Determining resolution in the transmission electron microscope: object-defined resolution below 0.5Å

B. Freitag[1] and C. Kisielowski[2]

1. FEI Company, Building AAE, Achtseweg Noord 5, Eindhoven, The Netherlands
2. National Center for Electron Microscopy, Lawrence Berkeley National Laboratory, One Cyclotron Rd., Berkeley CA 94720, USA

Bert.Freitag@fei.com
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The Transmission Electron Aberration-corrected Microscope (TEAM) project was initiated by the US Department of Energy as a collaborative effort to redesign the electron microscope around aberration-corrected optics [1], and is aimed at achieving 50 pm resolution. But the ability to resolve deep sub–Ångstrom spacing entails a number of unresolved questions that can now be addressed. Among them is an ongoing debate about the physical meaning of resolution. Traditional strategies include the recording of Young's fringes, the detection of image Fourier components from STEM images, the demonstration of a suitable peak separation in periodic lattices or signal width measurements from images of single atoms, to name a few. The drawback is that seemingly conflicting results are produced [e.g. 2]. Further, these methods define resolution through a selectable object, unlike light microscopy where resolution is instrument-defined. Two limitations of this approach are electron channeling [3, 4] and elastic scattering at single crystals [5]. The TEAM Project adopted a pragmatic view of information transfer below 50 pm: detecting Young's fringes in TEM and (660) image Fourier components from gold (111) STEM images at 48 pm. Recently the TEAM 0.5 prototype microscope achieved this goal [1].

Figure 1 shows two amplitude images of channelling waves that were reconstructed from 30 experimentally recorded lattice images from gold crystals imaged in [110] and [111] direction with the TEAM 0.5 microscope. Gold atoms are spaced by 0.29 nm in [110] direction but by 7 nm in [111] direction. Their different spacing alters electron channelling significantly. It is seen from the line profiles in Figure 2 that the full width at half maximum of the signals is 67± 4 pm and 46 ± 3pm for Au [110] and Au [111], respectively. The results agree with predictions from multi-slice calculations that also predict similar effects for HAADF STEM images from gold [110] and gold [111]. Therefore, we conclude that the TEAM 0.5 microscope can resolve column spacings below 0.5 Å, close to the Rayleigh resolution limit, if the objects are carefully chosen and prepared. However, in general, electron channelling can limit the object-defined resolution to values above 50 pm in both STEM and TEM images.

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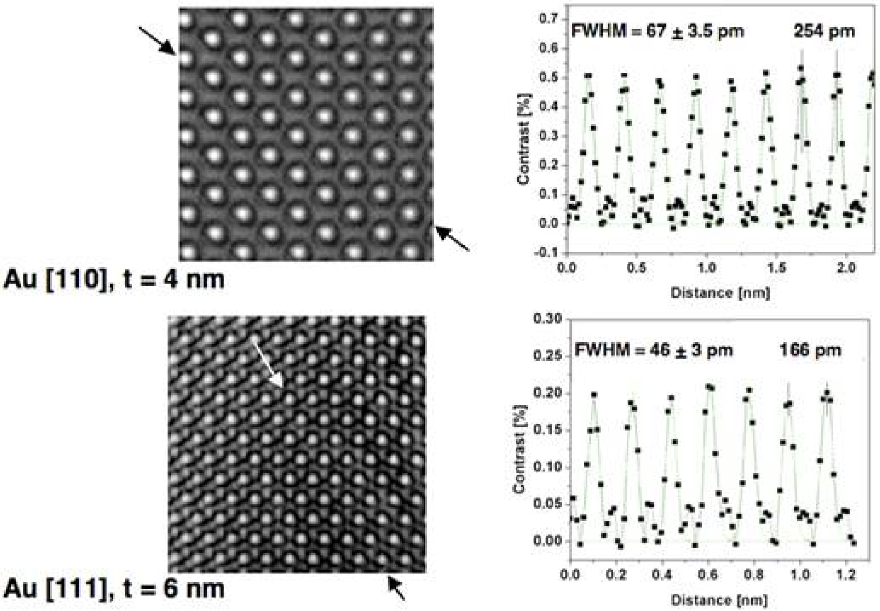

Figure 1. Amplitude images of channelling waves that were reconstructed from lattice images of gold [110] and gold [111] crystals recorded with the TEAM 0.5 microscope. The crystal thickness t is indicated. The extracted signal width from the associated line profiles proves that an object-defined resolution below 50 pm is obtained in Au [111] that increases to 67 pm in case of Au [110].