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3-D Electron Microscopy for Nano-Technology and the IC Industry

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The small dimensions and complex structures encountered in nano-technology and semiconductor devices result in new challenges for characterization techniques and an increasing need for three-dimensional structural information. Electron tomography is a widely recognized method (in life-science) to obtain high-resolution three-dimensional images by electron microscopy [1]: A sample is tilted around a single axis over a wide angular range (±60-70º) with electron micrographs obtained at small angular tilt increments [2]. Subsequently, the images of the tilt series are aligned and a reconstruction of the three-dimensional volume is calculated based on an interpretation of the TEM images in terms of mass-thickness (Figure 1).

The methodology of electron tomography can also be extended towards materials science, nano-technology, and IC applications. However, due to diffraction contrast from these (crystalline) materials, the classical approach using TEM bright field will be limited, as the contrast will strongly change over the tilt range. This results in a (significant) noise in the reconstructed image volume, which considerably limits an unambiguous interpretation of the results.

We are currently exploring the use of other electron microscopy techniques, such as ADF-STEM, HAADF-STEM, energy-filtered TEM, and hollow-cone TEM as alternative tomography methods for 3-D visualization of crystalline inorganic materials. In addition to reducing diffraction contrast, these electron microscopy techniques further need to result in 2D images that directly reflect the projected elemental- or mass-thickness in order to yield meaningful electron tomography reconstructions. Our evaluation of the above-mentioned methods indicates, that HAADF-STEM imaging results in accurate high-resolution electron tomography reconstructions for a wide range of applications such as life science [3], materials science [4], nano-technology, and the semiconductor devices (Figure 2). To mention one of the examples for HAADF-STEM tomography, Figure 2 shows an FIB prepared IC device, where the 3D reconstruction reveals defects that are not visible or cannot be localized in a simple 2D projection. Further details on the electron microscopy methods for tomography will be presented during the talk together with applications examples.

References

[1] J. Frank, Three-Dimensional Electron Microscopy of Macromolecular Assemblies, Academic Press, San Diego, 1996.
[2] Visit the FEI booth for a demonstration of the Tecnai™ G2 Sphera for fast and accurate automated TEM tomography.
[3] U. Ziese, C. Kübel, A.J. Verkleij, A.J. Koster, J. Struct. Biology, submitted.
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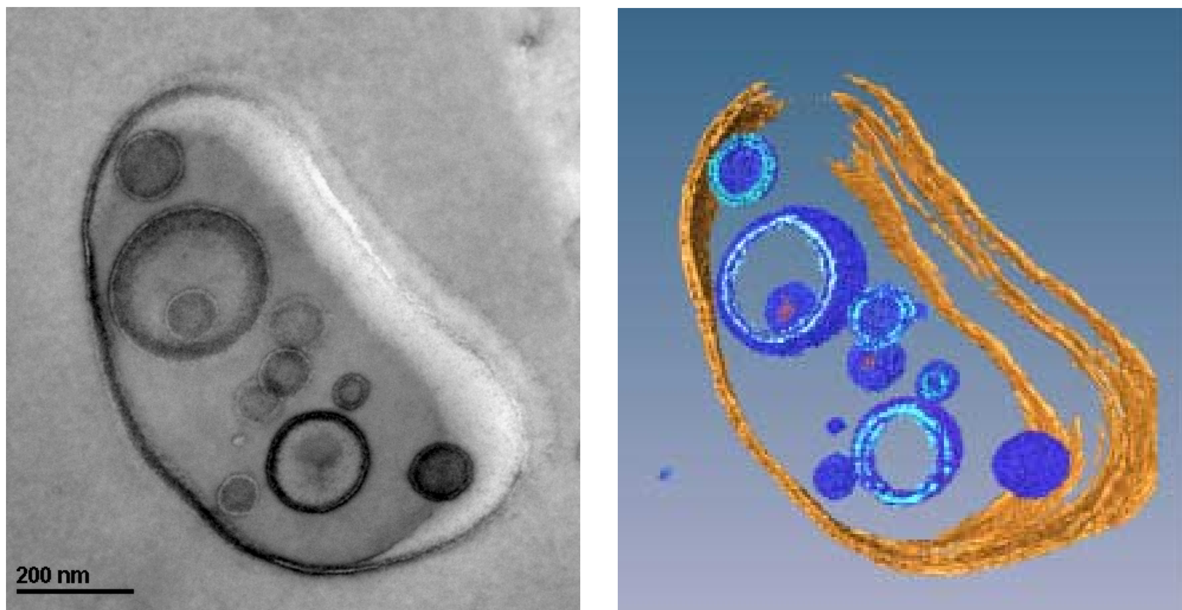

FIG 1. Electron tomography example showing a reference image at 0º tilt and the reconstructed 3D volume of a 150 nm thick epoxy section with stained block-copolymer vesicles. The bilayer was resolved in 3D with a feature width of 3 nm.

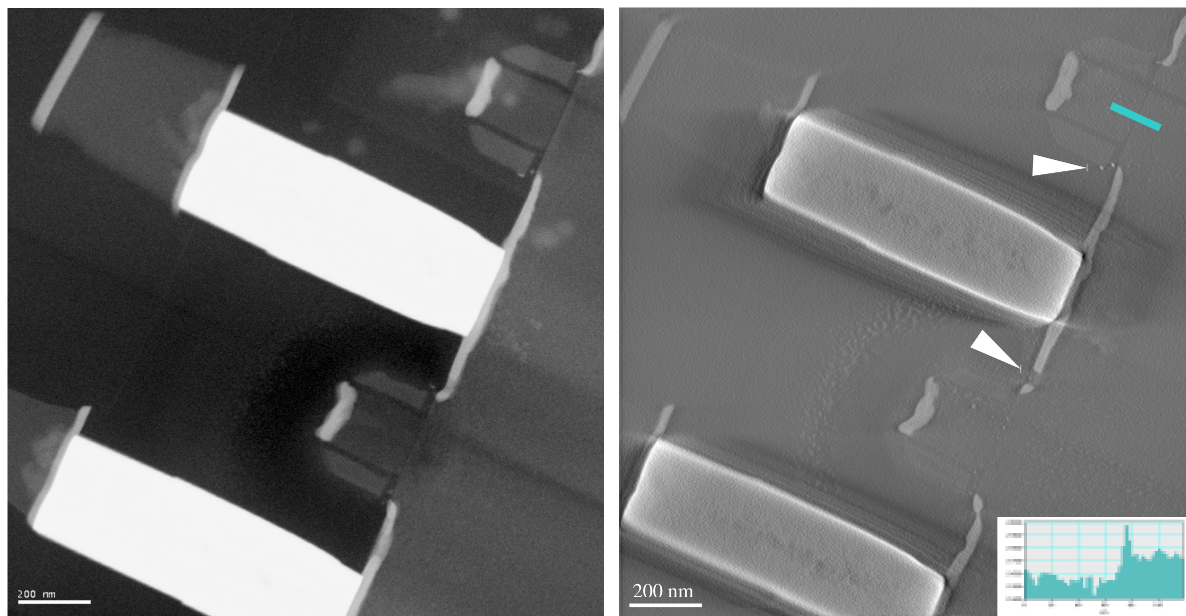

FIG 2. HAADF-STEM reference image at 0º tilt and a slice of the reconstruction of a 150 nm thick semiconductor section (transistor, tungsten via, aluminum connect) prepared by FIB (the inset shows a line profile of the gate oxide). In the reconstructed volume, various defects and the gate oxide are visible in 3D as well as variations of the barrier layers and holes in the via.

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