Supporting Information

SiO_2/TiO_2 Based Hollow Nanostructures as Scaffold Layers and Al-doping in Electron Transfer Layer for Efficient Perovskite Solar Cells

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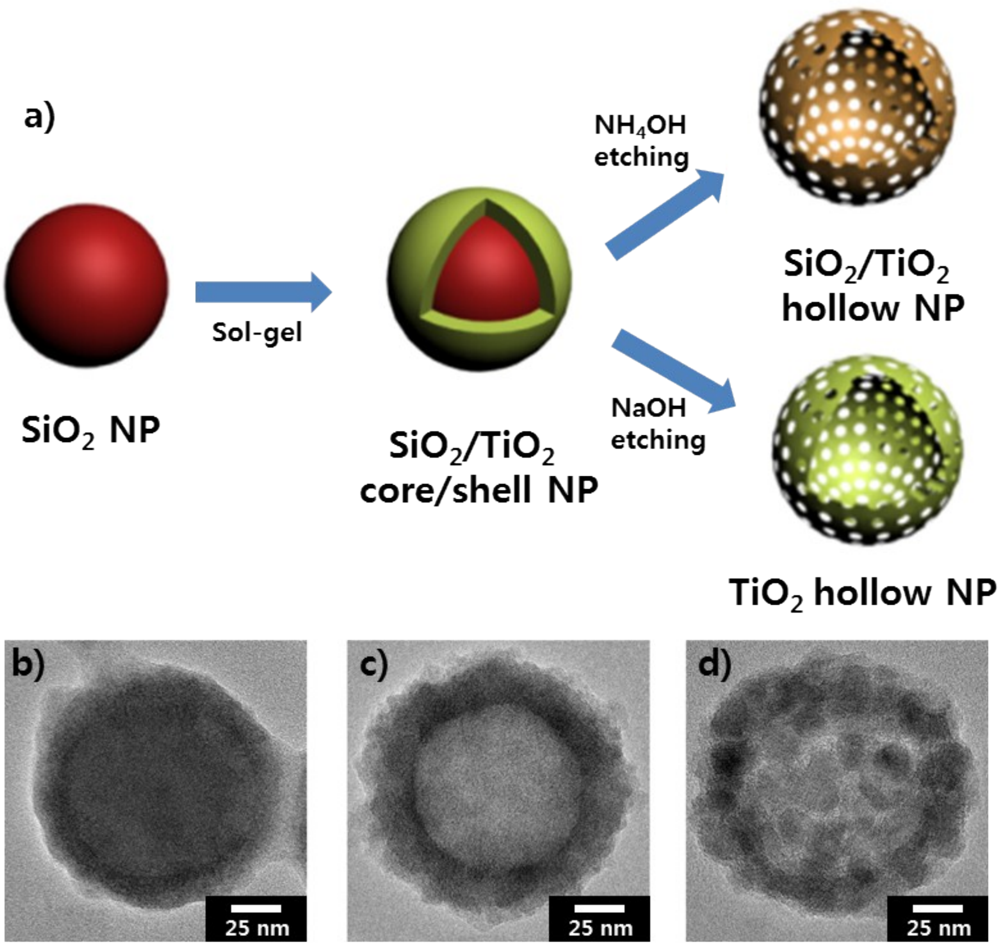


Fig. S1. a) Schematic illustration of the synthesis of hollow nanoparticles. HR-TEM images of b) STCSNP, c) STHNP, d) THNP.

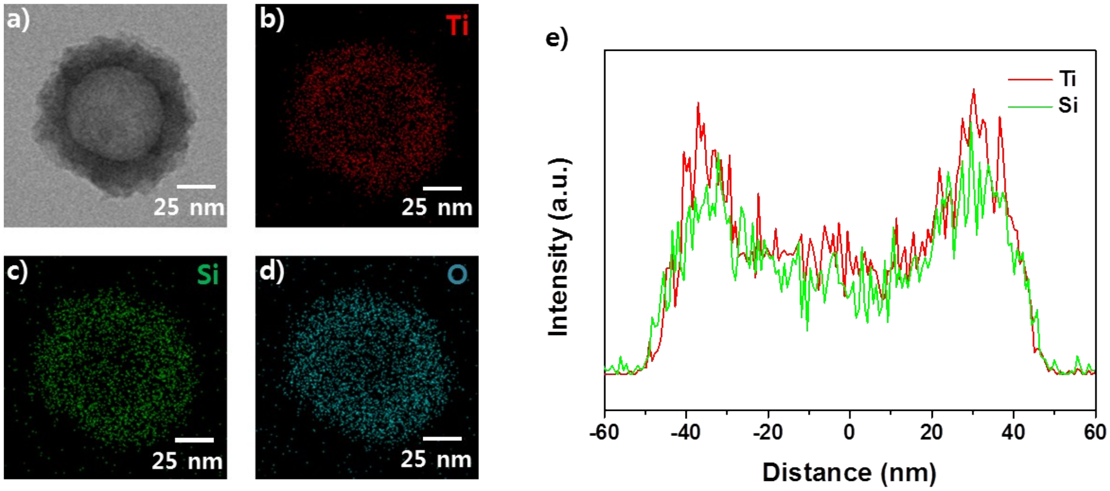


Fig. S2. a) STEM images of STHNP and elemental dot mapping of b) Ti, c) Si, d) O. e) STEM-EDS line mapping of STHNP.

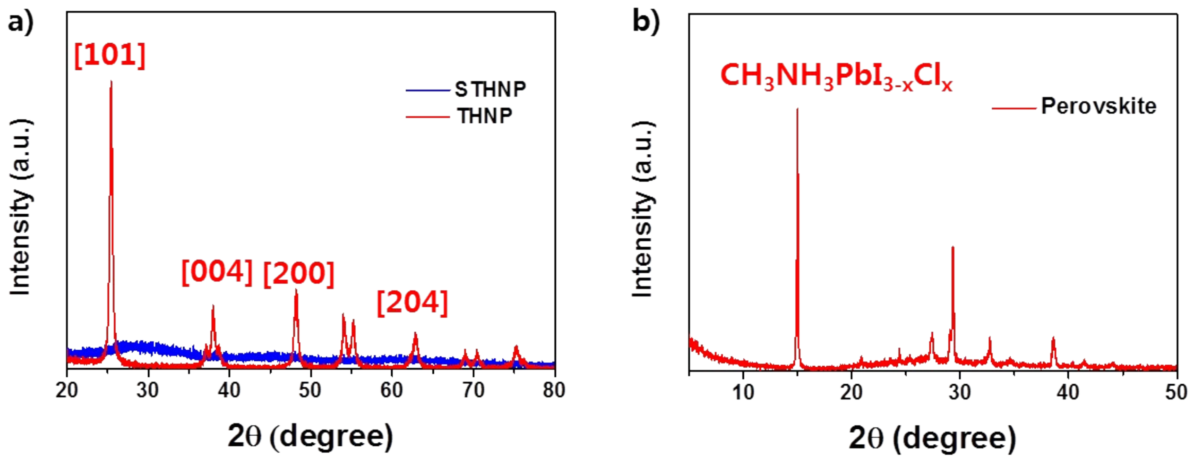
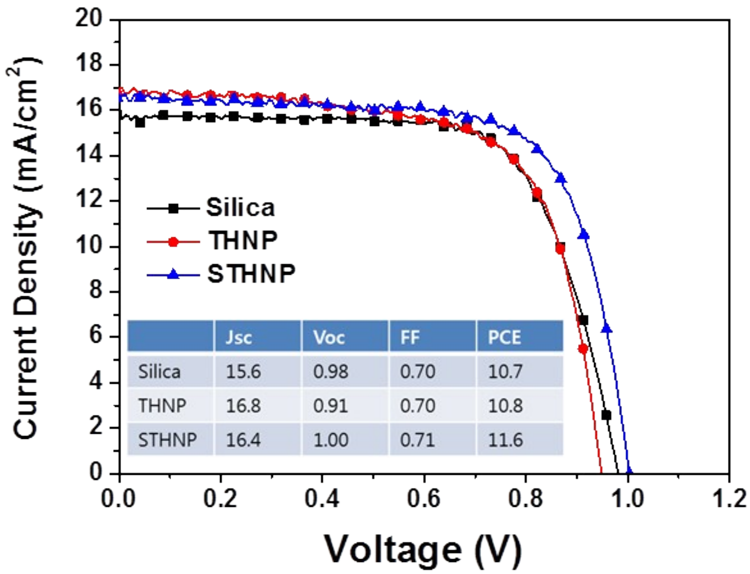
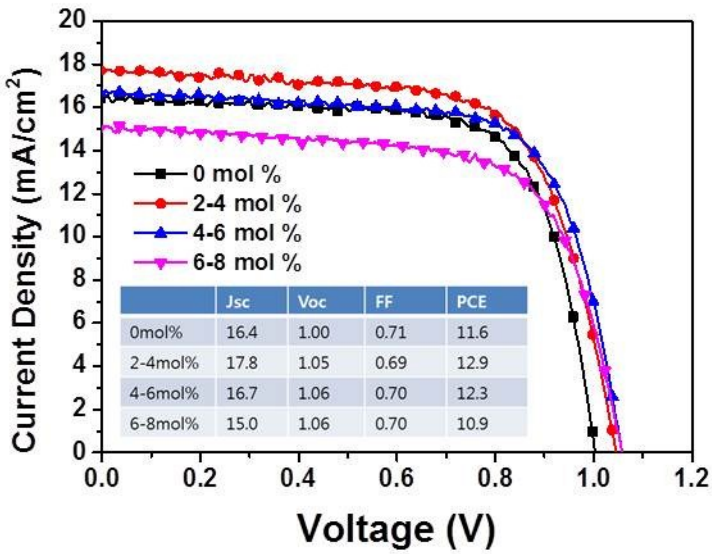


Fig. S3. XRD analysis of a) STHNPs and THNPs, b) annealed perovskite films.



	Jsc	Voc	FF	PCE
Silica	15.6	0.98	0.70	10.7
THNP	16.8	0.91	0.70	10.8
STHNP	16.4	1.00	0.71	11.6

Fig. S4. Current density-voltage curve of perovskite solar cells based on silica, THNPs, and STHNPs. Photovoltaic parameters are summarized in the inset table.



	Jsc	Voc	FF	PCE
0mol%	16.4	1.00	0.71	11.6
2-4mol%	17.8	1.05	0.69	12.9
4-6mol%	16.7	1.06	0.70	12.3
6-8mol%	15.0	1.06	0.70	10.9

Fig. S5. Current density-voltage curve of perovskite solar cells based on Al-doping concentration. Photovoltaic parameters are summarized in the inset table.

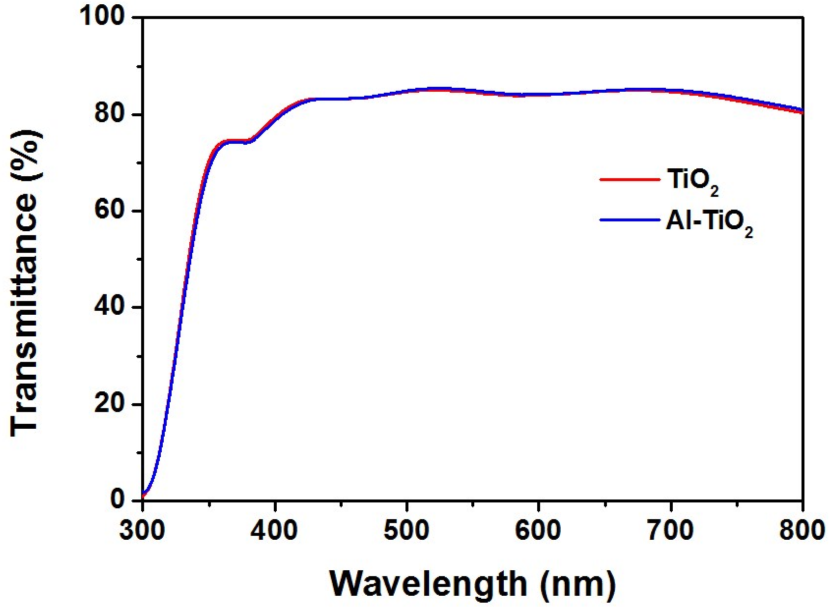
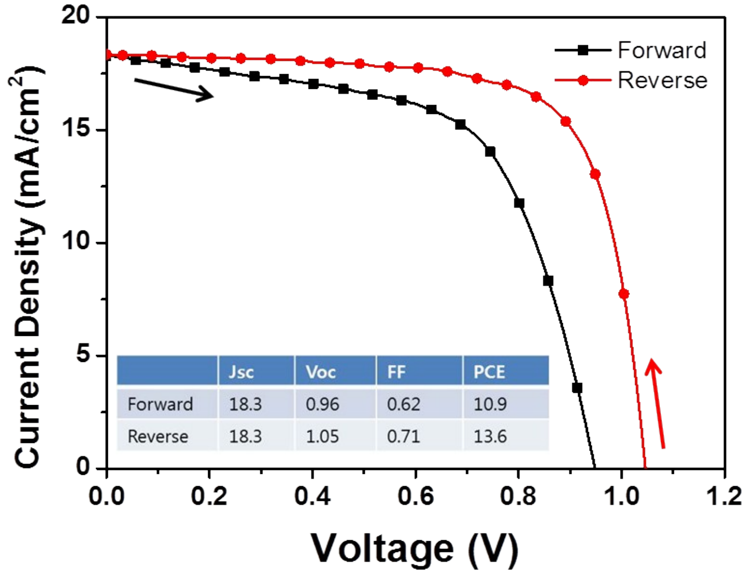


Fig. S6. Transmittance spectra of the TiO_2 and Al-TiO_2 compact layer.

The transmittance change of compact layer by Al-doping could effect on the current density of PSCs. Fig. S6 shows the transmittance spectra of TiO_2 and Al-TiO_2 compact layer. There was no change in the transmittance of compact layer after Al-doing (0.2-0.4 mol%) in TiO_2.



	Jsc	Voc	FF	PCE
Forward	18.3	0.96	0.62	10.9
Reverse	18.3	1.05	0.71	13.6

Fig. S7. Hysteresis analysis of PSC based on STHNPs as scaffold layer and Al-TiO_2 compact layer. Photovoltaic parameters are summarized in the inset table.

Fig. S7 exhibits the *J-V* curve for PSC based on STHNPs as scaffold layer and Al-TiO_2 compact layer in forward and reverse scan mode with 0.35 V/s scan rate. The inset table summarizes the photovoltaic parameters. The forward scan showed 18.3 mA/cm^2 of *Jsc*, 0.96 V of *Voc*, 0.62 of *FF*, and 10.9 % of PCE. On the other hand, the reverse scan exhibited 18.3 mA/cm^2 of *Jsc*, 1.05 V of *Voc*, 0.71 of *FF*, and 13.6 % of PCE, respectively.

Table S1. Conductivity of TiO_2 and Al-TiO_2 compact layer.

	TiO_2	Al-TiO_2
Conductivity (S cm^{-1})	1.58×10^{-4}	2.74×10^{-4}

The conductivity of TiO_2 and Al-TiO_2 compact film was measured by 2-point measurement using two gold electrodes to confirm the enhancement of electronic properties.[1] The channel length and the width were 0.2 mm and 1 mm, respectively. Table S1 certifies that the Al-doping in TiO_2 increased the conductivity. This increase could improve the carrier transport.

Reference

1. H.-H. Wang, Q. Chen, H. Zhou, L. Song, Z. S. Louis, N. D. Marco, Y. Fang, P. Sun, T.-B. Song, H. Chen and Y. Yang, *J. Mater. Chem. A*, 2015, **3**, 9108-9115.