Supporting Information

High Current Density Sn-Based Perovskite Solar Cells via Enhanced Electron Extraction in Nanoporous Electron Transport Layers

Yumi Miyamoto*[1], Shohei Kusumoto[1], Tomoyasu Yokoyama[1], Yu Nishitani[1], Taisuke Matsui[1], Takashi Kouzaki[1], Ryosuke Nishikubo[2], Akinori Saeki[2], and Yukihiro Kaneko[1]

[1]Technology Division, Panasonic Corporation, 3-1-1 Yagumo-naka-machi, Moriguchi, Osaka 570-8501, Japan

[2]Department of Applied Chemistry, Graduate School of Engineering, Osaka University, 2-1 Yamadaoka, Suita, Osaka 565-0871, Japan

*Email: miyamoto.yumi@jp.panasonic.com

Table S1. Valence band maximum (VBM), conduction band minimum (CBM), and band gap (E_g) of each material.

	VBM (eV)	E_g (eV)	CBM (eV)
np-TiO_2	-7.13	3.32	-3.81
np-Nb_2O_5	-7.73	4.34	-3.39
Sn-based perovskite	-4.90	1.35	-3.56

Table S2. Performance values of Sn-based perovskite solar cells as previously reported.

device structure	V_{OC} (V)	J_{SC} (mA cm^{-2})	FF	efficiency (%)	reference No.
p-i-n	0.53	24.1	0.71	9.0	4
p-i-n	0.58	21.3	0.72	8.9	5
p-i-n	0.62	21.2	0.73	9.6	6
p-i-n	0.56	22.8	0.74	9.4	7
n-i-p	0.32	23.7	0.63	4.8	11
p-i-n	0.46	22.1	0.60	6.1	12
n-i-p	0.24	24.5	0.36	2.1	13
p-i-n	0.88	16.8	0.42	6.4	14
n-i-p	0.23	26.0	0.39	2.3	15
n-i-p	0.43	24.3	0.64	6.6	16
p-i-n	0.59	14.4	0.69	5.9	17
n-i-p	0.48	22.5	0.66	7.1	18
n-i-p	0.49	22.9	0.64	7.1	19
p-i-n	0.94	17.4	0.75	12	20

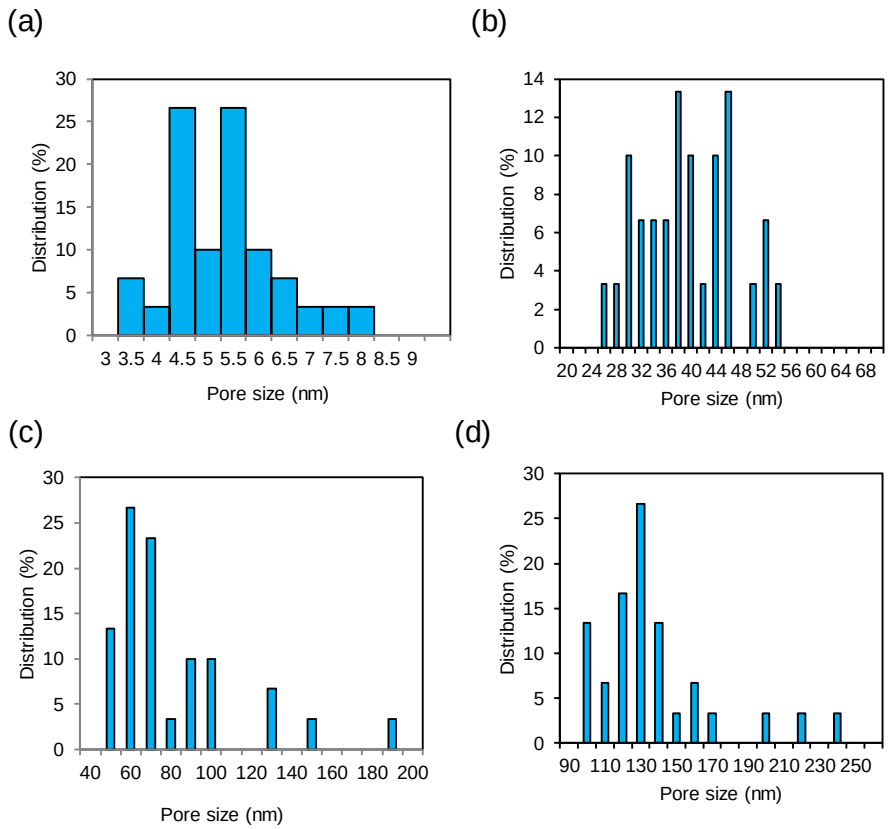

Figure S1. Pore size distribution of np-Nb_2O_5 (average pore size of (a) 5 nm, (b) 38 nm, (c) 75 nm, and (d) 131 nm).

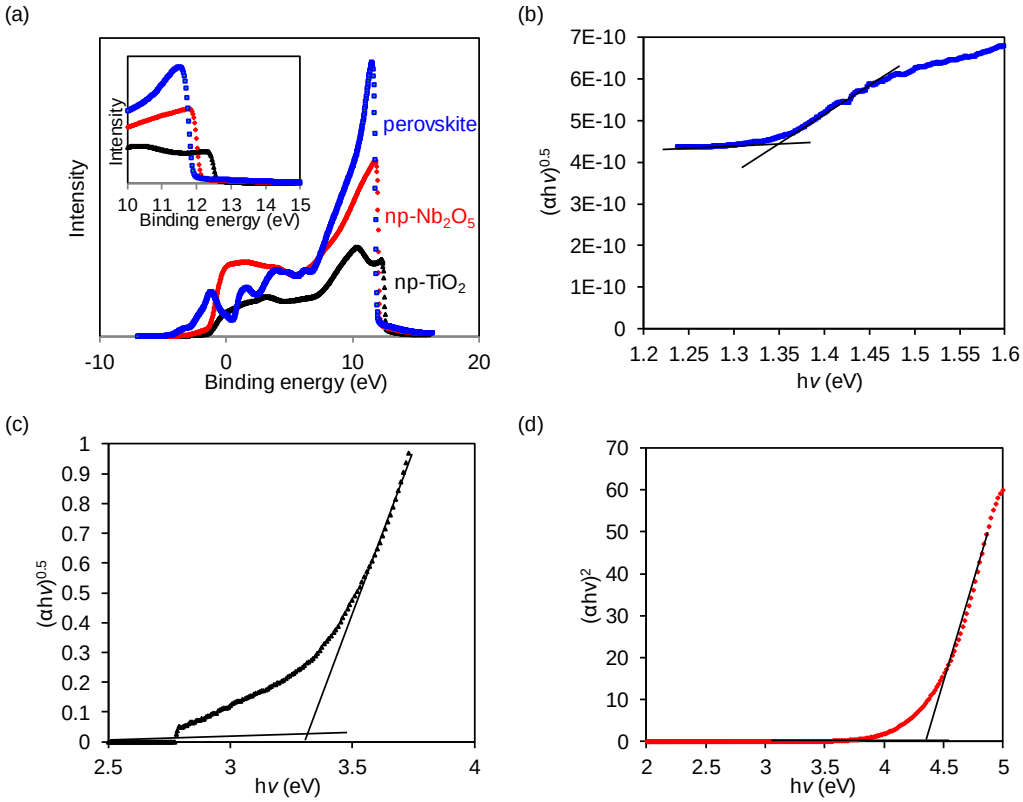

Figure S2. (a) UPS spectra of Sn-based perovskite, np-TiO_2, and np-Nb_2O_5 measured under an applied bias voltage of 5 V. Tauc-plot of (b) Sn-based perovskite, (c) np-TiO_2, and (d) np-Nb_2O_5.

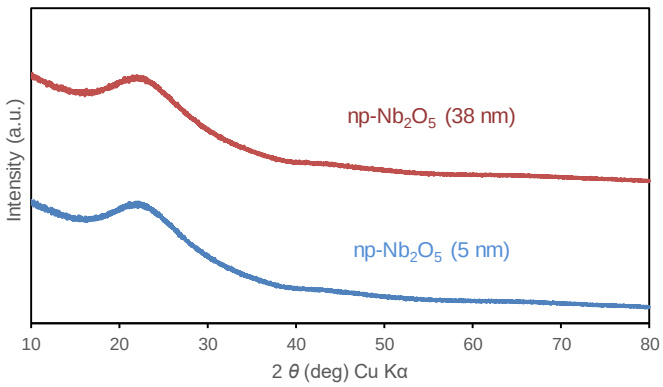

Figure S3. XRD patterns of the np-Nb_2O_5 ETLs.

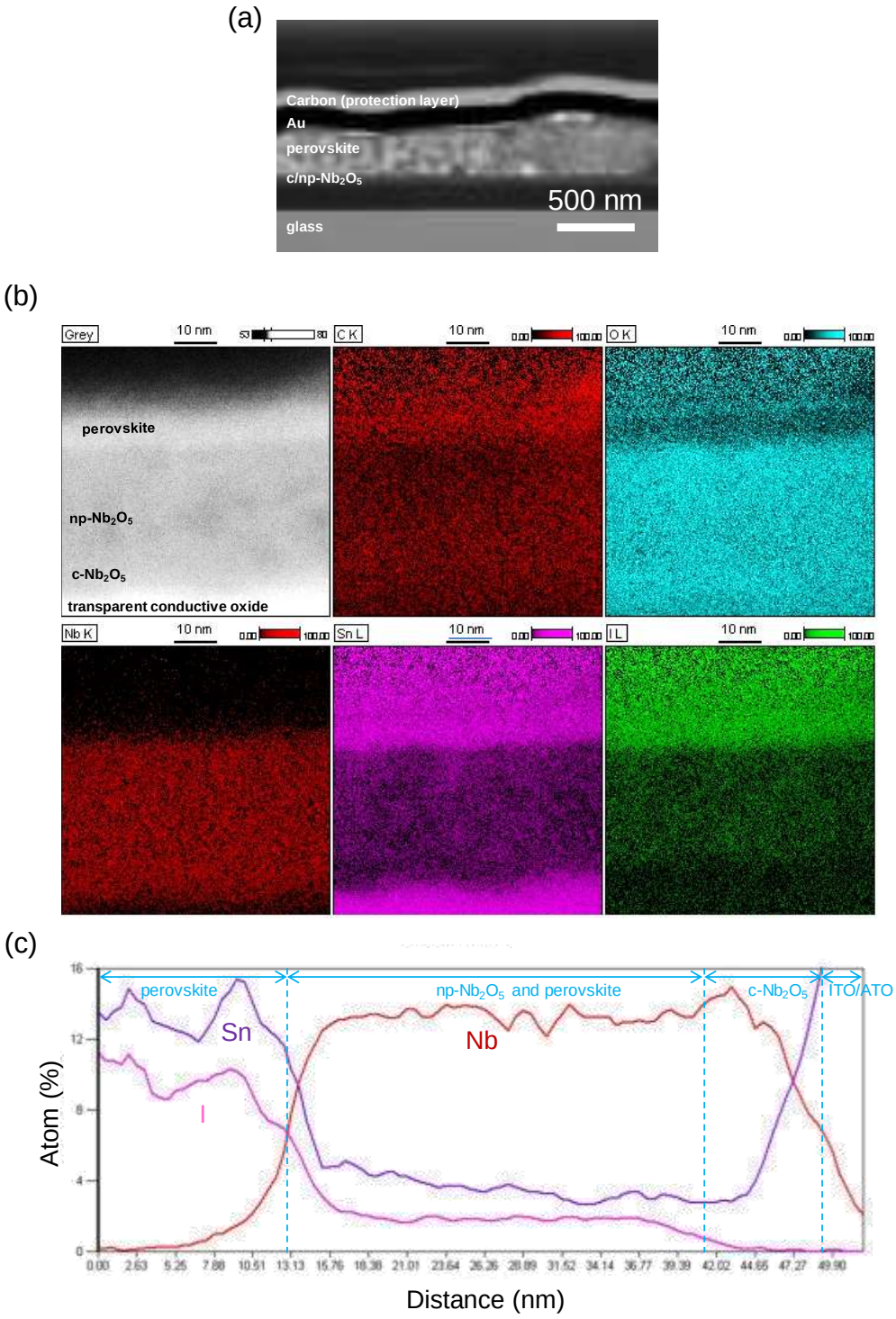

Figure S4. (a) TEM image, (b) TEM-EDX analyses, and (c) atomic distributions of the cross section of the Sn-based perovskite solar cell with np-Nb_2O_5 (pore size 5 nm). A part of the perovskite layer is shown in (b).

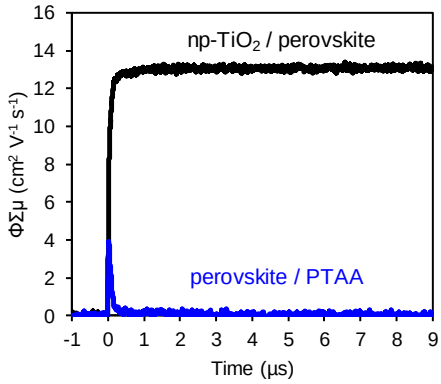

Figure S5. TRMC transients of Sn-based perovskite thin films. Light was irradiated onto the substrate side.

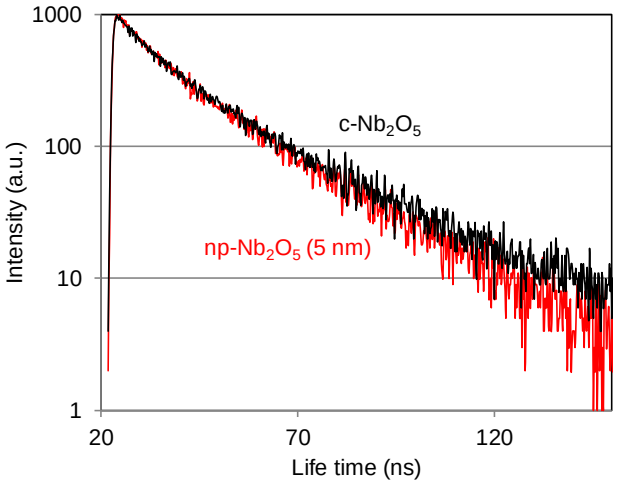

Figure S6. Time-resolved photo luminescence (TRPL) of the Sn-based perovskite formed on the Nb_2O_5 ETLs.

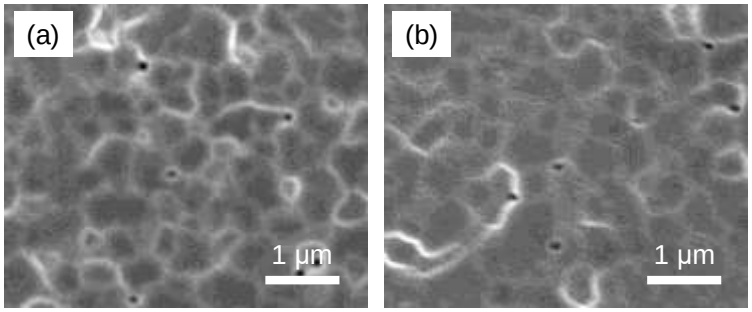

Figure S7. SEM images of Sn-based perovskites formed on (a) np-Nb_2O_5 (pore size 38 nm) and (b) np-Nb_2O_5 (pore size 75 nm). Perovskite layers were formed by annealing at 45 °C for 10 min followed by 65 °C for 20 min and 120 °C for 30 min annealing.

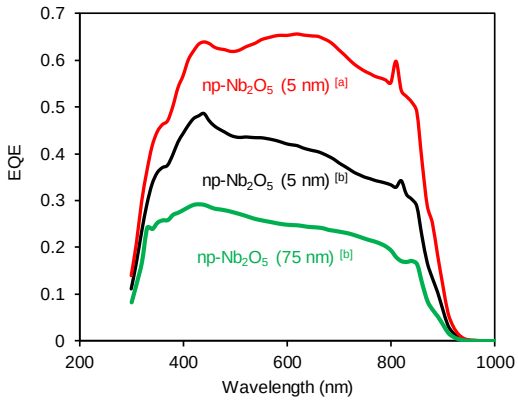

Figure S8. External quantum efficiency (EQE) of the perovskite solar cells with different ETLs. Sn-based perovskite layers were formed at [a] 140 °C for 30 min, [b] 40 °C for 10 min, 65 °C for 20 min, 120 °C for 30 min.