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

Supporting Information

Efficient all-air processed mixed cation carbon-based perovskite solar cells with ultra-high stability

Junshuai Zhou[a], Jiaojiao Wu[a], Nan Li[a], Xitao Li[a], Yan-Zhen Zheng[*a], Xia Tao[*a]

a State Key Laboratory of Organic-Inorganic Composites, Beijing University of Chemical Technology, Beijing 100029, China

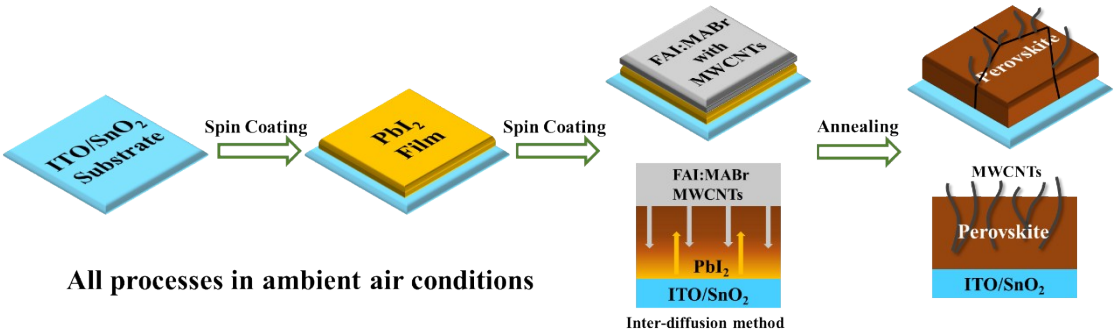

Fig. S1 Schematic illustration of inter-diffusion two-step method of fabricating perovskite films.

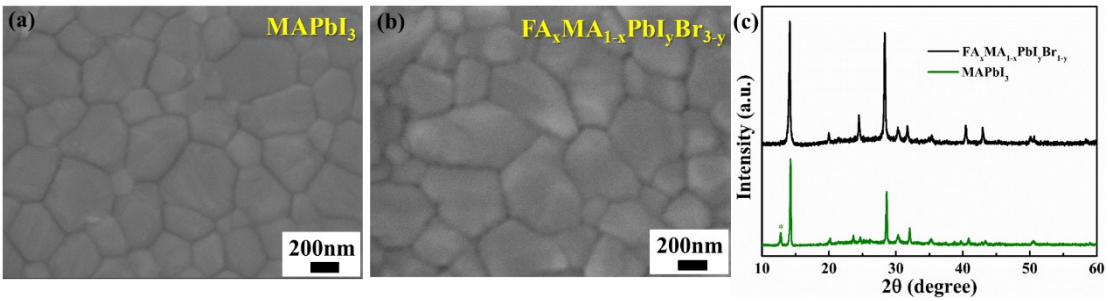

Fig. S2 (a,b) Top view SEM image of $MAPbI_3$ and $FA_xMA_{1-x}PbI_yBr_{1-y}$ perovskite films and (c) XRD patterns of $MAPbI_3$ and $FA_xMA_{1-x}PbI_yBr_{1-y}$ perovskite films. Asterisks denote the major reflections of PbI_2.

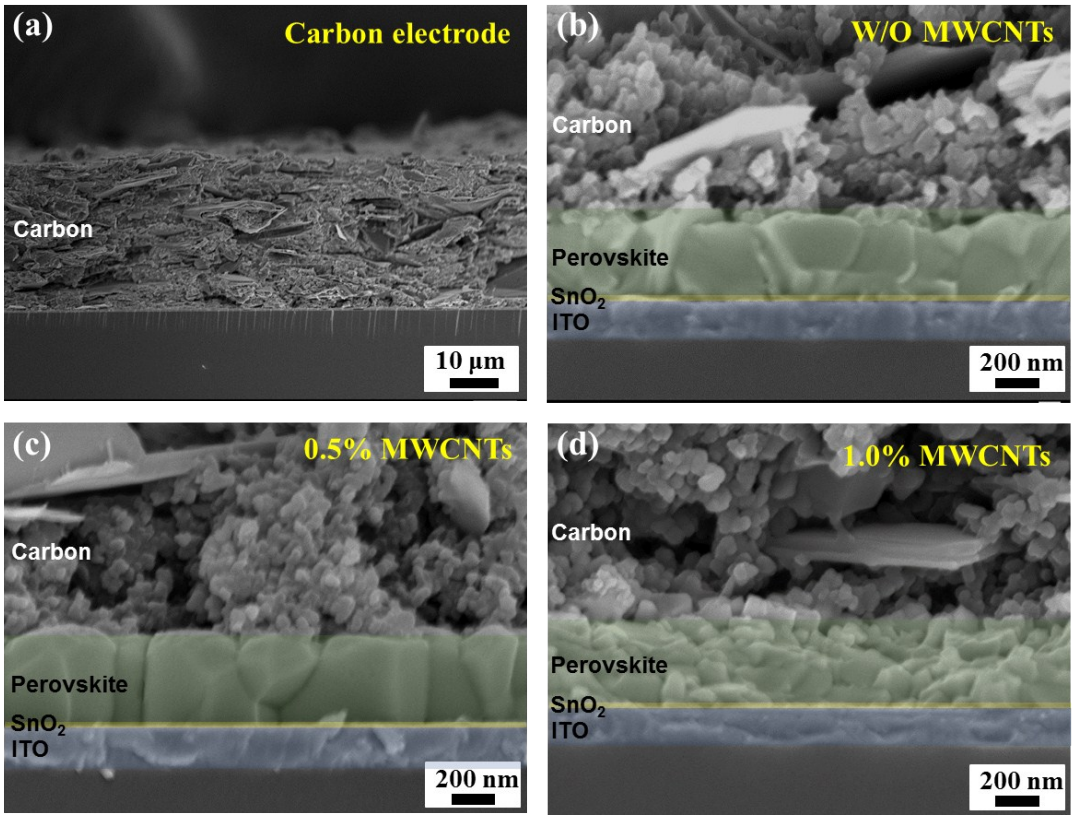

Fig. S3 (a) Cross-sectional SEM image of carbon electrode in ITO/SnO_2/$FA_xMA_{1-x}PbI_yBr_{3-y}$ with MWCNTs/C device. (b-d) Cross-sectional SEM images of C-PSC devices with different MWCNTs doping contents.

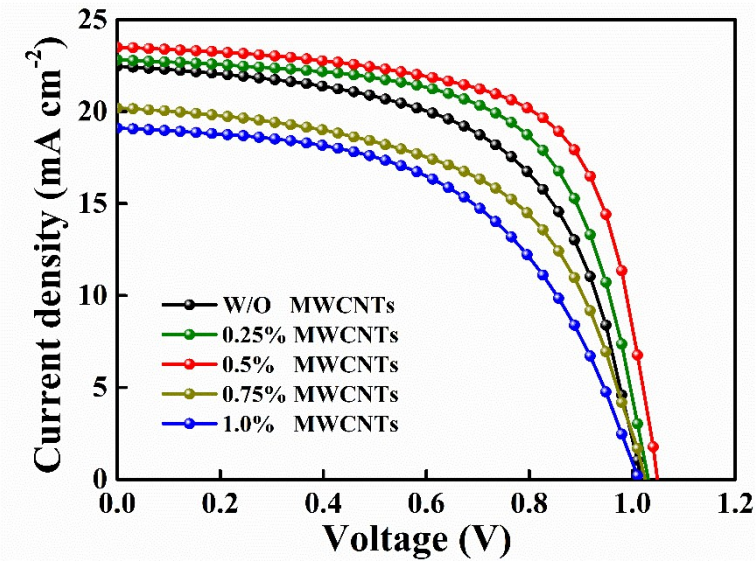

Fig. S4 *J-V* curves of the C-PSCs using the perovskite films with different MWCNTs (W/O, 0.25%, 0.5%, 0.75%, and 1.0%) under AM 1.5G 100 mW cm^{-2} illumination.

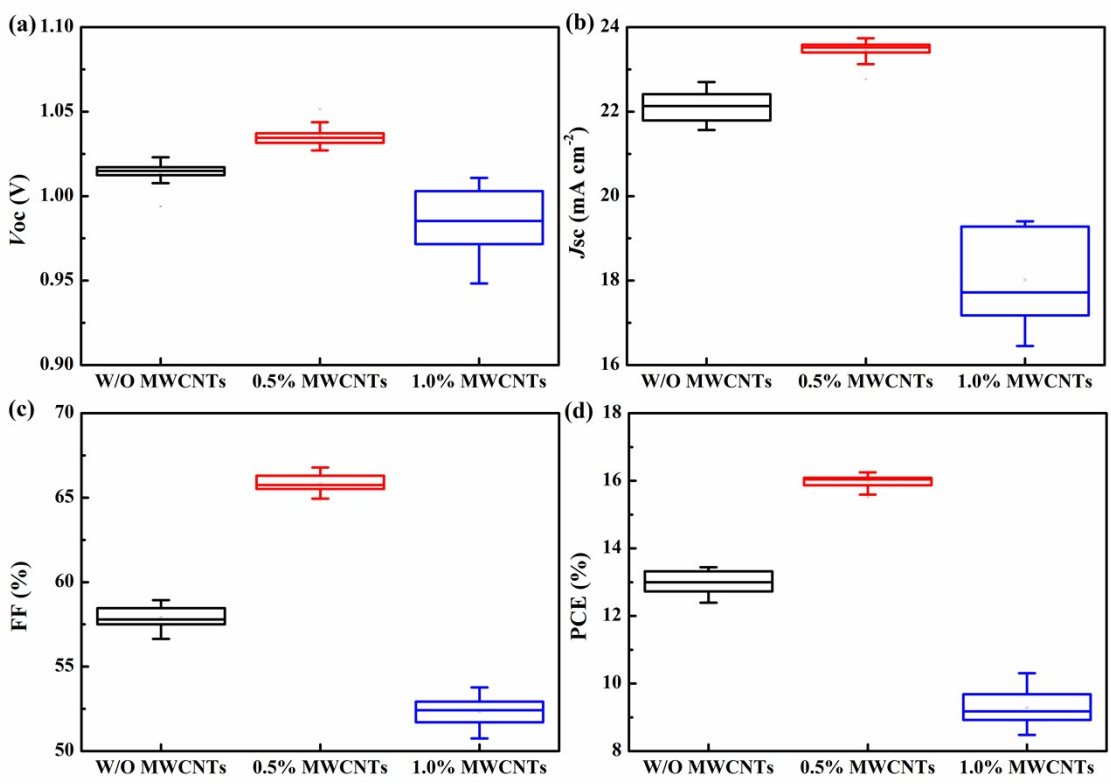

Fig. S5 Photovoltaic parameters statistics of 40 perovskite devices with different MWCNTs (W/O, 0.5% and 1.0%).

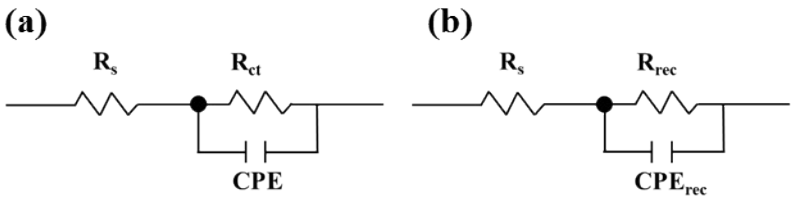

Fig. S6 The equivalent circuit model for C-PSCs in EIS under AM 1.5G illumination (a) and under dark condition (b).

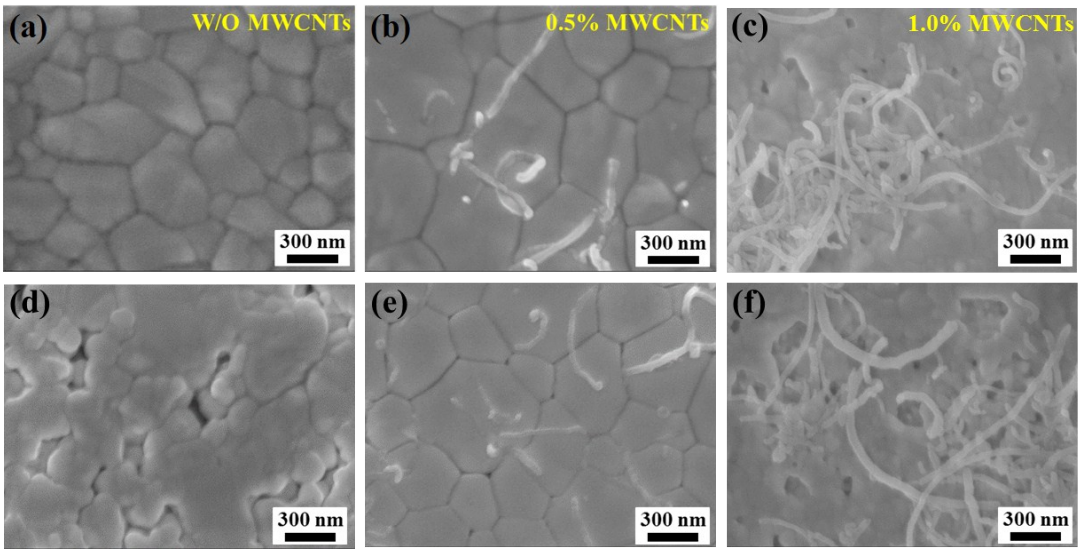

Fig. S7 SEM images of fresh (a-c) and air-aged (60 days, d-f) perovskite films with different MWCNTs (W/O, 0.5%, 1.0%) in air with a relative humidity of 30-80%.

Table S1 Parameters of the TRPL spectroscopy based on the perovskite films with different MWCNTs doping contents.

Samples	τ_1	% of τ_1	τ_2	% of τ_2	τ_{ave}
W/O MWCNTs	3.14	33.67	23.16	66.33	16.42
0.5% MWCNTs	2.73	35.86	19.85	64.14	13.71
1.0% MWCNTs	6.16	30.35	33.15	69.65	24.96

Table S2 Photovoltaic parameters of the best-performing C-PSCs with different MWCNTs doping content (W/O, 0.25%, 0.5%, 0.75% and 1.0%).

Samples	V_{oc} (V)	J_{sc} (mA cm^{-2})	FF (%)	PCE (%)
W/O MWCNTs	1.02	22.47	58.69	13.43
0.25% MWCNTs	1.03	22.81	62.82	14.76
0.5% MWCNTs	1.04	23.50	66.45	16.25
0.75% MWCNTs	1.02	20.19	57.15	11.66
1.0% MWCNTs	1.01	19.09	53.76	10.37

Table S3 Photovoltaic parameters statistics of 40 devices of the perovskite devices with different MWCNTs (W/O, 0.5% and 1.0%) measured under reverse scan (from V_{oc} to 0).

Samples	V_{oc} (V)	J_{sc} (mA cm^{-2})	FF (%)	PCE (%)
W/O MWCNTs	1.01±0.01	22.14±0.34	57.91±1.02	13.00±0.43
0.5% MWCNTs	1.04±0.01	23.45±0.26	65.84±0.61	15.98±0.27
1.0% MWCNTs	0.99±0.02	18.02±1.32	52.31±1.45	9.28±1.03

Table S4 Summary of photovoltaic performance and ambient stability for various PSCs.

Structure	PCE	Ambient Stability	RH	Ref.
FTO/bl-TiO_2/mp-TiO_2/mp-ZrO_2/ Carbon(5-AVAI-$CH_3NH_3PbI_3$)	9.53%	—	—	1
ITO/PEDOT:PSS/$CH_3NH_3PbI_{3-x}Cl_x$ /PCBM/C_{60}/Al	12.98%	80% for 120 h	50%	2
FTO/n-TiO_2/$CH_3NH_3PbI_{3-x}Cl_x$ /P3HT/Au	13.70%	—	35%	3
FTO/n-TiO_2/$CH_3NH_3PbI_{3-x}(SCN)_x$ /spiro-OMeTAD/Au	15.12%	86.7% for 500 h	70%	4
FTO/bl-TiO_2/$CH_3NH_3PbI_{3-x}(SCN)_x$ /spiro-OMeTAD/Au	16.59%	95% for 45 days	70%	5
FTO/nano-TiO_2/$CH_3NH_3PbI_{3-x}Cl_x$/ spiro-OMeTAD/Au	17.56%	70% for 96 h	60%-80%	6
FTO/bl-TiO_2/mp-TiO_2/$(FAPbI_3)_{1-x}$ $(MAPbBr_3)_x$/spiro-OMeTAD/Au	17.60%	—	—	7
FTO/bl-TiO_2/mp-TiO_2/ $Cs_x(FA_{0.83}MA_{0.17})_{(1-x)}Pb(I_{0.83}Br_{0.17})_3$/ Spiro-OMeTAD/Au	20.80%	93.75% for 18 weeks	20%-35%	8
ITO/SnO_2/PbI_2-FAI:MABr with 0.5% MWCNTs/Carbon	16.25%	93% for 22 weeks	30%-80%	**This Work**

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