Electronic Supplementary Material (ESI) for Journal of Materials Chemistry A.
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Supporting information

Application of a New π-Conjugated Ladder-Like Polymer in Enhancing Stability and Efficiency of Perovskite Solar Cells

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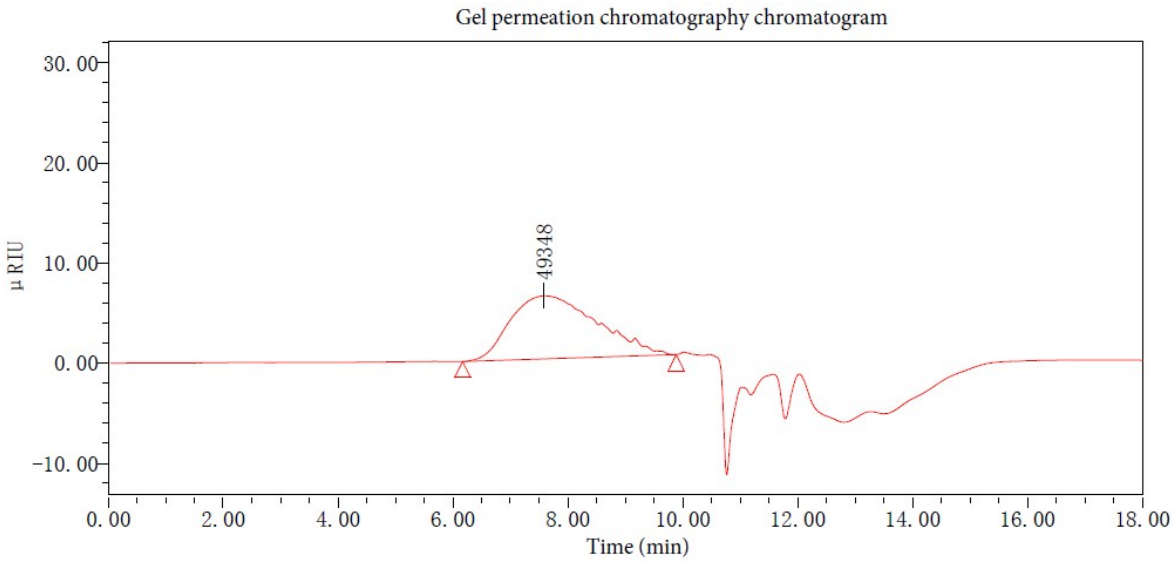

Fig. S1. Gel permeation chromatography (GPC) chromatogram of P-Si, Mn~ 23000, Mw=42019, peak molecular weight (Mp)=49348.

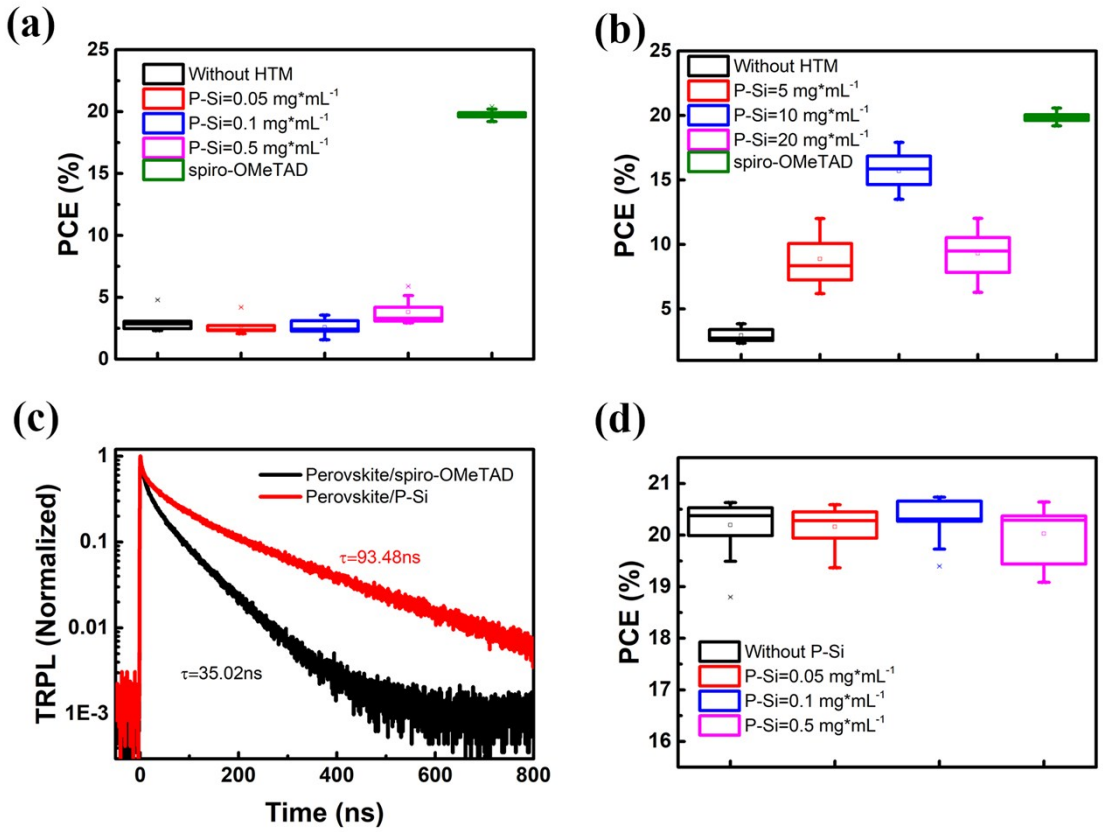

Fig. S2. Box statistical diagrams for a) and b) PSCs based on different HTMs (Device A); c) TRPL spectra of samples with a structure of Al_2O_3/perovskite/spiro-OMeTAD and Al_2O_3/perovskite/P-Si; d) PSCs with a configuration of ITO/SnO_2(20 nm)/PCBA-$(FAPbI_3)_x(MAPbBr_3)_{1-x}$ (600 nm)/P-Si/spiro-OMeTAD/Au (Device B). For statiscs, the number of devices under the same conditions is 10.

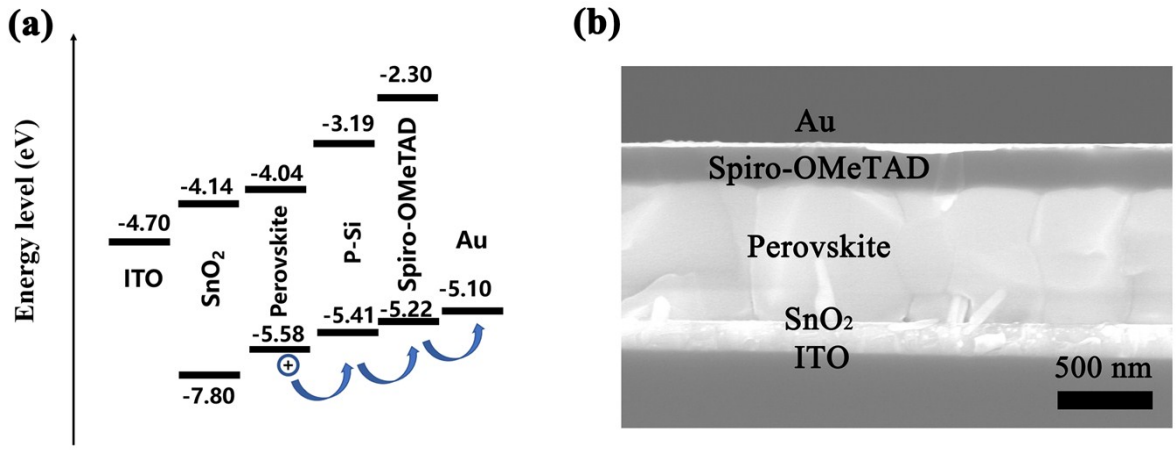

Fig. S3. a) Energy level diagram of PSCs and b) cross-sectional SEM image of PSCs.

Table S1. Statistical results of the photovoltaic parameters of PSCs prepared using different amounts of P-Si in anti-solvent CB.

Devices	Jsc ($mA * cm^{-2}$)	Voc(V)	FF	PCE(%)
Without P-Si	24.5±0.1 (24.8)	1.10±0.01 (1.11)	0.74±0.01 (0.76)	20.2±0.2 (20.6)
P-Si=0.05 mg ml^{-1}	24.9±0.1 (25.0)	1.11±0.01 (1.12)	0.74±0.01 (0.76)	20.5±0.3 (20.9)
P-Si=0.1 mg ml^{-1}	24.8±0.2 (25.1)	1.11±0.01 (1.13)	0.75±0.01 (0.77)	20.9±0.3 (21.5)
P-Si=0.5 mg ml^{-1}	24.9±0.1 (25.2)	1.09±0.01 (1.11)	0.75±0.01 (0.76)	20.3±0.3 (20.8)

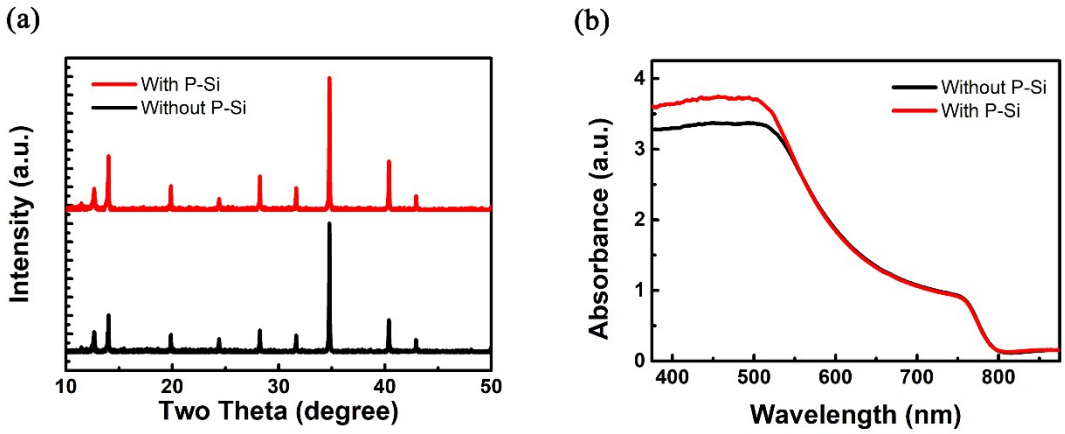

Fig. S4. a) XRD patterns of the perovskite films with and without P-Si, b) UV-vis absorption spectra of perovskite films with and without P-Si.

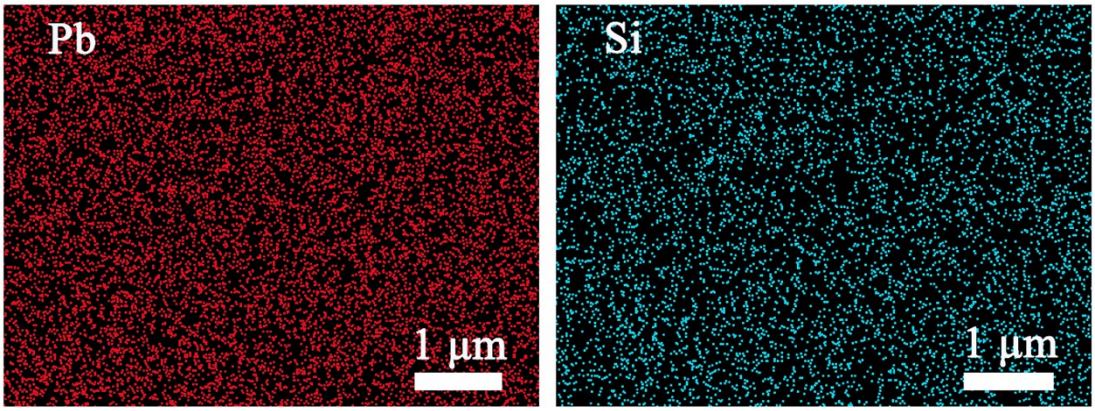

Fig. S5. The EDX analysis of Pb and Si elements on the surface of perovskite films with P-Si (0.1 mg ml^{-1}).

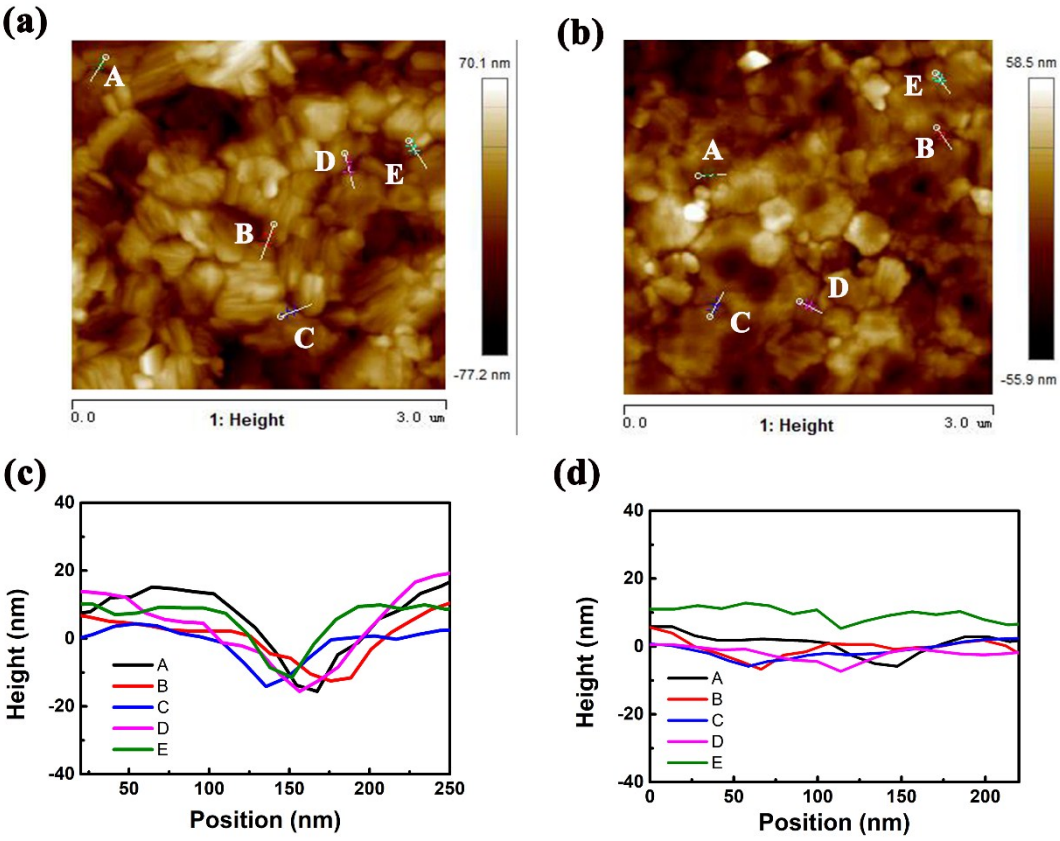

Fig. S6. AFM morphology images and corresponding height profiles across grain boundaries of the perovskite films ((a, c) without; (b, d) with P-Si (0.1 mg ml^{-1}).

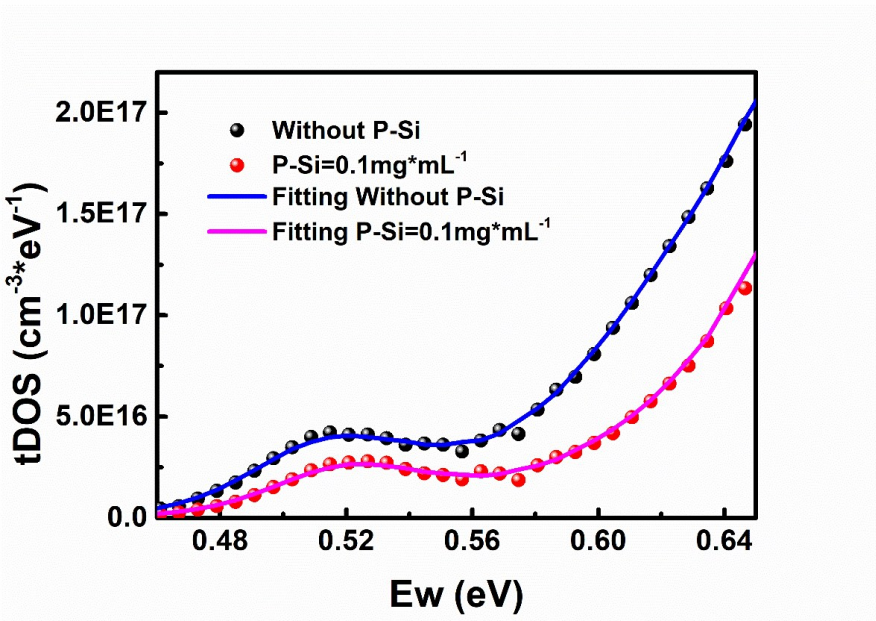

Fig. S7. t_{DOS} of the PSCs without and with P-Si (0.1 mg ml^{-1})

Table S2. Detailed fitting parameters of TRPL of the perovskite films prepared using different amounts of P-Si in anti-solvent CB.

Films	A_1	τ_1 (ns)	A_2	τ_2 (ns)	Average decay time τ (ns) [a]
Without P-Si	0.54	241.83	0.46	728.81	465.84
P-Si=0.05 mg mL^{-1}	0.59	241.53	0.41	722.84	438.85
P-Si=0.1 mg mL^{-1}	0.56	209.60	0.44	617.52	389.08
P-Si=0.5 mg mL^{-1}	0.53	126.74	0.47	29.90	81.23

[a] Average decay time is calculated according to the equation: $\tau = (A_1\tau_1 + A_2\tau_2)/(A_1 + A_2)$.

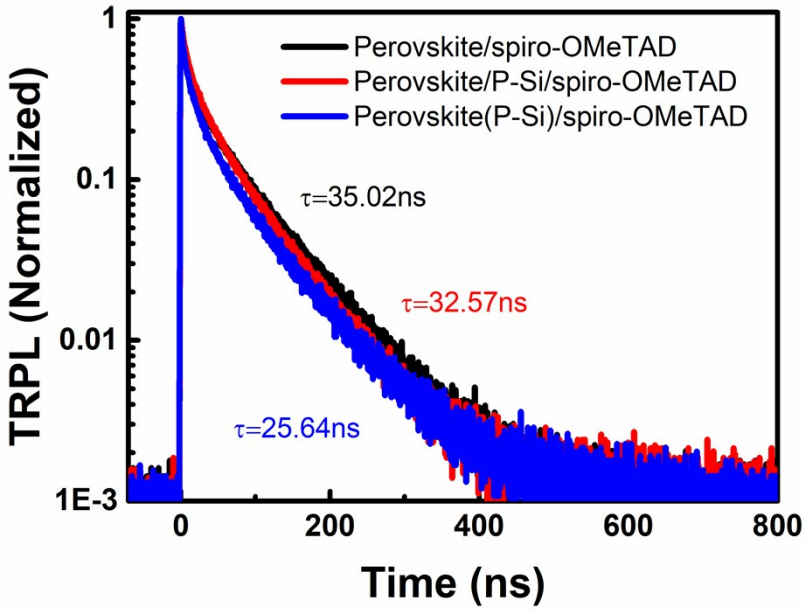

Fig. S8. TRPL spectra of samples with a structure of Al_2O_3/perovskite/Spiro-OMeTAD. The PVSK films were prepared by polymer containing the CB ((0.1 mg ml^{-1}) or with the pure CB.

Table S3. Detailed fitting parameters of TPV of the perovskite films prepared using different amounts of P-Si in anti-solvent CB.

Films	A_1	τ_1 (μs)	A_2	τ_2 (μs)	Average decay time τ_v (μs) [a]
Without P-Si	0.66	146.22	0.34	47.21	112.56
P-Si=0.05 mg ml^{-1}	0.40	56.02	0.60	195.46	139.68
P-Si=0.1 mg ml^{-1}	0.50	211.05	0.50	211.05	211.05
P-Si=0.5 mg ml^{-1}	0.10	121.72	0.90	22.31	32.25

[a] Average decay time is calculated according to the equation: $\tau_v = (A_1\tau_1 + A_2\tau_2)/(A_1 + A_2)$.

Table S4. Detailed fitting parameters of TPC of the perovskite films prepared using different amounts of P-Si in anti-solvent CB

Films	Average decay time τ_c (μs)
Without P-Si	1.21
P-Si=0.05 mg ml^{-1}	0.80
P-Si=0.1 mg ml^{-1}	0.75
P-Si=0.5 mg ml^{-1}	0.75

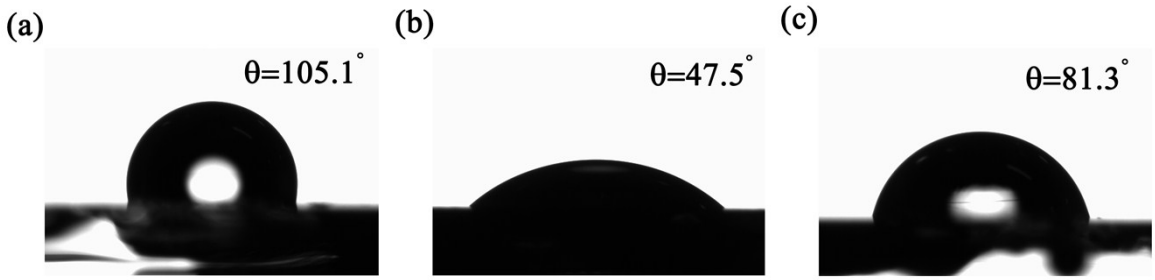

Fig. S9. The contact angle test of different samples a) P-Si film, b) pure perovskite film, c) 0.1P-Si/perovskite film.

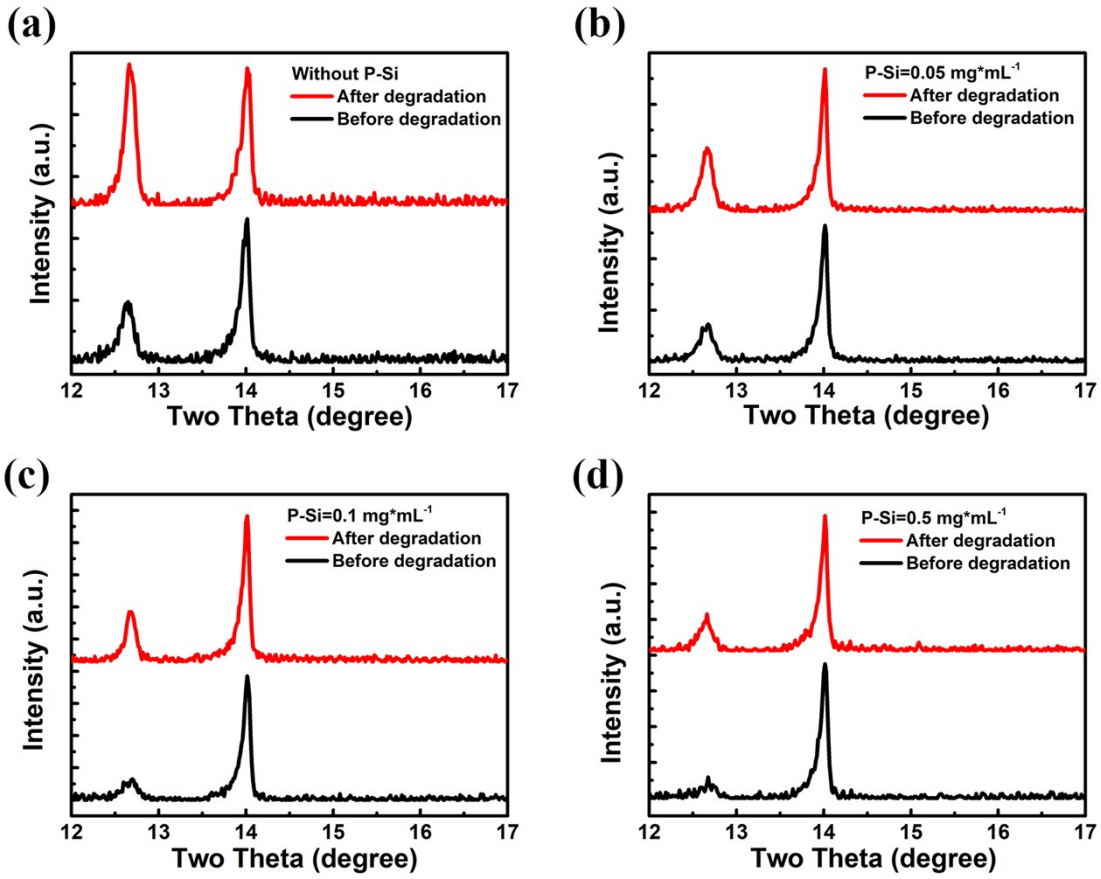

Fig. S10. The XRD characterization of the different perovskite films with and without P-Si, treated under 60% RH and 60 °C. The time of degradation is 90 min.

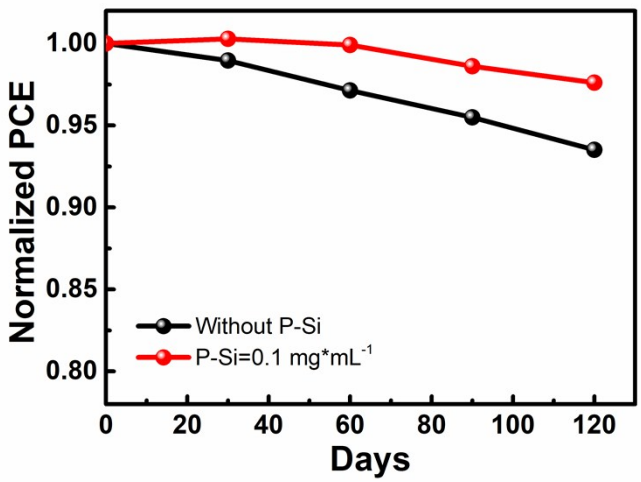

Fig. S11. Stability test. The average PCE of the PSCs changes with time under different conditions for the PSCs without and with 0.2 mg ml^{-1} P-Si dissolved in the anti-solvent CB. Each average (symbol) was calculated from 20 un-encapsulated devices.