

## Electronic supplementary information (ESI)

### Electrosprayed TiO<sub>2</sub> Nanoporous Hemi-spheres for Enhanced Electron Transport and Device Performance of Formamidinium Based Perovskite Solar Cells

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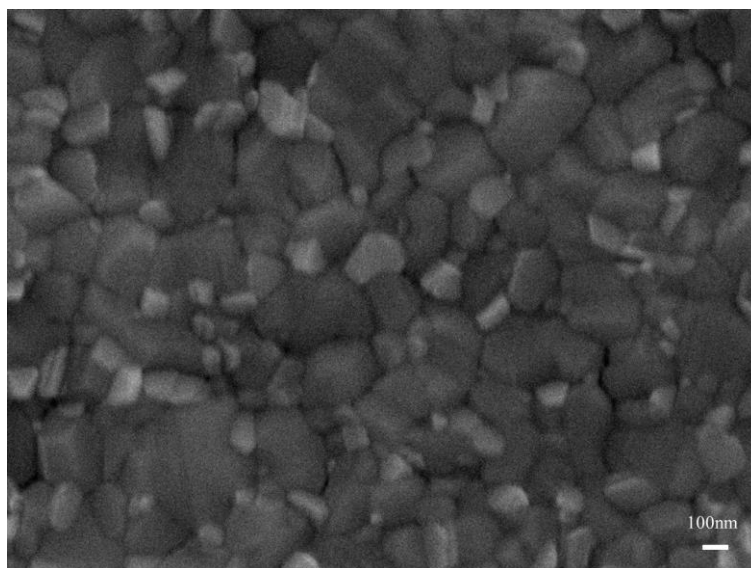
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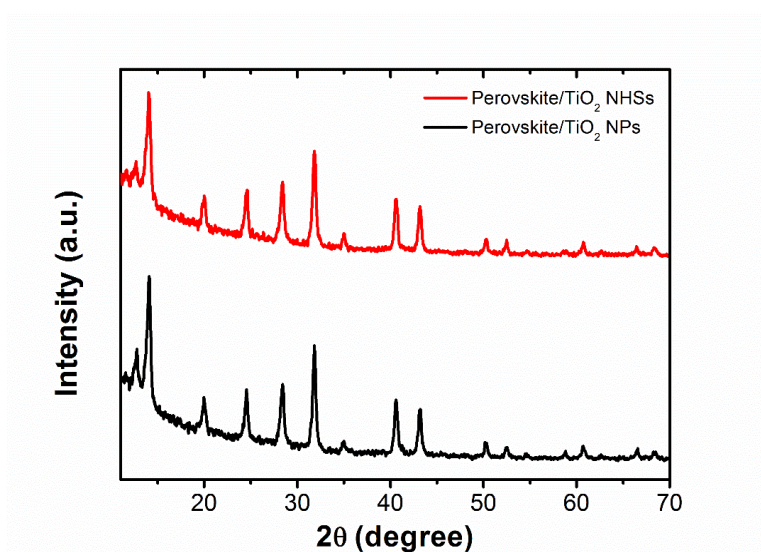
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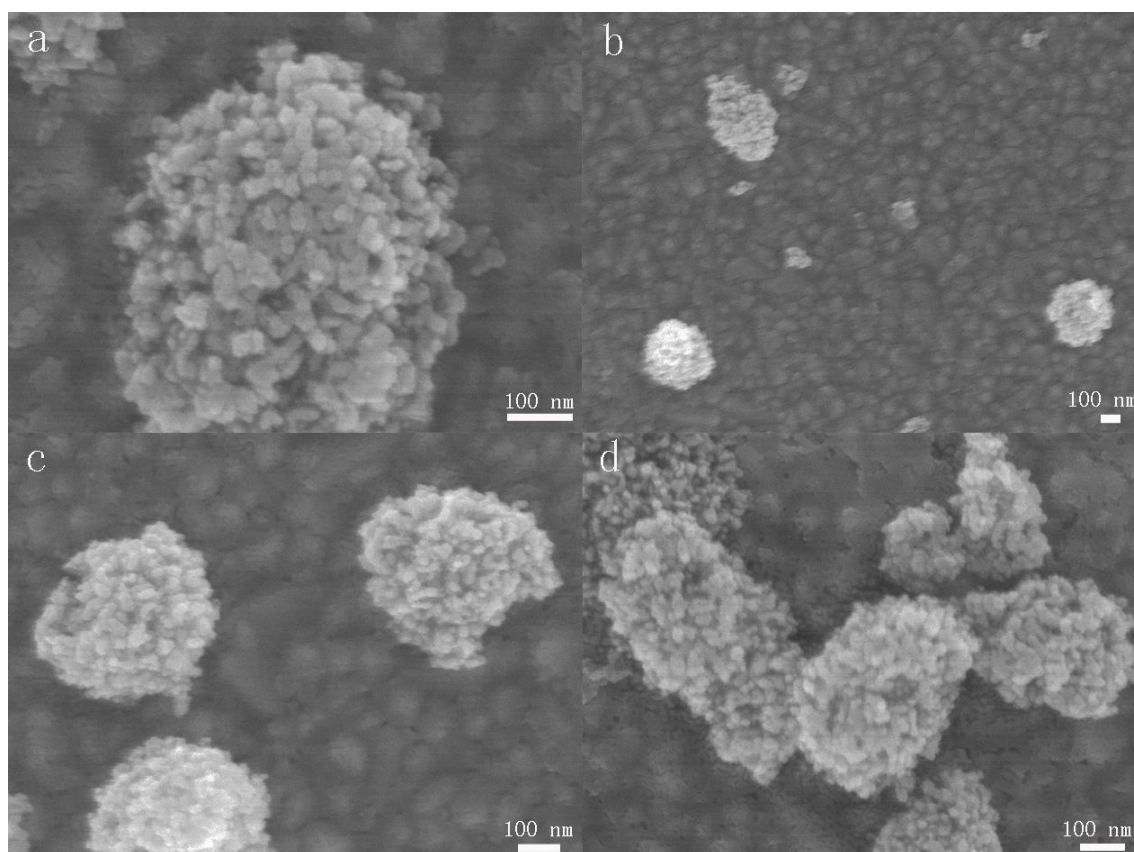
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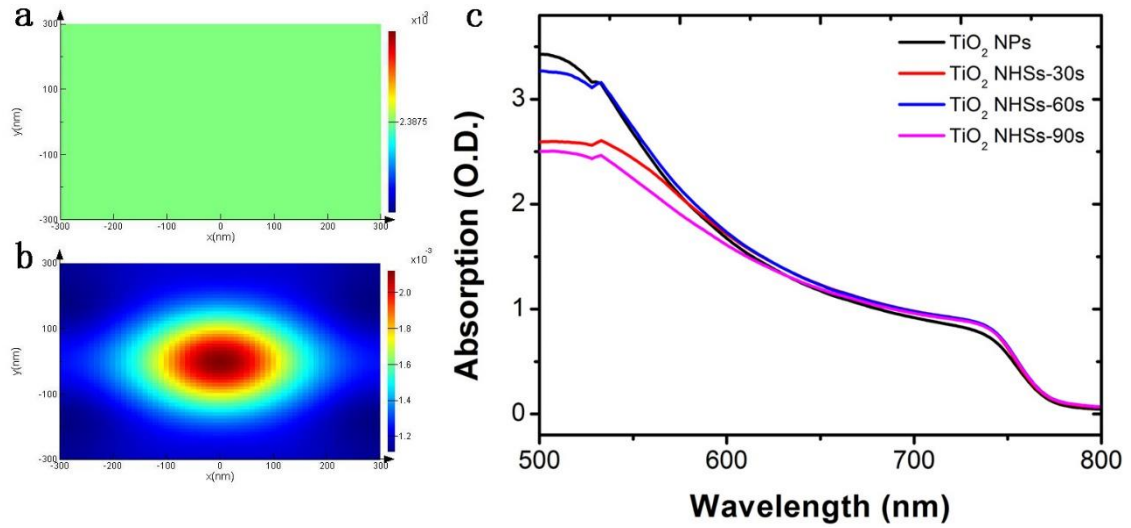
**Fig. S1.** SEM image of prepared  $\text{FA}_{0.81}\text{MA}_{0.15}\text{Pb}(\text{I}_{0.836}\text{Br}_{0.15})_3$  film on top of  $\text{TiO}_2$  NPs layer.



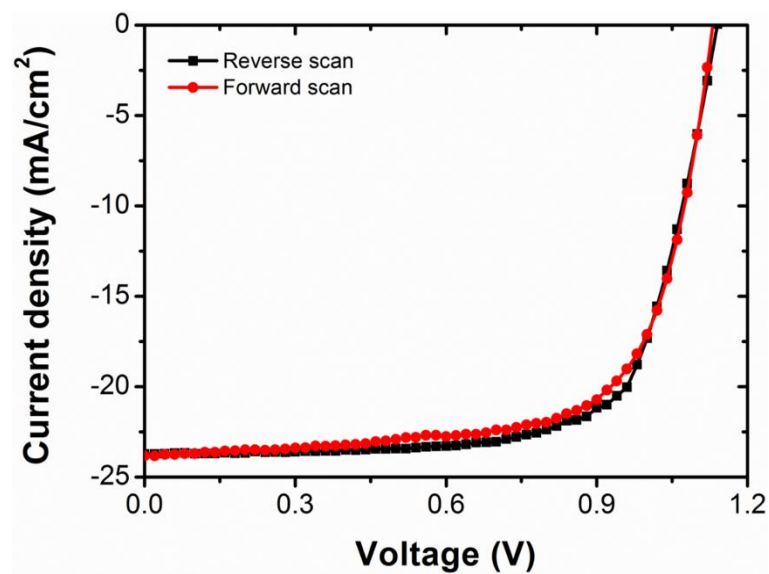
**Fig. S2.** XRD results of the fabricated  $\text{FA}_{0.81}\text{MA}_{0.15}\text{Pb}(\text{I}_{0.836}\text{Br}_{0.15})_3$  films on top of  $\text{TiO}_2$  NHSs and NPs layers, respectively.



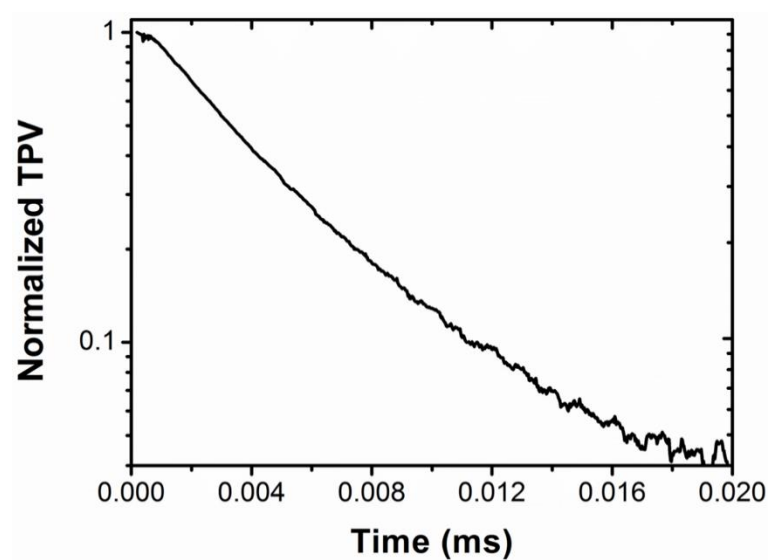
**Fig. S3.** SEM images of the prepared TiO<sub>2</sub> NHSs. a) shows the nanoporous structure for the prepared NHS; b) shows the TiO<sub>2</sub> NHSs layer with 30 s collecting time, c) shows the TiO<sub>2</sub> NHSs layer with 60 s collecting time and d) shows the TiO<sub>2</sub> NHSs layer with 90 s collecting time. TiO<sub>2</sub> NHSs pile up with the 90 s collecting time.



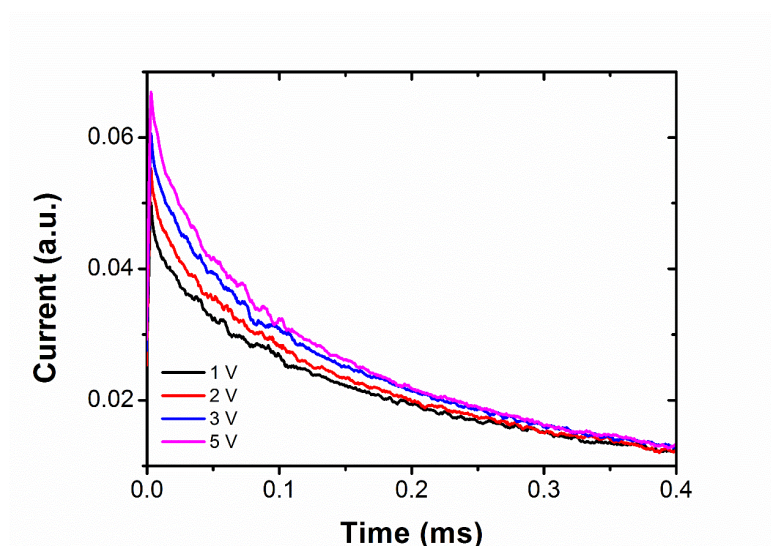
**Fig. S4.** The simulated optical power distribution at TiO<sub>2</sub>/perovskite interface of a) FTO/C-TiO<sub>2</sub>/Meso-TiO<sub>2</sub> NPs/perovskite and b) FTO/C-TiO<sub>2</sub>/TiO<sub>2</sub> NHS-60 s/perovskite samples; c) the absorption spectra of the FTO/C-TiO<sub>2</sub>/Meso-TiO<sub>2</sub>/perovskite samples based on TiO<sub>2</sub> NPs and TiO<sub>2</sub> NHSs with different collecting times (30 s, 60 s and 90 s). The FDTD model were set as follows, for a): radius of TiO<sub>2</sub> NHS was 200 nm, distance between two adjacent TiO<sub>2</sub> NHSs centres was 600 nm, and thickness of TiO<sub>2</sub> NHS-60 s/perovskite layer was 600 nm; and for b): thickness of meso-TiO<sub>2</sub> NPs layer was 200 nm and thickness of perovskite layer was 600 nm, and both input light wavelengths were 700 nm.



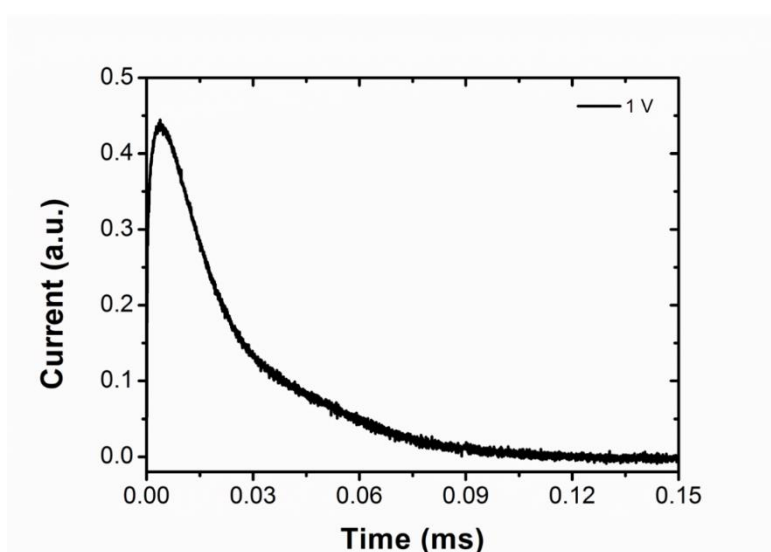
**Fig. S5.** *J-V* characteristics of the PSC based on TiO<sub>2</sub> NHSs measured under simulated 1 sun condition with forward and backward scans. As for the reverse scan:  $J_{sc}$ : 23.8 mA/cm<sup>2</sup>;  $V_{oc}$ : 1.14 V;  $FF$ : 0.72 and PCE of 19.6%. Little hysteresis can be seen in this kind of device.



**Fig. S6.** TPV result of the control group device (based on TiO<sub>2</sub> NPs). The TPV lifetime is just 4  $\mu$ s when the back level is 1 V.



**Fig. S7.** TOF result of the TiO<sub>2</sub> NHSs device with different positive background voltages.



**Fig. S8.** TOF result of the control group device (based on TiO<sub>2</sub> NPs) with positive 1 V background voltage. Hole mobility of  $1.0 \times 10^{-3} \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$  is obtained for the control group device (the thickness of the perovskite/HTM heterojunction is 650 nm).

**Table S1.** Photovoltaic parameters for the stability of perovskite solar cell measured under simulated 1 sun (solar cell was encapsulated and stored in a dessicator).

	$V_{oc}$ (V)	$J_{sc}$ (mA/cm <sup>2</sup> )	$FF$	PCE (%)
Initially	1.14	23.8	0.71	19.3
10 days	1.15	23.9	0.71	19.6
20 days	1.14	23.7	0.70	19.1
60 days	1.13	23.6	0.69	18.6

**Table S2.** The lifetime versus voltage parameters extracted from TPV experiment with an error range of  $\pm 2\%$ .

Back (mV)	200	400	500	800
Lifetime ( $\mu$ s)	174	164	115	102