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Low-Voltage (40 kV) Aberration-corrected, Monochromated Imaging for Carbon Nanostructures

David C. Bell[1], Dmitry V. Kolmykov[3] and Christopher J. Russo[1,2]

[1] School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138
[2]Harvard-MIT Division of Health Sciences and Technology, Cambridge, MA
[3] Carl Zeiss NTS GmbH, Carl Zeiss, Oberkochen Germany

There are distinct advantages to imaging carbon and low atomic number materials with lower voltage TEM, including reduced beam induced damage [1]. The cross sections for carbon sputtering drop off almost completely below a 50 kV threshold energy. Opening up the research space to investigate previously inaccessible materials systems is the motivation driving "low" voltage aberration corrected high-resolution TEM research. The critical limiting factor in low kV imaging is the chromatic aberration; thus, C_c correction or the use of a monochromator are the only practical ways of achieving the high resolutions required, with the added benefit of improving the sample contrast. The advantages of low voltage TEM imaging have been known for many years, but this recent practical incorporation of monochromation and aberration corrected optics will allow low kV atomic scale imaging to make a significant contribution to nanoscale research.

The energy spread of Harvard's Zeiss Libra TEM field emission source is reduced by the incorporation of an Omega type monochromator in the field emission gun [2]. The energy spread is reduced from 600 meV to 100 meV at 200 kV, to 70 meV at 80 kV and after tuning the platform to perform at an accelerating voltage of 40 kV, we obtain an energy spread of ~ 50 meV FWHM with suitable remaining brightness for high-resolution imaging (Fig 1.). (Our FWHM value for 40 kV is only approximate due to the dispersion limit of the energy filter). This decreased energy spread reduces the effect of chromatic aberration, providing increased resolution at lower voltages and produces atomic resolution at the Ångstrom level. Using a simple geometric model, we can predict the resolution at different accelerating voltages of our TEM for various monochromator slit widths (Fig. 2.) and at accelerating voltage of 40kV, we predict resolution better than 0.14 nm, whilst retaining sufficient imaging intensity.

We present the results of our investigations and the application of this technique to produce HRTEM and EFTEM imaging on various materials systems. The key application of this research is to provide atomic resolution at the interfaces between metal nanoparticles and carbon based nanotubes or biological materials such as ligands. Nanotube structures, graphene and biomaterials can be incorporated with Au and Ag metal nano-particles to provide nanomarkers for cancer research, or centers for laser excitation. These instruments will allow us insight to in materials classes previously excluded from high-resolution analysis due to their beam-sensitivity. This will include light element materials that can now be investigated with an unprecedented contrast and spatial resolution. Tunable Cs correction, monochromator and in-column energy filtering combined on one instrument platform provide a foundation for the future with a high resolution transmission electron microscope with advanced resolution and contrast capabilities.

References

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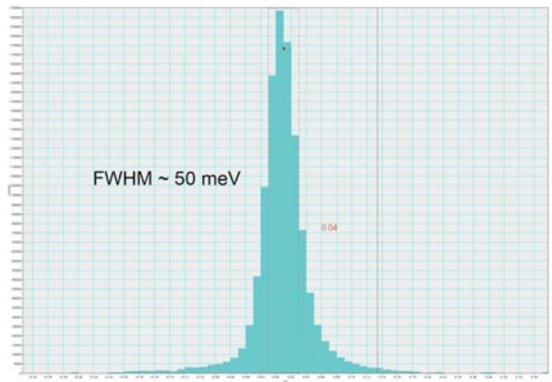

Fig.1. Zero-loss peak at 40 kV accelerating voltage showing the energy spread of the electron source with a 1 µm monochromator slit of 50 meV.

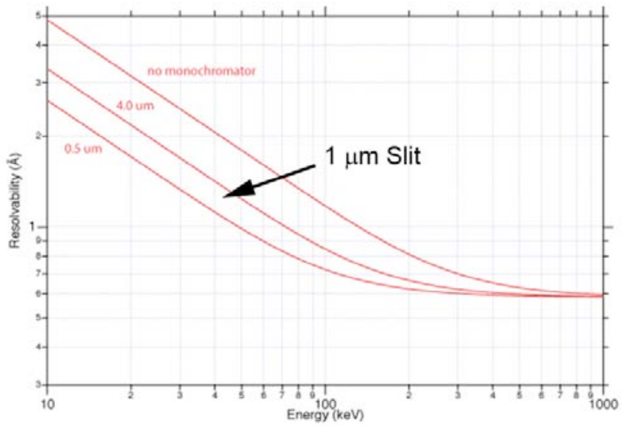

Fig.2. A simple geometric model to predict the resolution at different accelerating voltages with the curves representing different monochromator slit widths (energy-spreads), the 1um slit width position is indicated.

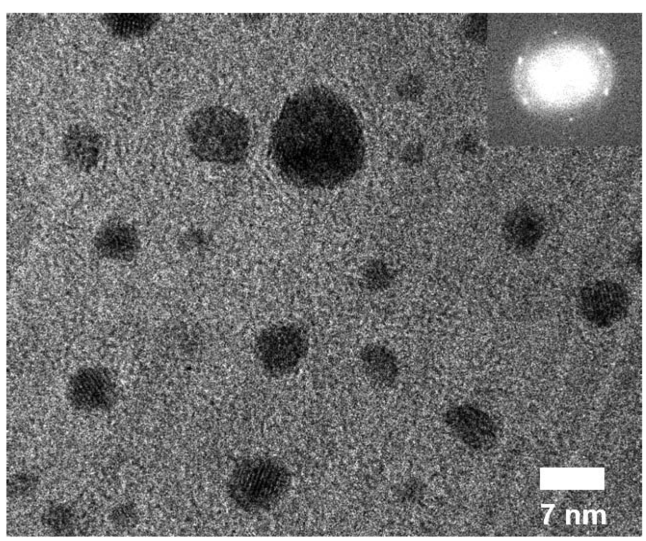

Figure 3. A 40 kV C_s-corrected monochromated image of Au nanoparticles on a grapheme film, showing clearly the surrounding ligand complexes, in this image the Au lattice fringes are clearly visible (inset, FFT of image revealing the Au lattice spacing).

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