Electronic Supplementary Material (ESI) for Nanoscale.

aEfficient perovskite/fullerene planar heterojunction solar cells with enhanced charge extraction and suppressed charge recombination

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To further clarify the photovoltaic characteristics, a model which is derived from the single heterojunction solar cell is used to analyze the *J-V* characteristic of the device. According to the equivalent circuit, the current density flowing through the external load, which is marked as *J* here, can be expressed in the following form,

$$J = J_L - J_0\left[\exp(\frac{e}{AK_BT}(V + JR_s)) - 1\right] - \frac{V+JR_s}{R_{sh}} \qquad (1)$$

where J_L and J_0 are the light induced current density and reverse saturated current density of a *pn* heterojunction respectively, R_s and R_{sh} are the series and shunt resistance respectively, V is the bias voltage applied at the device, K_B is the Boltzmann constant, e is the elementary charge, T is the absolute temperature, and A is the ideality factor of a heterojunction. When R_{sh} is very large, it can be deduced that

$$-\frac{\mathrm{d}V}{\mathrm{d}J} = R_s + \frac{AK_BT}{e}(J_{sc} - J + J_0)^{-1} \qquad (2)$$

$$J_{sc} - J = J_0\left[\exp(\frac{e}{AK_BT}(V + JR_s)) - 1\right] \qquad (3)$$

Given the very small amount of J_0 generally, Eq. (2) can be expressed as

$$-\frac{dV}{dJ} = R_s + \frac{AK_BT}{e}(J_{sc} - J)^{-1} \qquad (4)$$

Plot ($-\mathrm{d}V/\mathrm{d}J$) vs $(J_{sc}-J)^{-1}$ and the linear fit curves according to Eq. (4) of the devices fabricated through one/two steps and with/without TIPD layer at illumination. There is a good linear relationship between ($-\mathrm{d}V/\mathrm{d}J$) and $(J_{sc}-J)^{-1}$. The series resistance R_s and ideality factor A of the device, which can be derived from the intercept and slope of the linear fitting results. Moreover, applying the value of R_s obtained above, plot ($J_{sc}-J$) vs ($V+JR_s$) and the fit curves according to Eq. (3). The ideality factor A and reverse saturated current density J_0 are also derived from the fitting results. The reverse saturated current density (J_0) of device with TIPD is 1.04 $\times 10^{-8}$ and 8.66$\times 10^{-9}$ A/cm^2 for one-step and two-step synthesized perovskite, respectively, two orders higher than that (8.80$\times 10^{-6}$ and 6.39$\times 10^{-7}$ A/cm^2) of devices without TIPD layer.

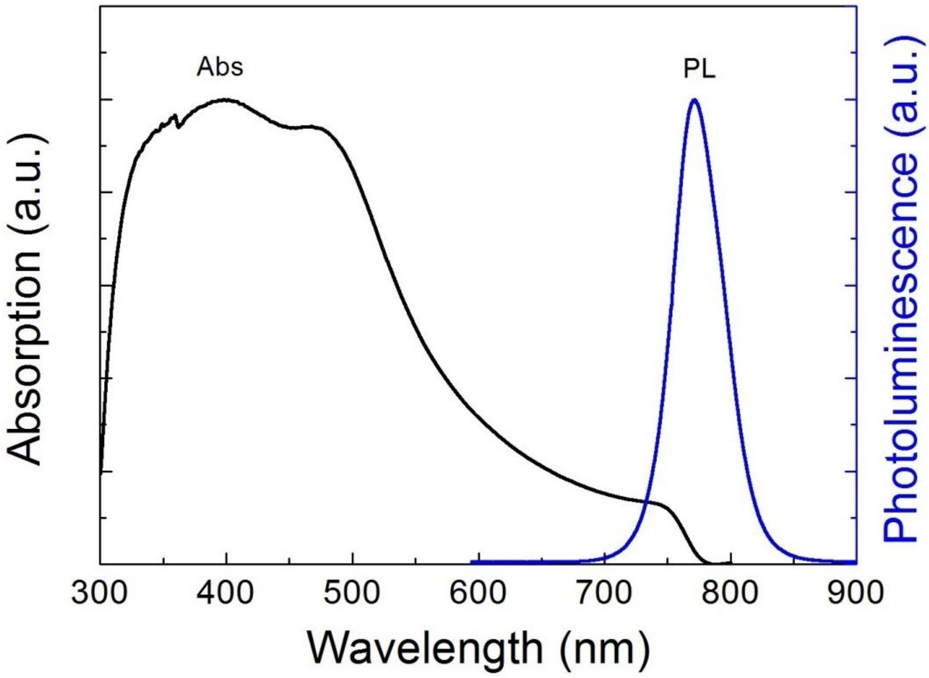

Figure S1. Absorption and photoluminescence spectra of two-step synthesized $CH_3NH_3PbI_3$ perovskite thin film spin-coated on quartz slides.

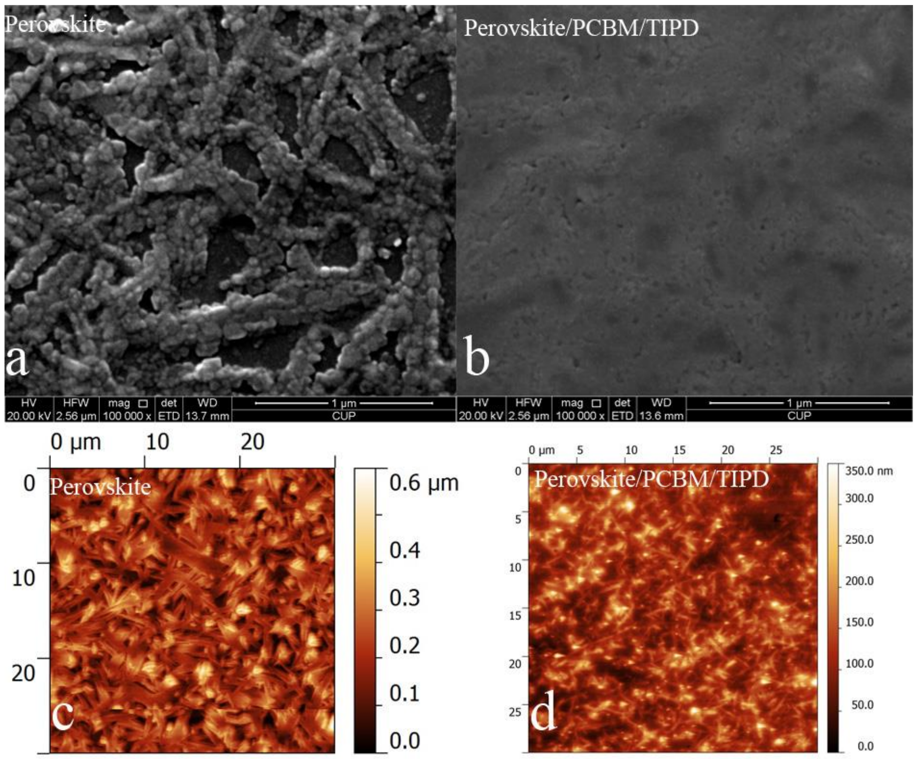

Figure S2. (a, b) SEM and (c, d) AFM images of one-step synthesized perovskite and perovskite/PCBM/TIPD layer spin-coated on FTO/PEDOT:PSS substrate, respectively.

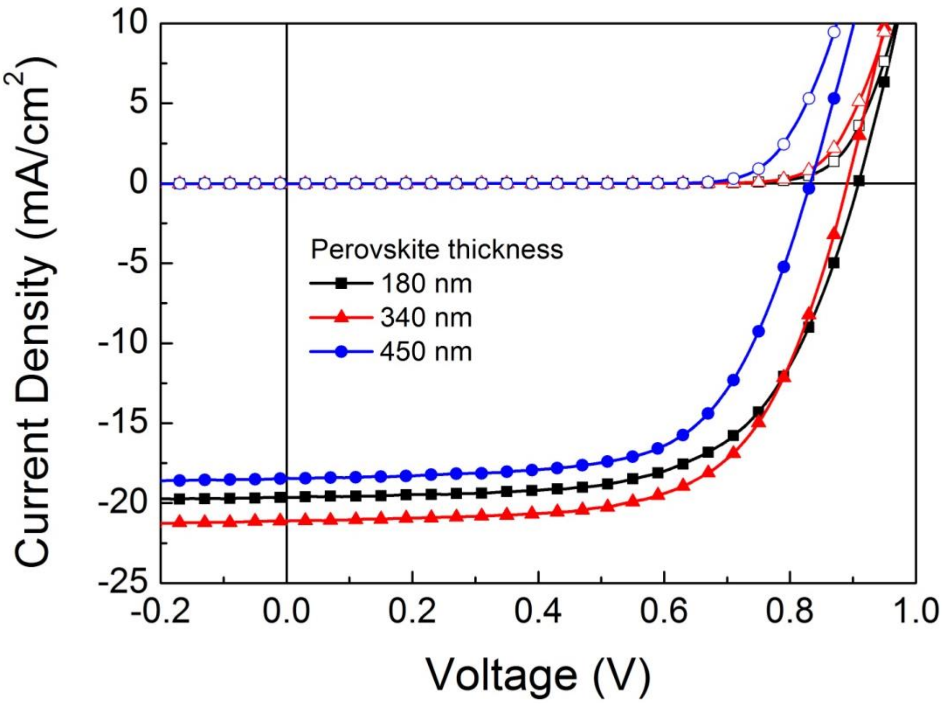

Figure S3. *J-V* curves of devices based on two-step synthesized perovskite with different $CH_3NH_3PbI_3$ thickness.

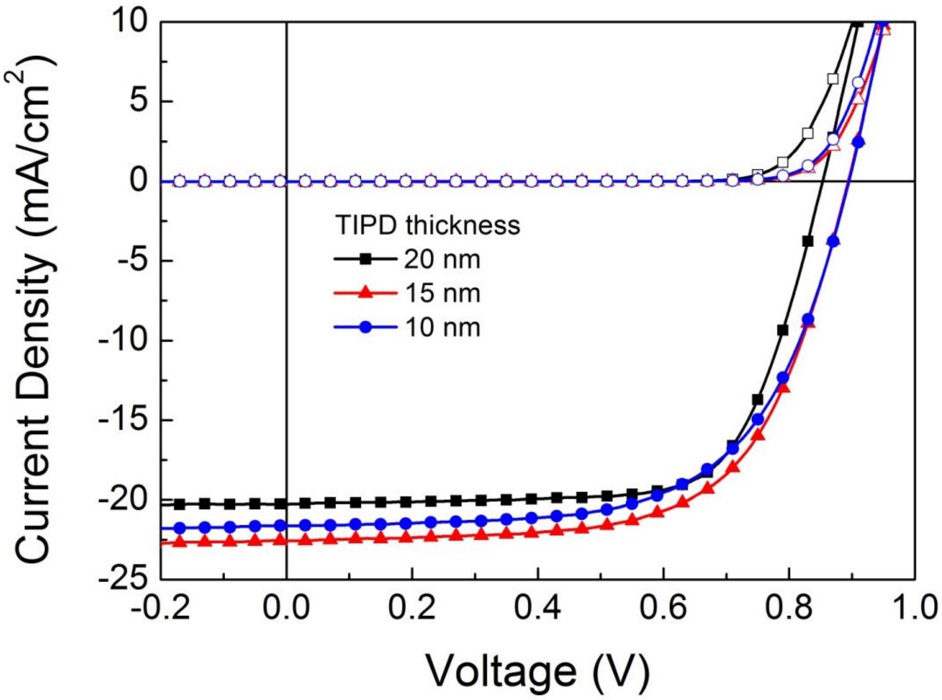

Figure S4. *J*-*V* curves of devices based on two-step synthesized perovskite with different TIPD thickness.

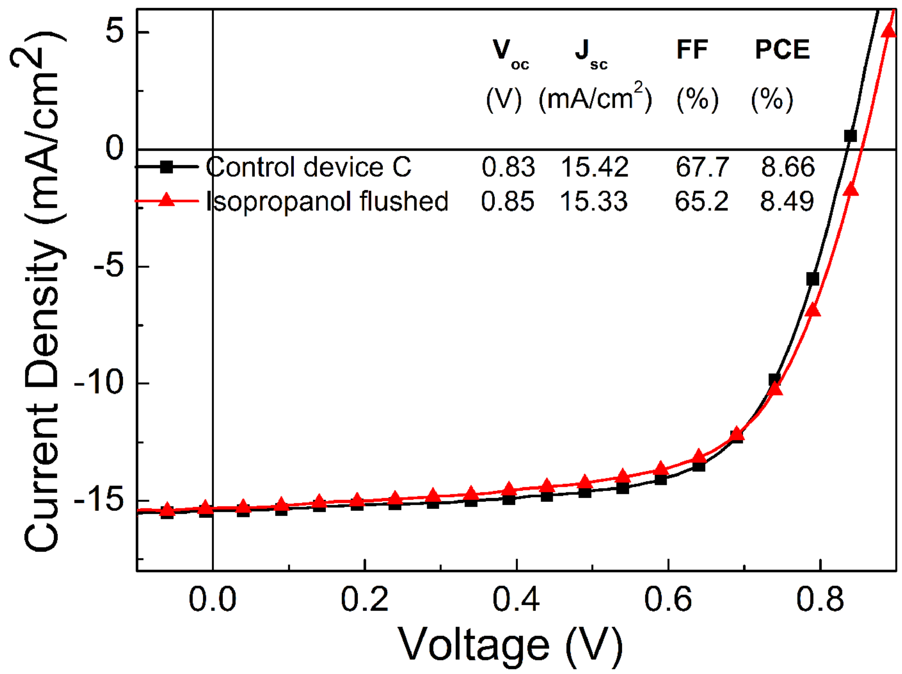

Figure S5. *J*-*V* curves of devices based on two-step synthesized perovskite without and with isopropanol flushed.

Table S1. Photovoltaic parameters of the perovskite solar cells with different $CH_3NH_3PbI_3$ and TIPD layer thickness.

	Thickness (nm)	Voc (V)	Jsc (mA/cm^2)	FF (%)	PCE (%)
Perovskite	180	0.90	19.65	63.9	11.30
	340	0.89	21.20	64.4	12.15
	450	0.83	18.45	64.7	9.91
TIPD	20	0.85	20.20	71.3	12.24
	15	0.89	22.57	64.5	12.95
	10	0.89	21.61	63.0	12.11

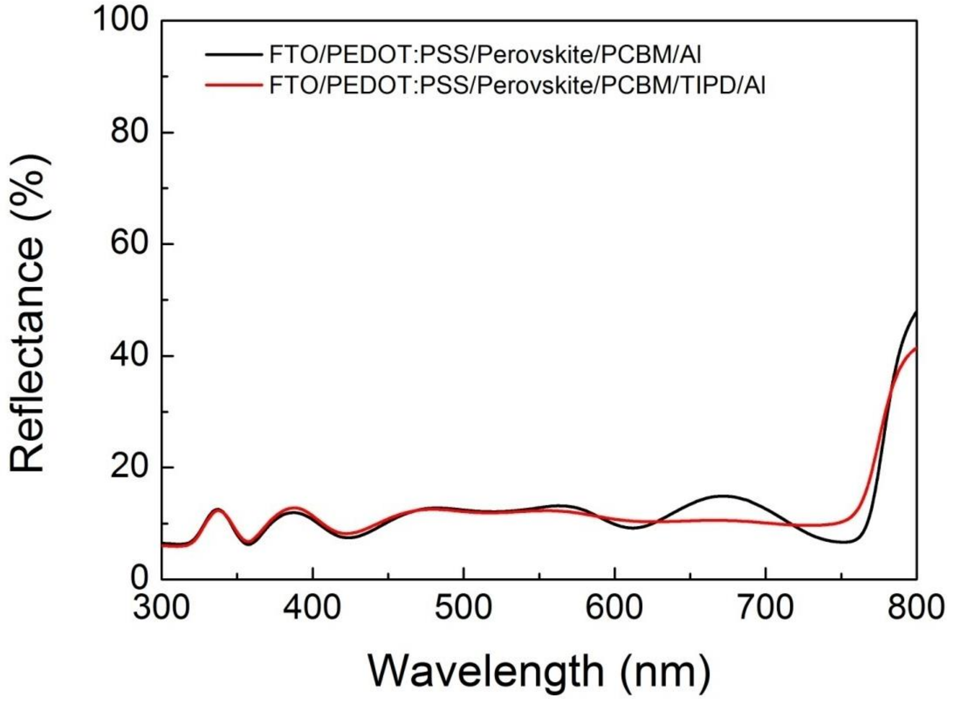

Figure S6. Reflection spectra of perovskite solar cells with and without TIPD layer.