Electronic Supplementary Material (ESI) for New Journal of Chemistry.

Multifunctional strategy of two-dimensional WS_2 modified absorbers for efficient planar perovskite solar cells

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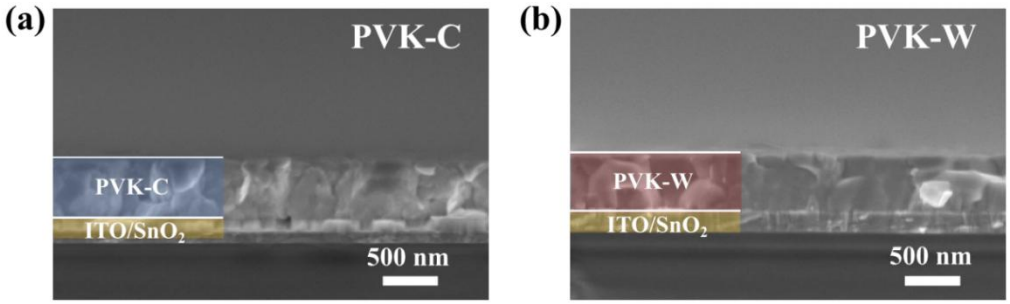


Figure S1. Cross-sectional SEM images of different absorbers: (a) PVK-C and (b) PVK-W.

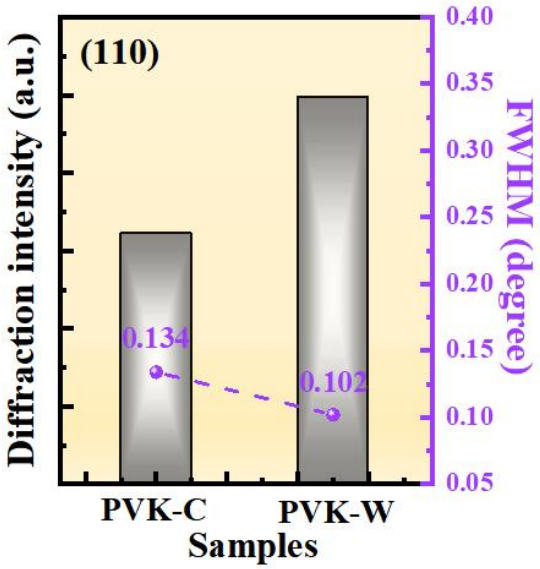


Figure S2. FWHM and diffraction intensity of PVK-C and PVK-W films.

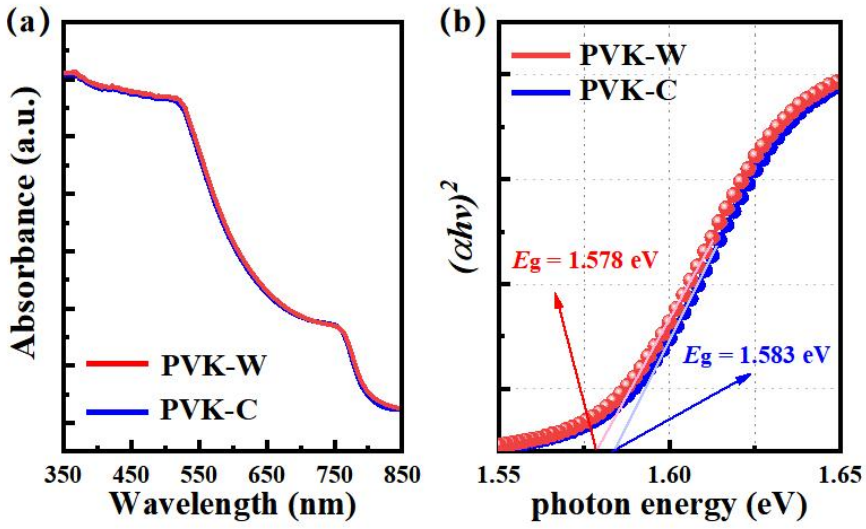


Figure S3. (a) UV−vis absorption spectra and (b) Tauc plots of perovskite films with and without WS_2 NSs. The E_g of the samples with and without WS_2 were calculated to be 1.578 and 1.583 eV, respectively, using the formula $\alpha h\nu = A\ (h\nu - E_g)^n$, where α is the absorption coefficient, $h\nu$ is photon energy, A is a constant, and n varies according to allowed or forbidden direct and indirect transitions. The value n = 1/2 is employed in this case since the perovskite is regarded as a direct band-gap semiconductor.

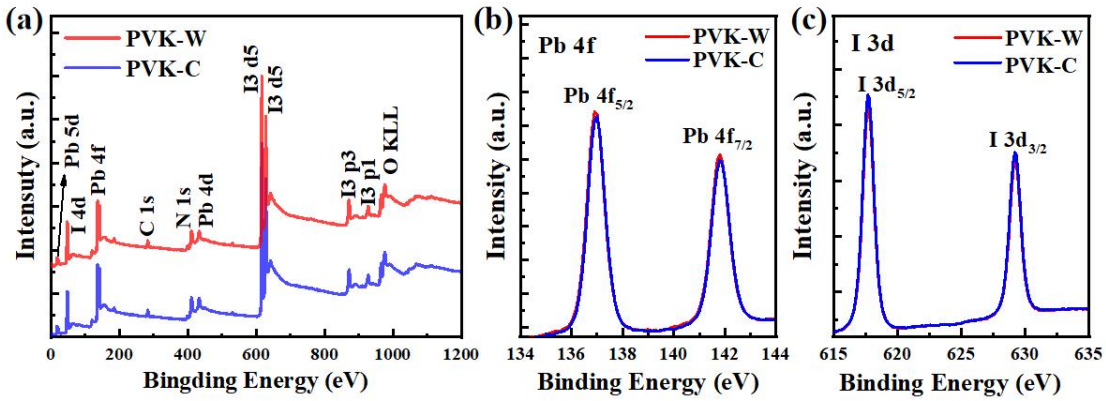
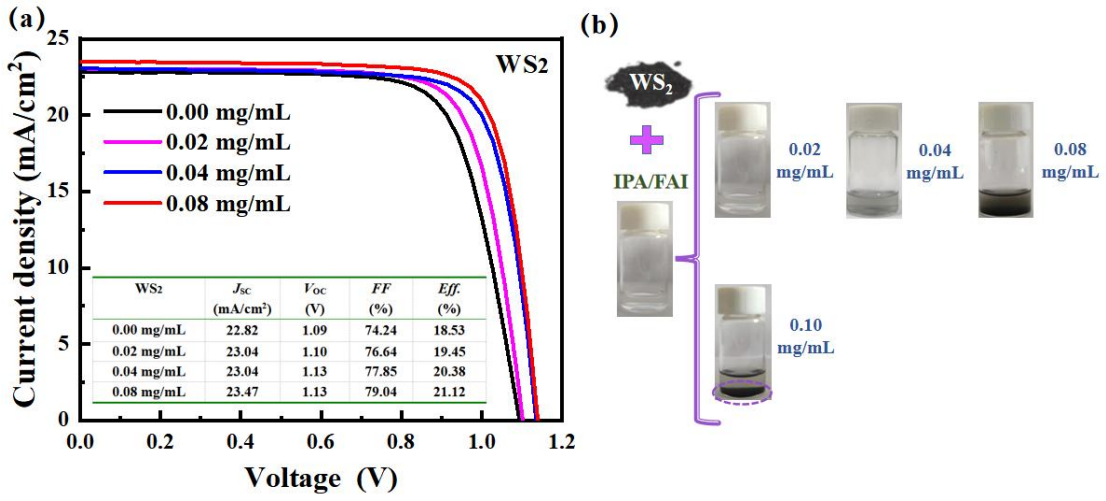


Figure S4. (a) XPS spectra of PVK-C and PVK-W films. High-resolution XPS spectra of the corresponding samples: (b) Pb 4f and (c) I 3d.



WS2	J_{SC} (mA/cm²)	V_{OC} (V)	*FF* (%)	*Eff.* (%)
0.00 mg/mL	22.82	1.09	74.24	18.53
0.02 mg/mL	23.04	1.10	76.64	19.45
0.04 mg/mL	23.04	1.13	77.85	20.38
0.08 mg/mL	23.47	1.13	79.04	21.12

Figure S5. (a) *J*−*V* curves of planar PSCs fabricated with the WS_2 concentrations of 0.00 mg/mL, 0.02 mg/mL, 0.04 mg/mL, and 0.08 mg/mL, respectively. (b) Photographs of dispersions fabricated using WS_2 of 0.00, 0.02, 0.04, 0.08, and 0.10 mg/mL.

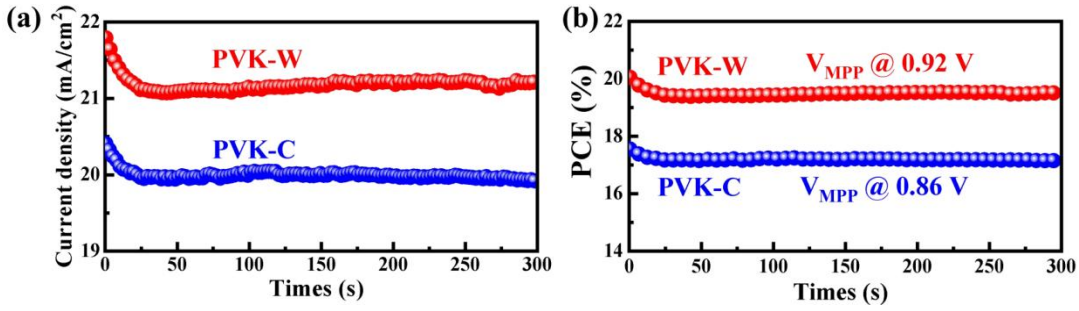


Figure S6. (a)−(b) Stable current densities and PCEs measured under constant bias of 0.86 V (PVK-C device) and 0.92 V (PVK-W device).

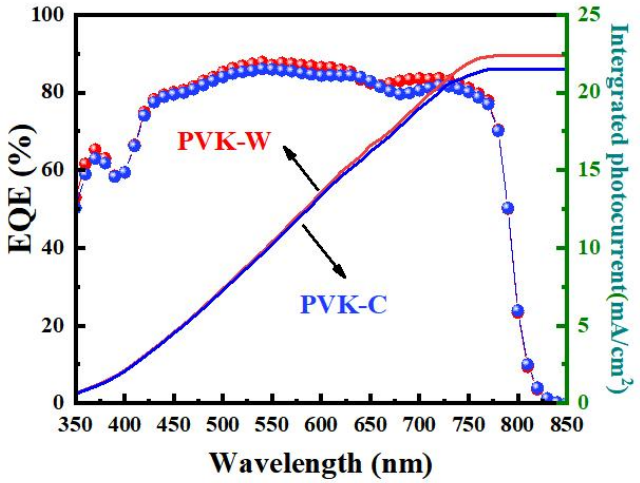


Figure S7. EQE spectra of the best-performing planar devices based on PVK-C and PVK-W devices.

Table S1

Dynamic parameters from TRPL curves.

Samples	A_1	τ_1 (ns)	A_2	τ_2 (ns)
PVK-C	4104	8.3	2038	33.9
PVK-W	1005	2.8	490	22.8

Table S2

Fitting parameters from EIS.

Samples	R_s (Ω)	R_{tr} (Ω)	R_{rec} (Ω)	C_{tr} (F)	C_{rec} (F)
PVK-C	31.20	52.35	185.8	1.05×10^{-8}	6.7×10^{-9}
PVK-W	17.46	32.26	327.5	1.04×10^{-8}	8.2×10^{-9}

Table S3

Photovoltaic parameters of PVK-W PSCs. The *J–V* curves were measured in R-S under the AM 1.5G illumination. Average data were calculated from 12 devices for each condition.

PVK-W PSCs	J_{SC} (mA/cm^2)	V_{OC} (V)	*FF* (%)	*Eff.* (%)
1	22.82	1.10	78.86	19.89
2	23.52	1.12	77.03	20.43
3	23.25	1.10	75.25	19.36
4	23.15	1.11	78.63	20.24
5	23.35	1.11	78.12	20.32
6	23.65	1.12	78.92	21.03
7	23.11	1.10	77.09	19.64
8	23.94	1.14	75.52	20.74
9	24.12	1.13	76.58	20.96
10	24.23	1.13	76.31	20.87
11	23.71	1.09	75.96	19.80
12	23.59	1.10	76.66	20.03
Average	**23.53±0.41**	**1.11±0.02**	**77.07±1.24**	**20.27±0.53**

Table S4

Photovoltaic parameters of PVK-C PSCs. The *J–V* curves were measured in R-S under the AM 1.5G illumination. Average data were calculated from 12 devices for each condition.

PVK-C PSCs	J_{SC} **(mA/cm^2)**	V_{OC} **(V)**	***FF*** **(%)**	***Eff.*** **(%)**
1	22.31	1.11	73.72	18.35
2	22.63	1.13	73.22	18.73
3	21.42	1.09	73.10	17.03
4	22.80	1.12	73.26	18.76
5	21.46	1.10	70.98	18.24
6	22.27	1.13	74.41	17.63
7	23.01	1.13	74.87	19.49
8	22.93	1.13	74.74	19.38
9	22.83	1.12	73.40	18.90
10	22.52	1.10	73.78	18.30
11	23.27	1.13	74.69	19.75
12	22.75	1.13	73.88	19.02
Average	**22.51±0.56**	**1.11±0.02**	**73.67±1.01**	**18.63±0.75**