Electron tomography with sub-5-second temporal resolution for dynamic in situ transmission electron microscopy

Authors: Vadim Migunov (1), Rowan K. Leary (2), María de la Mata (3), Eleonora Russo-Averchi (4), Gözde Tütüncüoglu (4), Anna Fontcuberta i Morral (4), Jordi Arbiol (3, 5), Rafal E. Dunin-Borkowski (1)

1. Ernst Ruska Centre for Microscopy and Spectroscopy with Electrons and Peter Gruenberg Institute, Forschungszentrum Juelich, Jülich, GERMANY
2. Department of Materials Science and Metallurgy, University of Cambridge, Cambridge, UK
3. Catalan Institute of Nanoscience and Nanotechnology (ICN2), CSIC and The Barcelona Institute of Science and Technology (BIST), Campus UAB, Bellaterra, Barcelona, Catalonia, SPAIN
4. Laboratoire des Matériaux Semiconducteurs, Ecole Polytechnique Fédérale de Lausanne, Lausanne, SWITZERLAND
5. Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, Catalonia, SPAIN

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Corresponding email: v.migunov@fz-juelich.de
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Electron tomography (ET) is an important technique for the study of the three dimensional morphology, structure and chemical composition of nanoscale materials in the transmission electron microscope (TEM). Although ET is potentially a powerful tool for *in situ* three-dimensional TEM studies of catalytic reactions, growth processes, phase transformations, switching mechanisms and defect nucleation, motion and interactions, its application to dynamic experiments has been limited, since typical acquisition times for tilt series are typically tens of minutes or longer [1].

We have recently demonstrated the rapid acquisition of a tomographic tilt series comprising approximately 3500 images between +30° and -70° in only 3.5 s, as shown in Fig. 1) [2]. Here, we apply the technique to the three-dimensional imaging of the thermal segregation of an InAs V-shaped nanomembrane [3]. The membrane was heated *in situ* in an FEI Titan TEM up to a temperature of 420 °C. Changes in membrane morphology were tracked by acquiring images on a Gatan K2-IS camera at 400 frames per second while continuously tilting the specimen between +60° and -65°. Each tilt series (i.e., one rotation in one direction) was acquired in approximately 4.3 s and comprised ~1700 frames. Selected frames are shown in Figs 2 and 3.

The reconstruction of time-dependent (four-dimensional) tilt series can be performed using two approaches: i) Reconstruction of each individual tilt series and interpolation between each reconstruction in the time domain, resulting in a time resolution that is limited by the acquisition time for each tilt series (i.e., 4.3 s); ii) Model-based reconstruction, involving tracking of changes between individual frames within each tilt series, resulting in sub-second temporal resolution. We are presently pursuing both approaches.

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References:

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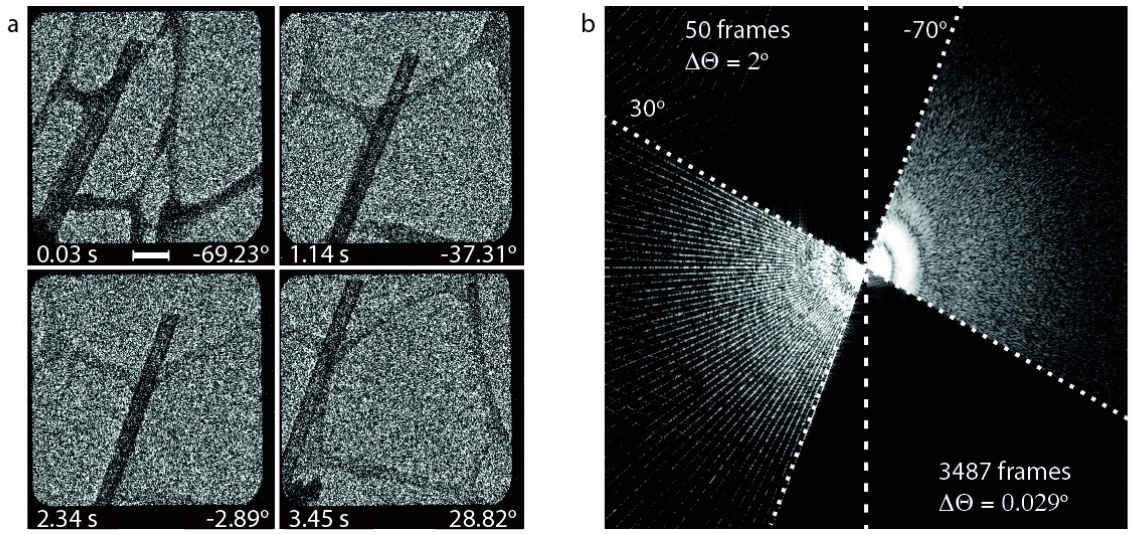
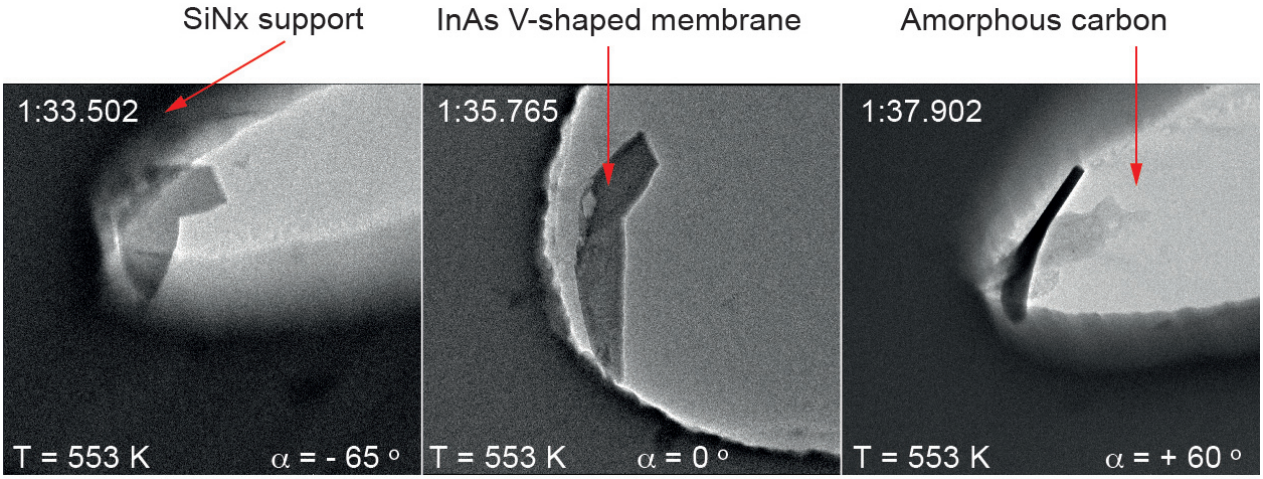
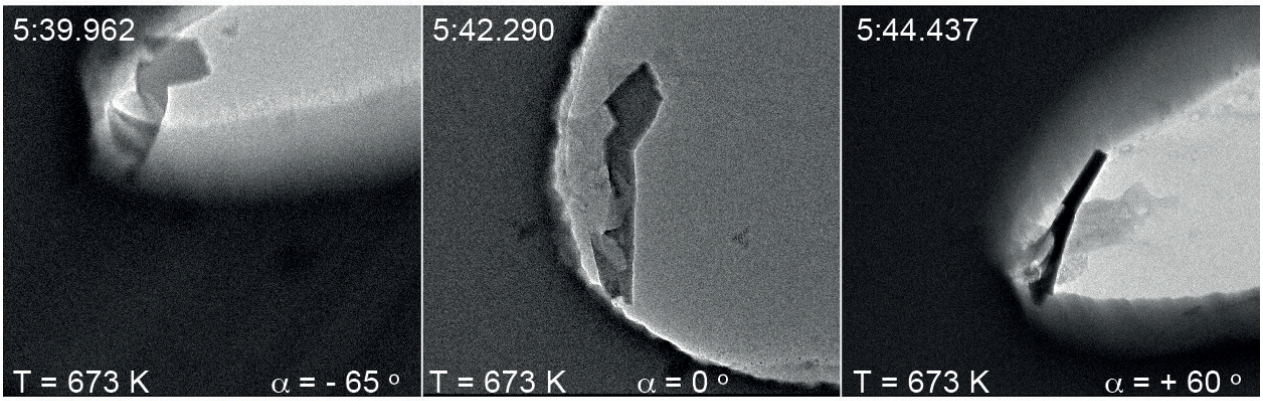


Continuous tilt series comprised of 3487 images taken over a range of −70° to +30° of a nanotube on a lacey C. The labels in (a) indicate the time elapsed and the tilt angle. The scale bar is 200 nm. b) The filling of Fourier space with projection data for a subset of 50 images and for the full series with increments of 2° and ~0.03°. Adapted from [2].



Snapshots taken from a tilt series of an InAs V-shaped membrane acquired at 553 K. For each frame, the total elapsed time (shown as “minutes: seconds”) during the heating experiment is shown at the top, while the specimen tilt angle α is shown at the bottom.



Snapshots taken from a tilt series of an InAs V-shaped membrane acquired at 673 K. For each frame, the total elapsed time (shown as “minutes: seconds”) during the heating experiment is shown at the top, while the specimen tilt angle α is shown at the bottom.