Supporting Information

Low temperature growth of hybrid ZnO/TiO2 nano-sculptured foxtail-structures for dye-sensitized solar cells


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Figure S-1. Cross-sectional SEM image of the bare-ZnO NRs obtained after 4hrs growth (Z0). Scale bar is 3μm.

Figure S-2. TEM image of a single ZnO core-TiO2 shell hybrid structure with the modification time of 120mins (TZ4). Scale bar is 200nm. The thickness of the shell is around 55nm.

Figure S-3. (a) Cross section of the TZ4 and (b) the corresponding EDS line scan.
Impedance spectra

Equivalent circuit used to fit EIS results are followed by previous studies \cite{1,2,3}. The fitting was achieved by zview software (Scribner Associates, Inc.) using non-linear least squares regression. Constant phase elements (CPEs) are used to replace all capacitances to improve quality of fits. However, the EIS results do not show a clear transmission-line feature in this experiment, which is commonly attributed to a good electron transport in the semiconductor oxide (i.e. ZnO) \cite{4,5}. For this reason, it is not possible to extract reliable values from the equivalent circuit-fitting and we limited our study to analyse the recombination behavior of the NRs and hybrid nanostructures.

The details of the circuit are:

- $R_s$: series resistance, including the sheet resistance of TCO glass and contact resistance of the cell
- $R_{co}$: resistance at ITO/seed layer/nanostructure contact
- $C_{CO}$: the capacitance at ITO/seed layer/nanostructure contact
- $R_{Ct}$: the charge-transfer resistance and the corresponding double-layer capacitance at exposed ITO/electrolyte interface
- $r_t$: the transport resistance of electrons in ZnO/TiO$_2$ nanostructure
- $r_{ct}$: charge-transfer resistance of the charge recombination process
- $C_{Pt}$: the capacitance of the nanostructure/electrolyte interface
- $R_{Pt}$: charge-transfer resistance at the counter electrode (Pt coated ITO)
- $C_{Pt}$: double-layer capacitance at the counter electrode (Pt coated ITO)
- $Z_d$: Warburg element showing the Nernst diffusion of I$_3$- in electrolyte

Electron transport

Measurements of electron transport time followed procedures reported in Ref. \cite{6}. A square-wave pulse was applied to a white-light LED, used to illuminate the DSSCs. The modulation amplitude produced a $<10\%$ change in DSSC current. The current was determined by ohm law and an average of 5 photocurrent transient signals was recorded for each test.
Fig. S-4(a) shows representative transient photo current decay at a short circuit work condition for Z0, TZ2, and TZ4. Each transient is fitted by the following equation:

\[ y = y_0 + A e^{-t/\tau_{tr}} \]

where \( \tau_{tr} \) is the characteristic time for electron transport. The values of characteristic time for \( \tau_{tr} \) under a range of light intensities are plotted against the corresponding short-circuit current density \( J_{SC} \) in Fig. S-4(b).

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