Electronic Supplementary Information

21.7% Efficiency Achieved in Planar *n-i-p* Perovskite Solar Cells via Interface Engineering with Water-Soluble 2D TiS_2

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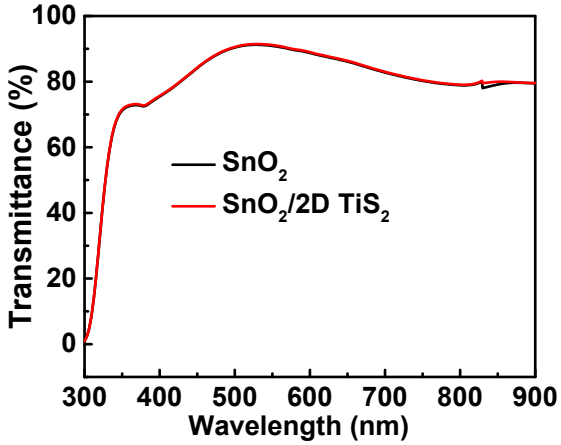

Fig. S1 UV-vis spectra of SnO_2 and SnO_2/2D TiS_2 on ITO substrates.

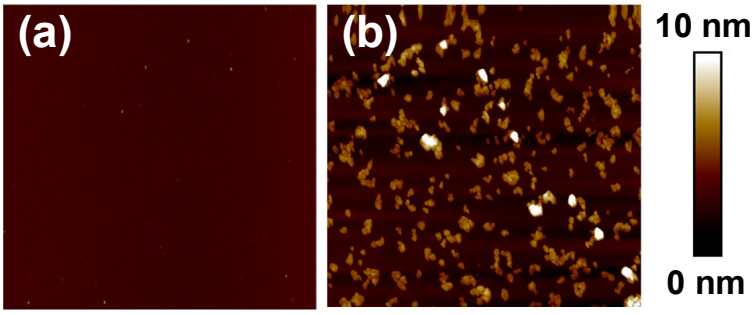

Fig. S2 AFM height images of (a) silicon wafer and (b) silicon wafer/2D TiS_2. The scan area of both images is 2 × 2 μm^2.

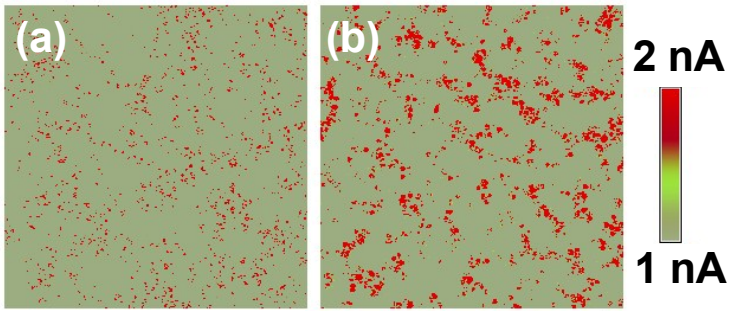

Fig. S3 c-AFM images of (a) ITO/SnO_2 and (b) ITO/SnO_2/2D TiS_2. The scan area of both images is 5 × 5 μm^2.

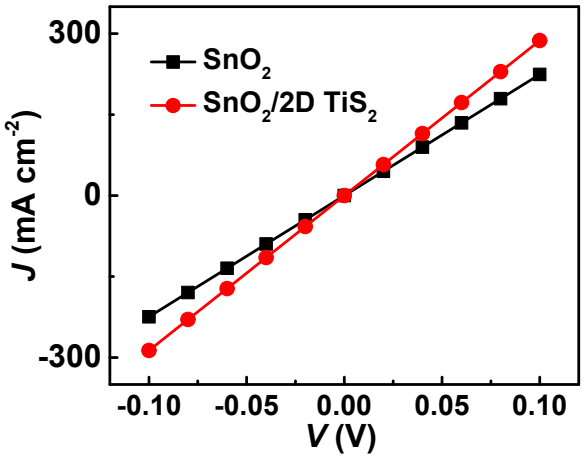

Fig. S4 *J-V* characteristics of devices with configuration of ITO/(SnO_2 or SnO_2/2D TiS_2)/Al.

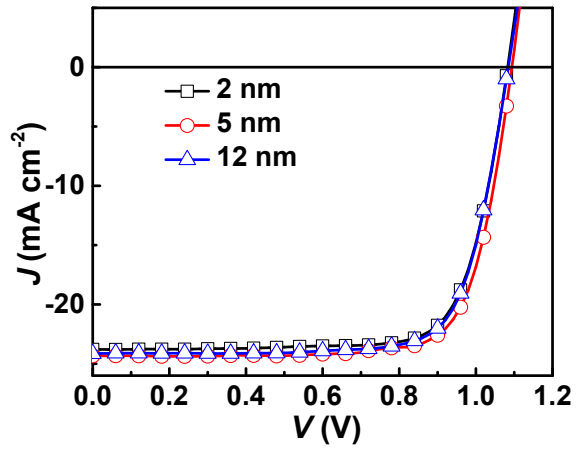

Fig. S5 *J-V* curves of Pero-SCs with different thicknesses of 2D TiS_2 as interlayer.

Table S1. Optimization of the thickness of 2D TiS_2 as interlayer in Pero-SCs.

Thickness (nm)	*V* (V)	J_{sc} (mA cm^{-2})	FF (%)	PCE (%)
2	1.08	23.79	76.02	19.58
5	1.09	24.34	76.39	20.34
12	1.09	24.34	73.68	19.54

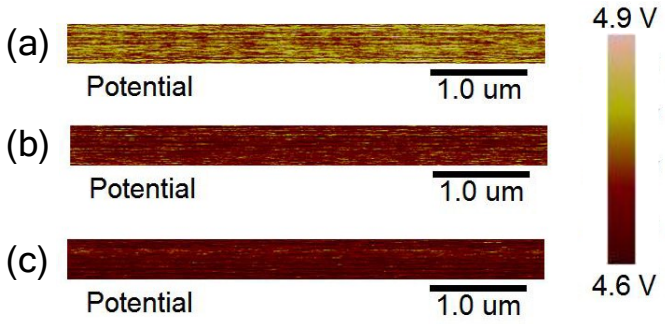

Fig. S6 Surface potential images of (a) bare ITO, (b) ITO/SnO_2 and (c) ITO/SnO_2/2D TiS_2 films.

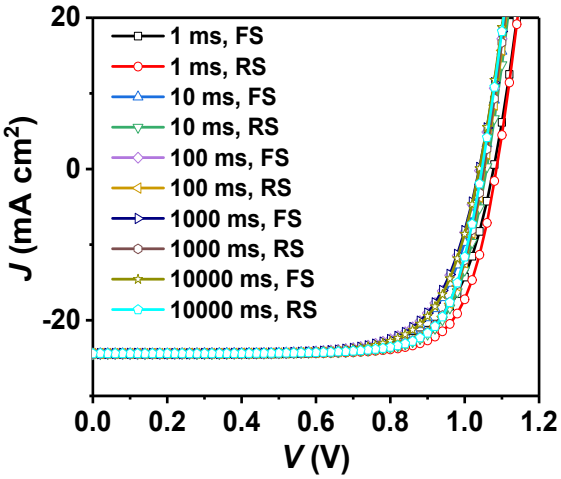

Fig. S7 *J-V* curves of Pero-SCs for the different delay time.

Table S2. Device parameters of Pero-SCs for the different delay time.

Condition	V_{oc} (V)	J_{sc} (mA cm^{-2})	FF (%)	PCE (%)
1 ms, FS	1.08	24.44	73.2	19.29
1 ms, RS	1.09	24.45	76.9	20.40
10 ms, FS	1.05	24.46	71.9	18.39
10 ms, RS	1.06	24.42	76.3	19.72
100 ms, FS	1.04	24.41	71.3	18.12
100 ms, RS	1.05	24.40	76.2	19.57
1000 ms, FS	1.04	24.39	71.7	18.17
1000 ms, RS	1.05	24.41	76.3	19.56
10000 ms, FS	1.04	24.39	72.5	18.38
10000 ms, RS	1.05	24.41	76.9	19.63

Table S3. n and J_0 extracted from the J-V curves in the dark.

ETL	n	J_0 (mA cm^{-2})
SnO_2	2.47	6.5×10^{-9}
SnO_2/2D TiS_2	2.18	6.6×10^{-10}

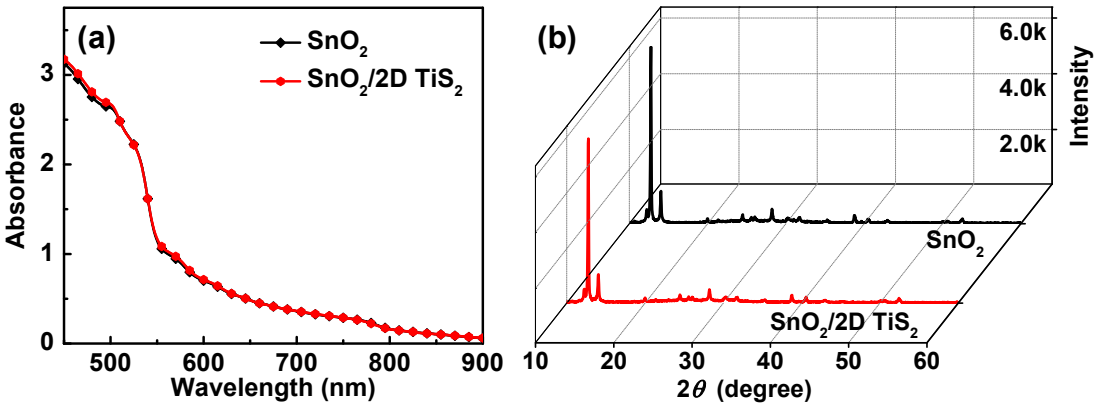

Fig. S8 (a) UV-vis absorption spectra and (b) XRD patterns of Pero-TFs on different ETLs.

Table S4. The parameters of the equivalent circuit for Pero-SCs based on different ETLs.

ETLs	R_s (Ω)	R_{tr} (Ω)	C_1 (nF)	R_{rec} (Ω)	C_2 (nF)
SnO_2	24.3	45.9	3.3	52.9	7.1
SnO_2/2D TiS_2	27.6	17.4	4.0	111.1	3.5

Table S5. Lifetimes and weighted fractions fitted from the transient PL spectra.

ETL	τ_1 (ns)	f_1 (%)	τ_2 (ns)	f_2 (%)
SnO_2	16.6	22.2	121.6	77.8
SnO_2/2D TiS_2	11.6	29.1	83.9	70.9

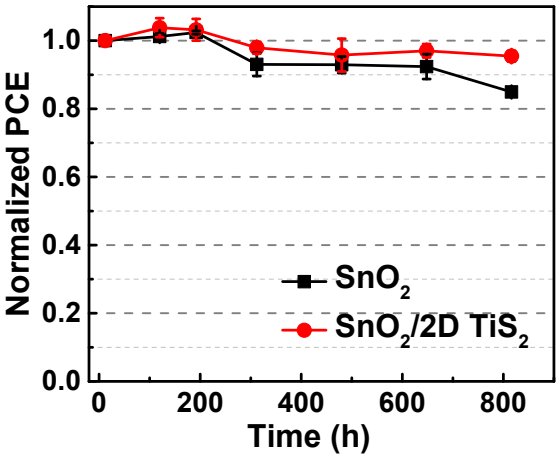

Fig. S9 Time dependent PCE of Pero-SCs based on different ETLs. The test was conducted at dry air (10% relative humidity).