Conventional and 360º electron tomography of a micro-crystalline silicon solar cell

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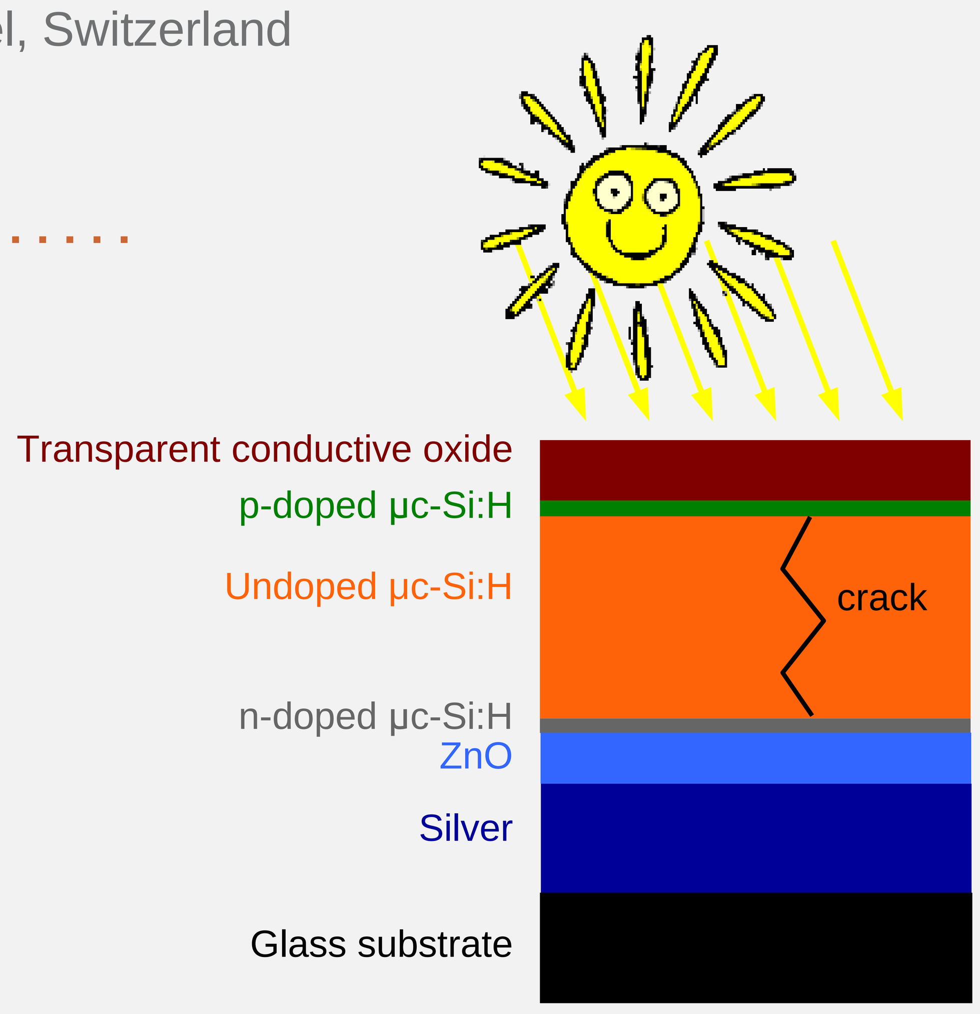
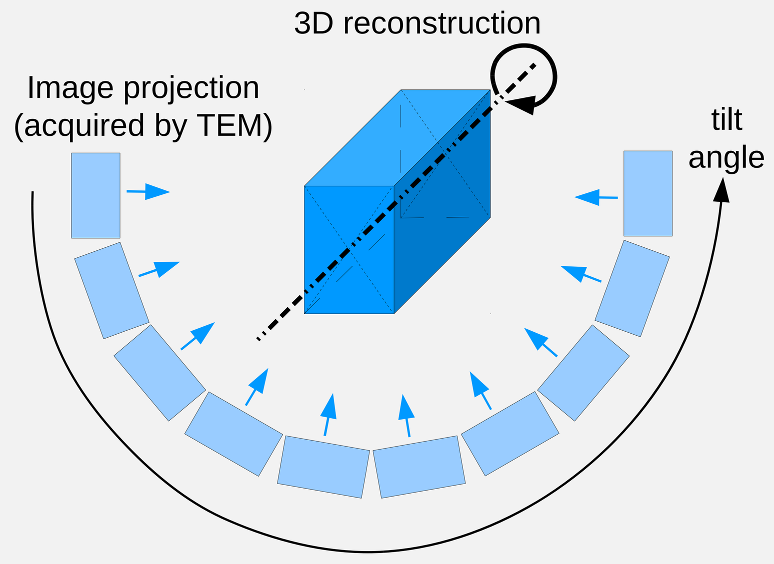
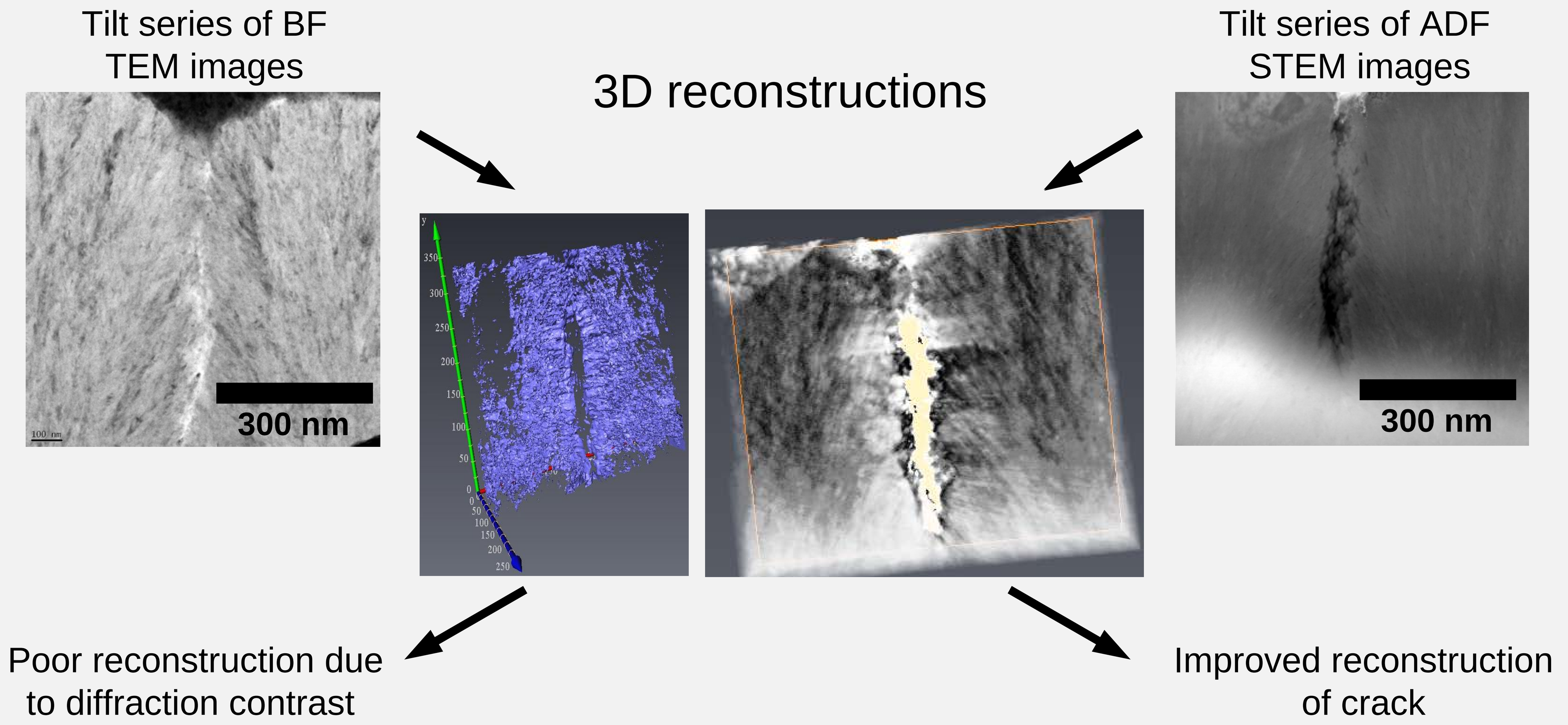
The light trapping efficiencies of micro-crystalline silicon (µc-Si:H) solar cells prepared by plasma-enhanced chemical vapor deposition are improved when they are grown on rough substrates [1, 2]. However, the presence of defective regions, such as cracks between agglomerates of nanocrystals, is thought to decrease their electrical performance [3].





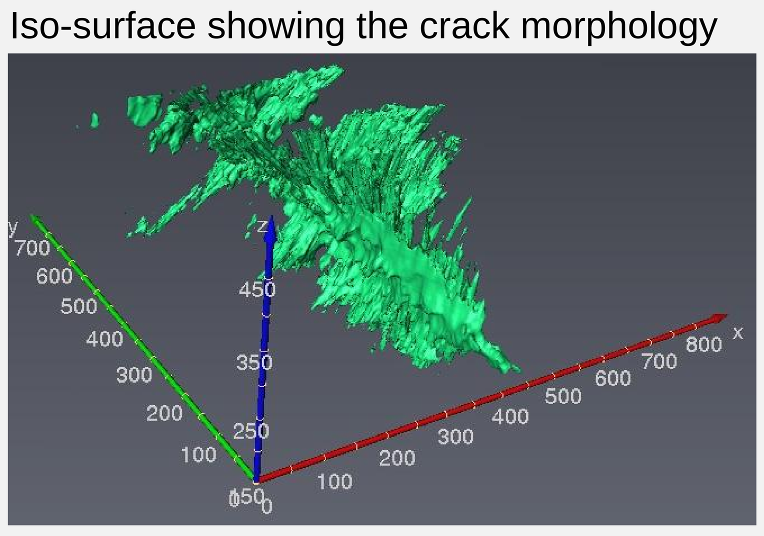
Electron tomography in the transmission electron microscope (TEM) provides 3D information about nanoscale materials from projections acquired as a function of specimen tilt angle. Here, we present an initial study of the use of both conventional thinned and needle-shaped specimens for tomographic studies of µc-Si:H solar cells [4, 5].

Crack characterization in a lamellar specimen

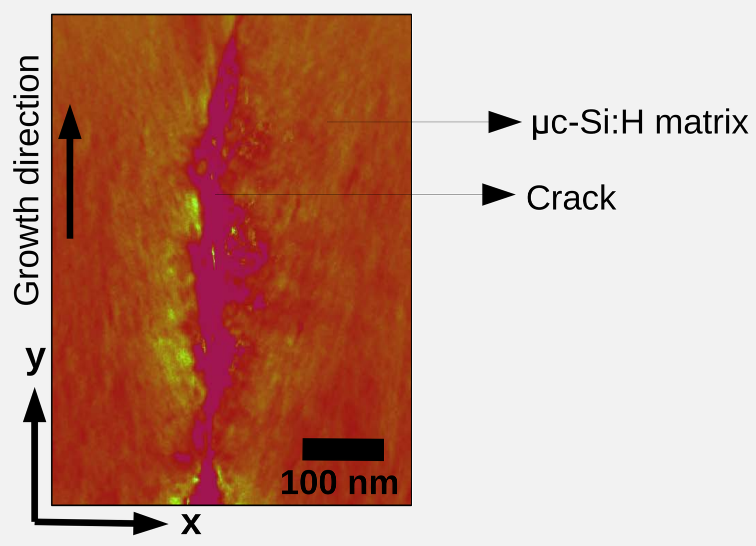


Crack reconstruction using ADF images

Iso-surface showing the crack morphology

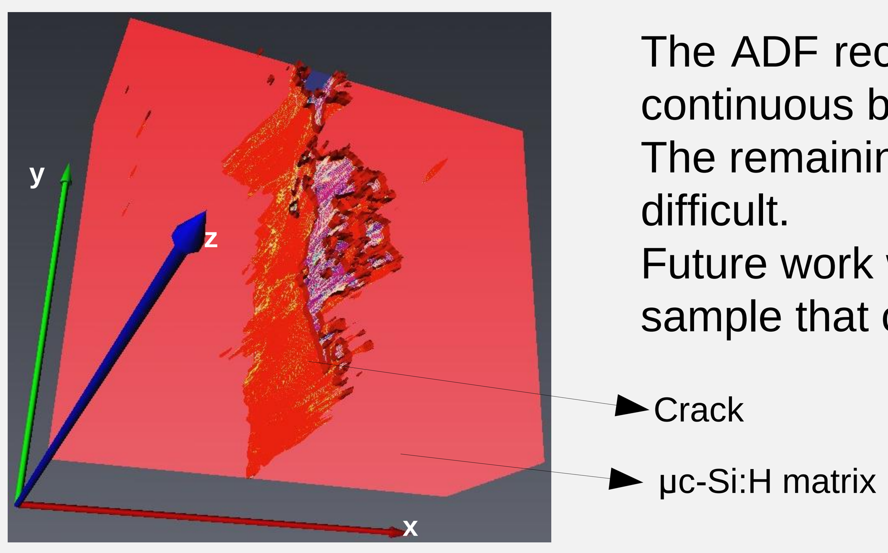


The limited tilt range results in artefacts (±60º)



Section through reconstructed volume

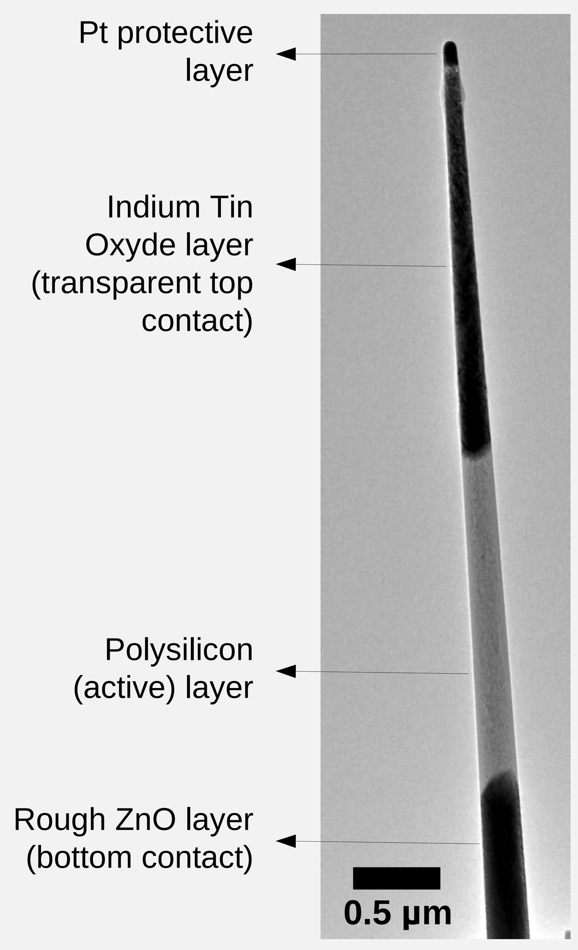
Region of interest extracted from the centre of the reconstructed volume



The ADF reconstruction shows that the crack is continuous between the polycrystalline grains.
The remaining artefacts make interpretation difficult.
Future work will involve making a needle-shaped sample that contains a crack.

Poly-silicon characterization in a needle-shaped specimen

FIB-prepared needle-shaped TEM sample



The µc-Si:H matrix is composed of ~20 nm crystals grown on a rough ZnO layer. Here, we assess whether a grain boundary-free path exists in the growth direction. In order to minimize reconstruction artefacts, a needle-shaped sample allowing 360º tilting was made using FIB milling.

- Tilt series of BF and ADF: increment of 2º, from 0º to 180º
- Post-acquisition manual alignment was performed

BF electron tomography

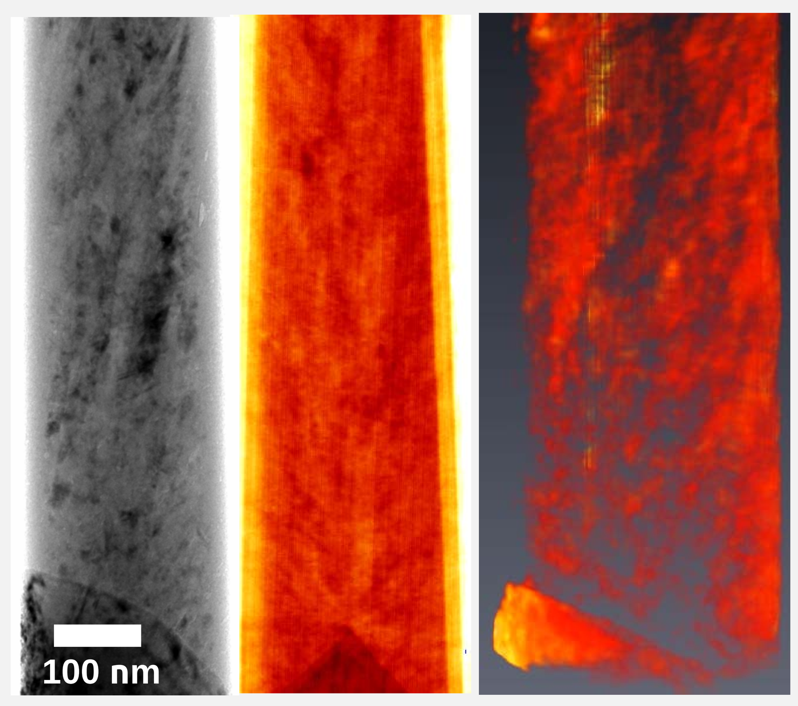


Image from tilt series | Section through reconstructed volume | Voltex projection

ADF electron tomography

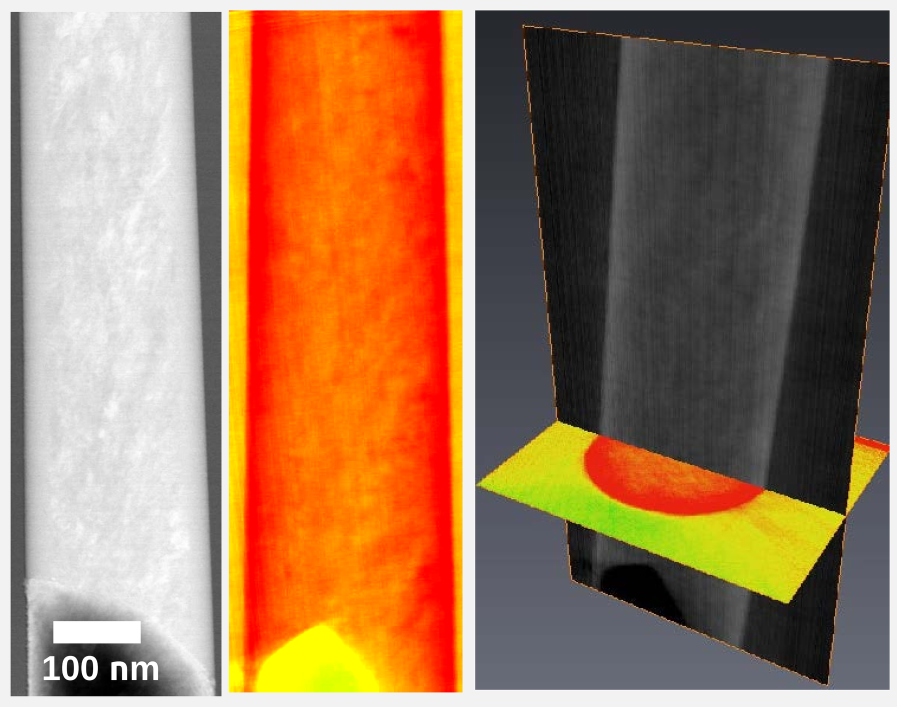


Image from tilt series | Section through reconstructed volume | Orthogonal cross-sections

Full interpretation to locate grain boundaries in three dimensions is ongoing and will be presented elsewhere.

Experimental details

100-nm-thick lamella and 250-nm-diameter needle-shaped specimens were prepared using focused ion beam (FIB) milling in an FEI Helios microscope.
Bright-field (BF) TEM images were acquired at 120kV in an FEI Tecnai T20. Annular dark field (ADF) scanning (S) TEM images were acquired at 120kV in an FEI Titan ST, using 47,4 and 10,2 mrad inner ADF detector semi-angles for crack and polysilicon characterization, respectively.
A high angle triple-axis (HATA) holder and a Fischione on-axis holder were used for studies of studies of lamellar and needle-shaped samples, respectively.
Tilt series were aligned manually due to the limited number of recognizable figures. Reconstructions were performed in 30 iterations of SIRT algorithm using FEI Inspect3D software.

The authors acknowledge the support of the European Union through the project *Silicon-Light and Dr. Satoshi Hata from Kyushu University for the HATA holder*

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