Hidden defects and unexpected properties of graphene - How advanced TEM contributes to materials development

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Graphene and its chemically modified derivatives have widely been studied for more than a decade. Nonetheless, this highly interdisciplinary field, interdigitating with research on other (quasi-2D) layered materials like the chalcogenides, bears unexpected electronic, optical, chemical and mechanical properties almost every day. To understand novel properties and prospectively tailor functionality for application, it is indispensable to correlate to the material's local structure, chemistry and defects.

We will present outstanding examples, how state-of-the-art transmission electron microscopy, being highly sensitive to the material's crystal and atomic structure, its chemistry and even its topography down to the nm-scale, contributes to fundamental research as well as to material development:

i) Graphene from highly intact oxo-functionalized graphene (graphene oxide): We present a scalable route to prepare highly intact monolayer graphene oxide from graphite and its gentle reduction by low"energy electrons (Fig. 1, Ref. 1).

ii) Linear magnetoresistance of SiC graphene: Basal-plane partial dislocations, occasionally named "strain solitons", introduce a change of the local stacking order of bi-/few-layer graphene and may consequently cause a unique degree of disorder such as in SiC graphene. Each dislocation's strain field alters the local electronic properties of the material, which explains the perfect linear magnetoresistance up to field strengths of more than 60 T (Fig. 2, Ref. 2-4).

iii) Nanoscale topography of freestanding graphene membranes: Non-destructive dark-field TEM tomography allows us to determine the topography of crystalline membranes with exceptional nm"resolution. Together with complementary TEM (membrane thickness, crystal structure, defects, impurities), this provides comprehensive insight to understand, e.g., the mechanical properties (strain relaxation, plasticity, energy dissipation) of such thin membranes and resonators.

References:

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[4] D Waldmann et al, ACS Nano 7 (2013), pp. 4441

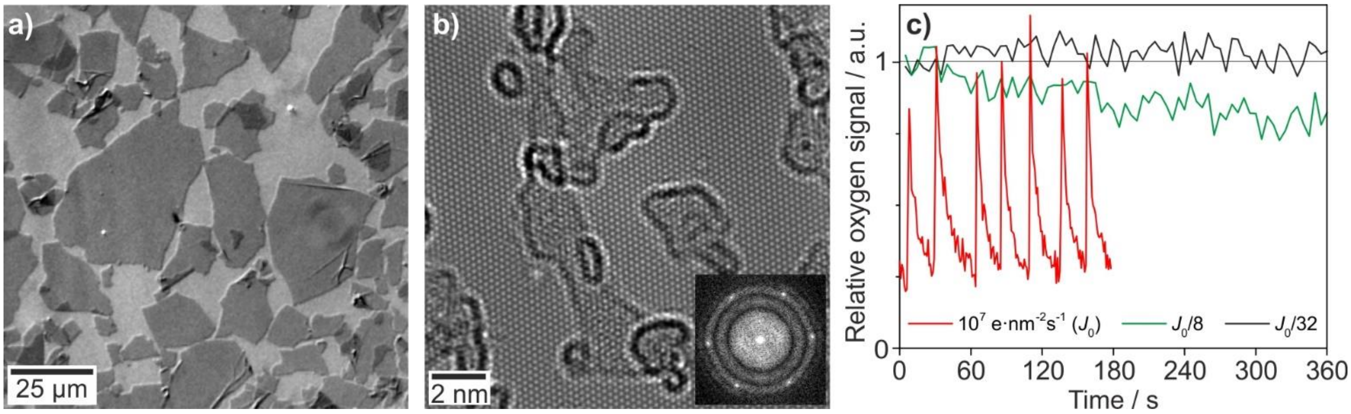

Figure 1: a) Optical micrograph of monolayer oxo-functionalized graphene flakes, b) integrity of underlying carbon framework of monolayer flake proven by aberration-corrected HRTEM, c) reduction of oxo-functionalized graphene by 80 kV electrons (dependency on beam current density). (Ref. [1])

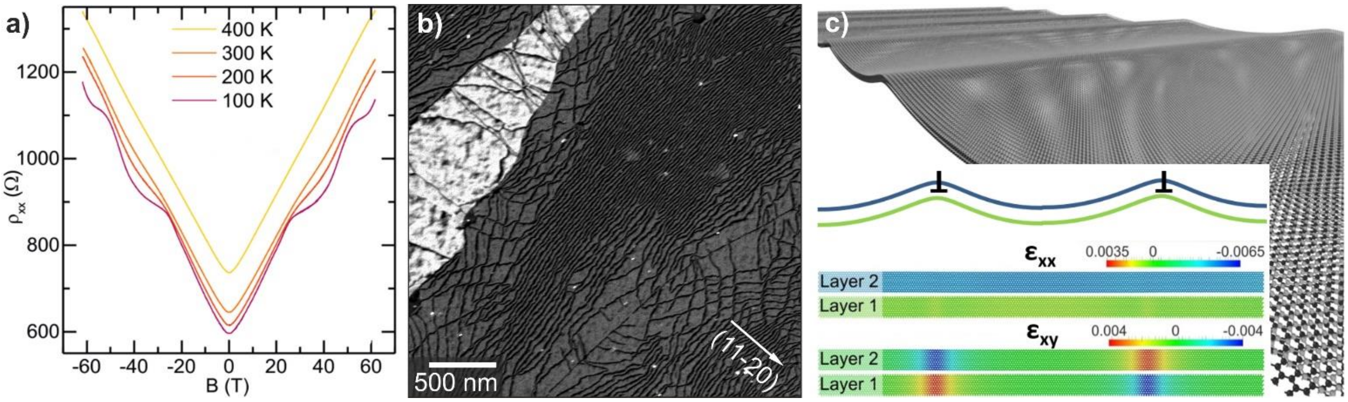

Figure 2: a) Perfect linear dependency of in-plane resistivity of SiC graphene on perpendicular magnetic field, b) dislocation network (dark lines) in bilayer and trilayer SiC graphene (DF-TEM micrograph), c) atomistic model of bilayer graphene topography at partial dislocation cores, inset: strain distribution as proven by dark-field TEM imaging. (Ref. [2-4])