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Ultra-low energy SEM/STEM of graphene

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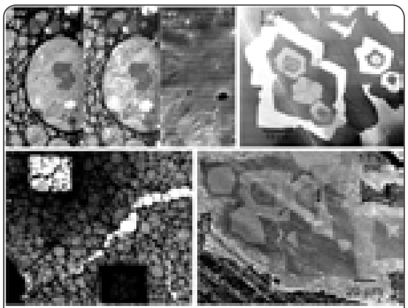
Graphene sheets, including multilevel stacks, are nearly fully transparent for electrons at energies standard in electron microscopes. Graphene has even been considered an ideal substrate for the deposition of, for example, organic macromolecules for their observation in a scanning (transmission) electron microscope (SEM/STEM). The cathode lens principle with a negatively biased sample in the SEM/STEM enables one to obtain an arbitrarily low energy of electrons securing an ultimately reduced interaction volume providing the image information. The image contrast has been found to be sufficient for distinguishing graphene flakes at tens and units of eV in the STEM, and the electron transmissivity surprisingly showed values in units of percent only in this energy range. Expectations based on the usual extension of the inelastic mean free path of electrons below some 50 eV have not been confirmed. The electron transmissivity at tens of eV has proven a reliable tool for counting the graphene layers as an alternative to Raman spectroscopy providing much enhanced lateral resolution. Graphene layers grown by the CVD method on substrates exhibit contrasts connected with electron reflectivity fluctuations below about 8 eV and also in a second band around 15 eV in the ultra-low-energy SEM. This phenomenon can also be employed for counting the graphene layers because we get n-1 minima of reflectivity on n graphene layers. Observation at ultra-low electron energies, in particular under standard high-vacuum conditions, faces surface contamination owing to the electron-beam-induced deposition of carbon from spontaneously adsorbed hydrocarbon precursors. This fatal phenomenon mostly prevents us from performing true surface studies under the standard high vacuum (10-6 to 10-7 mbar). However, electrons bombarding surfaces at tens of eV have proven themselves to release hydrocarbon molecules instead of decomposing them, so ultimately cleaned surfaces are obtained.



Recent Publications:

1. Mikmeková E, Bouyanfif H, Lejeune M, Hovorka M, Unčovský M, Frank L (2013) Very low energy electron microscopy of graphene flakes. Journal of Microscopy 251:123-127.
2. Frank L, Mikmeková E, Müllerová I, Lejeune M (2015) Counting graphene layers with very slow electrons. Applied Physics Letters 106:013117, 1-5.
3. Mikmeková E, Frank L, Müllerová I, Li BW, Ruoff RS, Lejeune M (2016) Study of multi-layered graphene by ultra-low energy SEM/STEM. Diamond & Related Materials 63:136-142.
4. Frank L, Mikmeková E, Lejeune M (2017) Treatment of surfaces with low-energy of electrons. Applied Surface Science 407:105-108.
5. Frank L, Hovorka M, Mikmeková Š, Mikmeková E, Müllerová I, Pokorná Z (2012) Scanning electron microscopy with samples in an electric field. Materials 5:2731-2756.

Biography

Ludek Frank is a senior researcher at the Institute of Scientific Instruments of the Czech Academy of Sciences. He has expertise in the methodology of electron microscopy and spectroscopy with an emphasis on low-energy electron applications. Currently he is studying the scanning transmission electron energy at near-zero energies of electrons and its application in material as well as biomedical sciences. Eliska Mikmekova is a staff researcher at the same Institute and head of the Group of Microscopy and Spectroscopy of Surfaces. She has expertise in the generation and diagnostics of ultrafine layers and 2D crystals. She is also developing and promoting the method of electron-stimulated desorption of adsorbed hydrocarbons.

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