Thin films in solar cells: electron microscopy study of cross-section combined with depth profiling by Raman spectroscopy

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The efficiency of multilayered thin film solar cells having nanocrystalline silicon layers depends on crystalline fraction in the layer and on the size distribution of the nanocrystals. This is why an accurate determination of the crystallite sizes and the crystalline phase fraction is of primary importance [1]. The properties of the solar cells additionally depend on the stability of the layers, i.e. durability of the electrode layer surface during the deposition of the active Si layer, the adhesion of the silicon layers at the electrode and the physical and chemical stability of the Si layers.

The silicon thin films were deposited on the multilayered SnOx/ZnOx electrode by radio frequency plasma enhanced chemical vapor deposition. The structure of Si thin film was varying from amorphous to nano-crystalline across the depth of the layer. STEM and HRTEM were used to study the structure and chemistry of deposited Si layers, their homogeneity and adhesion to the electrode layer. For electron microscopy observations we used JEOL JEM-2010F transmission and scanning electron microscope (TEM/STEM), equipped with an ultra-high-resolution objective pole-piece and operating at 200 keV. Cross-sectioned samples were prepared using conventional techniques. The chemical homogeneity and possible oxidation in the layers were studied by EDXS. The microscopy results were compared with micro-Raman deep profiling.

The amorphous and nano-crystalline Si layers were clearly distinguished by the STEM (Fig. 1a). The silicon multi-layer had constant thickness and followed the roughness of the electrode layer. Small cracks were observed in the lower part of the Si layer in the regions of large curvature of the electrode surface. EDXS spectra acquired from the cross-section of the film indicated the oxidation in the vicinity of the film surface (Fig. 2b). The crystalline fraction and the crystallite sizes within Si layers of the same sample were estimated from Raman spectra using the ratio of areas under the corresponding transversal optical (TO) phonon bands and the shifts of the TO mode for nano-crystalline Si. The observed crystalline TO peak varied in positions between 503 and 521 cm^{-1} with the change of the depth of laser focus within the same multilayered sample (Fig. 2). These positions correspond to average crystal sizes between 3 and 20 nm, which was confirmed with HRTEM observation. In order to avoid possible structural changes in the Si thin films due to heating during depth profiling RS measurements, the laser power was carefully optimized.

Our results showed a good agreement between HRTEM, STEM and EDXS results with the results obtained using the RS deep profiling. A more detailed comparison and discussion in view of chemical and physical stability of layers in solar cells is given in stated reference. Possible artifacts due to TEM sample preparation and/or due to the changes induced by electron and/or laser beam should be considered and minimized by optimization of experimental parameters.

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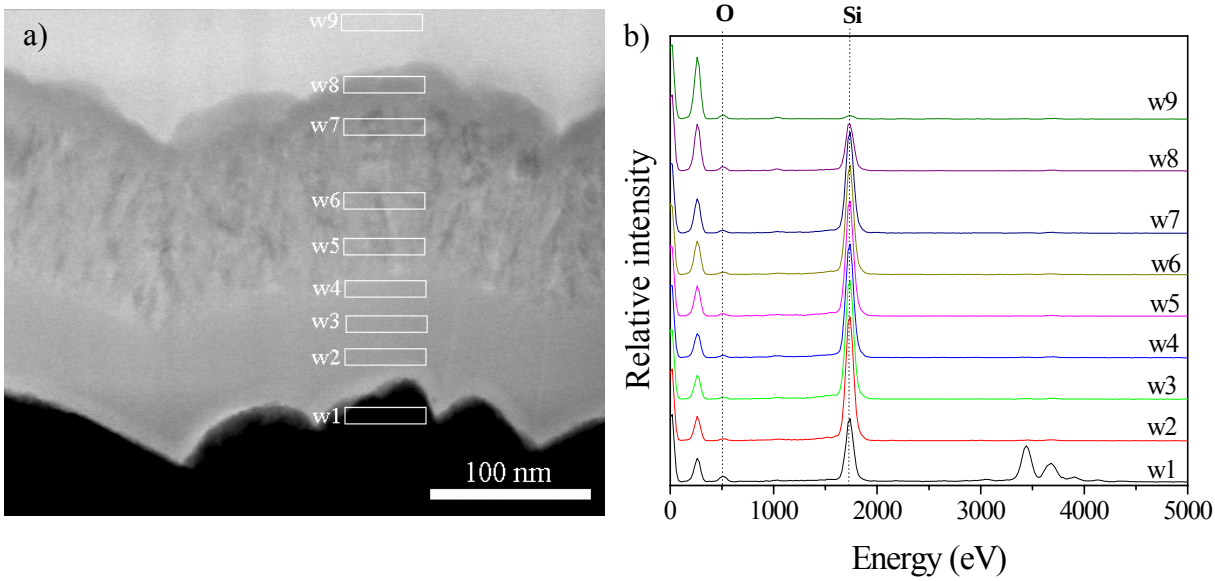

Figure 1. a) STEM bright-field image of thin Si film deposited on SnO_x electrode layer. The windows of EDXS analyses are marked with white rectangles. b) EDXS spectra acquired from the marked windows.

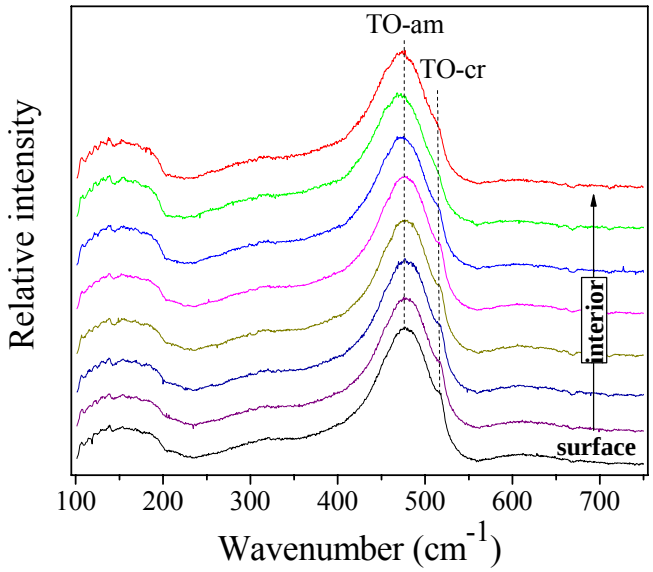

Figure 2. Micro-Raman spectra obtained from different sample depths in multilayer silicon thin films. Position of TO modes for crystalline (cr) are amorphous (am) silicon are denoted.