Growth structures of ZnO transparent electrical contacts for thin-film silicon solar cells

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In comparison to silicon single crystal-based solar cells, silicon thin-film cells offer significantly lower production costs and also versatility in type and shape of substrate material, and could therefore provide an important contribution to supplying the world's future energy needs. While crystalline and/or amorphous silicon layers are the active, photogenerating parts of the devices, transparent electrical contacts are also essential components.

In the IMT laboratory at Neuchâtel, low-pressure chemical vapour deposition (LP-CVD) ZnO films are being used as these transparent electrical contacts [1]. The effectiveness of the films has been found to depend greatly on the LP-CVD growth parameters. In particular, certain conditions generate films with pyramidal surface structures (see Figure 1). Such structures beneficially scatter the light passing through the films, increasing the probability of light absorption in the cell, and hence the photogenerated current.

Considering the importance of ZnO film topography for cell efficiency, it is critical to understand how it relates to both the general nature of the films and the LP-CVD process parameters. Electron microscopy is being used to address these questions, in conjunction with other techniques such as AFM and XRD. For instance, cross-section imaging of test films using a Zeiss NVision 40 CrossBeam provides a rapid tool for identifying their grain structure. As shown in Figure 2, using the Zeiss, SEM imaging of FIB-milled sections with a 1.5 kV beam reveals grain contrast with a resolution of <30 nm, making clear the lateral overgrowth of dominant grains that leads to the pyramidal surface structures.

Figure 2 also shows how changes in the LP-CVD process parameters lead to significant differences in the growth of the ZnO films. If the films are to be optimized, it is imperative to understand the formation and growth kinetics that create such differences. Therefore, TEM studies are being undertaken to identify preferential growth orientations and facets, correlating the results with XRD measurements for average grain orientations. TEM and HRTEM analyses are also being made of the nucleation layer, with particular aims of identifying whether nuclei are randomly or preferentially oriented, and how their size is affected by temperature (see Figure 3). In this way, it is aimed to develop a model of kinetics and sticking of adatoms during ZnO grain nucleation and growth.

While the beneficial scattering of light by the LP-CVD films has primarily been attibuted to result from the ZnO surface roughness, it is also possible that other structural features, such as grain boundaries, play a role in this. It is planned to investigate this possibility using a cathodoluminescence system being installed on a JEOL 2200FS FEG(S)TEM, perhaps in conjunction with low-loss electron energy-loss spectroscopy of the

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type performed by Ong et al. [2], in order to develop further our understanding of the parameters critical to maximizing efficiency of the photovoltaic cells.

1. S. Faÿ et al., Solar Energy Mater. Solar Cells **90** (2006) 2960.
2. H.C. Ong et al., Appl. Phys. Lett. **77** (2000) 1484.

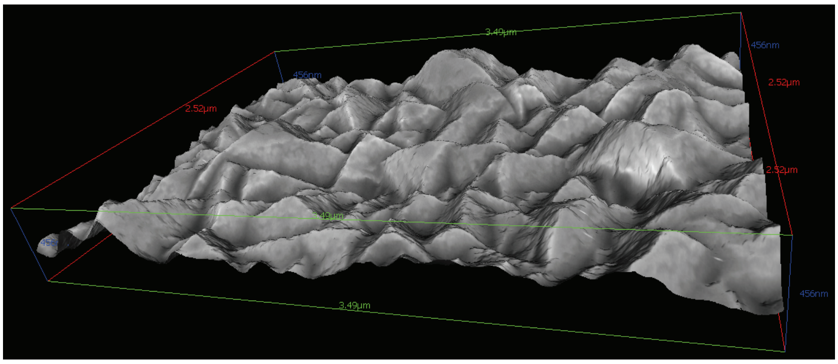

Figure 1. Surface topography of LP-CVD grown ZnO. The topology map was calculated from a set of 3 stereoscopic SEM images using MeX 5.0 software for 3D reconstruction (Alicona Imaging), providing data competitive with AFM imaging in a time-efficient manner.

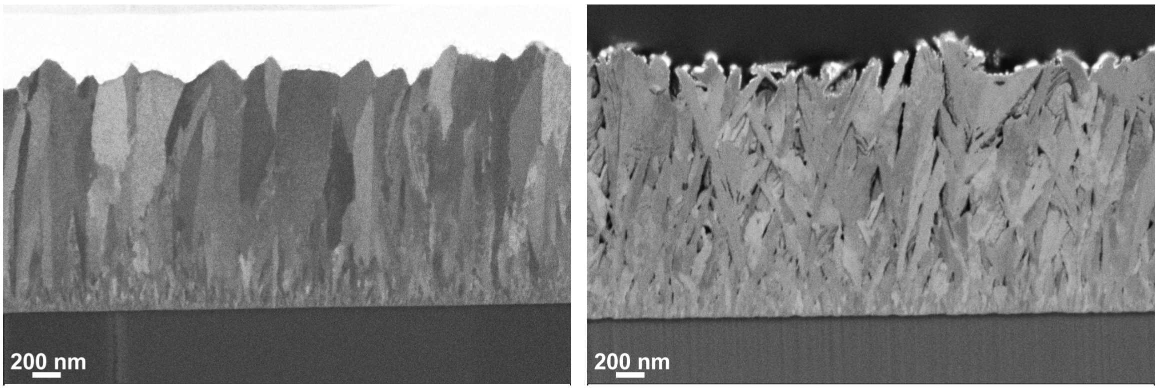

Figure 2. Cross-section images of ZnO films grown at two different temperatures, taken with a Zeiss NVision 40 CrossBeam, using a 1.5 kV beam and the ESB detector. The "standard" temperature sample (left) shows a lateral overgrowth of certain grains with increasing film thickness that results in the pyramidal surface structures shown in Figure 1. The higher-temperature sample (right) instead shows a well-defined V-shaped growth, along with extensive voiding between grains.

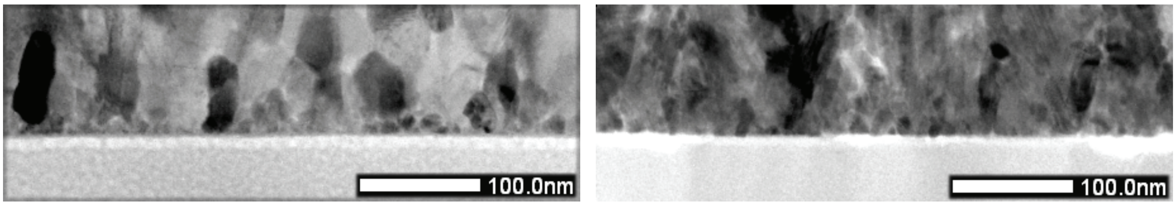

Figure 3. Images of nucleation region of ZnO films grown at "standard" (left) and higher (right) temperatures, taken using bright-field STEM with a JEOL 2200FS; a technique found to offer relatively good discrepancy of the nm-scale grains in this film/substrate interface region. Analysis of the data gives tentative support for the theoretical expectation of larger nuclei in the higher temperature sample.

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