ENHANCING PHOTOVOLTAIC PERFORMANCE BY SURFACE MODIFICATION OF SEMICONDUCTOR NANOPARTICLES

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ABSTRACT

TiO_2 nanoparticles-based dye sensitizing solar cells (DSCs) offer significant economic and environmental advantages over conventional photovoltaic devices because of their relatively inexpensive manufacturing costs, energy saving process, and low toxicity. Since the application of dye-sensitized solar cells in solar energy conversion was first reported in 1991, the increase in conversion efficiency has been primarily due to improvements in organic sensitizers and liquid electrolytes. In contrast to these improvements, little work has been done in improving the TiO_2 nanoparticles based photoelectrode. However, inefficient carrier transport in the photoelectrode such as backward electron transfer and carrier trapping at grain boundaries between nanoparticles, have limited DSCs from achieving higher efficiencies.

Surface modification of TiO_2 nanoparticles is one of promising strategies to improving energy conversion efficiency. For examples, coating TiO_2 nanoparticles with a metal oxide has enhanced the conversion efficiency of the cell. We have found that a coating of MgO on TiO_2 nanoparticles by the topotactic reaction between $Mg(OH)_2$ and MgO can improve the energy conversion efficiency by 45 %. The improved performance resulting from the MgO coating is attributed to retarding electron-hole recombination at the organic-inorganic interface and the high specific surface area of the nanoporous MgO layer. Also, influence of nitric oxide adsorption on TiO_2 photoelectrode was investigated and the enhancement in cell performance was discussed in terms of retarding back electron reaction with electrolyte.

A nanoporous $CaCO_3$ overlayer-coated TiO_2 film was prepared by the topotactic thermal decomposition of $Ca(OH)_2$, and its performance as an electrode of a dye-sensitized solar cell was investigated. As compared to bare TiO_2, nanoporous $CaCO_3$-coated TiO_2 provided higher specific surface area, and subsequently a larger amount of dye adsorption; this in turn increased short circuit current (Jsc). Furthermore, the $CaCO_3$ coating demonstrated increased impedance at the TiO_2/dye/electrolyte interface and increased lifetime of the photoelectrons, indicating the improved retardation of the back electron transfer which increases Jsc, open circuit voltage (Voc) and fill factor (ff). Thereby, higher energy conversion efficiency of the solar cell improved from 7.8% to 9.7% (the improvement of 24.4 %) as the nanoporous $CaCO_3$ coating was applied to TiO_2.

We also improved the carrier extraction and transport properties of TiO_2 nanoparticles based photoelectrode by acid treatment and explored the physics underlying the change in the DSCs performance. The TiO_2 photoelectrode was treated in nitric acid before adsorbing dyes and then, the influence of surface nitric oxide groups on the DSCs performance was investigated. The energy conversion efficiency for the nitric acid-treated TiO_2 photoelectrode was significantly improved from 8.6 % to 9.6 as compared to bare TiO_2 photoelectrode. The enhanced solar cell performance is mainly attributed to the increase in photocurrent. Transient photovoltage and impedance analysis of the nitric acid-treated solar cell demonstrates that the acid-treated photoelectrodes retard back electron transfer at the interface with the electrolyte and increase the amount of adsorbed dyes.