Supporting information

SnO$_2$ nanorod@TiO$_2$ Hybrid Materials for Dye–Sensitized Solar Cells

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The EDS mapping of SnO$_2$ nanorod@TiO$_2$ hybrid materials is shown in Fig. S1, noting the successfully synthesis of hybrid structure. SnO$_2$ nanorods are uniformly coated by TiO$_2$.

The SEM image of SnO$_2$ nanorod@TiO$_2$ after annealing at 450 °C for 30 min has been given in Fig. S2, suggesting the morphology of SnO$_2$ nanorod@TiO$_2$ hybrid materials has not obviously changed in the annealing process.
Fig. S3 SEM of photoelectrode films after TiCl$_4$ treated (a) cross-sectional SEM image of P25 film, (b) top-view SEM image of P25 film, (c) cross-sectional SEM image of SnO$_2$ nanorod@TiO$_2$ film, (d) top-view SEM image of SnO$_2$ nanorod@TiO$_2$ film

Fig S4 shows the cross-sectional and top-view SEM images of P25 and SnO$_2$ nanorod@TiO$_2$ films after TiCl$_4$ treated. From the cross-sectional images it can be observed the thicknesses of the films are about 12 μm, and the films are both porous. The top-view of the P25 film shows a uniform film made up of P25 nanoparticles. The morphology of the SnO$_2$ nanorod@TiO$_2$ materials has not been obviously changed, during the fabrication process of DSCs (Fig. S4d).
Fig. S4 High resolution XPS spectra of SnO$_2$ nanorod@TiO$_2$ and SnO$_2$ nanorod@TiO$_2$ film after TiCl$_4$ treated (a) Ti, O, Sn, C, (b) Sn3d, (c) Ti2p, (d) O1s.  

High resolution XPS spectra of SnO$_2$ nanorod@TiO$_2$ and SnO$_2$ nanorod@TiO$_2$ film are shown in Fig. S5. The peaks of xps spectra have not been obviously changed after the DSCs fabrication process. The positions of the peaks (Sn 3d, Ti2p, O1s) are almost the same, however the intensity of the peaks are different. The peak intensity of Sn 3d got weaker, while that of Ti2p and O1s got stronger after fabricating into films. That is probably because of the TiCl$_4$ treated and the annealing process.
**Fig. S5** (a) Nitrogen adsorption-desorption isotherms of SnO$_2$ nanorod@TiO$_2$, (b) corresponding pore size distribution of SnO$_2$ nanorod@TiO$_2$, (c) Nitrogen adsorption-desorption isotherms of SnO$_2$ nanorods, (d) corresponding pore size distribution of SnO$_2$ nanorods.

Fig. S3 shows the nitrogen adsorption-desorption isotherms and the BJH analysis of desorption isotherms of the samples. The BET specific surface area of SnO$_2$ nanorod@TiO$_2$ hybrid material is 34.7 m$^2$/g (Fig. S3c), much higher than that of SnO$_2$ nanorods (11.9 m$^2$/g, Fig. S3a). This is mainly owing to the high pore volume of SnO$_2$ nanorod@TiO$_2$ hybrid material. The total pore volume of SnO$_2$ nanorod@TiO$_2$ is 0.123 cm$^3$/g (Fig. S3d), while that of SnO$_2$ nanorods is only 0.061 cm$^3$/g (Fig. S3b). In addition, there are some TiO$_2$ nanoparticles existing on the surface of the SnO$_2$ nanorod@TiO$_2$ hybrid materials, owing to the excessive of TiCl$_4$ vapor gas.
Electron transport properties were investigated using electrochemical impedance spectroscopy (EIS) under illumination. As shown in Fig. S6, two well-defined semicircles in the Nyquist plots represent the charge transfer resistance of the redox reaction of I$_3^-$/I$^-$/ at the Pt/electrolyte interface (at high frequencies) and at the photoelectrode/electrolyte interface (at low frequencies), of which a smaller diameter circle indicates faster charge transfer. The semicircle for SnO$_2$ nanorods electrode has the smallest diameter, showing the highest charge transfer ability. However the dye loading capacity of SnO$_2$ nanorods anode is much lower, so the power conversion efficiency is the lowest. The semicircle for the SnO$_2$ nanorod@TiO$_2$ electrode has a bigger diameter than SnO$_2$ nanorods electrode, but much smaller diameter than that of P25, indicating SnO$_2$ nanorod@TiO$_2$ have much faster charge transfer ability than P25.
The band positions of conventional SnO$_2$ and TiO$_2$ are given in Fig. S6.\(^1\) It is obviously that the conduction band edge of SnO$_2$ is much positive than that of TiO$_2$. Therefore in our experiment the electrons in TiO$_2$ can be easily injected into the SnO$_2$ nanorods, leading to fast electron separation to the current-collecting surface.

**Reference**