INTERFACE, SURFACE AND SINGLE ATOMS STUDIES BY ABERRATION-CORRECTED ELECTRON MICROSCOPY

Ondrej L. Krivanek[1,2], Andrew L. Bleloch[1], Niklas Dellby[1], Michael Hotz[1] and Tracy C. Lovejoy[1]

[1] *Nion R&D, 11515 NE 118th St., Kirkland, WA 98034, USA*

[2] *Department of Physics, Arizona State University, Tempe, Arizona, USA*

The capabilities of electron microscopes have advanced very significantly since the start of the new millennium. The first major advance was the successful implementation of electron-optical aberration correction, which allowed scanning transmission electron microscopes (STEMs) to reach direct sub-angstrom resolution in 2002 [1,2].

The performance improvement due to the correction has made imaging of single atoms very straightforward. It has also allowed the elemental type of single atoms to be determined by electron energy loss spectroscopy (EELS) and energy-dispersive X-ray spectroscopy (EDXS), and charge transfer and other local bonding phenomena to be studied by EELS. Because each atomic column contains many atoms, elemental mapping of aligned crystals by EELS and EDXS, at atomic resolution, is even more straightforward. The implications for interface and surface studies have been very major. Charge transfer can now be studied with atomic resolution in many types of buried oxide interfaces, and single atoms on solid surfaces can be identified and their bonding analyzed.

Another major development has been the improvement of energy resolution of EELS due to the introduction of ultra-stable monochromated STEMs. The latest such instruments can resolve about 7 meV at 60 keV primary energy. They have made it possible to perform vibrational spectroscopy in the electron microscope (Fig. 1) with a spatial resolution that can approach about 1 nm [3,4]. Strongly bonded hydrogen is the easiest element to detect using this technique, and vibrational spectroscopy promises the ability to map hydrogen concentrations on surfaces and at interfaces, as well as an ability to recognize different organic compounds by their vibrational signature.

References:
1. P.E. Batson et al., Nature 418 (2002) 617.
2. P.D. Nellist et al., Science 305 (2004) 1741.
3. O.L. Krivanek et al., Nature 514 (2014) 209-212, see also Nature 514 (2014) 177-178.
4. P. Rez et al., Nature Communications (2016), DOI: 10.1038/ncomms10945

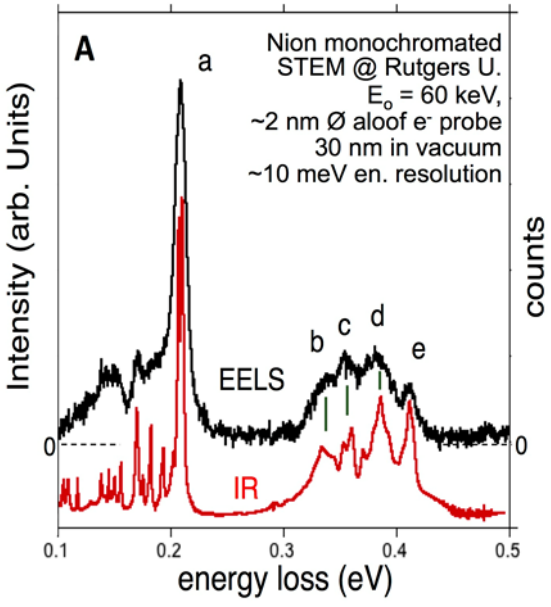

Fig. 1. Electron energy loss spectrum of guanine acquired in an electron microscope compared to an infrared spectrum of the same material.