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Influence of inelastic scattering on EFTEM images - exemplified on graphene and silicon at 20kV

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When the accelerating voltage is decreased to as low as 20kV, all objects are strong scatterers [1]. In this case, the standard calculation and interpretation of TEM images, which are based on elastic scattering theory, is not sufficient anymore and inelastic scattering must be taken into account especially for low-Z objects. In the case of inelastic scattering the incident electron excites the object from the initial state to any allowed state, accompanied by a change of the wave function of the incident electron.

Inelastic scattering is incorporated into the image calculations by means of the Mixed Dynamic Form Factor (MDFF), introduced by Rose [2, 3]. The MDFF accounts for the interference of different scattered partial electron waves. The elastically scattered partial waves can interfere with each other, whereas the partial waves of the inelastically scattered electron can only interfere with each other if they are associated with the same excited object state. The calculation of the MDFF involves the propagation of two coupled waves. Therefore the image calculation involves 4D Fourier transforms, which is too time-consuming. In order to simplify the 4D FT as combinations of 2D Fourier transforms, we have derived an approximation based on independent atom model up to a resolution limit of 1Å. Our approximation is easy to calculate and can be optimized for different imaging conditions.

We calculated EFTEM images for the SALVE II machine, based on the experimental EELS spectra obtained at the SALVE I machine. Based on our calculations at 20kV, even for an one-atom thin structure like graphene, although only less than 1% of the electrons are inelastically scattered, the strong interference of these inelastically scattered waves results in dramatic decrease of the zero-loss filtered image intensity to 72%, compared with pure elastic case. For the thicker structure Silicon<110> (17nm thick), as much as 57% of the electrons are inelastically scattered, however the zero-loss filtered image intensity drops only to 60% compared with the pure elastic case. The examples show that especially for low-Z materials such as carbon-based structures, the interference between the inelastically scattered waves dominates the image intensity. Our two examples show that in general the influence of inelastic scattering cannot be neglected at 20kV. The analysis on the zero-loss and plasmon-loss filtered images shows that the total intensity is conserved.

We may speculate now and further investigate in due course that absorption caused by the interference between inelastically scattered waves is another factor contributing to the Stobbs factor [4] also at higher voltages. We will report further EFTEM experiments for graphene and silicon as soon as the SALVE II microscope is fully operable and functional.

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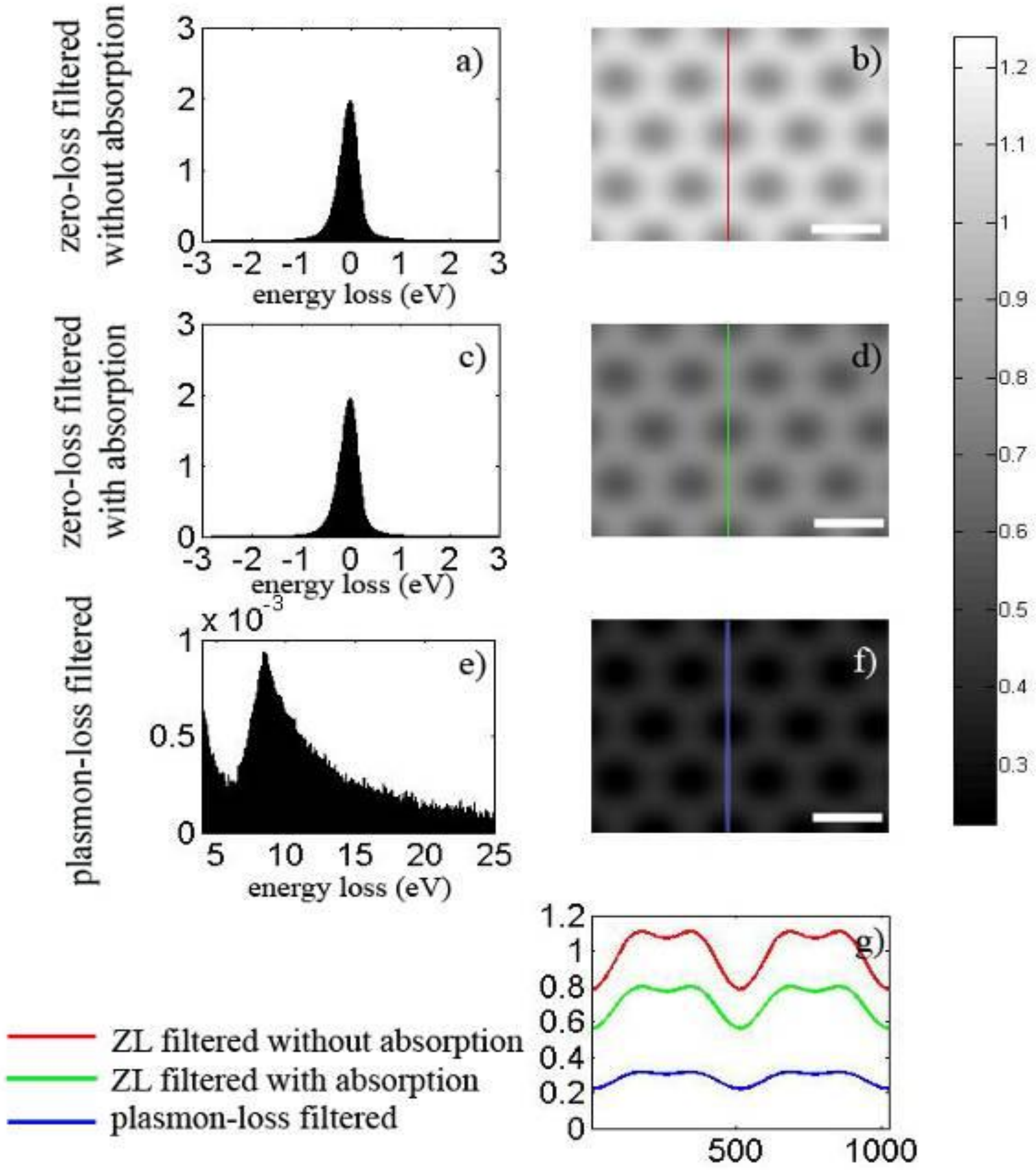

Figure 1. Calculated EFTEM images for graphene at 20kV for the SALVE II microscope (2nd column) based on the experimental EELS spectra (1st column)(Atoms in the images are white). a) The normalized zero-loss peak; b) The zero-loss filtered image without absorption; c) The zero-loss peak extracted from the normalized EELS spectra; d) The zero-loss filtered image with absorption; e) The plasmon peak; f) The plasmon-loss filtered image; g) The line profiles marked in the image b),d) and f). The y-axis shows the intensity and the x-axis shows distance in pixels. Aberration parameters: C_c=0, C_s=-2µm and Δf=42Å. scale bar: 2Å