Properties of graphene and other low-dimensional objects obtained from imaging and spectroscopy experiments in a transmission electron microscope

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The atomic structure and electronic properties of graphene and other low-dimensional objects are obtained by analytical low-voltage aberration-corrected high-resolution transmission electron microscopy [1,2]. We investigate in-situ electron beam-induced modifications of graphene functionalized by dopants [3], defects [4] or molecules. We discuss the determination of knock-on damage thresholds in two-dimensional objects [5,6] and how, under the influence of the electron beam, point defect cluster and dislocation form and annihilate [7] and how grain boundaries migrate on the atom-by-atom base [8]. Moreover we discuss structural changes under the influence of Joule heating and address the basic question how the amorphous phase of 2D objects is formed and can it can be described from direct images [9,10] . We discuss then electron-beam-induced transformation route of different nano-carbon structures [11,12]. Most of our experiments were combined by atomistic simulations.

In the spectroscopy mode we show that the monochromatic low-energy electron beam enables the acquisition of EELS spectra with exceptionally low background noise [1]. In addition to the energy of electronic excitations, also the momentum information can be accessed in a TEM. We determine the dispersion behavior for π and $\pi+\sigma$ plasmons in free-standing single-layer graphene [13] and multilayers with increasing thickness (number of layers).

In addition, we report on the property of graphene as substrate for transmission electron microscopy and – furthermore - to sandwich electron-beam sensitive materials protecting it similarly to a carbon nanotube.

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