Electronic Supplementary Information

Achieving high-performance planar perovskite solar cell with Nb-doped TiO_2 compact layer by enhanced electron injection and efficient charge extraction

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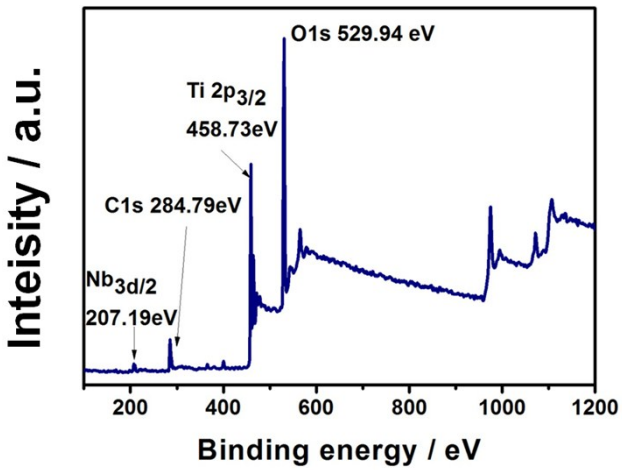

Fig. S1. XPS survey spectrum of 2% Nb-doped TiO_2.

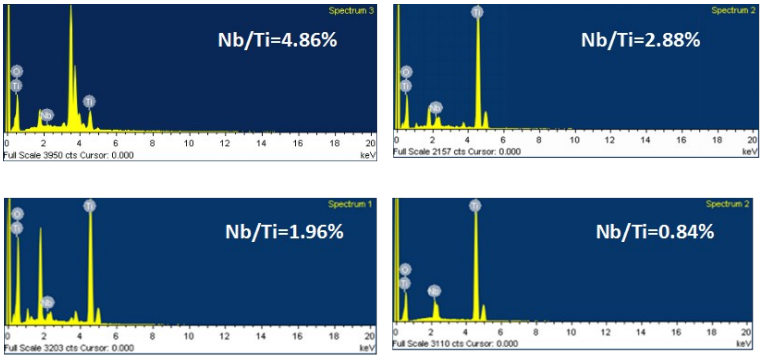

Fig. S2. Quantitive analysis of the content of Nb dopant by energy dispersive spectroscopy (EDS) whose theoretical molar ratio are 5%, 3%, 2% and 1%, respectively.

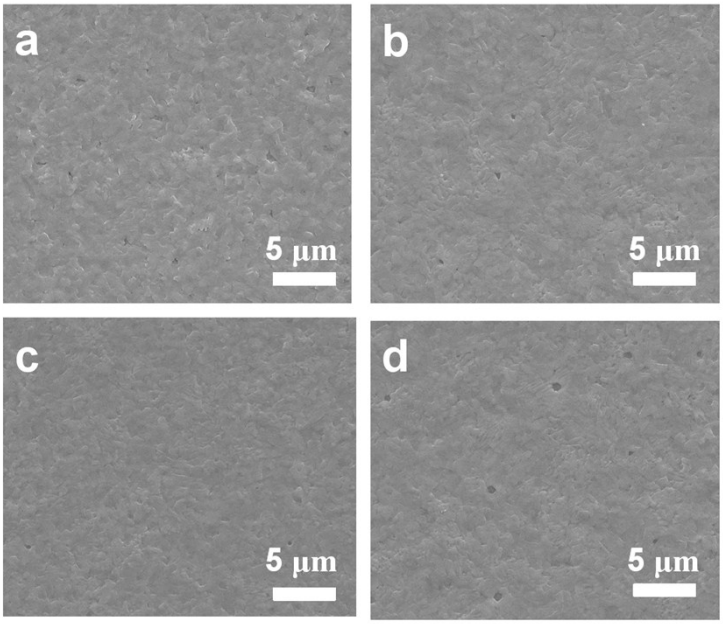

Fig. S3. The top-view SEM images of perovskite films deposited on pristine TiO_2 (a), 1% Nb-doped TiO_2 (b), 3% Nb-doped TiO_2 (c) and 5% Nb-doped TiO_2 (d), respectively. The number of pinholes in perovskite layer deposited on Nb-doped TiO_2 compact layer have first decreased from 0% to 2%, whereas retained nearly the same for 3% Nb doping. However, as the doping content increased to 5%, the pinholes turned to be more serious and the coverage of perovskite reduced sharply.

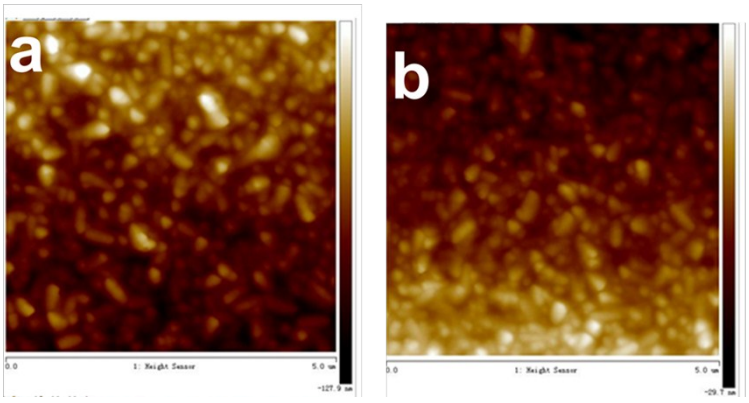

Fig. S4. AFM images of 2% Nb-doped TiO_2 (a),TiO_2 (b) films on FTO substrates with calculated roughness of 18.4 and 18.6, respectively.

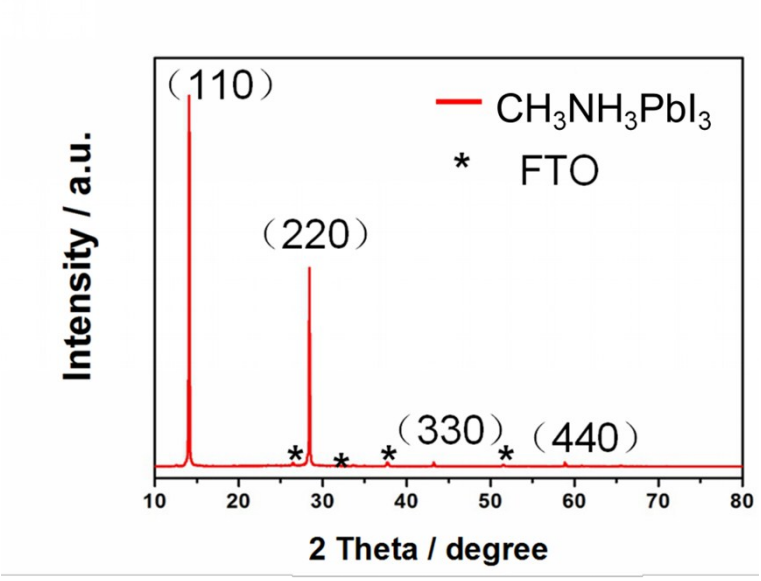

Fig. S5. XRD patterns of $CH_3NH_3PbI_3$ film deposited on FTO substrate.

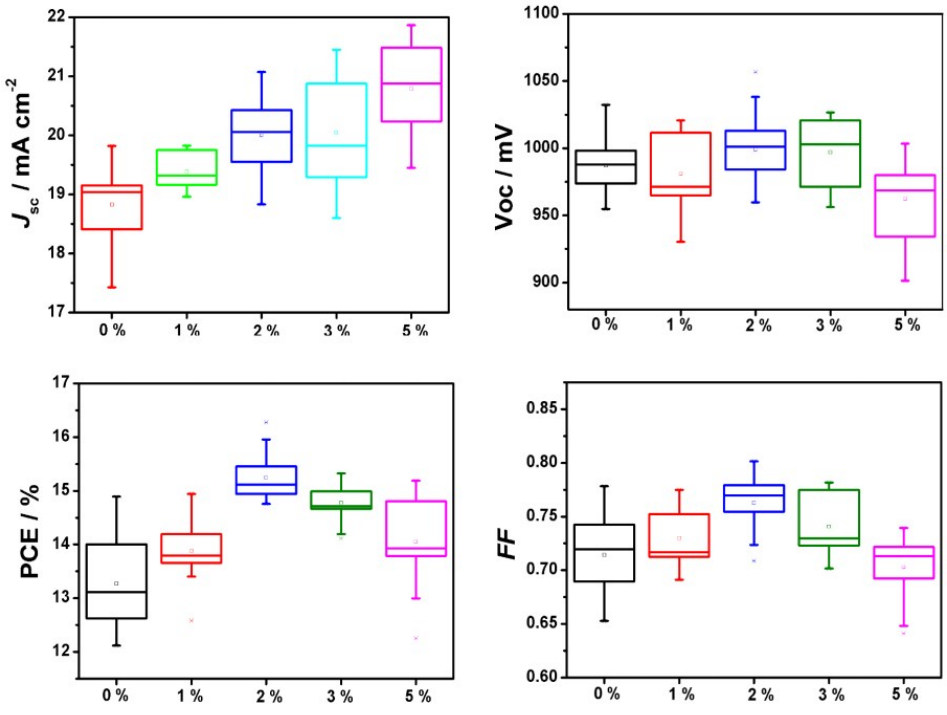

Fig. S6. The box-chart images of photovoltaic parameters which extracted from measuring current density-voltage curves for devices based on TiO_2 with various Nb doping contents at simulated one sun illumination (100 mW cm^{-2}, AM 1.5G).

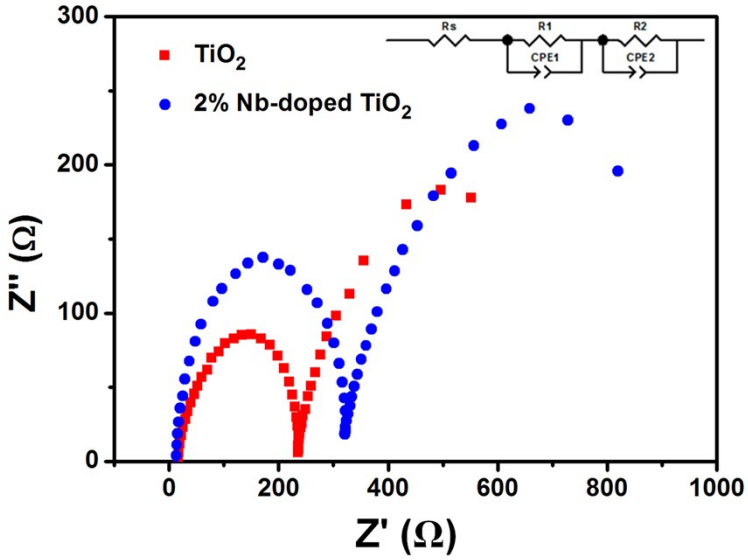

Fig. S7. Nyquist plot of the perovskite solar cells based on pristine TiO_2 and 2% Nb-doped TiO_2 compact layer at the open-circuit voltage under illumination (100 mW cm^{-2}).

Table S1. The photovoltaic parameters for PSC devices with 2% Nb-doped TiO_2 compact layer which extracted from measuring *J-V* curves at simulated one sun illumination (100 mW cm^{-2}, AM 1.5G) performed by FB-SC and SC-FB.

	Direction	J_{sc} **/ mA cm-2**	V_{oc} **/ mV**	**PCE / %**	***FF***
Pristine TiO_2	FB-SC	19.1	955	13.1	0.72
	SC-FB	19.1	900	10.7	0.62
	average	19.1	928	11.9	0.67
2% Nb-doped TiO_2	FB-SC	19.4	992	15.2	0.79
	SC-FB	194	965	13.6	0.73
	average	19.4	979	14.4	0.76

Table S2. The fitted parameters for EIS measurements acquired under 1 sun illumination at open-circuit potential.

	R_s **/ Ω cm²**	R_{rec} **/ Ω cm²**
TiO_2	17.8	610.1
2% Nb-doped TiO_2	8.7	691.5