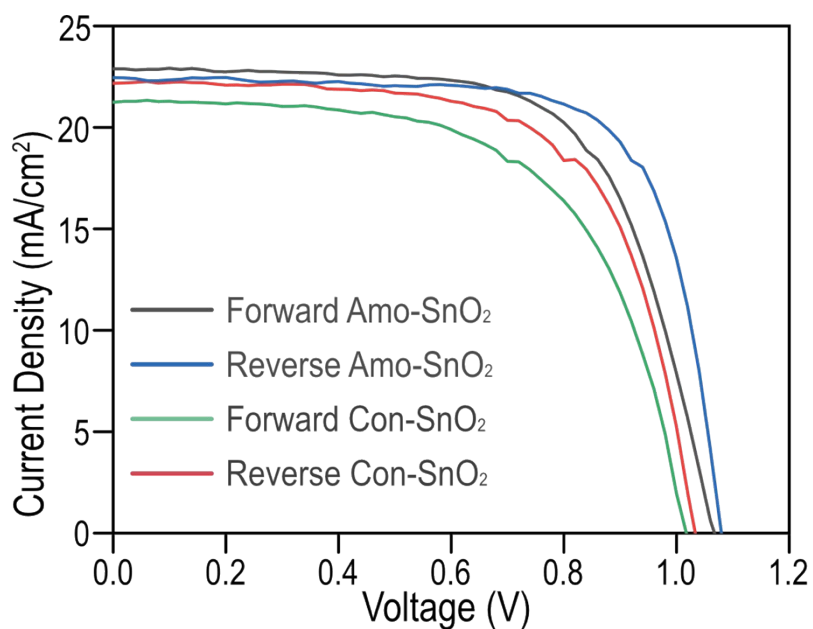


Figure S16. Forward and reverse scan of J-V curves of PSCs using Amo-SnO₂ or Con-SnO₂ as ETL.

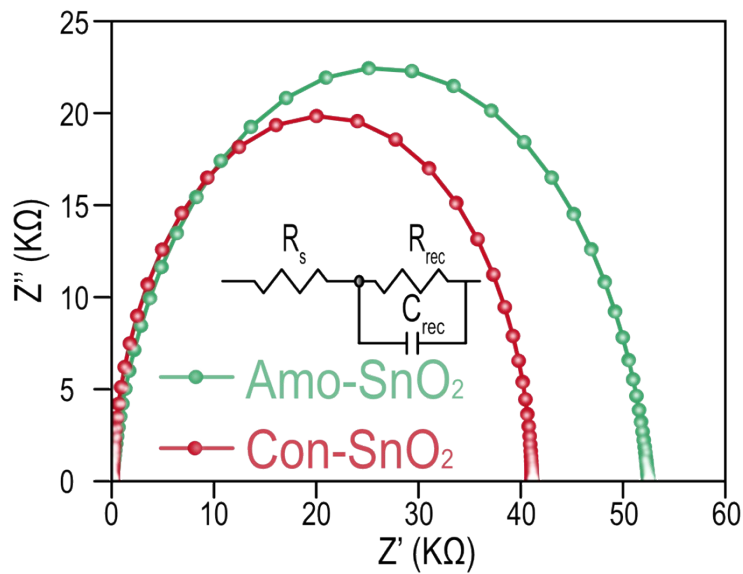


Figure S17. EIS results of SnO₂ films under light conditions: with a light source of atmospheric mass (AM) 1.5 G with 100 mW/cm² of incident light power density.

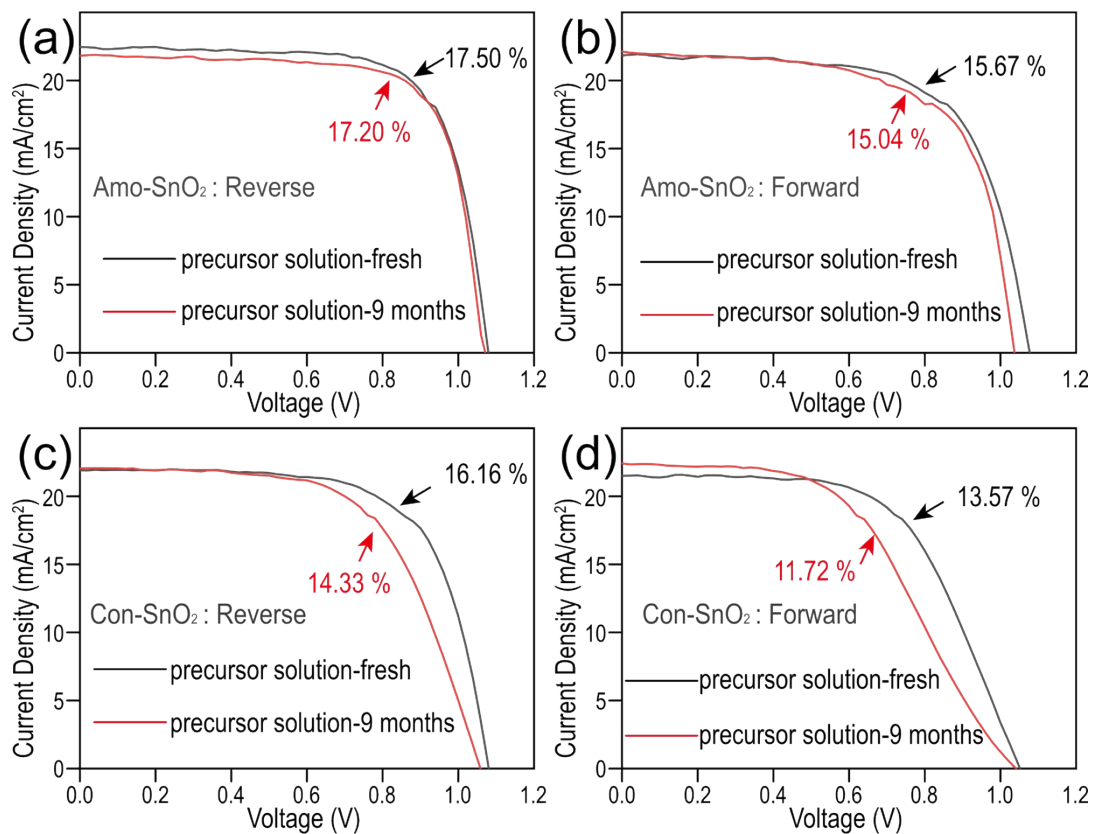


Figure S18. Forward and reverse scan of J-V curves of PSCs using Amo-SnO₂ or Con-SnO₂ as ETL, in which their precursor solutions were stored for 9 months.

Table S1. Device parameters of PSCs in which Amo-SnO₂ films are prepared by different concentrations of SnCl₂/DMF solution.

Concentration of SnCl₂ (mmol/mL)	V_{oc} (V)	J_{sc} (mA/cm²)	FF	PCE (%)
0.025	1.008	20.33	0.59	12.11
0.050	1.034	20.60	0.60	12.76
0.075	1.034	20.64	0.64	13.60
0.100	1.102	21.57	0.73	17.38
0.125	1.073	20.74	0.71	15.83
0.150	1.045	19.93	0.71	14.68

Table S2. Device parameters of PSCs in which Amo-SnO₂ films are prepared by different annealing temperatures.

T/°C	V_{oc} (V)	J_{sc} (mA/cm²)	FF	PCE (%)
100	1.045	19.51	0.67	13.61
150	1.054	20.22	0.75	15.89
200	1.090	21.25	0.76	17.64
250	1.049	20.43	0.70	14.90
300	0.968	19.97	0.74	14.23
350	0.930	21.37	0.67	13.35

Table S3. Performance comparison of PSCs obtained from this work and the reported works.

Device structure	V_{oc} (V)	J_{sc} (mA/cm²)	FF	PCE (%)	Reference
FTO/Amo-SnO ₂ /MAPbI ₃ / Spiro-OMeTAD /Ag	1.090	21.25	0.76	17.64	This work
FTO/Con-SnO ₂ /MAPbI ₃ / Spiro-OMeTAD /Ag	1.05	24.26	0.64	16.43	This work
FTO/SnO ₂ /MAPbI ₃ / Spiro- OMeTAD /Au	1.090	18.48	0.75	15.10	1
	1.11	23.23	0.67	17.21	2
ITO/SnO ₂ /MAPbI ₃ / Spiro- OMeTAD /Ag	1.06	19.72	0.74	15.61	3

Notes and references

- 1 W. J. Ke, D. W. Zhao, A. J. Cimaroli, C. R. Grice, P. L. Qin, Q. Liu, L. B. Xiong, Y. F. Yan and G. J. Fang, *J. Mater. Chem. A.*, 2015 **3** 24163-24168.
- 2 W. J. Ke, G. J. Fang, Q. Liu, L. B. Xiong, P. L. Qin, H. Tao, J. Wang, H. W. Lei, B. R. Li, J. W. Wan, G. Yang and Y. F. Yan, *J. Am. Chem. Soc.*, 2015 **137** 6730-6733.
- 3 H. X. Xie, W. X. Que, *Front. Chem.*, 2024 **12** 1361275.