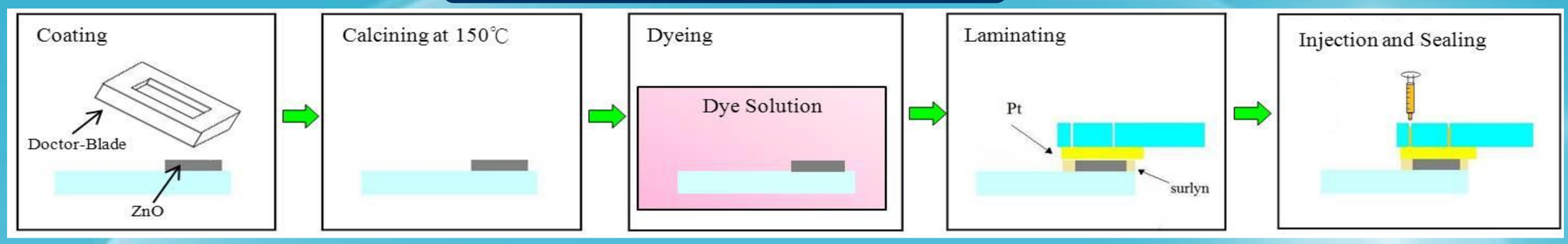
Novel ZnO Nanocrystallite Aggregates for Dye-Sensitized Solar Cells with Enhanced Energy Conversion Efficiency

Wei-Chen Chang, Chun-Min Lin, Shih-Chieh Hsu, and Wan-Chin Yu*
Institute of Organic and Polymeric Materials, National Taipei University of Technology, Taipei, Taiwan
*wanchin@ntut.edu.tw

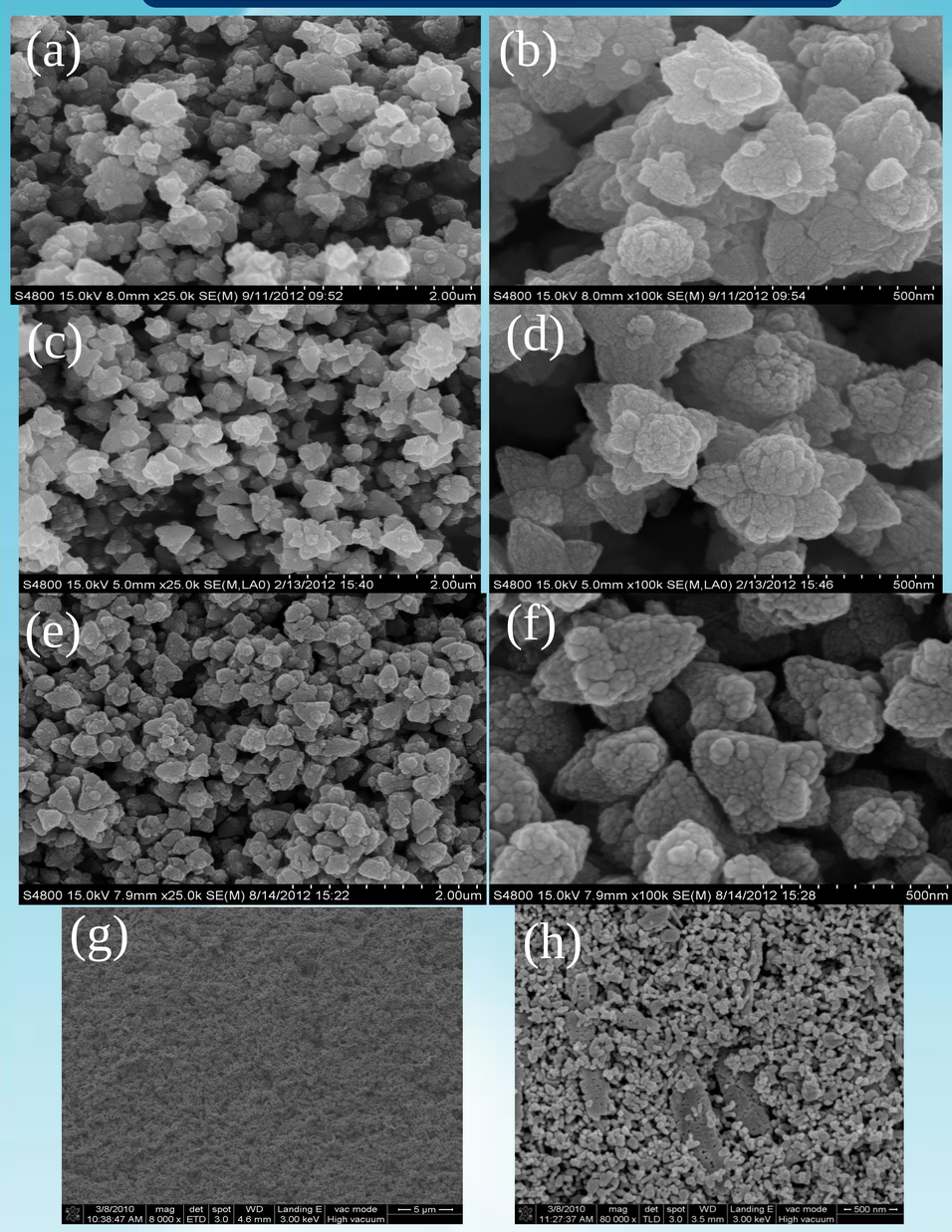
Abstract

Novel ZnO nanocrystalline aggregates were synthesized using a low-temperature (80˚C) aqueous solution method. This study shows that the reaction time plays a significant role in controlling the morphology of the nanostructures, ranging from randomly oriented aggregates at 2 h to a flower-like nanostructure at 4 h. By 8 h, most of the aggregates had lost their flower-like morphology, because of continued growth of the aggregates. These aggregates consisted of nanocrystallines having a diameter of 20 to 50 nm. The nanoflowers obtained at 4 h each comprised a spherical to oval-shaped core and several sharp-headed petals. The overall dimension of the nanoflowers ranged from 150 nm to 300 nm. The nanocrystalline aggregates obtained at various reaction times (referred to as NF2h, NF4h, NF8h, respectively) were fabricated into the photoanodes of dye-sensitized solar cells (DSSCs), and their photovoltaic performance was compared. The NF4h devices outperformed those based on the NF2h and NF8h aggregates, as well as those fabricated using commercial nanoparticles (NP). Under AM 1.5 G simulated sunlight with an intensity of 100 $mWcm^{-2}$, the NF4h-based DSSCs reached an overall conversion efficiency of 4.41%, which was accompanied by a relatively high short-circuit current density of 9.45 $mAcm^{-2}$. The superior photovoltaic performance of the NF4h device was due to higher dye loading and better light harvesting of the photoanode. Submicrometer-sized aggregates comprised of nanocrystallines have recently been utilized to enhance light scattering effects in the photoelectrode of DSSCs, while retaining a high specific surface area for dye molecule adsorption. Another desirable feature of the nanoflower structure reported here is the low calcination temperature (150˚C) used to prepare the photoelectrode films, which enables the future applications of this nanoflower structure to flexible polymeric substrates.

Fabrication Procedure for DSSCs

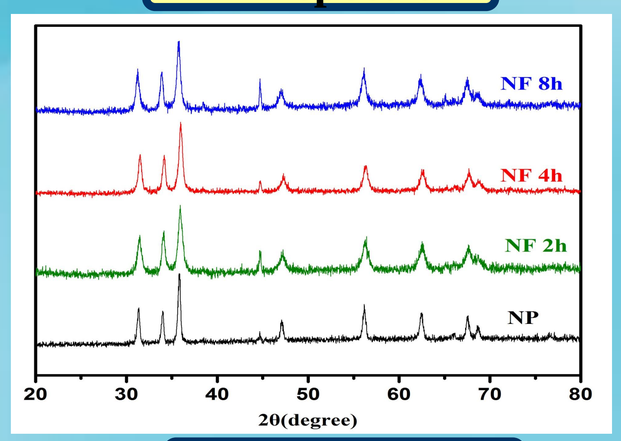


FE-SEM images of ZnO films

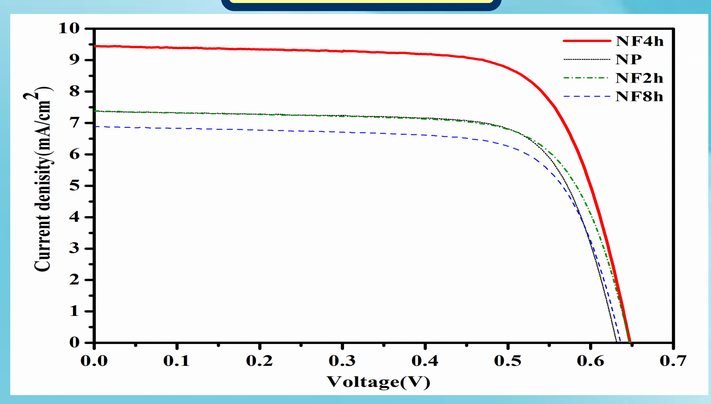


(a) and (b)) films based on NF2h aggregates; (c) and (d) films based on NF4h aggregates; (e) and (f) films based on NF8h aggregates; (g) and (h) films based on commercial nanoparticles. NF2h, NF4h, and NF8h represent aggregates formed at a reaction time of 2 h, 4 h, and 8 h, respectively.

XRD spectra

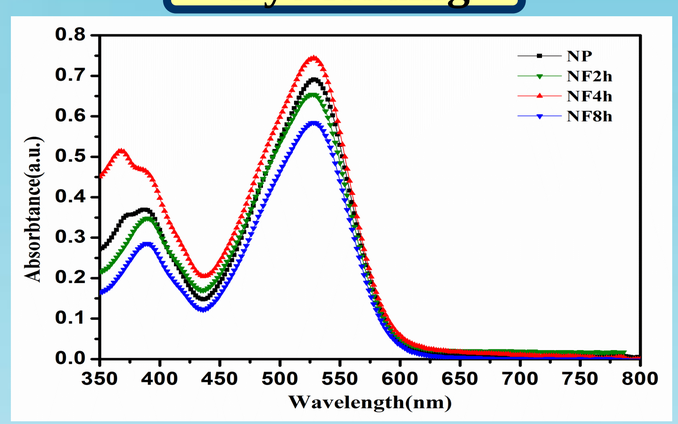


J-V curve

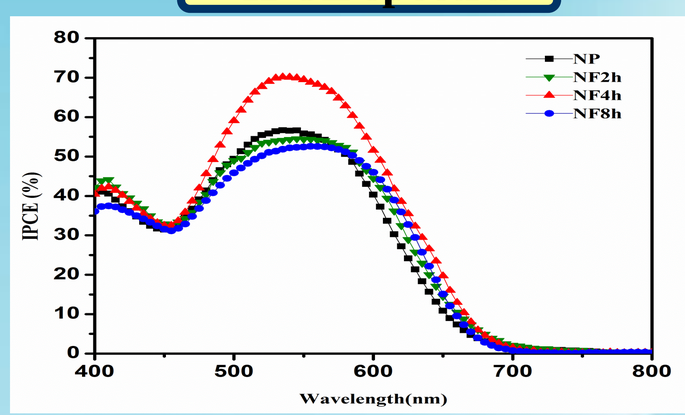


NF4h film thickness : 34 µm

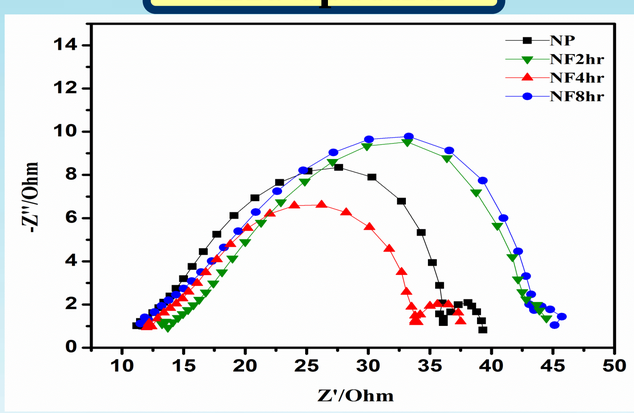
Dye-loading



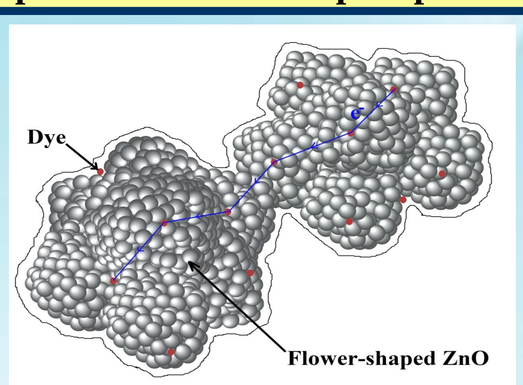
IPCE spectra



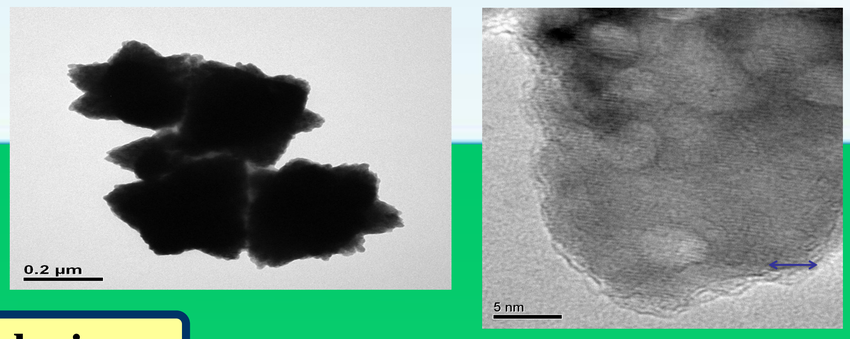
EIS spectra



Proposed electron transport pathway



TEM images of ZnO nanoflowers



Comparison of photovoltaic performance

Nanostructure	J_{SC} (mA/cm^2)	V_{OC} (V)	FF	η (%)
NP	7.372	0.631	0.737	3.428
NF2h	7.379	0.647	0.719	3.433
NF4h	9.450	0.648	0.720	4.409
NF8h	6.883	0.636	0.718	3.147

Calcination condition was 150˚C for 1 h

Conclusions

A novel nanocrystalline aggregate having a flower-like morphology has been successfully synthesized using a low-temperature aqueous solution method. The nanoflower-based DSSCs reached an overall conversion efficiency of 4.41% at a film thickness of 26 µm, considerably higher than that based on commercial nanoparticles (3.42%).