Supporting Information

Polymer-complexed SnO_2 Electron Transport Layer for High-Efficiency *n-i-p* Perovskite Solar Cells

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Materials

SnO_2 colloidal (15 wt% in H_2O), DMF(99.8%), DMSO (99.7%), Chlorobenzene (99.8%), 4-tBP (96%), LiTFSI (99.95%), IPA (99.99%) were obtained from Alfa Aesar. PbI_2 (99.99%), CsI (99.99%), $PbBr_2$ (98%), SpiroMeOTAD (99.5%), MAI, FAI, MACl, and MABr and ITO substrates were purchased from Preferred Tech Co., Ltd. Poly(amidoamine) (PM) was purchased from Chenyuan molecular New Mater. Co., Ltd.

Device Fabrication

ITO substrates were ultrasonically cleaned in acetone, ethanol, IPA and deionized water for 15 min, respectively. The cleaned ITO ware dried with air and treated with plasma for 15 min. Mix 0.5mL SnO_2, 2 mL deionized water and a certain amount of PM evenly (The final concentration of PM is 0~6 mg/mL). Then spin it onto the ITO substrate at 5000 rpm for 30 s then heated at 150℃ for 30 min. Firstly, a PbI_2 solution (1.5M, PbI_2 in DMF/DMSO (9:1)) was spin coated on SnO_2 electron transport layer at 1500 rpm for 45s. After 5 min, place it on a 70 ℃ hotplate and heat it for 1 min. Secondly, FA/MA solution (FAI/MABr/MACl=90/6/9 mg in 1 mL IPA) drop on top of the PbI_2, by spin coating at 1600 rpm for 45s. The obtained perovskite film was put on a hotplate and heated at 150 ℃ for 15 min in open air (T=25℃, H=35%). The hole-transport layer was prepared by spin-coating a Spiro-OMeTAD on top of perovskite (72.3 mg Spiro-OMeTAD, 18.5 μL Li-TFSI (520 mg mL^{-1} in acetonitrile), 28.8 μL 4-tBP in 1 mL of chlorobenzene). Finally, MoO_3 with a thickness of 5 nm and Ag with a thickness of 120 nm were evaporated successively to complete the device manufacturing.

Characterization

DLS measurements were carried out with alight-scattering apparatus (ALV/DLS/SLS- 5022F). The sample morphology were characterized by FE-SEM (JSM-7001F, Japan). Perovskite crystal structures were measured by X-ray diffraction (DX-2700). FTIR spectra were characterized by infrared spectrometer (Tensor 27, BRUKER). XPS test was measured by Thermo-Fisher system (ESCALAB 250Xi). PL and TRPL spectra were measured using a laser with wavelength of 514 nm (Renishaw inVia microRaman system, Hamamatsu C10910). The *J-V* curves were obtained using a

source-meter (Keithley 2400) and a solar simulator (Oriel 94023 A, Newport). The EQE measurement was conducted on an EQE measurement system (500ADX, USA).

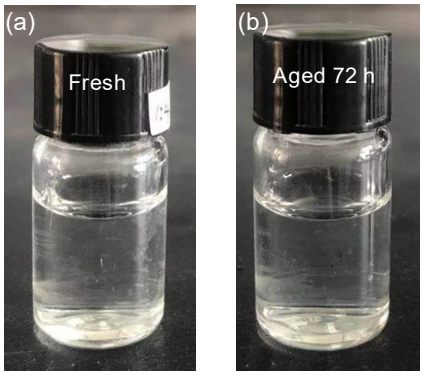

Figure S1. Photos of fresh (a) and aged SnO_2 (b) colloidal dispersions at 25℃ for 72h. Commercial SnO_2 colloidal dispersion diluted in water (volume ratio, 1:4).

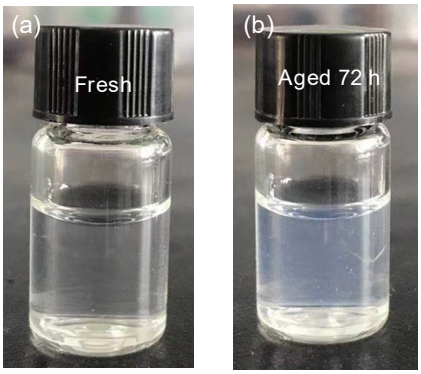

Figure S2. Photos of fresh and aged SnO_2 colloidal dispersions at 35℃ for 72h. (a) control and (b) aged-SnO_2 (Commercial SnO_2 colloidal dispersion diluted in water with volume ratio, 1:4).

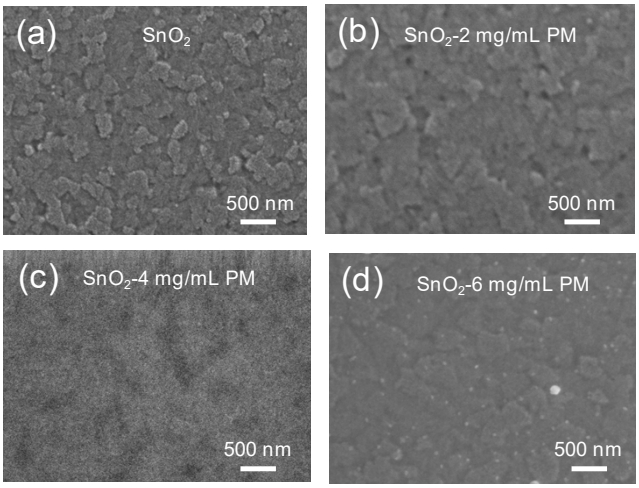

Figure S3. Top-view SEM images of SnO_2 films with different PM additions (a), (b), (c), and (d) control, 2 mg mL^{-1}, 4 mg mL^{-1}, and 6 mg mL^{-1}.

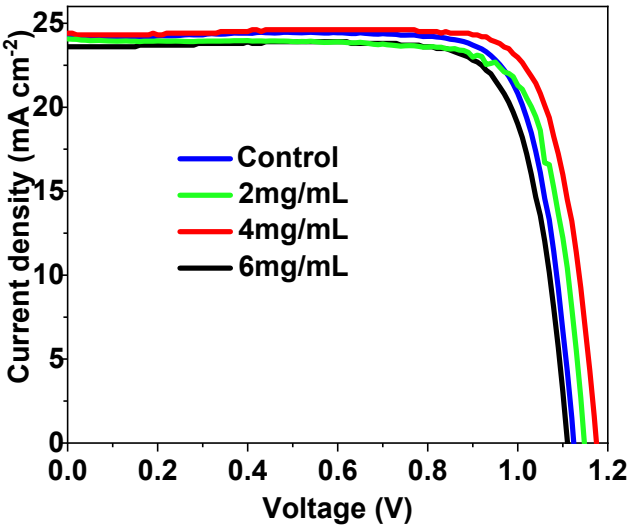

Figure S4. *J-V* curves of devices based on SnO_2 ETL with different PM additions (control/2/4/6 mg mL^{-1}).

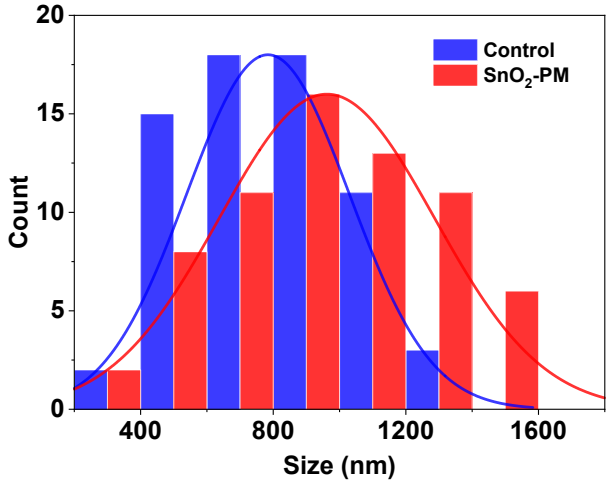

Figure S5. Distribution of perovskite grain size deposition on control and SnO_2-PM ETLs.

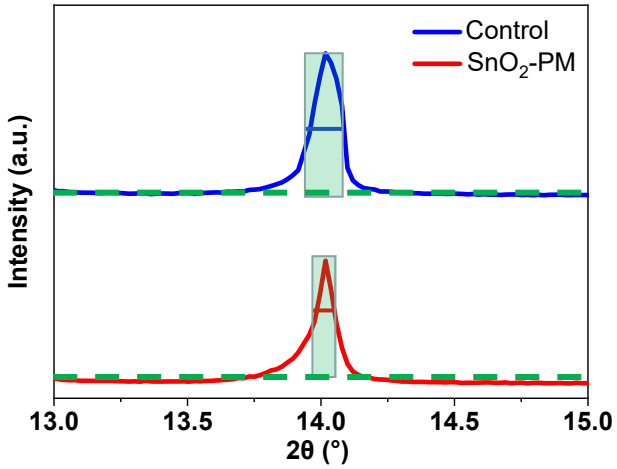

Figure S6. Full-width at half-maximum of perovskite characteristic peak at 14.05° based on control and SnO_2-PM, respectively

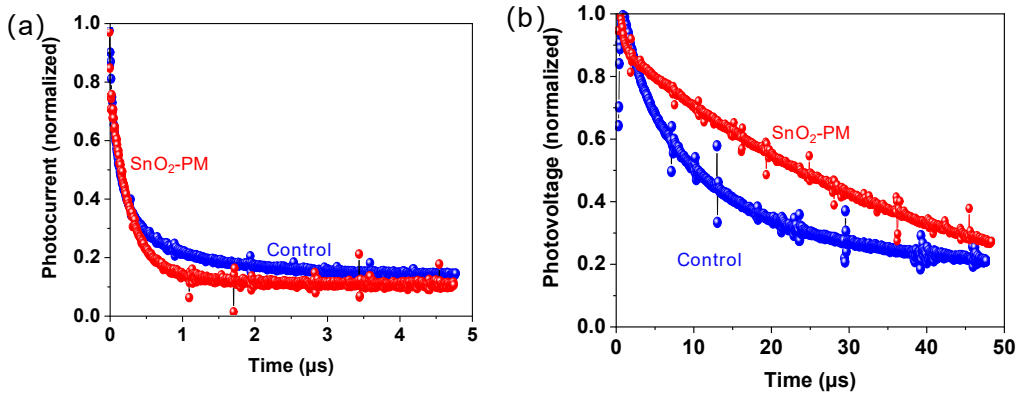

Figure S7. (a) TPC and (b) TPV for PSCs based on control and SnO_2-PM ETL.

Table. S1 Photovoltaic parameters of devices based on different SnO_2 ETL (PM concentration: 0/2/4/6 mg mL^{-1}).

Samples	J_{SC}/ mA cm^{-2}	V_{OC}/ V	*FF*	*PCE*/ %
Control	24.17	1.13	0.769	21.01
SnO_2-PM-2	24.18	1.12	0.797	21.69
SnO_2-PM-4	24.41	1.17	0.803	22.93
SnO_2-PM-6	23.60	1.11	0.790	20.70

Table. S2 TRPL fitting results of control and SnO_2-PM based PSCs.

Samples	τ_1	τ_2
Control	13.76	31.09
SnO_2-PM	21.06	5.91

Table. S3 Fitting results of electrochemical impedance spectroscopy control and SnO_2-PM based PSCs.

Samples	R_s (Ω)	R_{rec} (Ω)
Control	36	331
SnO_2-PM	28	586