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Towards understanding the influence of electron-gas interactions on imaging in an environmental TEM

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The latest generation of environmental transmission electron microscopes (ETEMs) incorporates aberration correction and monochromation, allowing studies of chemical reactions and growth processes with improved spatial and spectral resolution. These additions to the columns of commercial ETEMs have improved the point resolution to the sub-Ångström level [1] and reduced image delocalization, allowing images of surface and interface structures to be interpreted more directly [2]. However, when gas is present in the microscope the path of electrons along the column is modified due to gas-electron scattering [3].

In general there are two approaches for performing TEM experiments in the presence of gases. These approaches are based on a differential pumping scheme and the closed cell TEM holder approach and each has its advantages and disadvantages. In the closed cell approach, gas molecules are confined to a thin (typically 50-200 µm thick) slab around the sample, but the electrons interact with the window material (e.g. C, SiN) as well as with the gas and the sample. In addition, the field of view is typically smaller than in a conventional TEM and a limited range of sample geometries can be used. In the differential pumping approach, the gas is confined to the region around the specimen only by pressure-limiting apertures. In order to retain flexibility in the sample region, the pole piece gap and the highest pressure part of the column are relatively large (~7mm). As a result, electron scattering by gas molecules occurs both above and below the sample along a distance that is comparable to the focal length of the objective lens. Gas molecules are also present in the rest of the column, although at a pressure that is several orders of magnitude lower than that around the specimen due to the use of both pressure-limiting apertures and additional pumping capabilities.

In order to take full advantage of the aberration corrected objective lens system by retrieving quantitative information from images acquired in the presence of gas, the propagation of the electron wave in the entire microscope column, including electron scattering by gas molecules has to be understood.

The most basic effect on images acquired in the presence of gas is a simple decrease in intensity with increasing gas pressure and scattering cross-section of the gas molecules. Figure 1 shows a representative example of intensity profiles determined from bright-field images of a GaN specimen, plotted as a function of Ar pressure in a differential pumped FEI Titan microscope. Significantly, Fig. 1 shows that the details of the image contrast also change with pressure, primarily because the electron wave is modified by scattering from gas molecules. Furthermore, the electrons lose energy when they are scattered by gas molecules leading to a less isochromatic incident electron beam. Figure 2 shows a preliminary result of angle-resolved low-loss EELS acquired in the presence of 980 Pa of O_2 in the absence of a specimen.

Our on-going work involves the systematic measurements of images, diffraction patterns and energy-loss spectra acquired in the presence of gas, for a variety of different beam current densities, accelerating voltages and choices of specimen.

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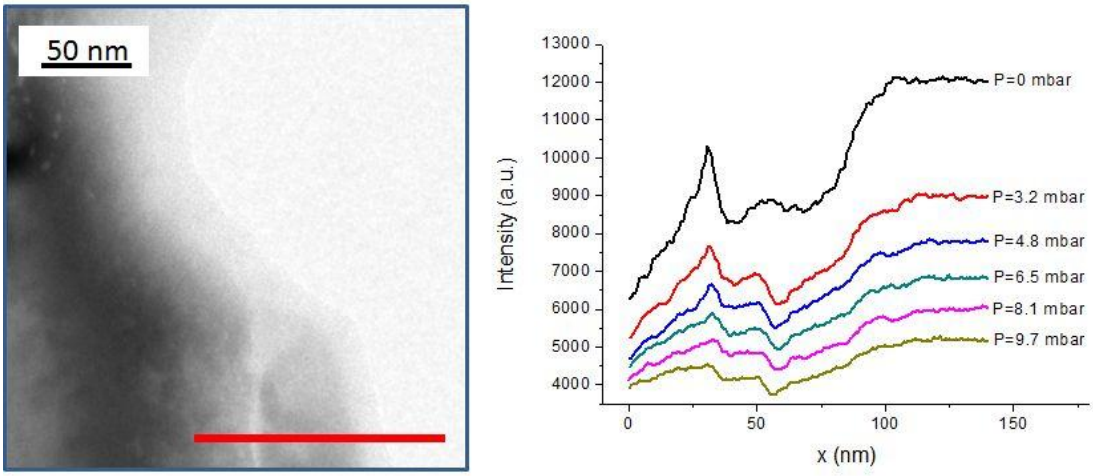

Figure 1. Bright-field image of a thin GaN film shown alongside the intensity profiles taken from the marked region as a function of Ar pressure at room temperature under consistent microscope conditions. Acceleration voltage is 300 kV.

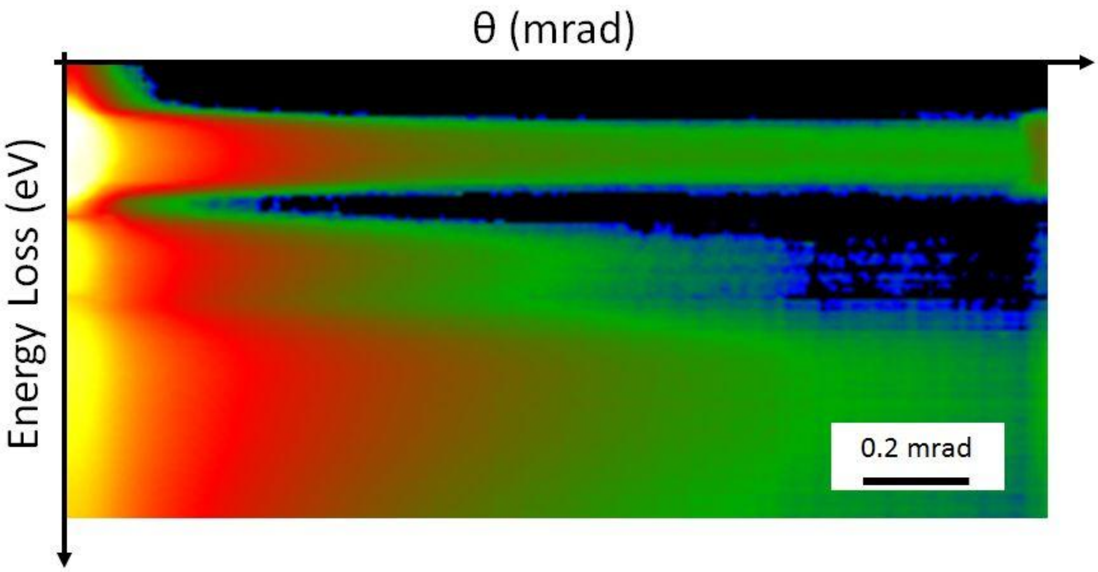

Figure 2. Montage of angle-resolved low-loss electron energy-loss spectra acquired from 980 Pa of O_2 in a differential pumped TEM with no specimen present. The plot was created from rotationally averaged diffraction patterns that had been acquired as a function of energy loss using a 0.3 eV energy-selecting slit width and an acceleration voltage of 300 kV. The colours represent the intensity of the signal (white: high, black: low).