ARTICLE

Supporting information

Carbon-based HTL-free modular perovskite solar cells with improved contact at the perovskite/carbon interfaces

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Fig. S1. The SEM images of unprocessed MWCNTs (a) and O-MWCNTs (b).



Fig. S2. XRD patterns of Fluorine-doped tin oxide (FTO) glass substrate.



Fig. S3. The top-view SEM images with different zoom factors of perovskite film incorporated with 1.0 mg/ml O-MWCNTs.



Fig. S4. J-V curves (cell area: 1cm²) of the champion performing C-based HTL-free modular PSCs, where the perovskite active layer doped with unprocessed MWCNTs and O-MWCNTs at optimized concentration of 0.5 mg/ml.



Fig. S5. The comparison of water contact angles for various electrodes deposited on perovskite layer: silver electrode (a), MWCNTs electrode (b) and O-MWCNTs electrode (c).



Fig. S6. J-V curves (cell area: 1cm²) of C-based HTL-free modular PSCs, where the C-electrode was prepared from unprocessed MWCNTs and O-MWCNTs.



Fig. S7. (a-d) Photovoltaic parameters statistics (Box chart) of modular HTL-free C-PSCs with different concentrations of O-MWCNTs in the modified anti-solvent, 15 samples were prepared and evaluated for each group of cells to confirm the reproducibility.



Fig. S8. J-V curves of typical PSCs with conventional spiro-OMeTAD HTL and Ag electrode under solar simulator AM 1.5.



Fig. S9. The equivalent circuit model for C-based HTL-free modular PSC in EIS (a) under AM 1.5G illumination (b) under the dark.

Table S1. Parameters of the TRPL spectroscopy based on the perovskite films doped with different concentration of O-MWCNTs.

Perovskite	$\tau_1(ns)$	$\tau_1(\%)$	$\tau_2(ns)$	$\tau_2(\%)$	$\tau_{ave}(ns)$
0.0 mg/ml O-MWCNTs	6.73	0.11	33.11	0.46	6.73
0.5 mg/ml O-MWCNTs	9.92	0.32	38.28	0.62	9.93
1.0 mg/ml O-MWCNTs	6.09	0.08	29.36	0.29	6.09