Electronic Supplementary Material (ESI) for Journal of Materials Chemistry A.
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Electronic Supplementary Information

Reduced Energy Loss in SnO_2/ZnO Bilayer Electron Transport Layer-Based Perovskite Solar Cells for Achieving High Efficiencies in Outdoor/Indoor Environments

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Table S1. Fitting results of TRPL decay curves of $MAPbI_3$ on different ETLs.

Film	A_1	A_2	τ_1 [ns]	τ_2 [ns]	τ_{ave} [ns]
Neat $MAPbI_3$	0.41	0.59	152.02	519.40	457.09
$MAPbI_3/SnO_2/ZnO$ (N/A)	0.40	0.60	53.57	186.43	163.46
$MAPbI_3/SnO_2/ZnO$ (A)	0.46	0.54	42.16	175.00	152.60

Table S2. Fitting results of EIS measurements of PSCs employing different ETLs.

ETL	R_s [Ω]	R_{trans} [Ω]	R_{rec} [Ω]
SnO_2/ZnO (N/A)	36.8	1.77	149
SnO_2/ZnO (A)	42.0	22.5	91.4

Table S3. Detailed summarization of photovoltaic parameters for PSCs under indoor light source reported elsewhere.

Perovskite	Light source/ Intensity	V_{OC} [V]	J_{SC} [μA cm^{-2}]	FF	PCE[a)] [%]	PCE[b)] [%]	Ref.
$CH_3NH_3PbI_3$	White LED (6500 K)/ 1000 lux	0.98	157.6	0.72	35.9	37.2	This work
$CH_3NH_3PbI_{2-x}BrCl_x$	Philip T2 15W E27/ 1000 lux	1.028	126.2	0.76	36.2	-	S1
$CH_3NH_3PbI_{3-x}Cl_x$	Philip T5 6500 K/ 1000 lux	0.85	137.5	0.77	27.4	-	S2
$CH_3NH_3PbI_3$	Osram Parathom Classic P25 LED/ 400 lux	0.895	64.5	0.72	26.9	-	S3
$CH_3NH_3PbI_3$	Osram L18W/ 1000 lux	0.87	150.1	0.75	35.2	-	S4
$CH_3NH_3PbI_3$	Philip T5 (6500K)/ 1000 lux	0.91	139	0.75	30.1	-	S5
$CH_3NH_3PbI_3$	Philip T5 6500K/ 1000 lux	0.858	129.5	0.75	27.0	-	S6
$CH_3NH_3PbI_3$	CFL/400 lux	0.775	58	0.72	25.4	-	S7
$CH_3NH_3PbI_3$	White LED/400 lux	0.842	47.7	0.59	13.32	-	S8
$(FAPbI_3)_{0.84}(MAPbBr)_{0.16}$	White LED/200 lux	0.797	26.4	0.72	23.4	-	S9
$(Rb_{0.01}Cs_{0.05})(MA_xFA_{1-x})_{0.94}Pb(Br_xI_{1-x})_3$	CFL/0.12 mW cm^{-2}	0.883	59	0.69	21.4	-	S10
$CH_3NH_3PbI_{2.9}Cl_{0.1}$	White LED/ 2.2 mW cm^{-2}	0.956	622	0.77	20.8	-	S11

a) PCE obtained from J-V measurements.
b) PCE obtained from stabilized power output measurements for 300 s.

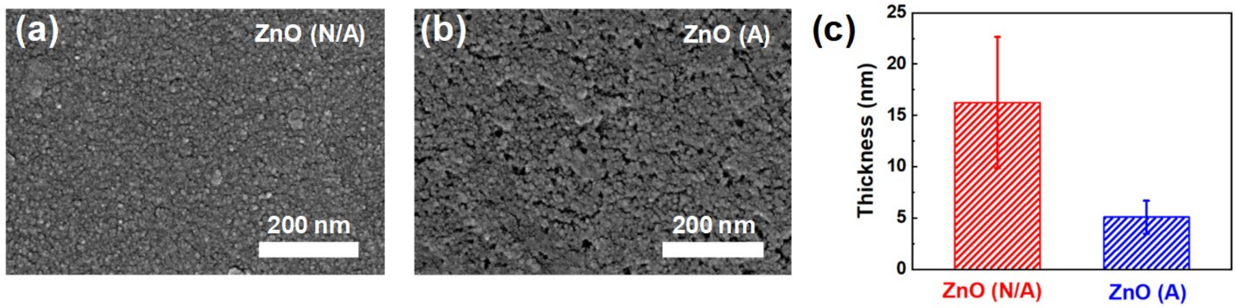

Figure S1. SEM images for ZnO (N/A) (a) and ZnO (A) (b) layer, and their thickness change upon thermal annealing.

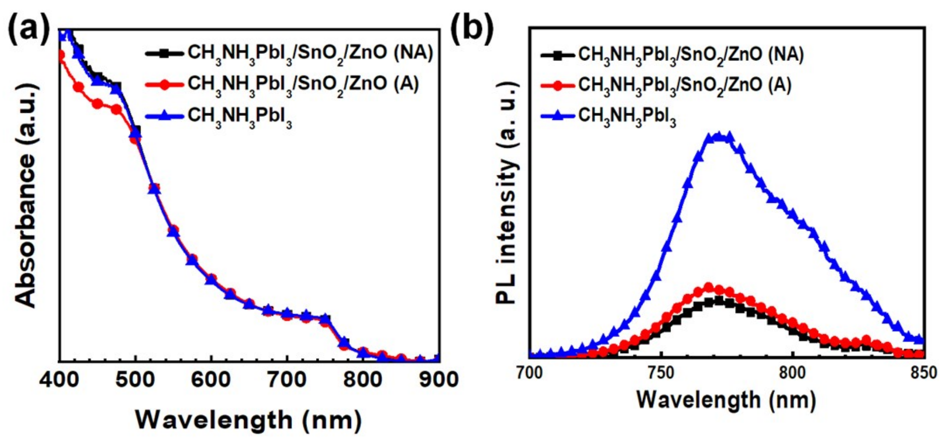

Figure S2. Absorption (a) and photoluminescence spectra (b) for $MAPbI_3$ layer on different ETLs.

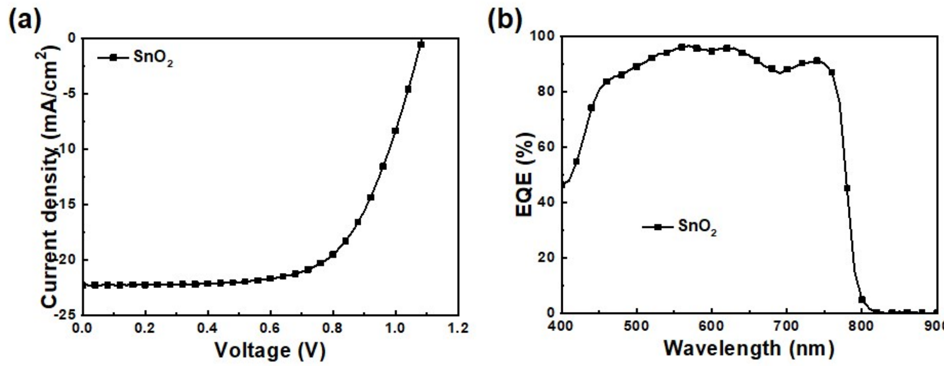

Figure S3. Representative *J–V* curve (a) and corresponding EQE spectum (b) of PSCs based on single ETL of SnO_2.

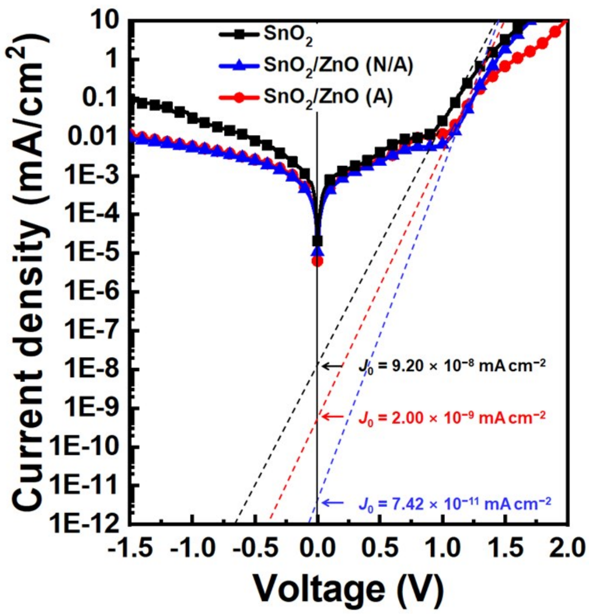

Figure S4. *J–V* curves for the devices with different ETLs in dark, and their regression line to predict saturated dark current density (J_0).

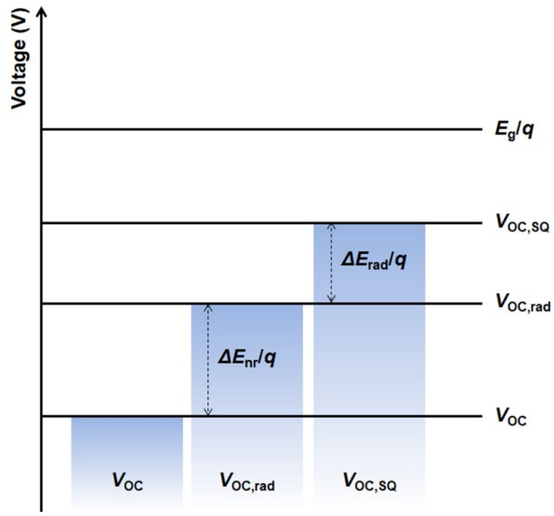

Figure S5. Schematic illustration of detailed energy loss in PSCs.

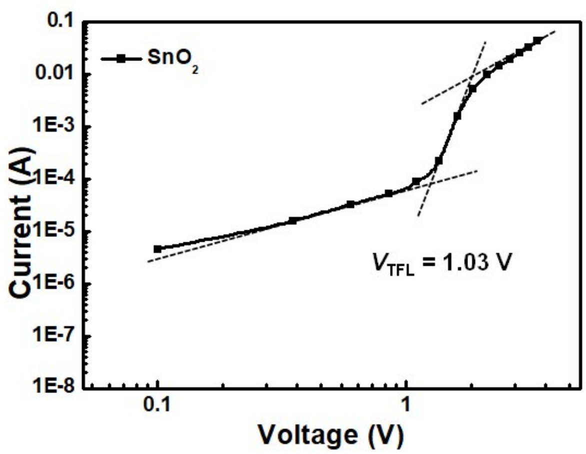

Figure S6. Dark *J–V* curve of the electron-only device with SnO_2.

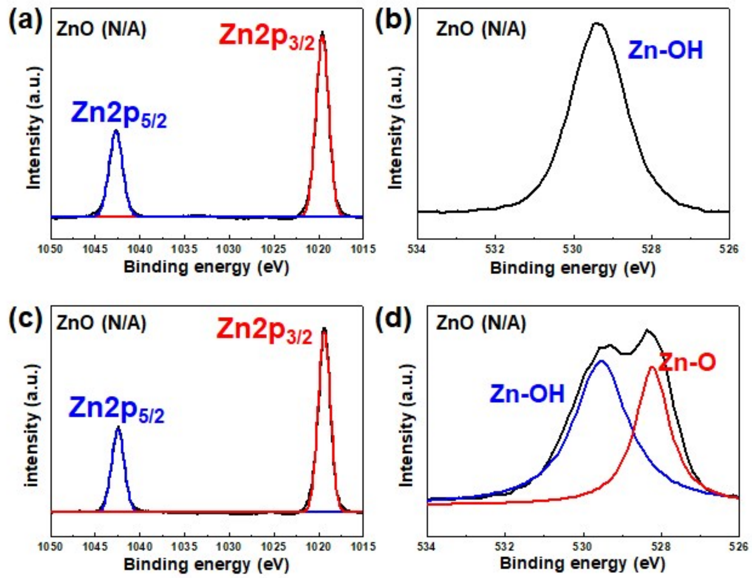

Figure S7. XPS core level spectra for Zn 2p (a, c) and O 1s (b, d) of ZnO (N/A) (a, b) and ZnO (A) (c, d) layer.

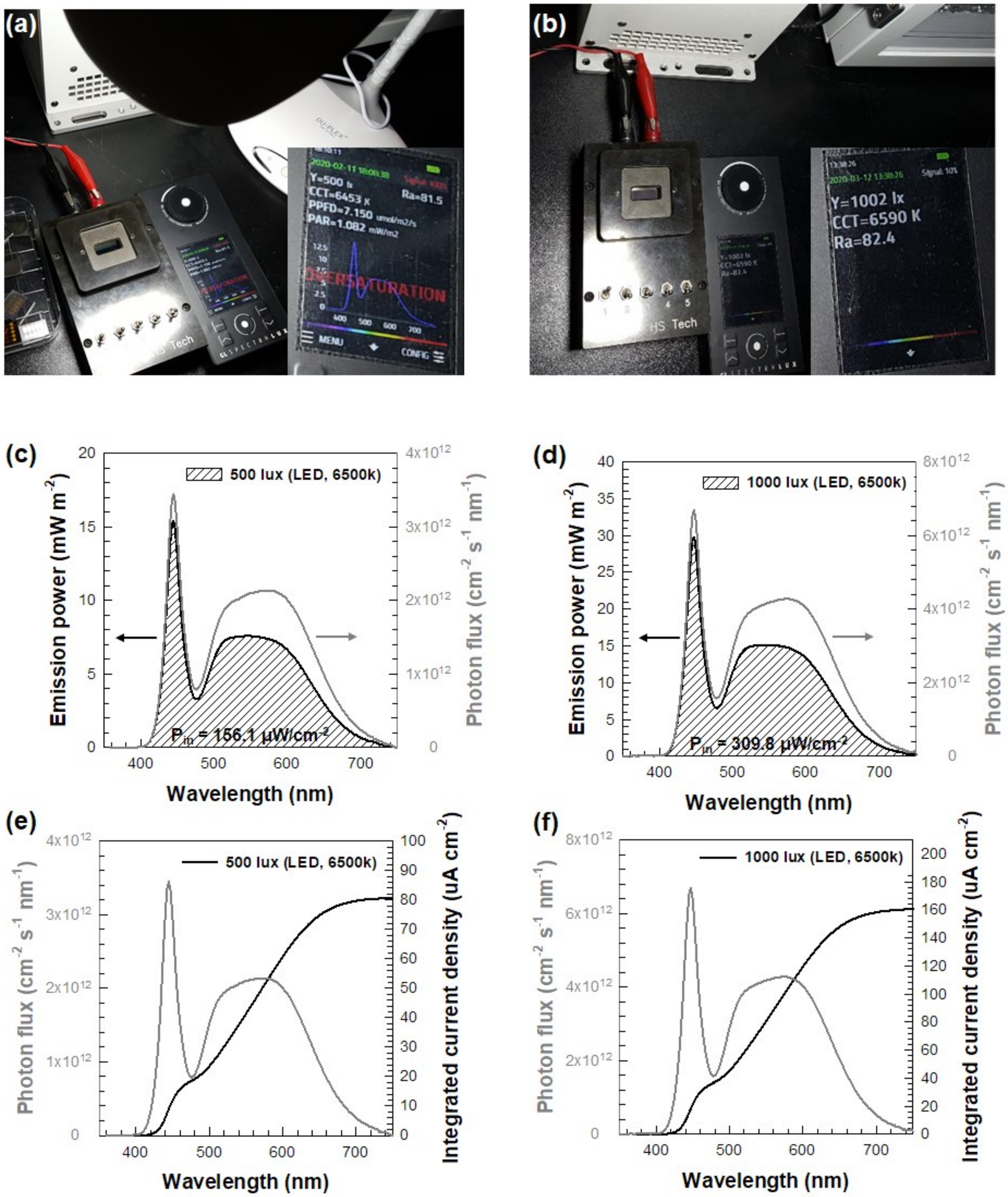

Figure S8. Photographic images for measurement condition under white LED light source at 500 lux (a) and 1000 lux (b), and their emission power and photon flux of 500 lux (c) and 1000 lux (d), and corresponding integrated current densities (e, f).

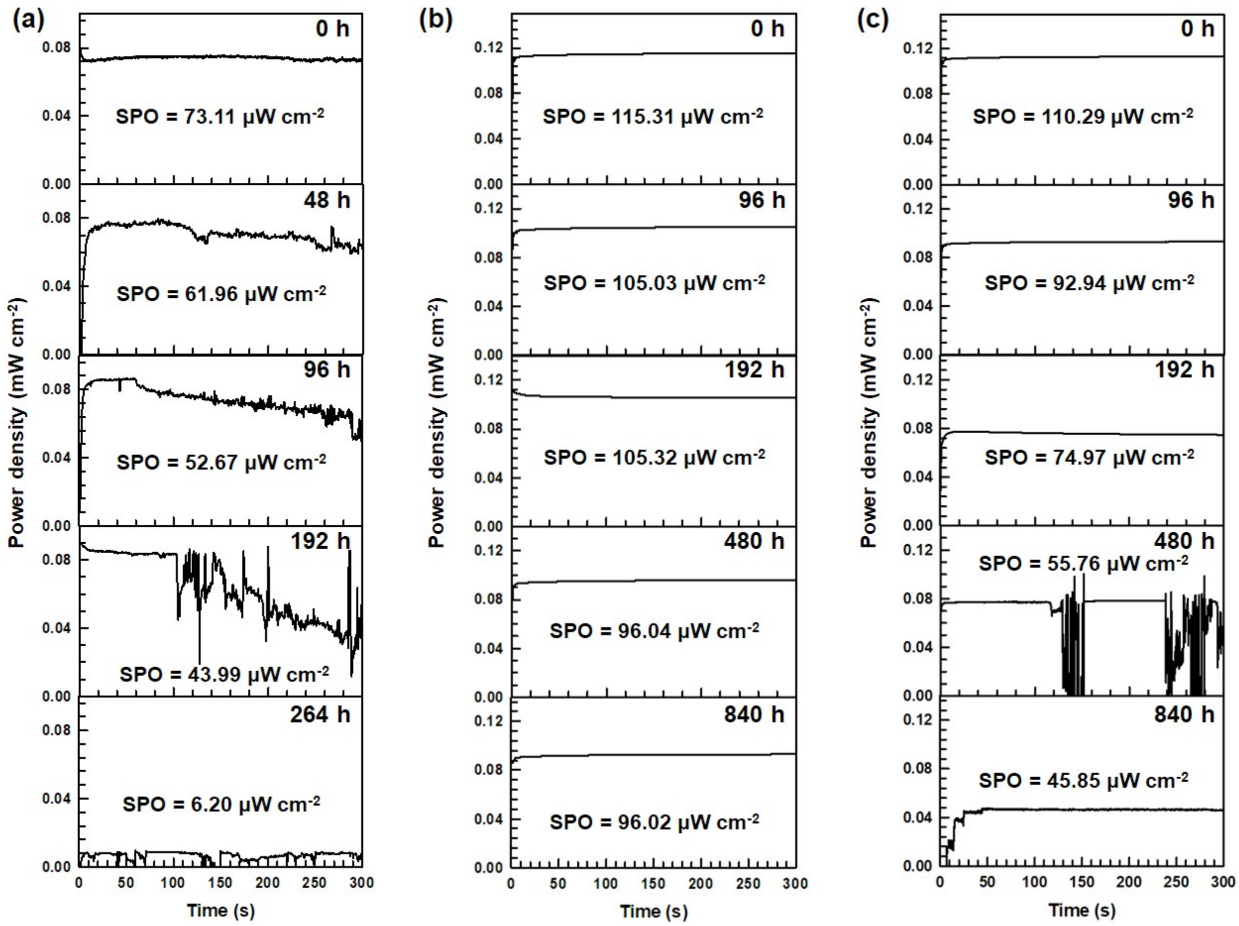

Figure S9. SPO measurements under white LED light source at 1000 lux for PSCs with SnO_2 (a), SnO_2/ZnO (N/A) (b), and SnO_2/ZnO (A) after continuous illumination of white LED light source (6500 K) in long-term storage in ambient condition.

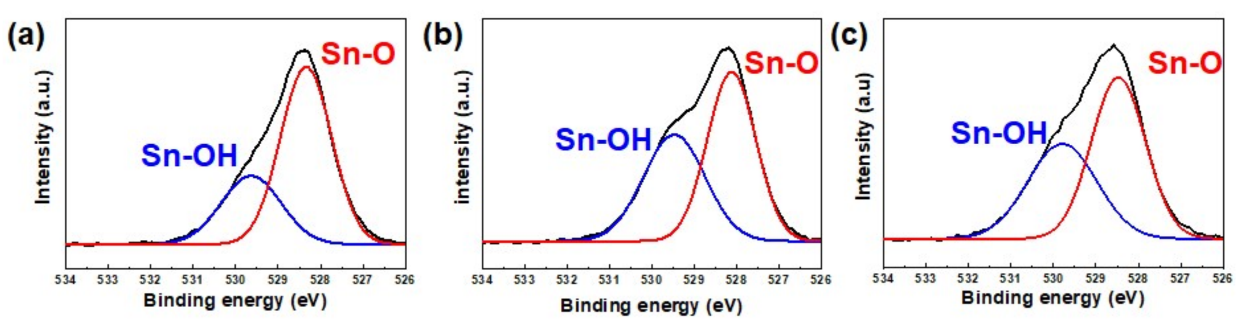

Figure S10. XPS core level spectra for O 1s (b, d) of SnO_2/ZnO (N/A) (a), SnO_2/ZnO (A) (b), and SnO_2 layer (c).

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