(Supplementary Information)

Improved efficiency and air stability of two-dimensional p-i-n inverted perovskite solar cells by Cs doping

Tzu-Chien Hsieh[1,5], Chung-Yueh Shih[1,5], Yu-Chiang Chao[2,*], I-Chun Cheng[3,4,6,*], Jian-Zhang Chen[1,5,6,*]

[1]Graduate Institute of Applied Mechanics, National Taiwan University, Taipei City 10617, Taiwan

[2]Department of Physics, National Taiwan Normal University, Taipei City 11677, Taiwan

[3]Graduate Institute of Photonics and Optoelectronics, National Taiwan University, Taipei City 10617, Taiwan

[4]Department of Electrical Engineering, National Taiwan University, Taipei City 10617, Taiwan

[5]Advanced Research Center for Green Materials Science and Technology, National Taiwan University, Taipei City 10617, Taiwan

[6]Innovative Photonics Advanced Research Center (i-PARC), National Taiwan University, Taipei City 10617, Taiwan

Corresponding Authors

*Jian-Zhang Chen Email: jchen@ntu.edu.tw

I-Chun Cheng Email: iccheng@ntu.edu.tw

Yu-Chiang Chao Email: ycchao@ntnu.edu.tw

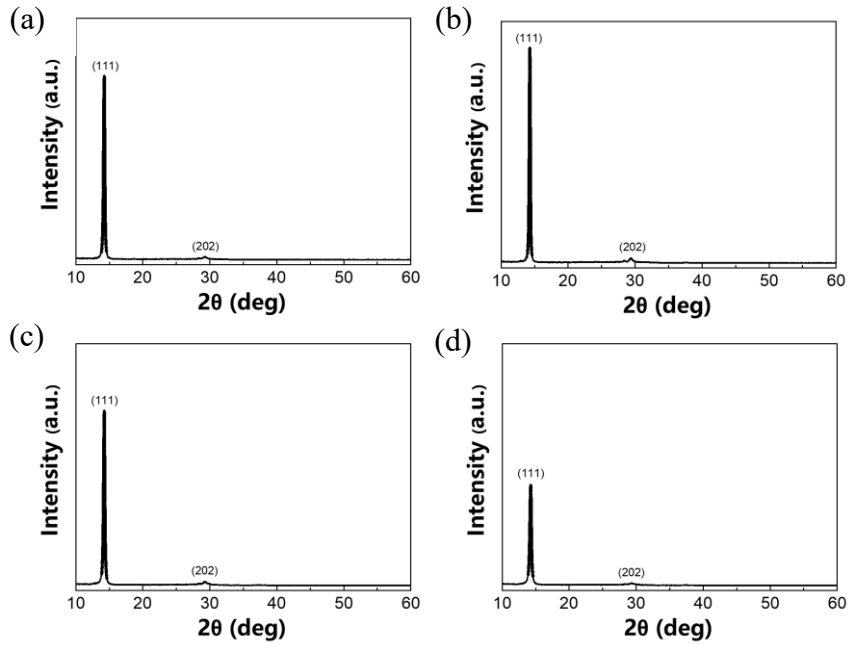


Figure S1. GIXRD diffraction patterns of 2D perovskite films doped with (a) 5%, (b) 10%, (c) 15%, and (d) 20% Cs.

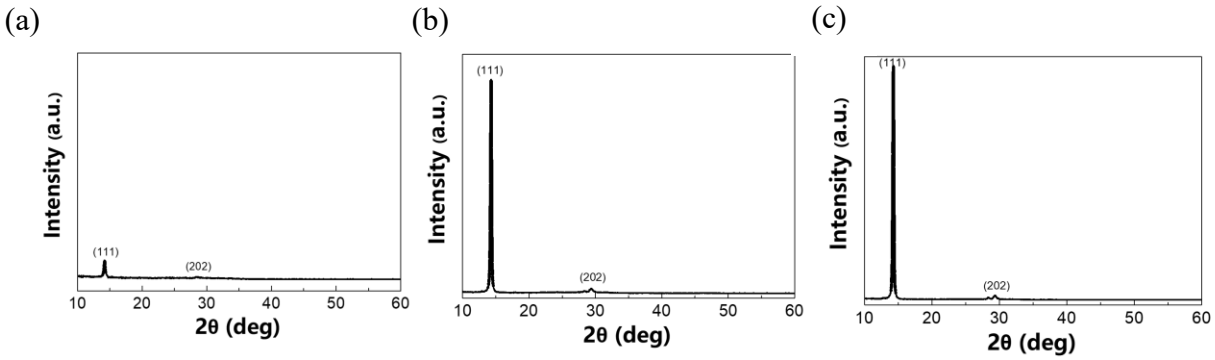


Figure S2. GIXRD diffraction patterns of 2D perovskite film with 10% Cs doping. The films were prepared with various constituent chemical molar concentrations: (a) 1.0 M , (b) 1.2 M , and (c) 1.4 M.

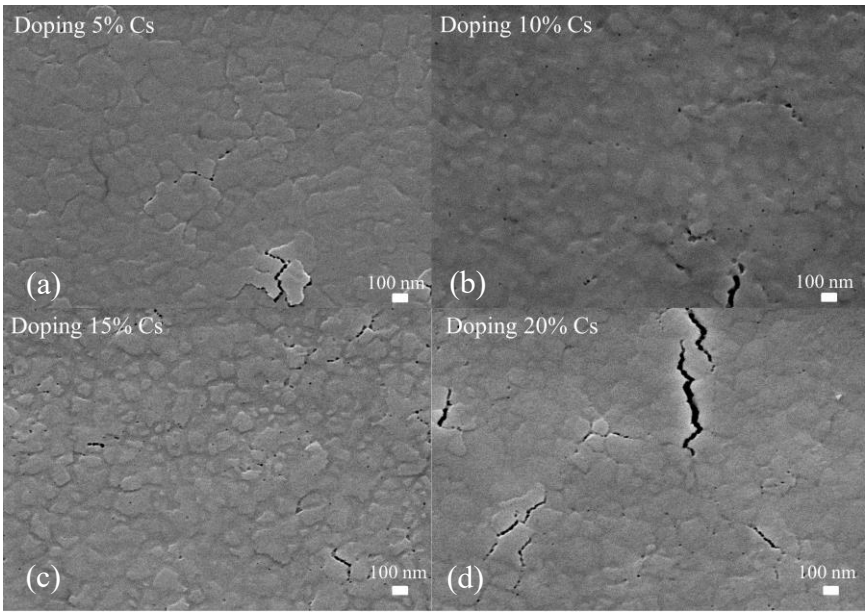


Figure S3. Topview SEM images of 2D perovskite films doped with (a) 5% , (b) 10% , (c) 15% , and (d) 20% Cs.

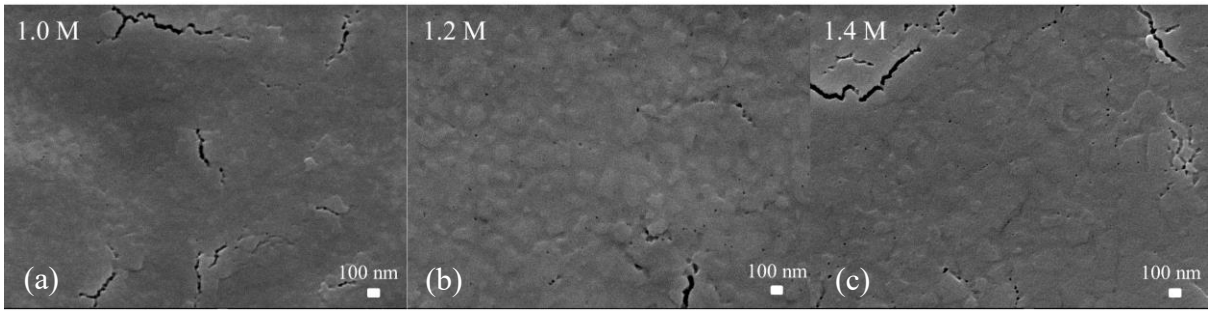


Figure S4. Top-view SEM images of 2D perovskite films with 10% Cs doping. The films were prepared with various constituent chemical molar concentrations: (a) 1.0 M , (b) 1.2 M , and (c) 1.4 M.

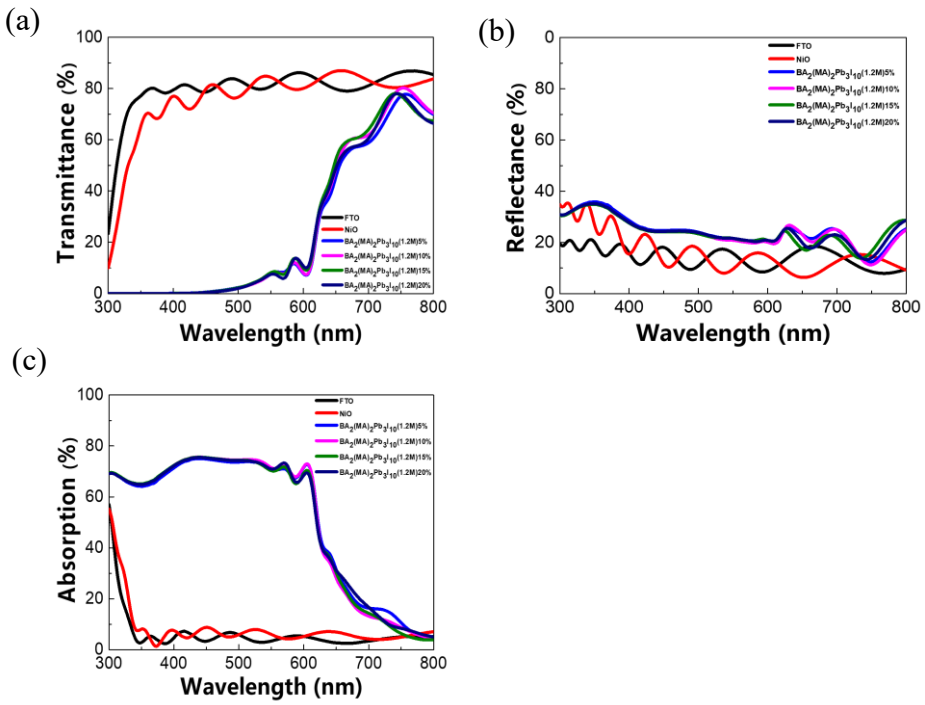


Figure S5. UV–Vis spectra of 2D perovskite films: (a) transmittance, (b) reflectance, and (c) absorption spectra.

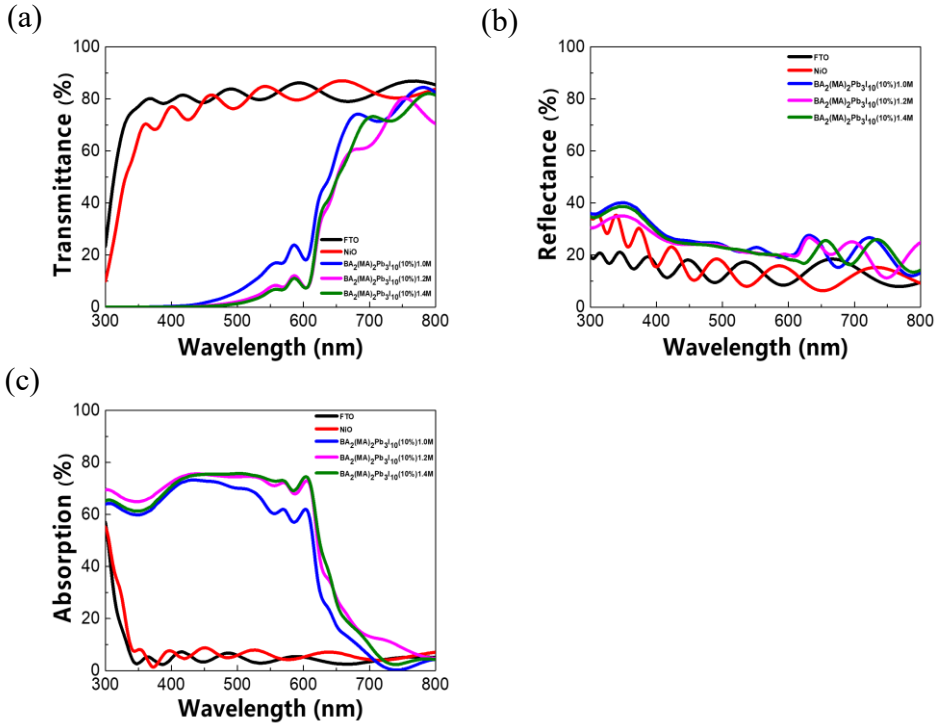
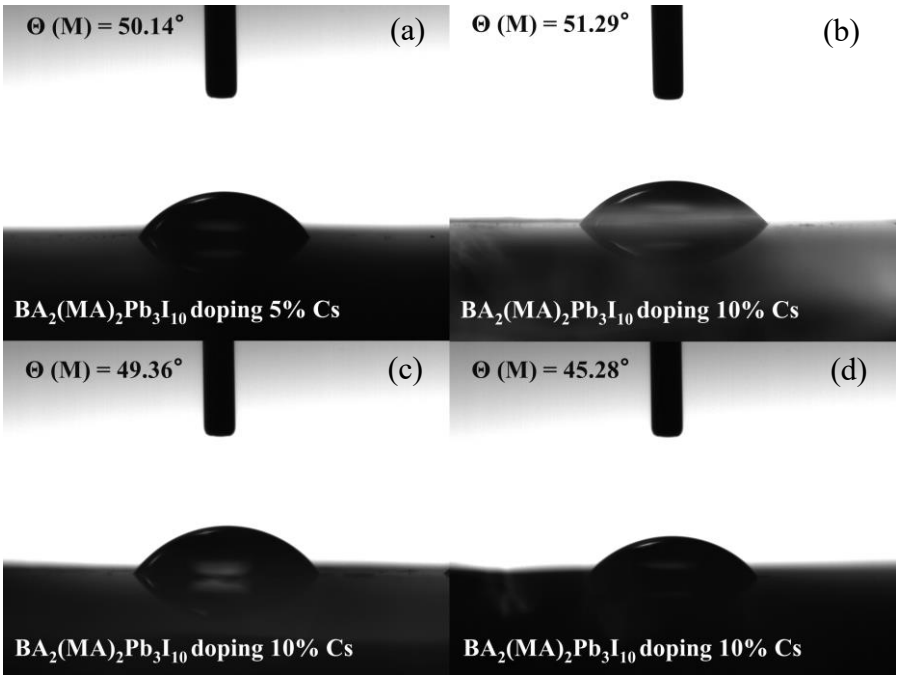


Figure S6. UV–Vis spectra of 2D perovskite films doped with 10% Cs doping but prepared with different constituent chemical molar concentrations: (a) transmittance, (b) reflectance, and (c) absorption spectra.



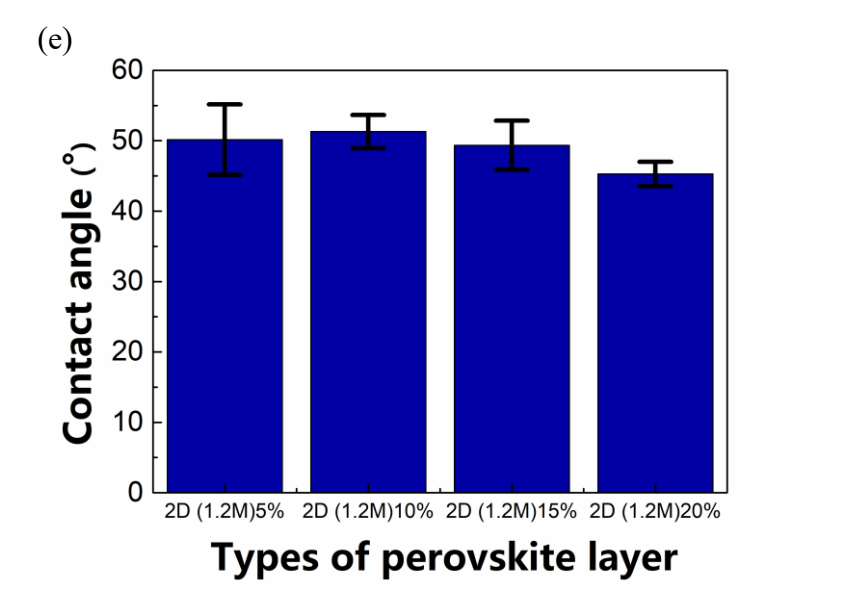
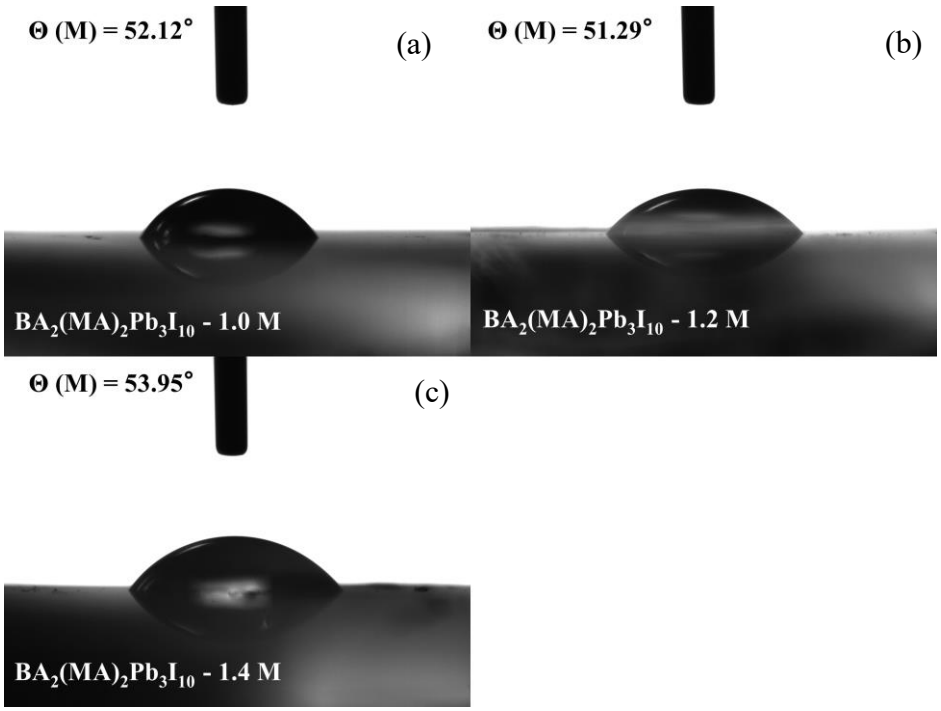


Figure S7. Water contact angle images of 2D perovskite films doped with (a) 5% , (b) 10% , (c) 15% , and (d) 20% Cs. (e) Comparison of water contact angles of perovskite films prepared with various Cs doping concentrations.



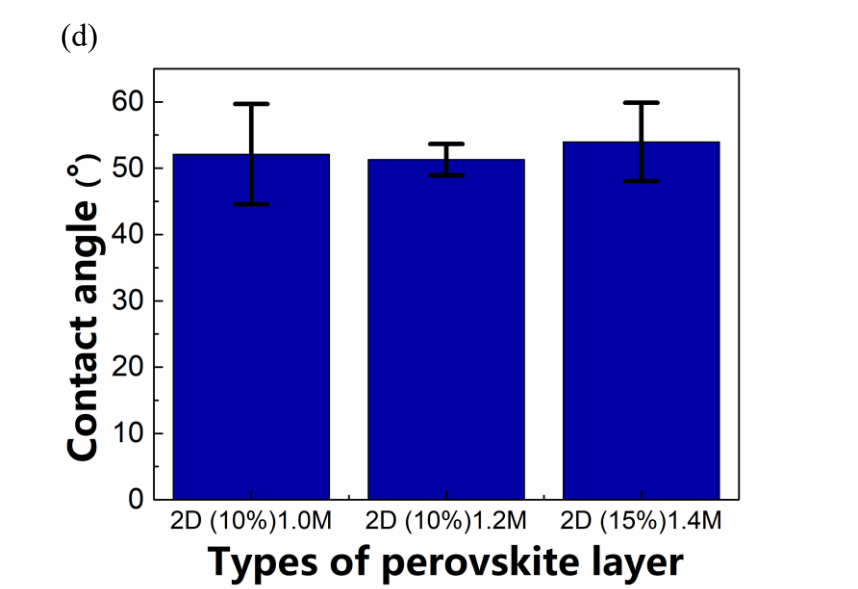


Figure S8. Water contact angle images of 2D perovskite films doped with 10% Cs but prepared with different constituent chemical molar concentrations: (a) 1.0 M , (b) 1.2 M , and (c) 1.4 M. (d) Comparison of water contact angles.

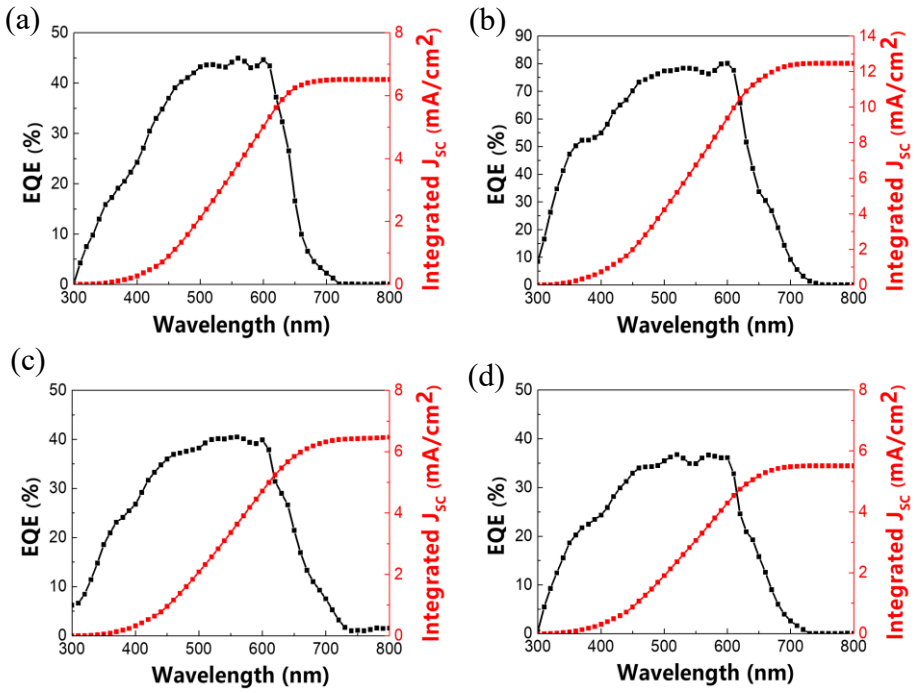


Figure S9. EQE and corresponding integrated photocurrent curve of PSCs doped with (a) 5%, (b) 10%, (c) 15%, and (d) 20% Cs.

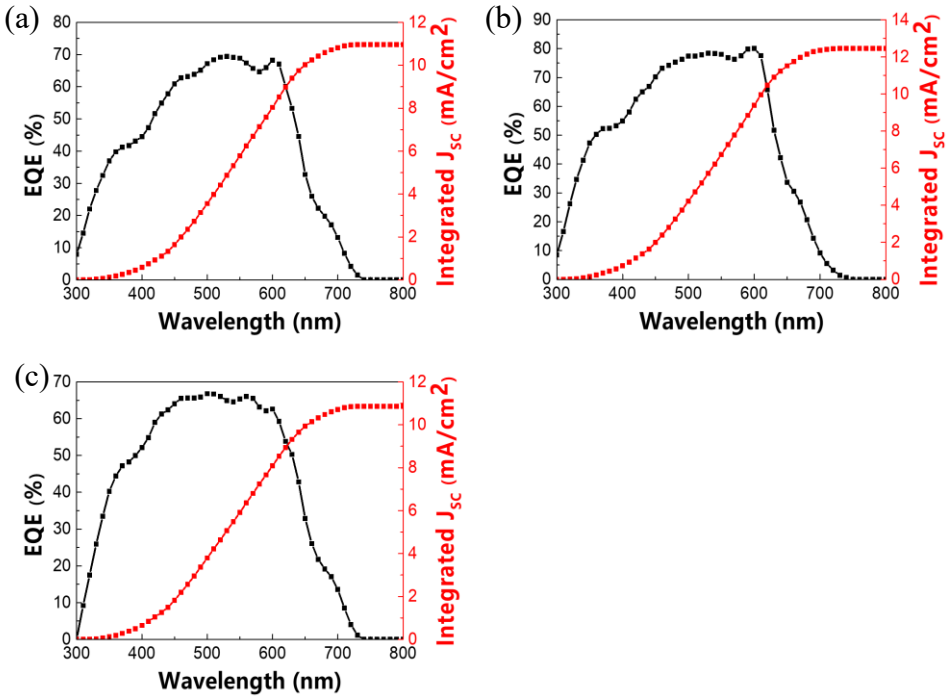


Figure S10. EQE and corresponding integrated photocurrent curves of PSCs doped with 10% Cs but prepared with different constituent chemical molar concentrations: (a) 1.0 M, (b) 1.2 M, and (c) 1.4 M.

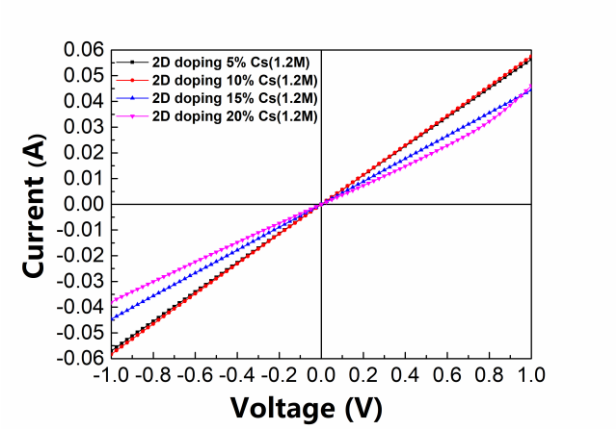


Figure S11. Through-plane conductivity measurement of perovskite films with various Cs doping concentrations.

Table S1. Through-plane conductivity of perovskite films with various Cs doping concentrations.

Perovskite film	**Conductivity ($mS \cdot m^{-1}$)**
1.2M $BA_2(MA)_2Pb_3I_{10}$ with 5% Cs doping	2.52 ± 1.51698 E-02
1.2M $BA_2(MA)_2Pb_3I_{10}$ with 10% Cs doping	2.56 ± 1.64175 E-02
1.2M $BA_2(MA)_2Pb_3I_{10}$ with 15% Cs doping	1.98 ± 6.89928 E-03
1.2M $BA_2(MA)_2Pb_3I_{10}$ with 20% Cs doping	1.68 ± 9.20934 E-02

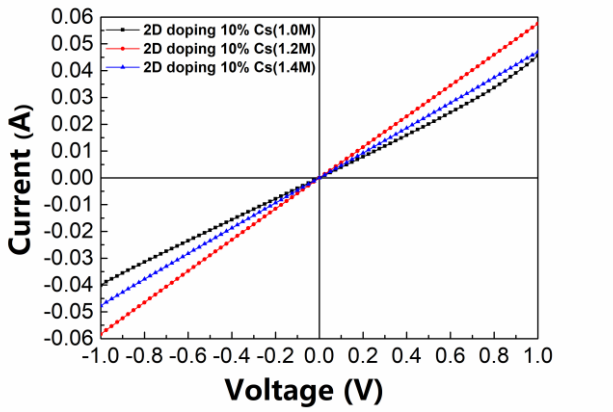


Figure S12. Through-plane conductivity measurement of perovskite films with 10% Cs doping but prepared with various constituent chemical molar concentrations.

.

Table S2. Through-plane conductivity of perovskite films with 10% Cs doping but prepared

with various constituent chemical molar concentrations.

Perovskite film	Conductivity (mS·m^{-1})
1.0M $BA_2(MA)_2Pb_3I_{10}$ with 10% Cs doping	1.78 ± 6.51451 E-02
1.2M $BA_2(MA)_2Pb_3I_{10}$ with 10% Cs doping	2.56 ± 1.64175 E-02
1.4M $BA_2(MA)_2Pb_3I_{10}$ with 10% Cs doping	2.08 ± 1.71285 E-02

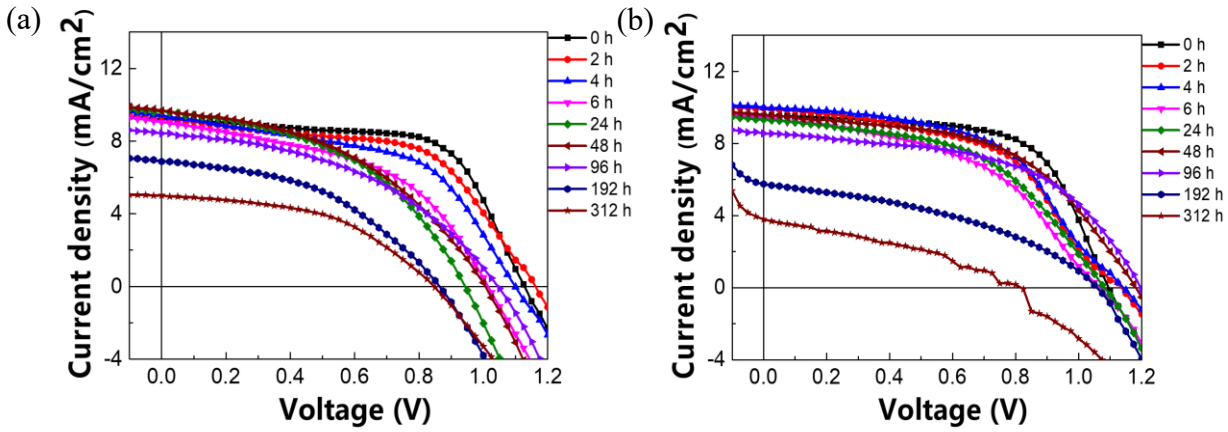


Figure S13. Evolutions of JV curves of PSCs without Cs doping when exposed to air: (a) reverse and (b) forward scans.

Table S3. Evolutions of PV parameters of PSCs without Cs doping when exposed to air.

Time		V_{oc} (V)	J_{sc} (mA/cm^2)	F.F. (%)	PCE (%)
0 h	Forward	1.096	9.528	63.087	6.588
	Reverse	1.121	9.192	65.058	6.702
2 h	Forward	1.171	9.949	48.738	5.676
	Reverse	1.160	9.373	55.953	6.084
4 h	Forward	1.139	9.986	51.466	5.853
	Reverse	1.099	9.431	52.770	5.469
6 h	Forward	1.064	9.440	46.943	4.716
	Reverse	1.014	9.044	47.887	4.393
24 h	Forward	1.081	9.323	49.603	4.997
	Reverse	0.944	9.655	45.804	4.174
48h	Forward	1.182	9.590	51.952	5.890

	Reverse	1.005	9.668	44.013	4.275
96 h	Forward	1.201	8.557	52.922	5.440
	Reverse	1.045	8.418	43.974	3.869
192 h	Forward	1.059	5.748	39.777	2.421
	Reverse	0.864	6.874	44.45	2.640
312 h	Forward	0.864	3.793	32.621	1.069
	Reverse	0.847	5.007	47.725	2.025

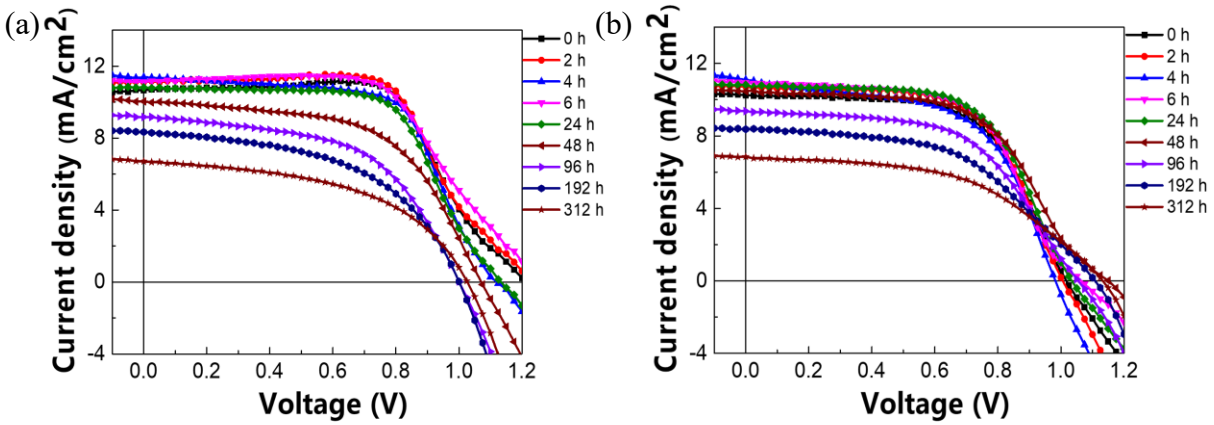


Figure S14. Evolutions of JV curves of PSCs with 10% Cs doping when exposed to air: (a) reverse and (b) forward scans.

Table S4. Evolutions of PV parameters of PSCs with10% Cs doping when exposed to air.

Time		V_{oc} (V)	J_{sc} (mA/cm^2)	F.F. (%)	PCE (%)
0 h	Forward	1.019	10.249	61.072	6.376
	Reverse	1.211	10.652	64.310	8.297
2 h	Forward	1.005	10.719	61.548	6.630
	Reverse	1.231	11.103	62.159	8.495
4 h	Forward	0.983	11.101	57.158	6.235
	Reverse	1.120	11.382	62.690	7.990
6 h	Forward	1.077	10.952	57.070	6.735
	Reverse	1.248	11.114	59.555	8.262
24 h	Forward	1.033	10.813	60.822	6.793
	Reverse	1.130	10.817	62.778	7.672
48h	Forward	1.151	10.462	54.684	6.586
	Reverse	1.071	10.039	56.953	6.122

96 h	Forward	1.054	9.366	55.370	5.466
	Reverse	1.002	9.173	54.154	4.975
192 h	Forward	1.109	8.368	50.722	4.705
	Reverse	1.003	8.336	50.606	4.230
312 h	Forward	1.134	6.850	50.331	3.910
	Reverse	1.029	6.708	49.952	3.447

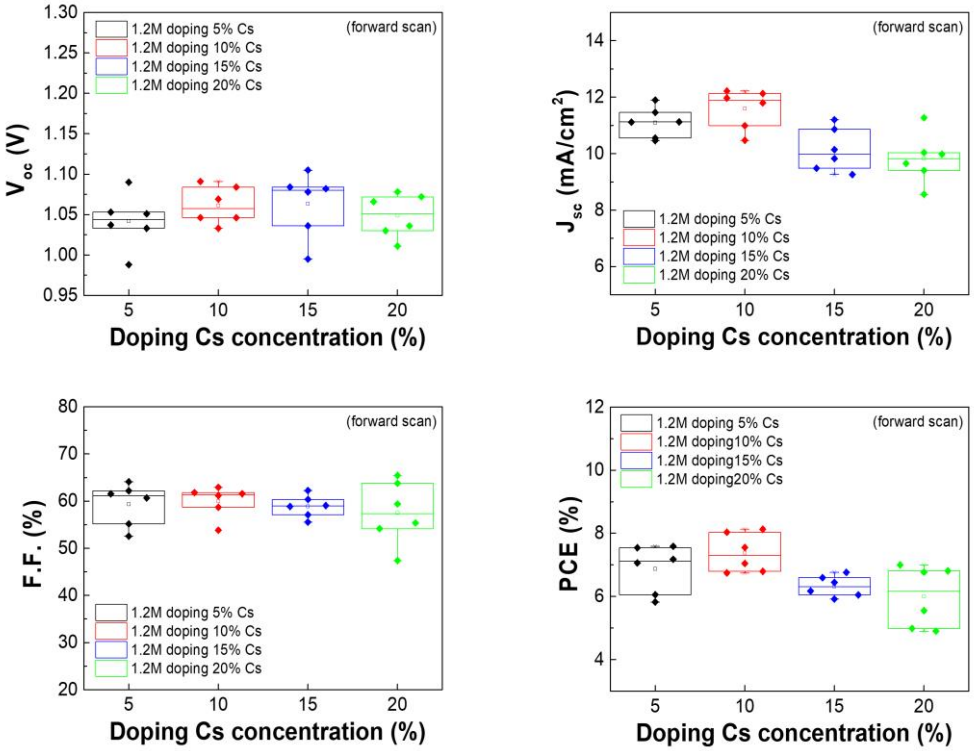


Figure S15. PV parameters of PSCs with different Cs doping concentrations (forward scan).

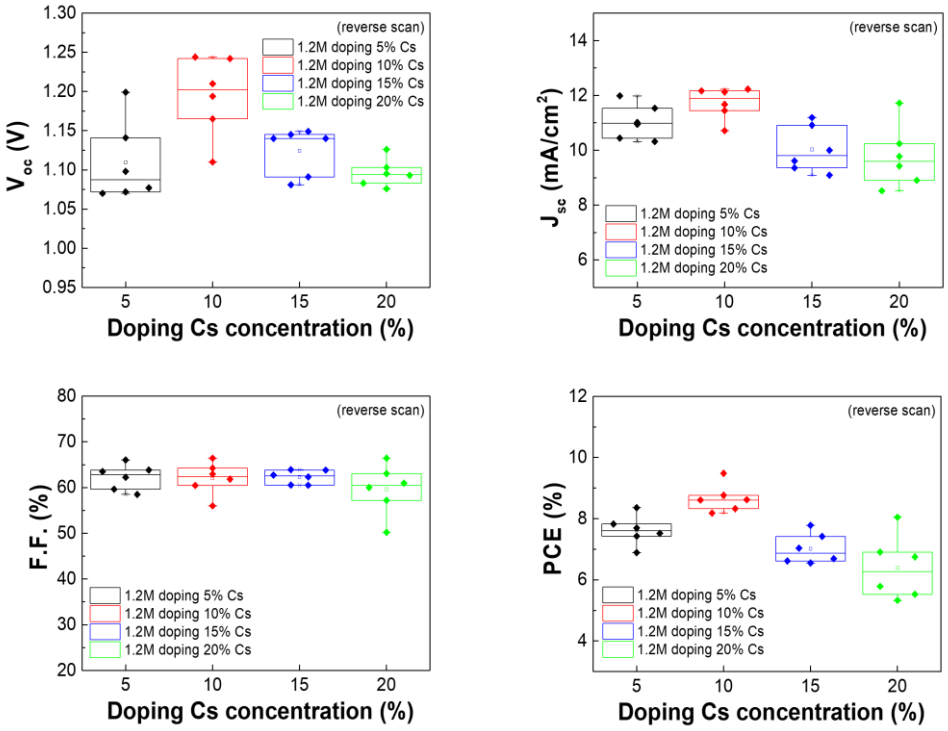


Figure S16. PV parameters of PSCs with different Cs doping concentrations (reverse scan).

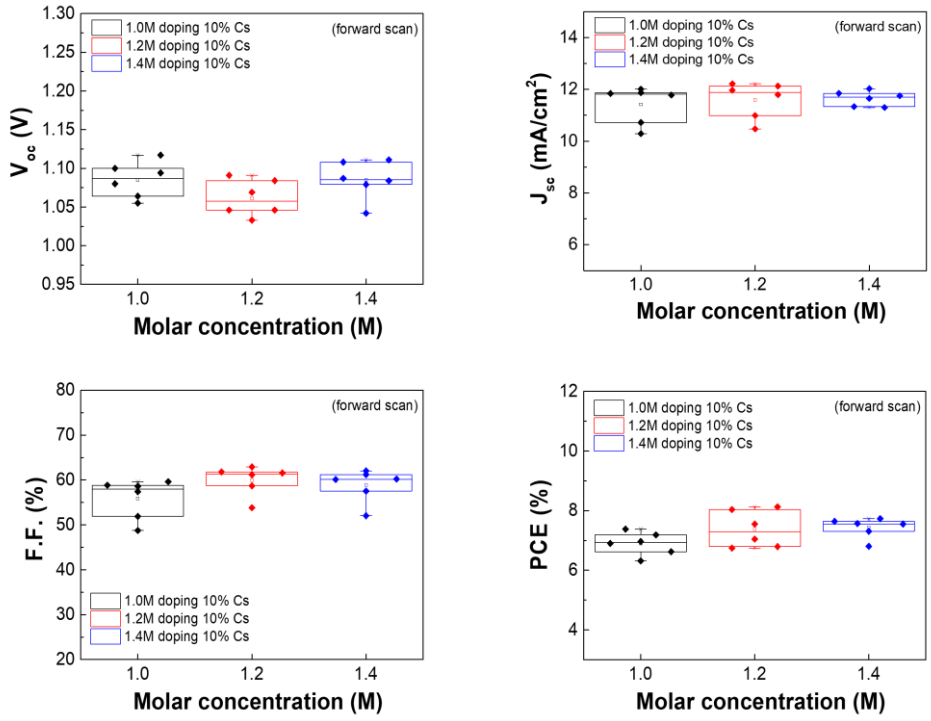


Figure S17. PV parameters of PSCs with 10% Cs doping but prepared with different constituent chemical molar concentrations (forward scan).

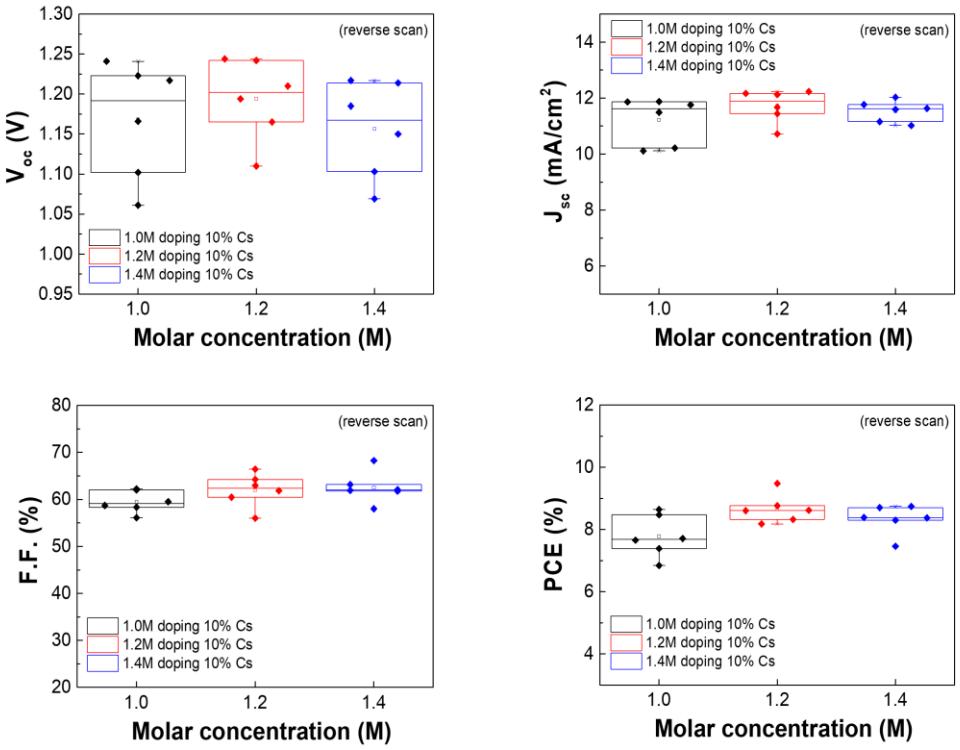


Figure S18. PV parameters of PSCs with 10% Cs doping but prepared with different constituent chemical molar concentrations (reverse scan).

Table S5. PV parameters of PSCs with various Cs doping concentrations.

Different Cs concentrations		V_{oc} (V)	J_{sc} (mA/cm^2)	F.F. (%)	PCE (%)
5 %	forward	1.042±0.033	11.101±0.543	59.369±4.493	6.875±0.756
	reverse	1.110±0.051	11.040±0.635	62.290±2.802	7.618±0.485
10 %	forward	1.062±0.023	11.595±0.703	59.994±3.328	7.383±0.612
	reverse	1.194±0.051	11.726±0.584	61.990±3.573	8.662±0.454
15 %	forward	1.089±0.037	10.183±0.840	59.429±2.256	6.591±0.665
	reverse	1.124±0.030	10.028±0.854	62.315±1.505	7.015±0.497
20 %	forward	1.049±0.027	9.816±0.893	57.588±6.699	6.002±0.968
	reverse	1.096±0.017	9.765±1.137	59.645±5.567	6.390±1.037

Table S6. PV parameters of PSCs with 10% Cs doping but prepared with different constituent chemical molar concentrations.

Different Cs concentrations	V_{oc} (V)	J_{sc} (mA/cm^2)	F.F. (%)	PCE (%)

1.0 M	forward	1.085±0.023	11.420±0.725	55.845±4.456	6.896±0.384
	reverse	1.168±0.072	11.218±0.828	59.483±2.333	7.785±0.675
1.2 M	forward	1.062±0.023	11.595±0.703	59.994±3.328	7.383±0.612
	reverse	1.194±0.051	11.726±0.584	61.990±3.573	8.662±0.454
1.4 M	forward	1.085±0.025	11.652±0.287	58.855±3.675	7.433±0.339
	reverse	1.156±0.061	11.533±0.378	62.526±3.309	8.327±0.462

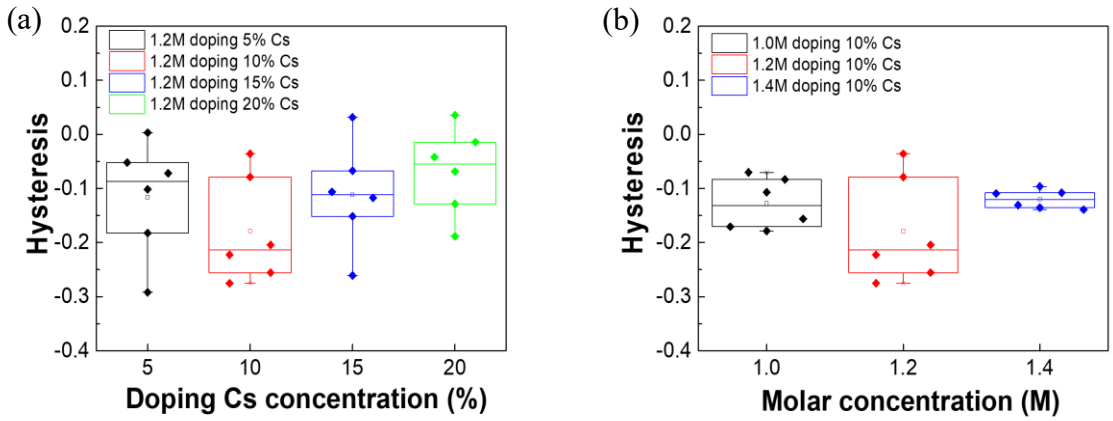


Figure S19. Hysteresis of PSCs (a) with various Cs doing concentrations, and (b) with 10% Cs doping but prepared with various constituent chemical molar concentrations.

Figure S20. Actual sample image of fabricated perovskite solar cells.