Properties of two-dimensional materials by high-resolution low-voltage aberration-corrected TEM

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To obtain structural and electronic properties of two-dimensional electron-beam-sensitive materials by analytical low-voltage spherical and chromatic aberration-corrected transmission electron microscopy we developed further three main topics:

(1) Theory and image processing [1-3]: For exact calculation of high-resolution (HR)-TEM images for low-Z materials at low voltages, the contribution of inelastic scattering cannot be neglected. For calculation of low-voltage energy-filtered (EF)-TEM images, the contributions of elastic and inelastic scattering to the image intensity cannot be separated from each other because the inelastic scattering amplitudes are influenced by elastic scattering, and vice versa. Moreover, we study the dependence of the signal-to-noise ratio, atom contrast and resolution on electron dose and sampling in order to achieve highest resolution.

(2) Sample preparation [4,5]: We demonstrate our successful method to clean graphene as a prerequisite for its use in TEM. Sandwiching radiation-sensitive low-dimensional objects in-between two graphene layers allows an effective reduction of electron-beam-induced damage of the objects. Moreover the exchange of hydrogen by deuterium allows to image the object at a factor of two higher electron dose.

(3) Low-voltage Cc/Cs-corrected TEM instrument [6,7]: We show unprecedented high resolution at low voltages from 80kV down to 20kV using our brand-new spherical and chromatic aberration corrected *SALVE* microscope [8]. We show that lowering the energy of the imaging electrons down to 20kV increases contrast and prevents various e.g. molecules on graphene from electron-beam stimulated damage.

The application of our strategies [9-11] on deriving the properties of different two-dimensional crystalline (ion-implanted graphene, MoS_2, $MoSe_2$, $TaSe_2$, WS_2, SiO_2) and amorphous (monolayer carbon, SiO_2) materials will be demonstrated.[12]

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