Atomic resolution tomography and dynamics of nano-objects

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The latest generation of aberration-corrected Transmission Electron Microscopes (TEM) have a resolution and sensitivity that is sufficient to detect even single light atoms from the periodic table of elements and to pinpoint their position with a lateral precision that reaches the wavelength of the imaging electrons. However the depth (z) information remains less certain. For the study of beam-sensitive crystalline nanoparticles such as catalysts there is a need for a tomographic method for fast characterization of the shape of pristine particles at atomic resolution 1]. In this work we describe a quantitative parameterless 3D reconstruction method that uses the exit wave obtained from only one viewing direction parallel to the atomic columns. In this configuration the strong dynamical scattering yields a signal that is stronger than the incoherent signal in HAADF STEM which allows to minimize the exposure of the object to the incident beam. The method is based on the “channeling” theory [2] which has all the ingredients for a full 3D quantification of the atomic structure since it is not influenced by channeling in neighboring columns up to thicknesses of tens of nm, so that the exit wave can be analyzed column by column. Furthermore the atoms of a column act as weak lenses, which focus the electron wave periodically with depth so that the exit wave of a column is a very sensitive peaked fingerprint of the “weigth” of the column. Every pixel in the exit wave function is a complex number. The theory of channeling is simple [3] and provides a way to interpret the exit wave, which can be visualized graphically by plotting the complex values of the pixels in complex 2D space. From the Argand plot of a column we can deduce the position of the column, the defocus distance (with sub-Angstrom precision), the total mass of the column and the residual aberrations [4]. By combining this information we can then reconstruct the object in 3D including profile of top and bottom surface with single atom sensitivity. We have applied this successfully to nanoparticles of Ge, MgO, Au [5]. We also developed a fast method to visualize the vertical position of atoms in a thin sheet and applied it to study the dynamics of thin graphene sheet in real time.

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