

Supplementary Information

Totally Room-temperature Solution-Processing Method for Fabricating Flexible Perovskite Solar Cells Using Nb₂O₅-TiO₂ Electron Transport Layer

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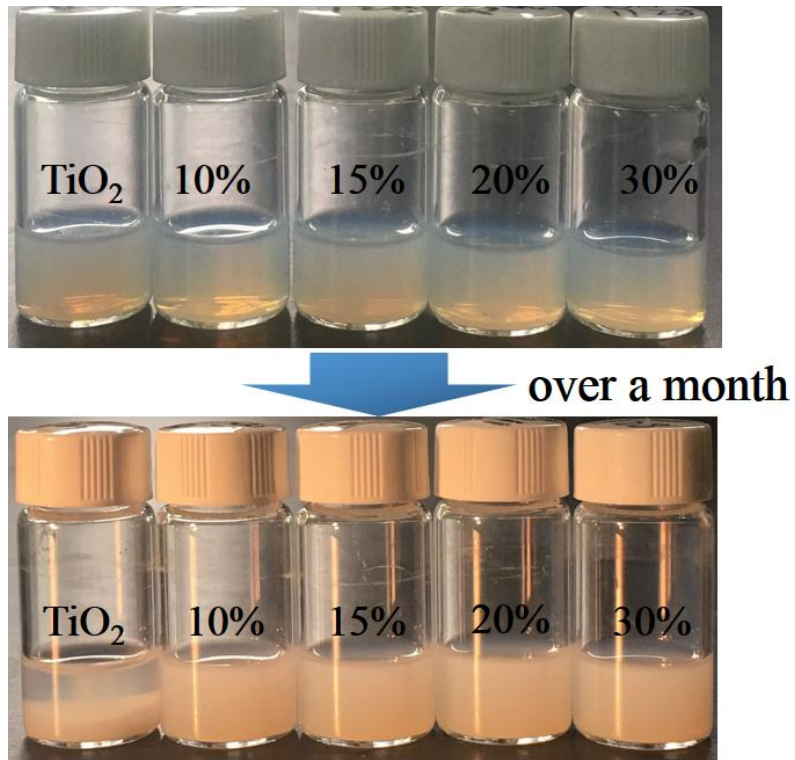


Fig. S1 Photo of TiO_2 particle distribution results from adding different concentrations of niobium ethoxide.

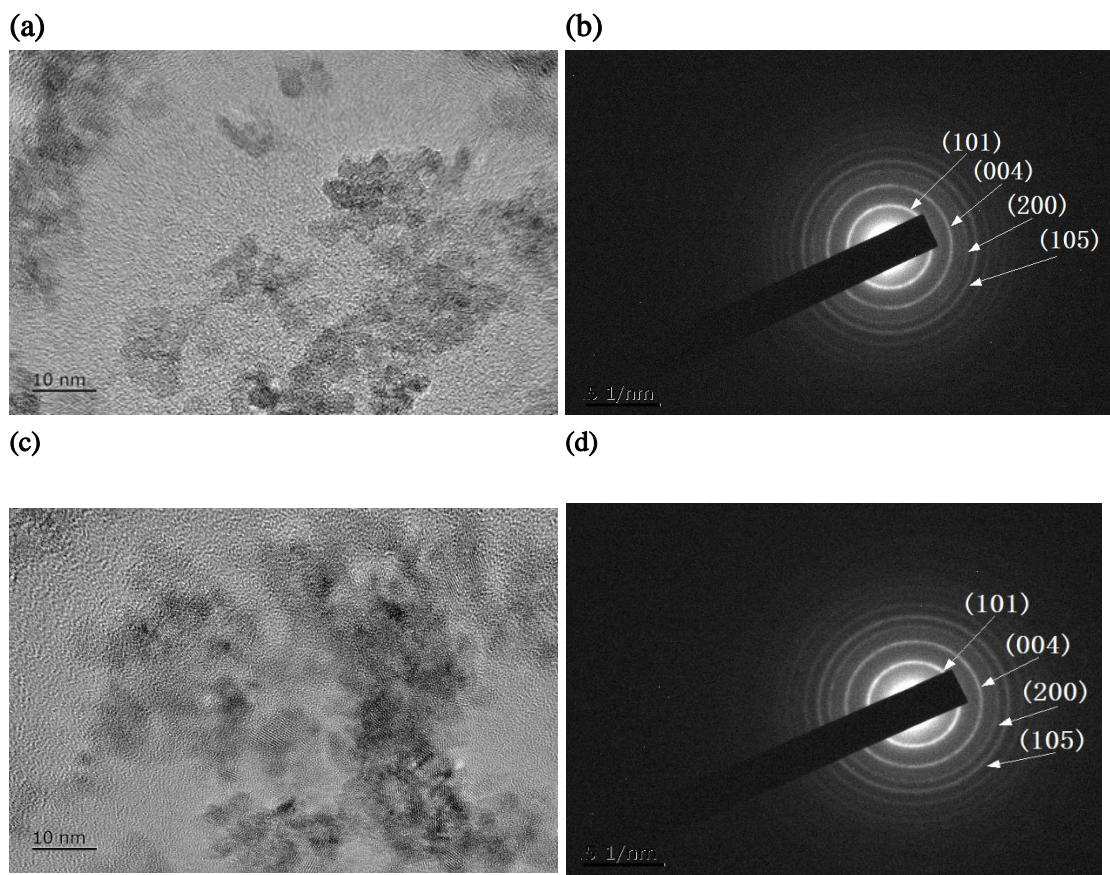


Fig. S2 (a) Bright-field HRTEM image of TiO₂ nanocrystals deposited on a carbon film. (b) A selected area electron diffraction of TiO₂ NCs. (c) Bright-field HRTEM image of Nb₂O₅-TiO₂ nanocrystals deposited on a carbon film. (d) A selected area electron diffraction of Nb₂O₅-TiO₂ NCs.

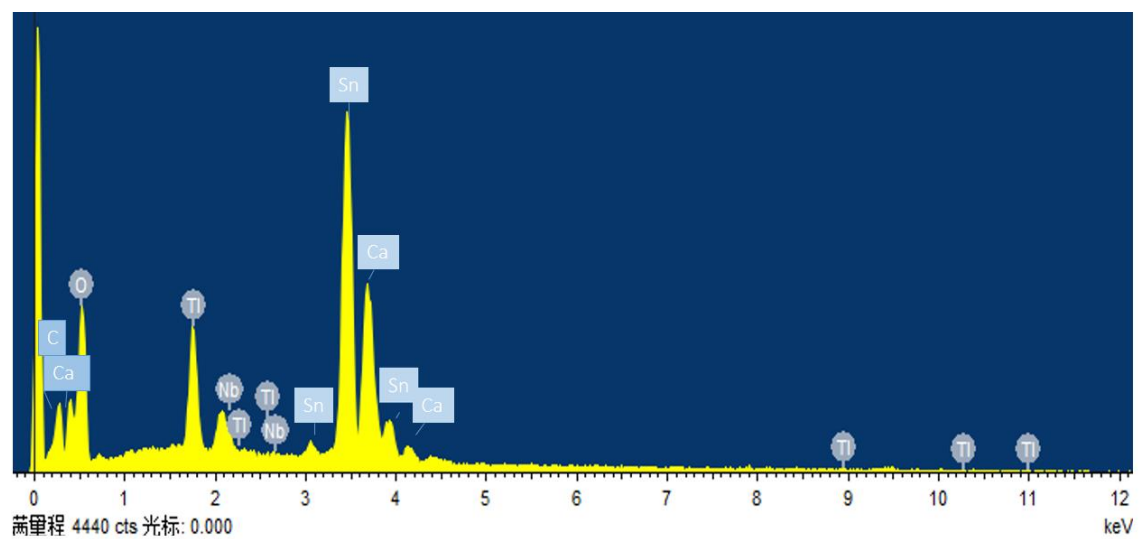


Fig. S3 Energy-dispersive spectroscopy (EDS) of the Nb₂O₅-TiO₂ film.

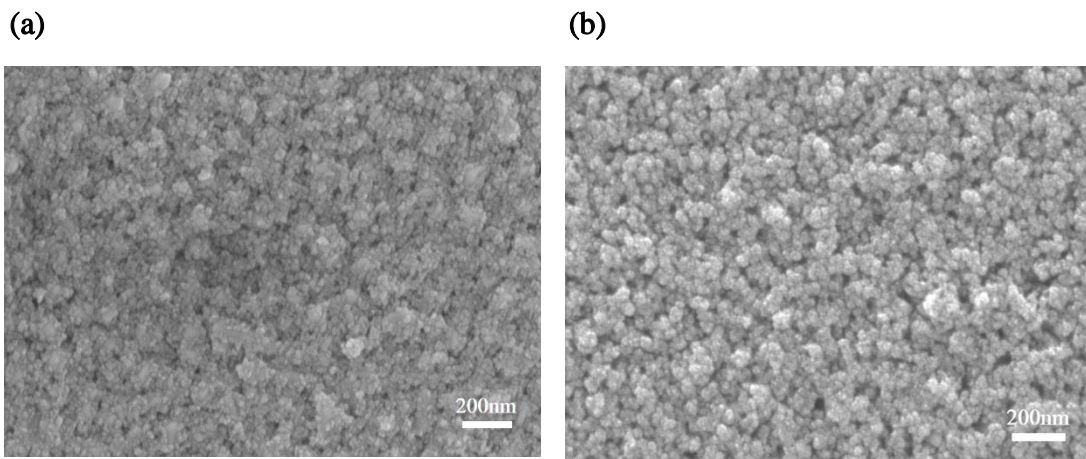


Fig. S4 SEM image of TiO_2 NCs films with over concentrations of niobium ethoxide (a) concentration of 30% and (b) concentration of 40%.

Electron mobility of TiO₂ and Nb₂O₅-TiO₂

Electron-only devices (Fig. S5b) were fabricated to calculate the electron mobility of the samples, including TiO₂ and Nb₂O₅-TiO₂ by the SCLC. The PCBM solution was prepared in chlorobenzene (20 mg/mL), and spin-coated on FTO/glass at 3000 rpm, then annealed at 100 °C for 15 min. The TiO₂ and Nb₂O₅-TiO₂ were deposited on PCBM surface. Sequentially, the PCBM films were fabricated on previous samples surface. The 100 nm-thick Ag were deposited. The dark *J-V* characteristics of the electron-only devices were measured by a Keithley 2400 source. The mobility is extracted by fitting the *J-V* curves by the Mott-Gurney.^{1, 2}

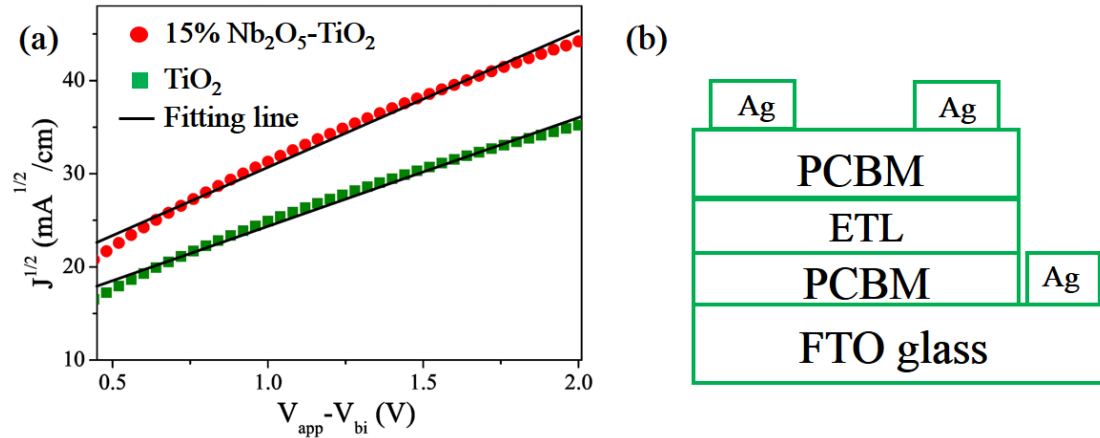


Fig. S5 (a) The electron mobility measurement of TiO₂ and Nb₂O₅-TiO₂ from the space charge limitation of current (SCLC) *J-V* characteristics obtained in the dark for electron-only devices. (b) The sample structure for this measurement.

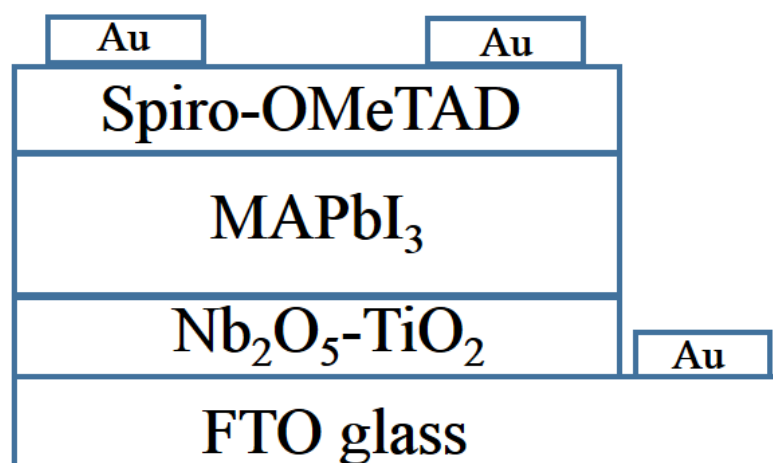


Figure S6 Device structure of the PSC.

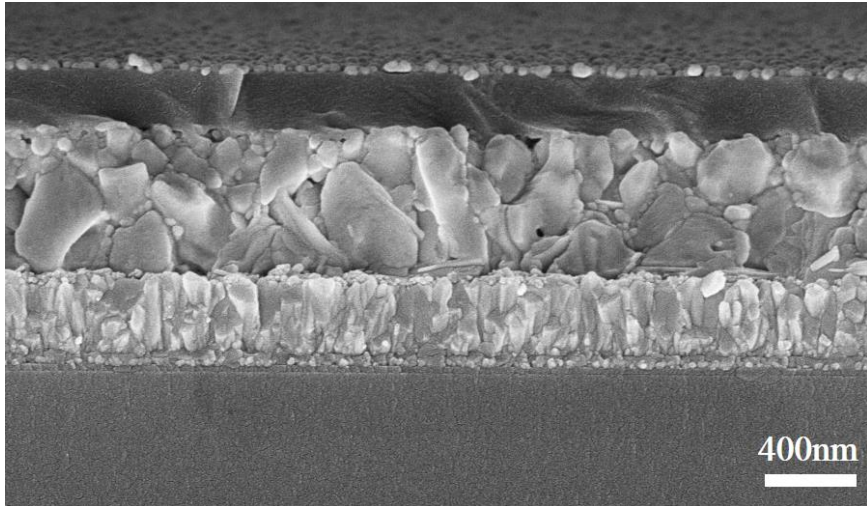


Fig. S7 Cross-sectional SEM image of the PSC completed device.

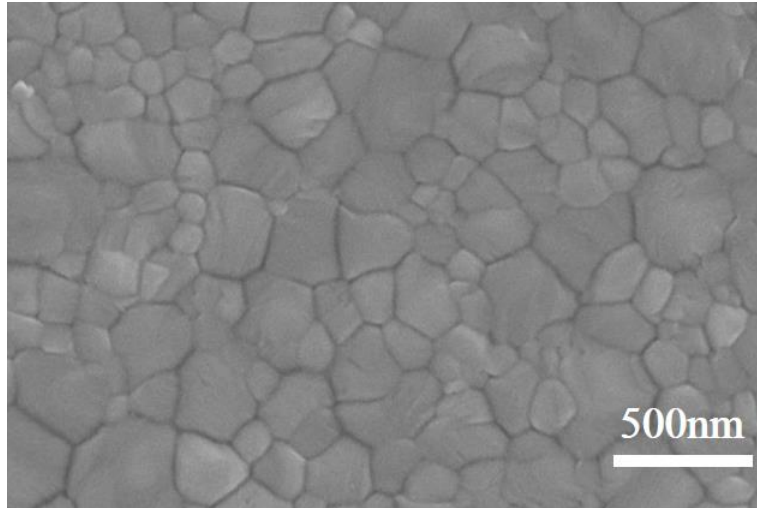


Fig. S8 Top-view SEM images of CH₃NH₃PbI₃ perovskite films coated on the Nb₂O₅-TiO₂ films.

	V_{oc} (V)	J_{sc} (mA/cm ²)	FF (%)	PCE (%)	R_s ($\Omega \cdot \text{cm}^2$)	R_{sh} ($\text{K}\Omega \cdot \text{cm}^2$)
TiO ₂	0.99	19.55	0.698	13.47	8.12	1.30
10% Nb ₂ O ₅ -TiO ₂	1.00	20.14	0.711	14.27	7.46	2.61
15% Nb ₂ O ₅ -TiO ₂	1.04	20.49	0.716	15.25	7.11	2.61
20% Nb ₂ O ₅ -TiO ₂	1.04	20.13	0.701	14.56	7.37	1.32
30% Nb ₂ O ₅ -TiO ₂	1.01	20.26	0.648	13.28	8.51	1.19
40% Nb ₂ O ₅ -TiO ₂	1.00	19.56	0.604	11.86	10.71	0.62

Table S1 Photovoltaic performance of TiO₂ and Nb₂O₅-TiO₂ ETLs

	Amplitude of τ_1 (%)	τ_1 (ns)	Amplitude of τ_2 (%)	τ_2 (ns)	τ_{ave} (ns)
glass/perovskite	1.89	1.05	98.11%	429.50	49.40
TiO ₂ / perovskite	2.93%	1.36	97.07%	255.33	39.48
Nb ₂ O ₅ -TiO ₂ / perovskite	11.68%	0.92	88.32%	223.58	7.60

Table S2 Time resolved photoluminescence (TRPL) parameters based on the glass/perovskite, TiO₂/ perovskite and Nb₂O₅-TiO₂/ perovskite, respectively.

	$V_{oc}(V)$	J_{sc} (mA/cm ²)	FF (%)	PCE (%)
R= ∞	0.99	20.04	0.69	13.60
R=10mm	0.97	19.92	0.67	13.03
R=5mm	0.94	19.45	0.58	10.70
R=3mm	0.82	13.75	0.30	3.39

Table S3 Photovoltaic parameters of the flexible PSCs obtained after recovery from bending at different radius (R).

References

- (1) Goodman, A. M.; Rose, A. Double Extraction of Uniformly Generated Electron-Hole Pairs from Insulators with Noninjecting Contacts, *J. Appl. Phys.* **1971**, 42(7), 2823-2830.
- (2) Goh, C.; Kline, R. J.; McGehee, M. D.; Kadnikova, E. N.; Frechet, J. M. J. Molecular-weight-dependent mobilities in regioregular poly(3-hexylthiophene) diodes, *Appl Phys. Lett.* **2005**, 86 (12), 122110.