Supplementary Information (SI) for Sustainable Energy & Fuels.

Electronic Supplementary Information

Optimal film thickness and Sn oxidation state of sputter-deposited SnO_2 electron transport layers for efficient perovskite solar cells

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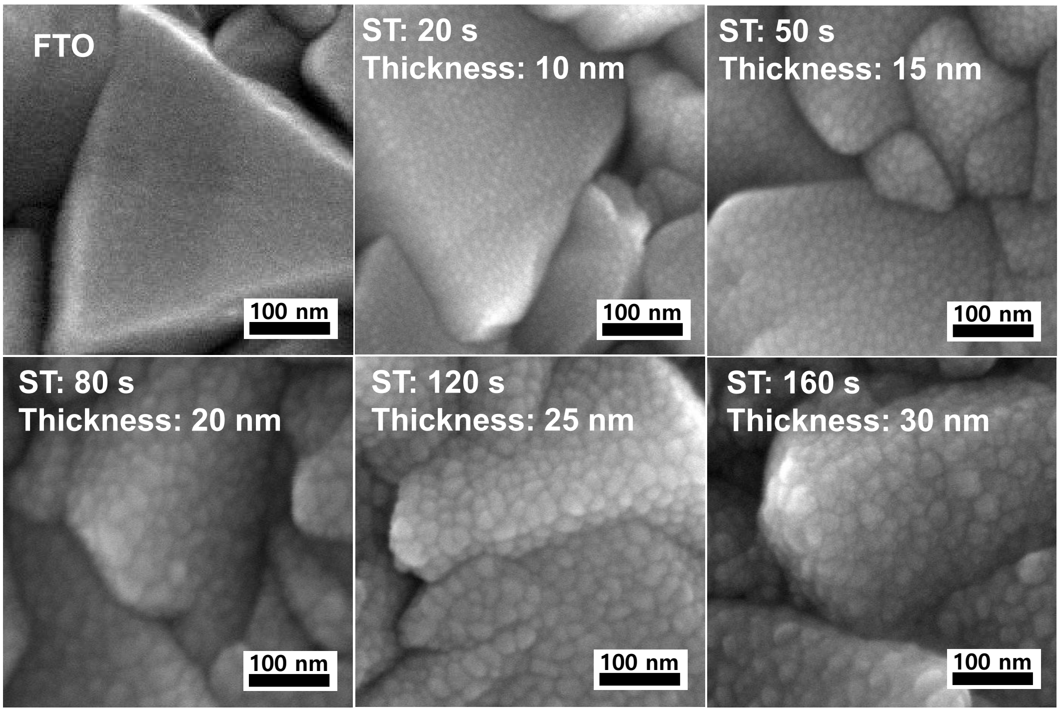


Fig. S1 Plan-view SEM images of metallic Sn films with various thicknesses deposited on FTO substrate. Thicknesses of the films were controlled by varying the sputtering time (ST).

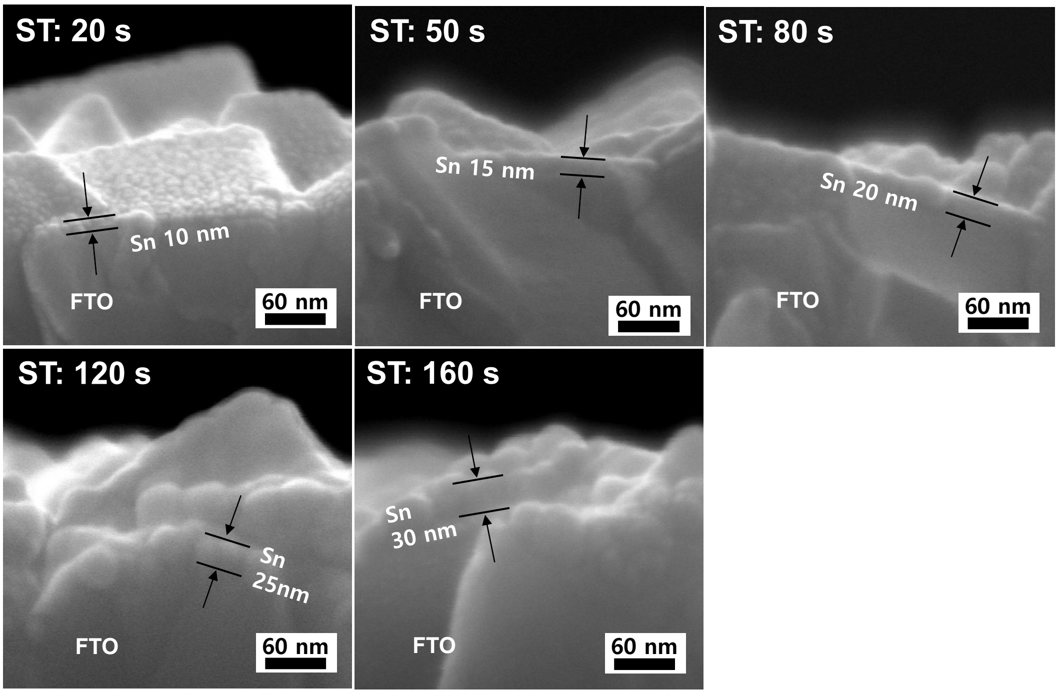


Fig. S2 Cross-sectional-view SEM images of metallic Sn films with various thicknesses deposited on FTO substrate. Thicknesses of the films were controlled by varying ST.

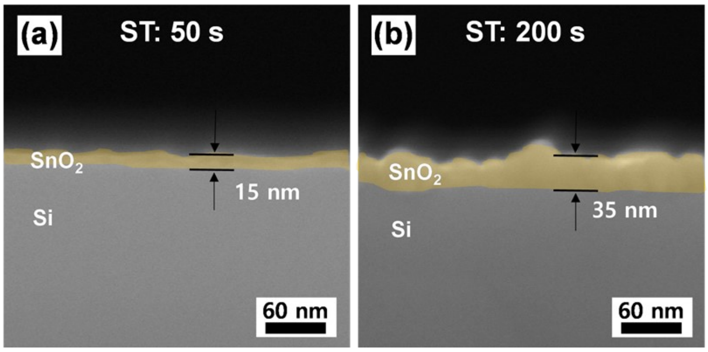


Fig. S3 Cross-sectional-view SEM images of the SnO_2 films on a Si substrate prepared by the ST of 50 s (a) and 200 s (b).

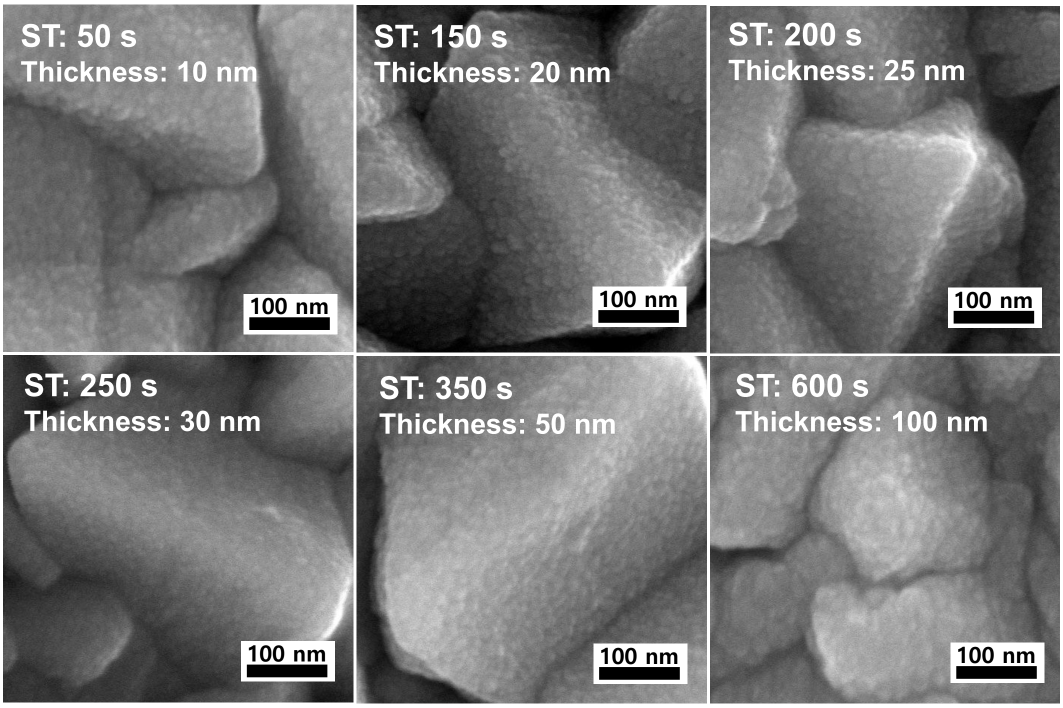


Fig. S4 Plan-view SEM image of TiO_2 films with various thicknesses deposited on FTO substrate. They were obtained by sputtering metallic Ti films, followed by heat treating at 500^{o}C in air. To control Ti thickness, ST was varied in the range of 50–550 s.

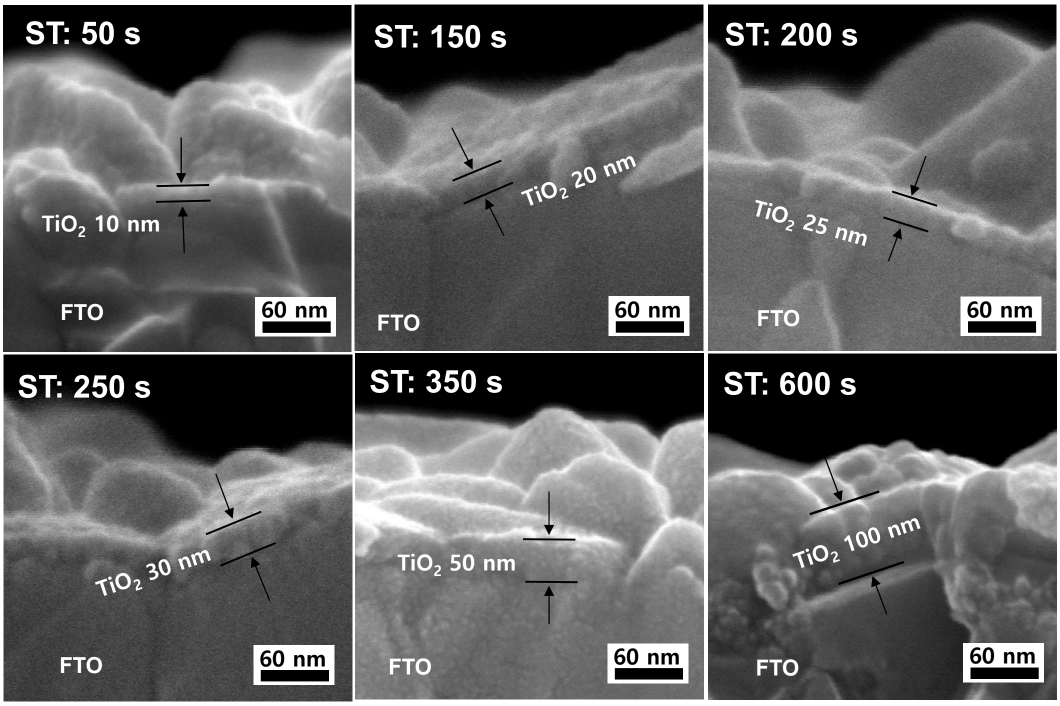


Fig. S5 Cross-sectional-view SEM image of TiO_2 films with various thicknesses deposited on FTO substrate. They were obtained by sputtering metallic Ti films, followed by heat treating at 500°C in air. To control Ti thickness, ST was varied in the range of 50–550 s.

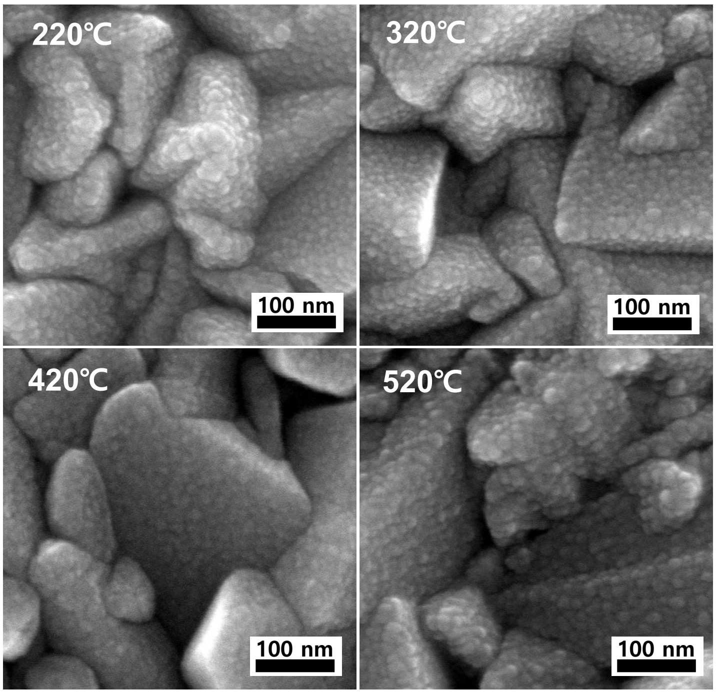


Fig. S6 Plan-view SEM images of SnO_2 films prepared by heat-treating 15 nm-thick metallic Sn films at various temperatures.

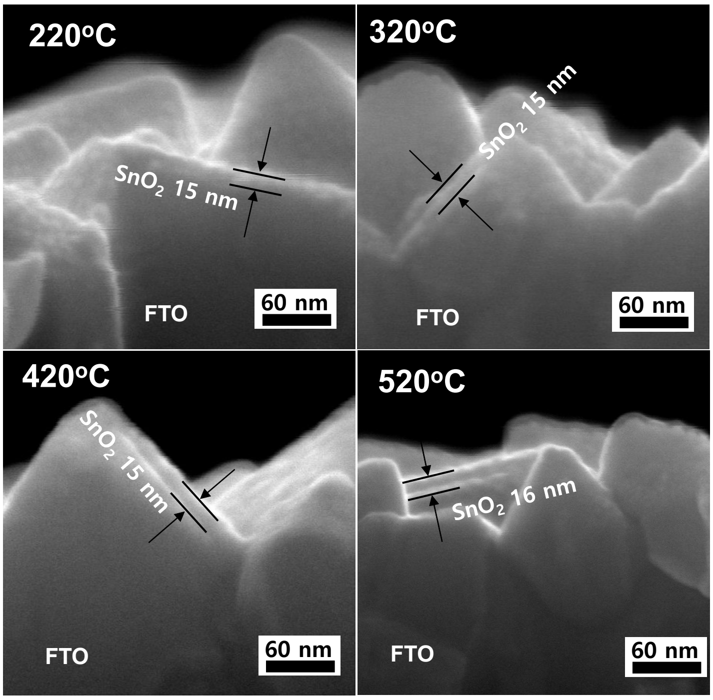


Fig. S7 Cross-sectional-view SEM images of SnO_2 films prepared by heat-treating 15 nm-thick metallic Sn films at various temperatures.

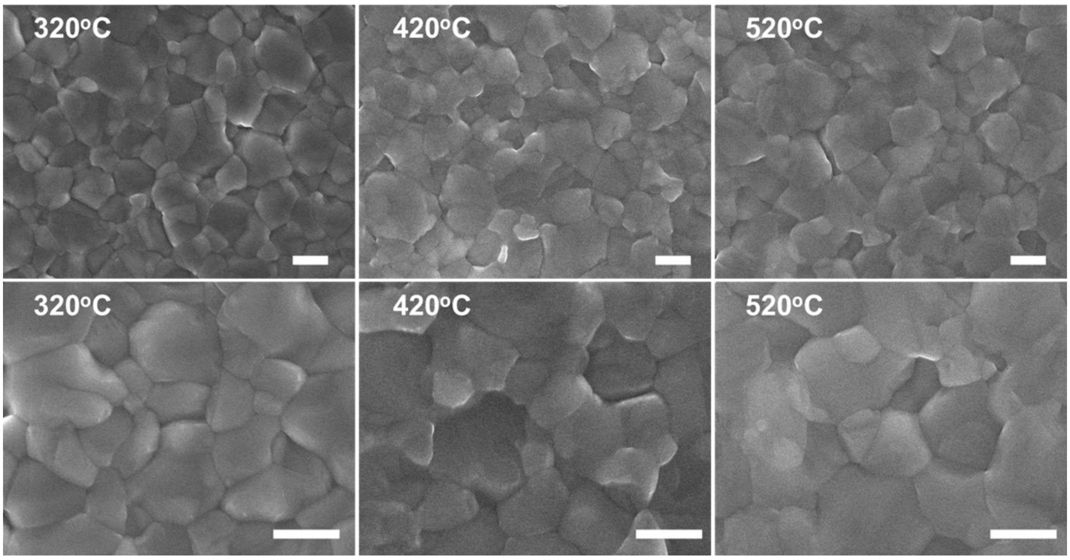


Fig. S8 Plan-view SEM images of perovskite films grown on the SnO_2 layers heat-treated at 320°C, 420°C, and 520°C, respectively. All scale bars represent 1 μm.

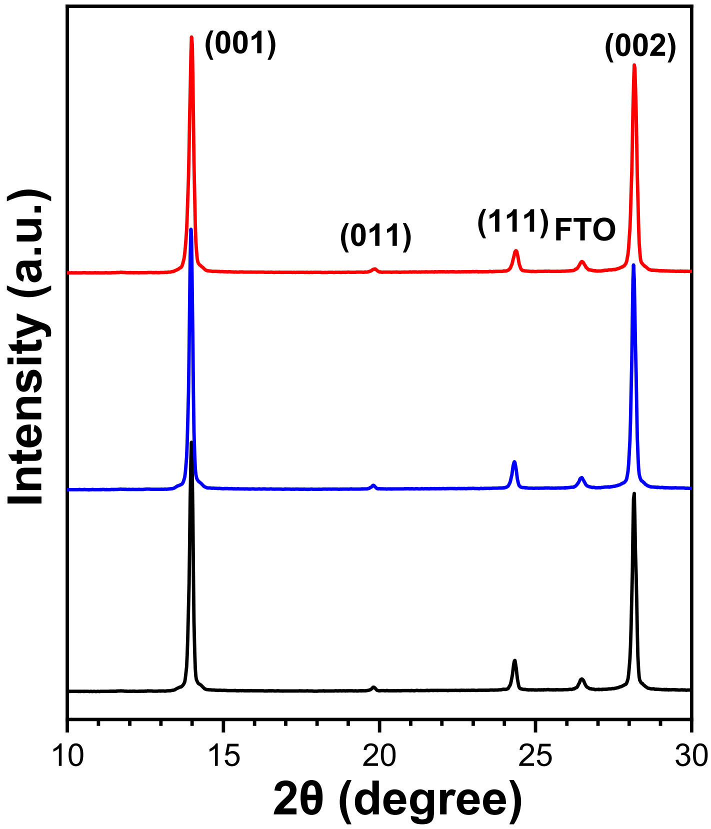
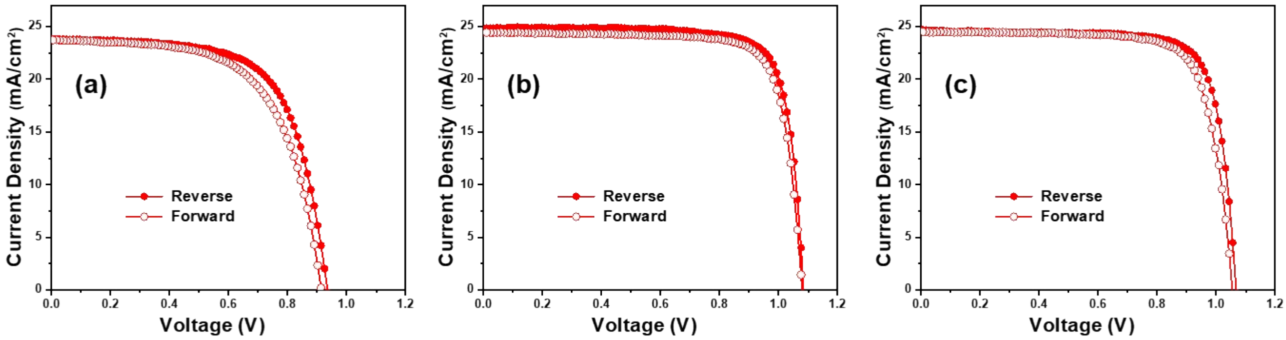


Fig. S9 XRD patterns of perovskite films grown on the SnO_2 layers heat-treated at 20^{o}C (black), 420^{o}C (blue), and 520^{o}C (red).



(d)

SnO_2 ETL annealing Temp. (°C)	Reverse /Forward	V_{oc} (V)	J_{sc} (mA/cm^2)	Fill Factor (%)	PCE (%)	Hysteresis index (%)
320	Reverse	0.935	23.79	69.63	15.49	10.5
	Forward	0.916	23.72	63.85	13.87	
420	Reverse	1.079	24.89	79.31	21.30	3.6
	Forward	1.076	24.45	78.08	20.54	
520	Reverse	1.066	24.66	78.30	20.58	4.6
	Forward	1.054	24.47	76.14	19.64	

Fig. S10 J-V curves of PSC-SnO_2-320 (a), PSC-SnO_2-420 (b), and PSC-SnO_2-520 (c) obtained from reverse and forward scans (scan rate: 50 mV s^{-1}). (d) Table exhibiting PV parameters and hysteresis indexes of various PSC devices. Hysteresis index was evaluated from the equation of $[(PCE_{reverse} - PCE_{forward})/PCE_{reverse}] \times 100\%$.

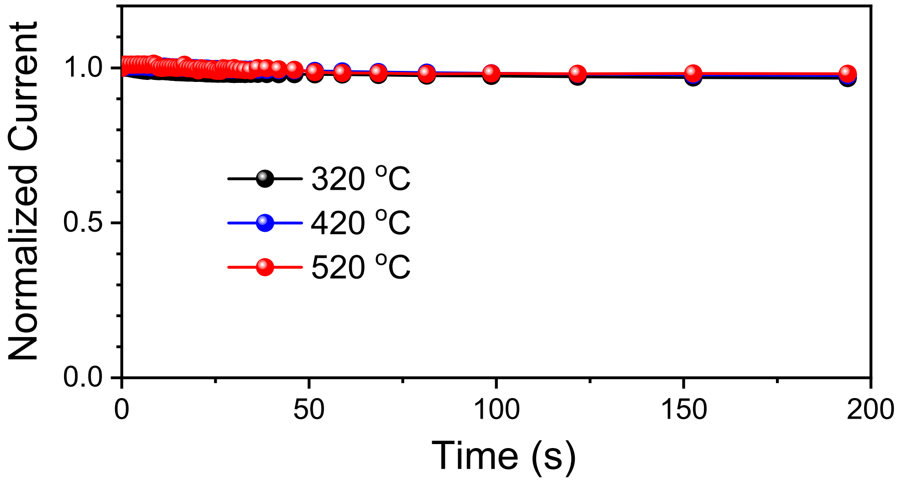


Fig. S11 Normalized current of PSC-SnO_2-320 (black), PSC-SnO_2-420 (blue), and PSC SnO_2 (red) at an applied bias voltage of 0.6 V under one sun irradiation.

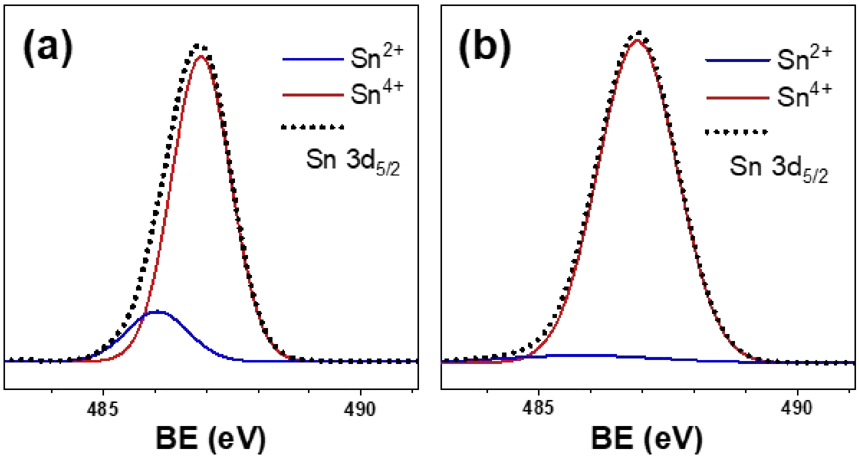


Fig. S12 XPS spectra of Sn $4d_{5/2}$ peaks for the 35 nm-thick SnO_2 films heat-treated at 420^{o}C (a) and 520^{o}C (b) for 30 min.

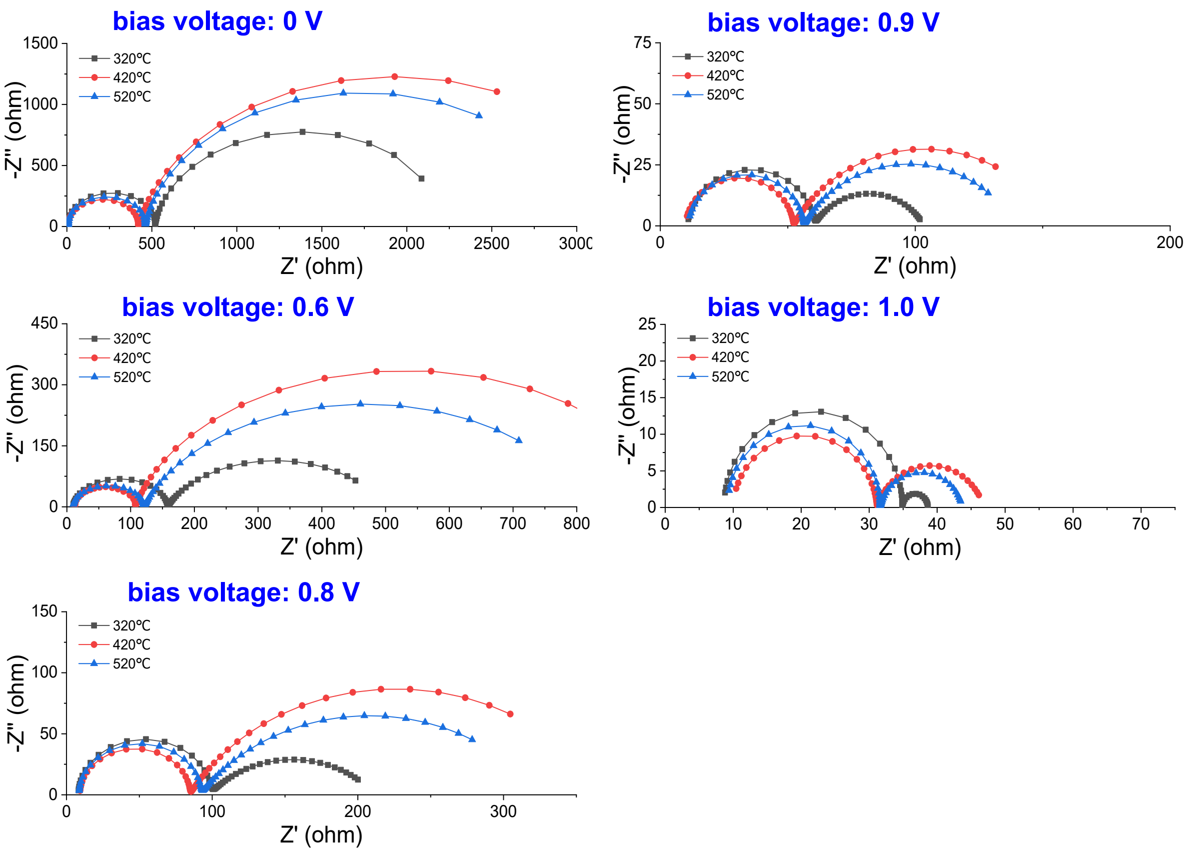


Fig. S13 Nyquist plots obtained at various bias voltages for PSC devices employing SnO_2-320, SnO_2-420, and SnO_2-520, respectively.