Sub-Ångstrom and Sub-half-eV Analysis by STEM

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Aberration correction has brought about a revolution in electron microscopy, with as much progress being made towards the enduring goal of better resolution over the last few years as over the previous few decades. Of course, the benefits of aberration correction are not limited to resolution alone; the images will be clearer, with more distinct features and a better signal to noise ratio. However, there are also some more surprising benefits: In Scanning Transmission Electron Microscopy, the depth of field is greatly reduced. This will allow a new form of three-dimensional imaging, similar to confocal optical microscopy, where a three-dimensional dataset of the sample is built up slice by slice [1,2], thus providing atomic resolution laterally as well as the single atom sensitivity of the Z-contrast imaging mode. Bright-field (BF) imaging is less commonly used in the STEM, because the need to have a small collection angle (to obtain a coherent image) means that such images are rather inefficient. However, the damping envelope, which is the same as for BF TEM imaging, depends on the product of the gradient of the aberration function and the collection angle. Thus aberration correction allows the use of a larger collection aperture and a subsequent increase of around two orders of magnitude in the collection efficiency. This is likely to lead to a resurgence in the use of the BF imaging mode in STEM. A benefit of the STEM is that the BF image can be acquired simultaneously with the Z-contrast image, which will assist the (notoriously difficult) interpretation of BF images. In a similar manner, it is possible to acquire the EEL signal at the same time as the Z-contrast image. With the addition of an EEL spectrometer, we have achieved a spatial resolution better than 0.8 Å [3] (fig. 1) and an energy resolution better than 0.4 eV. This will allow column-by-column spectroscopic analysis of a variety of materials at unprecedented resolution [4].

Fig. 1 (a) Image of Si [112] showing “dumbbells” separated by 0.78 Å are resolved. (b) The FFT verifies that the [444] spacing is transferred and suggests information transfer at 0.6 Å. (c) FFTs of the probe and a simulated image verify how the diffractogram represents resolution in Z-contrast imaging.

References
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