Supporting Information

\textbf{SiO}_2/\textbf{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.
Fig. S4. Current density-voltage curve of perovskite solar cells based on silica, THNPs, and STHNPs. Photovoltaic parameters are summarized in the inset table.
**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$_2$. 
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 $J_{sc}$, 0.96 V of $V_{oc}$, 0.62 of $FF$, and 10.9 % of PCE. On the other hand, the reverse scan exhibited 18.3 mA/cm$^2$ of $J_{sc}$, 1.05 V of $V_{oc}$, 0.71 of $FF$, and 13.6 % of PCE, respectively.
Table S1. Conductivity of TiO$_2$ and Al-TiO$_2$ compact layer.

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<th>TiO$_2$</th>
<th>Al-TiO$_2$</th>
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<tr>
<td>Conductivity (S cm$^{-1}$)</td>
<td>$1.58 \times 10^{-4}$</td>
<td>$2.74 \times 10^{-4}$</td>
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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