Flame made indium-zinc oxide nanoparticles as photoanodes for efficient DSSCs

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Nanoparticulate zinc oxide as a wide band gap semiconductor as well as trivalent doped zinc oxide nanoparticles (NPs) are economic and promising materials for the application in solar cells, transistors or sensors. Dispersed in organic solvents and deposited as thin film on e.g. flexible substrates or FTOs they can be used in printable electronic devices. Moreover, the morphological, optical and electronic properties of the particles can be tailored depending on the doping content and synthesis route (Hammarberg et al, 2009).

To cover the high demand of low cost materials a solvent free and energy efficient synthesis method with high production rates, for example a flame spray synthesis, is required. Utilizing this technique particle size, shape, composition, optical band gap and defect states of the particles can be controlled by the content of dopant and the synthesis route. In this work, a liquid precursor with varied amount of indium acetate and zinc acetylacetonate in 2-methoxyethanol is dispersed by a nozzle into the spray flame. In the flame, pyrolysis reactions lead to high supersaturation and therefore to particle nucleation with subsequent growth, agglomeration and sintering. The utilized reactor set-up allows producing In-Zn-O with mean primary particles in the size range of 7 nm up to 19 nm. These particles are then collected with a polyamide membrane filter.

Doping with In leads to a steadily decreasing primary particle size down to a minimum of 7.5 nm for 40 mol% indium, which can be determined by BET, XRD and SEM and is exemplarily shown by the doctor-bladed electrode films in figure 1.

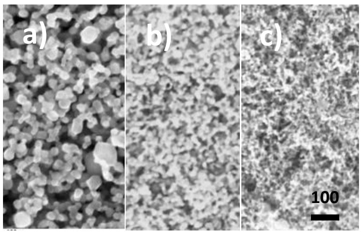

Figure 1. SEM images of pure a) ZnO, b) $In_{15}Zn_{85}O$, and c) $In_{80}Zn_{20}O$ films (Kunzmann et al., 2015)

Indium as a dopant obviously inhibits the particle growth mechanism of pure ZnO and is diminishing the wurtzite unit cell. Additionally, the crystalline phase changes between 40 mol% and 60 mol% indium into an amorphous/nanocrystalline phase. EDX and ICP-OES proof the precise composition of the trivalent doped powders. The optical band gap, determined by diffuse reflectance spectroscopy, first strongly declines from 3.25 eV in the light doping region, then linearly decreases till 60 mol% In and finally increases up to 2.98 eV for pure In_2O_3. PL measurements provide an overview about the defect states and the oxygen vacancies of the binary In-Zn-O particles.

Due to a precisely adjustable band gap the particles are beneficial for the usage as photoanodes in DSSCs. Electrochemical impedance spectroscopic assays exhibit that by incorporation of low amounts of indium charge transport resistances are reduced and electron recombination resistances are increased. Therefore, the charge collection efficiency is enhanced from 33 % to 83 % for devices with ZnO and $In_{15}Zn_{85}O$ photoanodes, respectively. Upon implementing an electron cascade photoanode architecture with $In_{15}Zn_{85}O$/ZnO a device efficiency of 5.77 % and a significantly high current density of 20.4 mA/cm^2 are achieved, see figure 2.

The aerosol synthesis will be described in detail, the properties of the indium doped zinc oxide particles will be discussed regarding morphology, composition and opto-electronical properties. Finally, the integration in DSSCs will be shown.

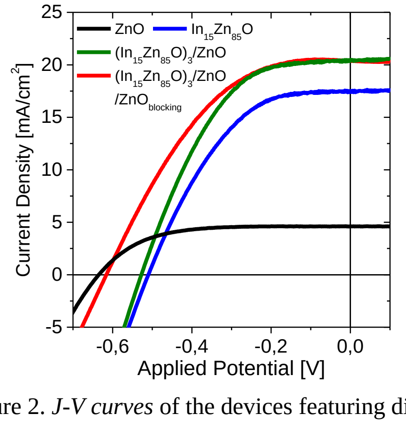

Figure 2. *J-V curves* of the devices featuring different photoanodes

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Hammarberg, E. Prodi-Schwab, A. & Feldmann, C. (2009). *Journal of Colloid and Interface Science*, 29-36

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