Accelerated Ageing Tests of Solar Cells

An *In Situ* Transmission Electron Microscopy Study

In situ transmission electron microscopy was used to investigate the ageing behaviour of Si-based solar cells. The structural and compositional changes of the NiSi layer of such cells were determined.

Introduction

Solar cell industry is still a fast growing market, especially due to rising prices for fossil fuels. Efficiency improvement of solar cells as well as optimisation of the various fabrication steps are current topics of research and development [1]. Furthermore analysing the aging behaviour of photovoltaic panels is a field of great importance. Since modern panels are released with proposed lifetimes in a range of 25 years, reliable information about thermal and radiation stress induced processes modifying the function of a solar cell are crucial. Accelerated aging experiments are a fast and effective possibility to obtain reliable data about the ageing behaviour [2] of a device.

In modern high efficient solar cells a silicide layer is applied between the bulk silicon and the metallic contact grid. Nickel monosilicide (NiSi) is a promising material to for this layer. In contrast to other silicides, NiSi can be cost efficiently applied using galvanic deposition followed by rapid thermal processing [3]. Due to thermal ageing the NiSi-layer can diffuse into the adjacent n-doped Si-layer. For correct function of a solar cell the thickness of the NiSi-layer may not exceed this n-doped Si-layer.

The aim of this study was a preliminary test if *in situ* transmission electron microscopy (TEM) is an appropriate way analysing the accelerated ageing behaviour of solar cells. Due to the limitations of TEM in analysing large regions, the described method cannot analyse the aging behaviour of a complete solar panel. Here the focus was set to thermal induced thickness and compositional changes of a solar cells NiSi-layer.

Method

All samples used for this investigation were supplied by NB technology. *In situ* transmission electron microscopy at elevated temperatures was used to analyse the ageing behaviour of the investigated solar cells. Prior to the TEM experiments, TEM lamellae with a thickness of about 70 nm were prepared using a focused ion beam milling device (Zeiss XB1540 Cross beam FIB). Elemental Analysis was done using energy dispersive X-Ray spectroscopy (EDS) prior and after the heating periods using a Zeiss Libra200 (CRISP) TEM with attached scanning unit. All heating experiments were performed in a 200 kV LEO922A TEM equipped with a LaB$_6$ emitter and a heating holder (Gatan, model 652). Heating temperature was 300 °C with a maximum duration of 120 min.

Results

Figure 1A shows a bright field (BF) TEM image at t = 0 of the heating experiment. The nickel monosilicide (NiSi) layer is clearly visible and has a mean thickness of 160 nm. The adjacent platinum layer was applied during sample preparation and is not part of the solar cell. Heating of the sample was performed in the TEM using a furnace integrated into the sample holder. The temperature range of this heating sample holder is between 25 and 1,000 °C. For the present study a temperature of 300 °C was used. This temperature was chosen in accordance to MIL standard ageing tests. Figures 1B–D show the changes of the sample after t = 15, 60 and 120 min. Already after 15 min an additional layer is formed and grows permanently over the heating period. The mean thickness of the newly formed layer was about 40 nm while the original NiSi-layer thickness did not change at all. The sample area in figure 1B–D varies slightly from the original position; strong carbon contamination occurred on the original area during an EDX-scan and influenced image contrast badly. The area imaged in figure 1B–D is adjacent to the original position. An originally planned *in situ* EDX investigation failed due to sample drift. Instead of life scanning, EDX-analyses were performed before and after the heating experiment. Figure 1 E and F show the HAADF images corresponding to these EDX scans. Care was taken to measure the same sample area as imaged in figure 1B–D. The Z-contrast of the HAADF images in figure 1E and F indicate a chemical composition with lower Ni content compared to the original layer. Figure 2 shows the compositianl analysis of the NiSi layer before and after the heating experiment. The bars represent the atomic ratio of Ni (blue) and Si (purple). The Pt-protection layer was measured as reference but not taken into account for the analysis. The original layer turns out as NiSi with good accuracy and remains its composition after the heating process. The newly formed layer is Si rich. An accurate phase determination was not possible within the accuracy of the EDX analysis.

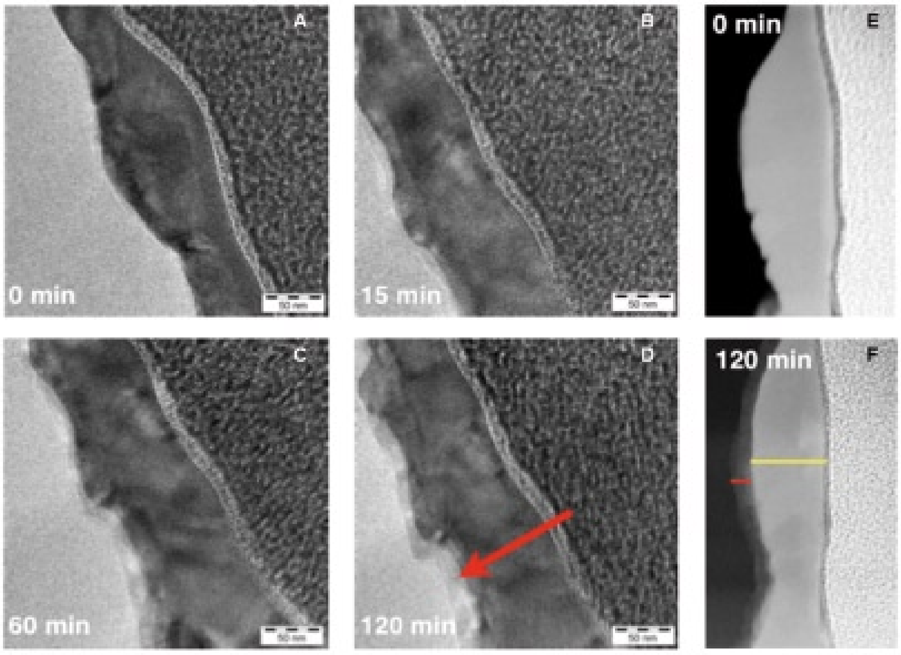

Fig. 1: A–D: Bright field TEM images of the NiSi-layer of a solar cell. The layers are from left to right: Si-bulk, NiSi, and Pt. The intermediate layer between NiSi and Pt occurs due to preparation issues. An additional NiSi-layer is visible in the images B–D (red arrow). E, F: HAADF-STEM images of the NiSi-layer before and after heating. The layers are from left to right: Si, NiSi and Pt. The lines indicate the regions where layer thickness was measured. The yellow line marks the original NiSi-layer while the red line corresponds to the second NixSiy phase, formed during the heating process.

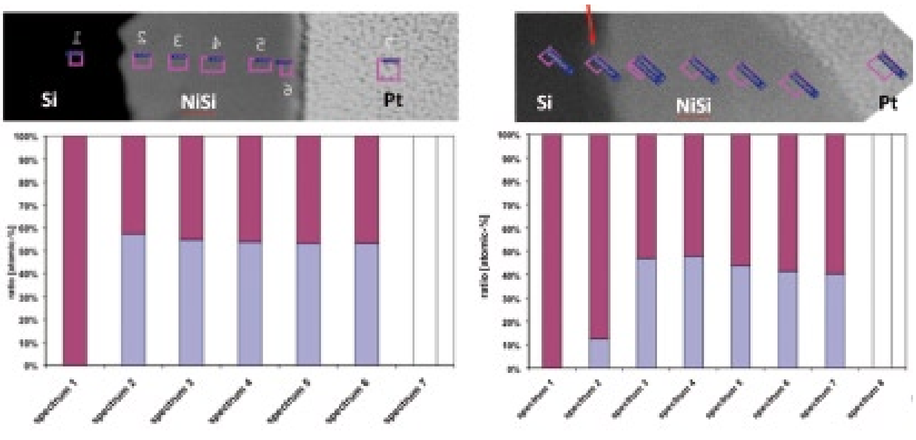

Fig. 2: EDX analysis of NiSi-layer before (left) and after heating (right) to 300 °C for 120 min. The chemical composition of the structure is marked in the HAADF images. The Au and Pt layers are protection layer for the FIB sample preparation. The squares mark the regions in which EDX spectra were recorded. The bar charts show the Si and Ni atomic ratios measured at these positions. The Pt position was measured as reference but not taken into account for the analysis. The red arrow in the right image marks the additional layer formed during the ageing at elevated temperature.

Conclusion

In situ transmission electron microscopy is a versatile tool for investigation of structural and compositional changes on nanometer and micrometer scale. Life imaging of the structural changes is possible. Testing the growth of the NiSi layer in solar cells during ageing is important. Si-based solar cells with such layers are commercialised for about 10 years and the knowledge of the ageing behaviour of the NiSi layers is poor. Furthermore no standards for testing Si based solar cells are available at the moment.

For a more quantitative approach more temperatures and longer exposure times have to be analysed.

References

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