Nanostructured ZnO Electrodes for Solar Cell Applications

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Dye-sensitized solar cells based on nanostructured TiO_2 electrodes are today by far the most investigated and the most efficient ones. From a fundamental viewpoint the ZnO bandgap energy of 3.2 eV and the position of the band edges are very similar to TiO_2, which makes a comparison between the two materials interesting. In our laboratory a thorough optimization of photoelectrochemical (PEC) solar cells based on nanostructured ZnO with respect to particle size, doping, film thickness, morphology and dye-adsorption has been performed.

The photocurrent yields measured for a comparison between two materials can be analysed by differences in the three terms in the expression of the theoretical incident monochromatic photon-to-current conversion efficiency, $\phi(\lambda)$, given by:

$$\phi(\lambda) = LHE(\lambda)\phi_{inj}\eta_c \tag{1}$$

where $LHE(\lambda)$ is the monochromatic light harvesting efficiency, ϕ_{inj} is the net yield for charge carrier injection and η_c is the efficiency of collecting the injected charge at the back-contact.

Bare nanostructured ZnO electrodes with one order of magnitude larger spherical particles (150 nm) than normally used in these systems demonstrated good electron transport properties: high photoconversion efficiencies indicate low recombination losses during the transport. In addition, no electron losses to electron scavenging species in the electrolyte were observed. Thus, η_c, presented by the third term in equation (1), can be concluded to be as efficient, if not better, for ZnO as for TiO_2. However, overall efficiencies of the dye-sensitized PEC solar cells based on ZnO were found relatively low compared with cells based on TiO_2. Results from incident monochromatic photon-to-current conversion efficiency measurements and IR- and Raman spectroscopies gave evidence of dye aggregation in the nanostructured ZnO film. The studies revealed that protons from frequently used N3 and N719 dyes caused the dissolution of

Zn surface atoms and the formation of Zn^{2+}/dye aggregates in the pores of the nanostructured ZnO film, which gives rise to a filter effect (inactive dye molecules). Consequently, the net yield for charge carrier injection, ϕ_{inj}, is decreased, whereas the light harvesting efficiency, $LHE(\lambda)$, is increased due to the large number of dye molecules in the film. Based on these facts, better solar cell based on ZnO should be prepared by optimization of the first and second term in equation (1). Under optimal conditions, the electron injection rate for ZnO is slightly slower than for TiO_2, but still lies in the femtosecond domain.

By improving the interfacial contact between dye and ZnO particles and avoiding aggregation, overall solar-to-electric energy conversion efficiencies were improved by at least a factor of two. Efficiencies of up to 5 % were obtained under 100 W/m^2 illumination using a solar simulator.