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Supporting Information

Highly Efficient $CsPbIBr_2$ Perovskite Solar Cells with Efficiency Over 9.8% Using Preheating-Assisted Spin-Coating Method

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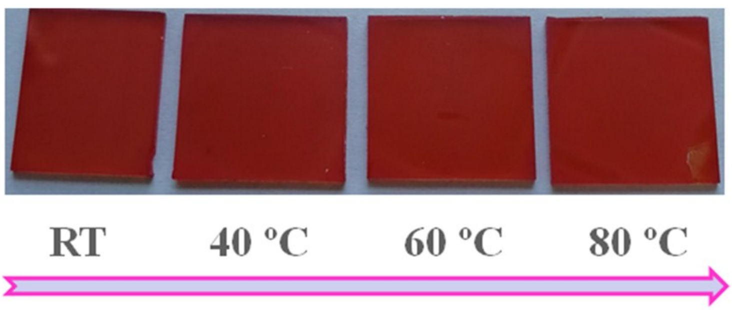

Fig. S1 Optical images of $CsPbIBr_2$ films formed at different substrate preheating temperatures.

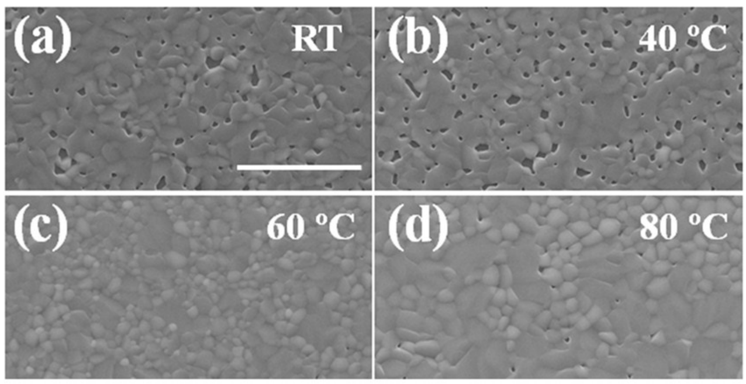

Fig. S2 Large-scale top-view SEM images of $CsPbIBr_2$ films formed at different substrate preheating temperatures, the scale bar is 10 μm.

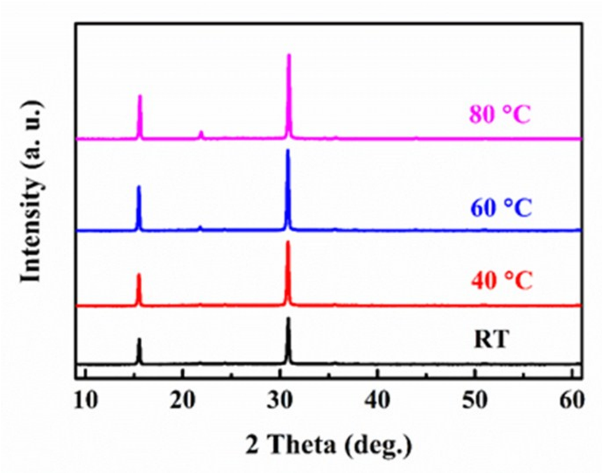

Fig. S3 XRD patterns of $CsPbIBr_2$ films formed at different substrate preheating temperatures.

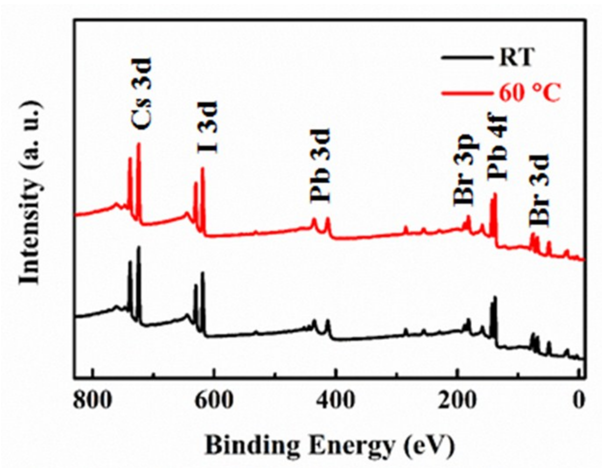

Fig. S4 XPS survey spectra of $CsPbIBr_2$ films formed at RT and a substrate preheating temperature of 60 ºC, respectively.

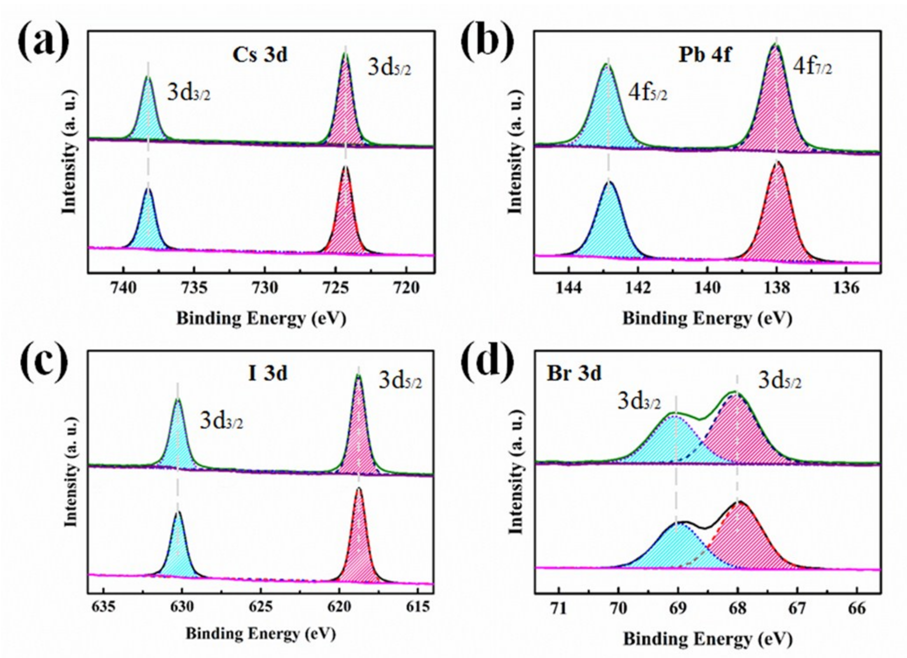

Fig. S5 (a) Cs 3d, (b) Pb 4f, (c) I 3d and (d) Br 3d XPS core spectra of $CsPbIBr_2$ films formed at RT (below) and a substrate preheating temperature of 60 ºC (above), respectively.

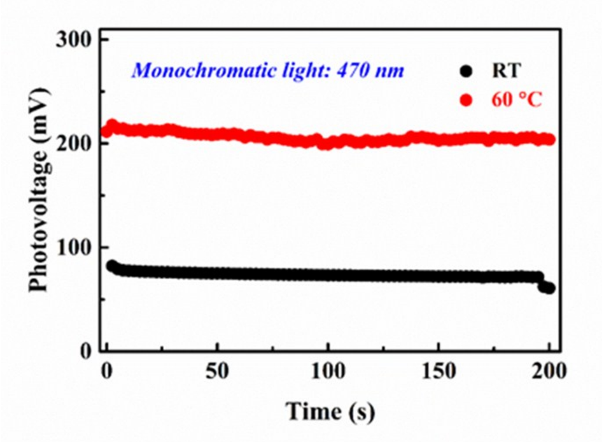

Fig. S6 SPV measurements of $CsPbIBr_2$ films formed at RT and a substrate preheating temperature of 60 ºC, respectively.

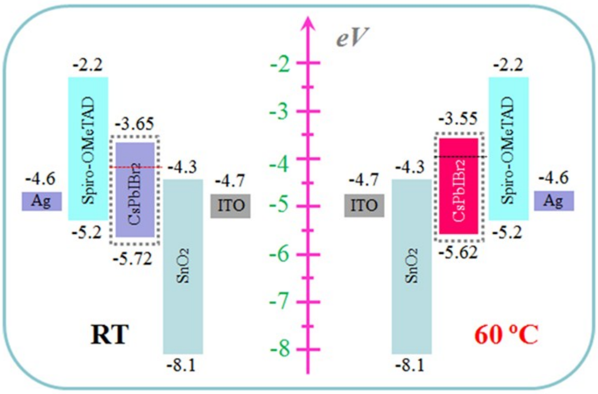

Fig. S7 Energy level diagrams of the devices based on $CsPbIBr_2$ films formed at RT and a substrate preheating temperature of 60 ºC, respectively. The dot line indicates the fermi level of perovskites.

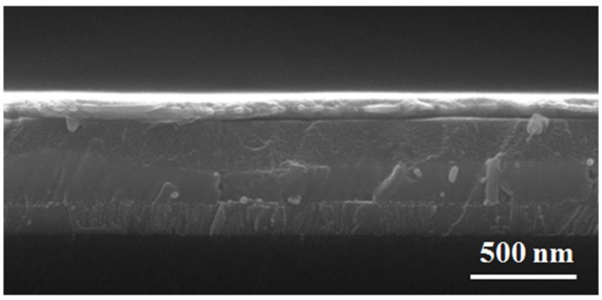

Fig. S8 Cross-sectional SEM image without color of the corresponding PSC structure.

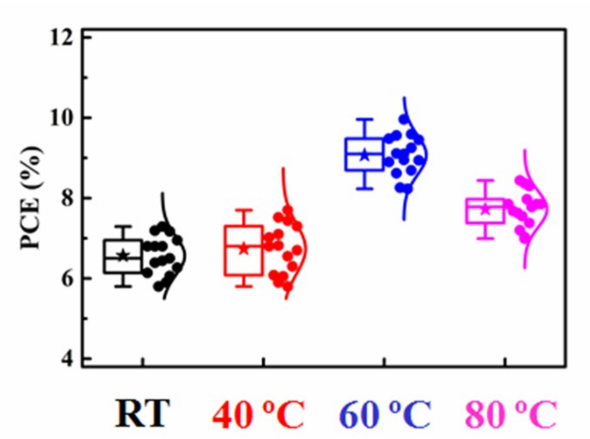

Fig. S9 Statistic PCEs distributions of 15 independent cells over $CsPbIBr_2$ formed at different substrate preheating temperatures.

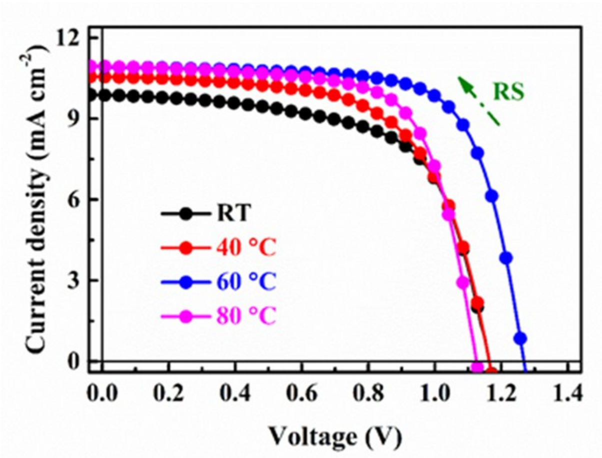

Fig. S10 J-V curves of the champion cells over $CsPbIBr_2$ formed at different substrate preheating temperatures.

Table S1 Photovoltaic parameters of the champion devices over $CsPbIBr_2$ formed at different substrate preheating temperatures.

Substrate preheating temperature	V_{oc} (V)	J_{sc} (mA cm^{-2})	FF	PCE (%)
RT	9.88	1.165	0.63	7.29
40 ºC	10.55	1.162	0.63	7.70
60 ºC	10.92	1.267	0.71	9.86
80 ºC	10.94	1.125	0.69	8.44

Table S2 The reported parameters of the cells over pure $CsPbIBr_2$ perovskite (measured under RS).

Cell structure	Perovskite fabrication method	V_{oc} (V)	PCE (%)	Ref.
FTO/TiO_2/$SmBr_3$/$CsPbIBr_2$/ Spiro-OMeTAD/Au	One-step spin coating	1.170	10.88	1
FTO/TiO_2(CsBr)/$CsPbIBr_2$/Carbon	One-step spin coating & Intermolecular exchange	1.261	10.71	2
FTO/c-TiO_2/$CsPbIBr_2$/Carbon	One-step spin coating	1.171	5.49	3
	One-step spin coating & Intermolecular exchange	1.245	9.16	
FTO/NiO_x/$CsPbIBr_2$/MoO_x/Au	One-step spin coating	0.850	5.52	4
FTO/c-TiO_2/$CsPbIBr_2$/ Spiro-OMeTAD/Au	One-step spin coating (Gas-assisted)	1.227	8.02	5
FTO/c-TiO_2/$CsPbIBr_2$/Au	Dual source evaporation	0.959	4.7	6
ITO/SnO_2/C_{60}/$CsPbIBr_2$/ Spiro-OMeTAD/Au	One-step spin coating (Antisolvent: chlorobenzene)	1.180	7.34	7
ITO/SnO_2/$CsPbIBr_2$/ Spiro-OMeTAD/Ag	One-step spin coating	1.165	7.29	**This work**
	One-step spin coating (Preheating-assist)	1.267	9.86	
ITO/In_2S_3/$CsPbIBr_2$/ Sprio-OMeTAD/Au	One-step spin coating	1.090	5.59	8
FTO/c-TiO_2/ $CsPbIBr_2$/Carbon	One-step spin coating	1.114	5.82	9
	One-step spin coating (Light Processing)	1.283	8.60	
ITO/SnO_2/$CsPbIBr_2$/Carbon	One-step spin coating	1.230	7.00	10
FTO/c-TiO_2/$CsPbIBr_2$ /spiro-OMeTAD/Au	One-step spin coating	1.100	6.36	11
	One-step spin coating (PEG-passivation)	1.280	7.31	
FTO/c-TiO_2/$CsPbIBr_2$/carbon	One-step spin coating (Precursor aging)	1.142	6.55	12
FTO/c-TiO_2/m-TiO_2/ $CsPbIBr_2$/Spiro-OMeTAD/Au	Two-step solution (Spraying assist)	1.127	6.3	13
FTO/c-TiO_2/m-TiO_2/ $CsPbIBr_2$/Carbon	Two-step solution	1.080	8.25	14
FTO/c-TiO_2/m-TiO_2/ $CsPbIBr_2$/Carbon	Two-step solution	0.960	6.14	15

FTO/NiO_x/$CsPbIBr_2$/ZnO/Al	Two-step solution	1.010	5.57	16

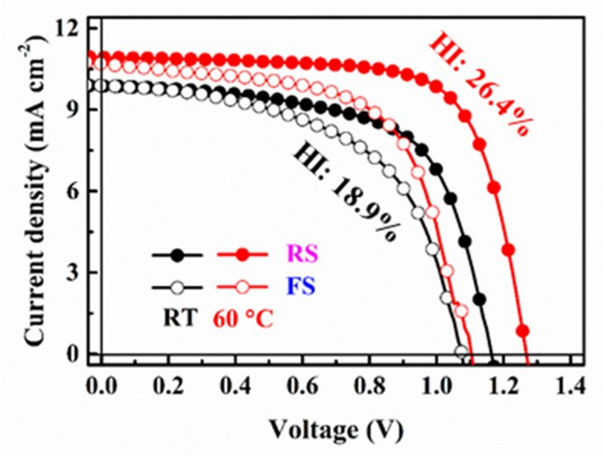

Fig. S11 J-V curves of cells measured under both forward and reverse scan directions.

Table S3 Summary of the electrochemical impedance spectra (EIS) parameters analyzed in Fig. 4g with fitting the Nyquist plots.

Substrate preheating temperature	R_s (Ω)	Transport resistance (R_{tr}) (Ω)	Recombination resistance (R_{rec}) (Ω)
RT	8.6	1140	260
60 ºC	6.7	1835	3250

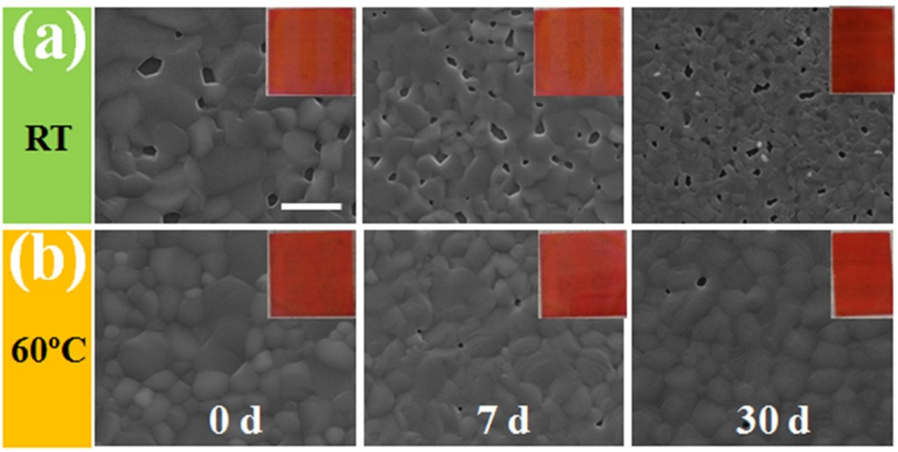

Fig. S12 The morphological evolution of the $CsPbIBr_2$ films formed at (a) RT and (b) a substrate preheating temperature of 60 ºC, respectively, under an ambient atmosphere of ~25 °C and ~35% RH. Insets are pictures of the corresponding perovskite films, and the scale bar is 2 µm.

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