Prospects for electron holography of atomic moments and potentials

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The prospect of achieving 2π/1000 phase sensitivity with close-to-atomic spatial resolution in electron holographic measurements of electrostatic and magnetic potentials is now offered by ultra-stable transmission electron microscopes that are equipped with high brightness electron sources, aberration correctors and sophisticated software for the automation of lengthy experiments. When considering experiments aimed at the retrieval of phase shifts of this magnitude, it is important to remember that the desired precision is smaller than the phase shift of one atomic layer of amorphous C (typically ~2π/200) and that the interpretation of the retrieved phase often requires careful comparisons with dynamical simulations. The latter point is illustrated by the multislice simulations in Fig. 1, which show that the phase shift of Au imaged at a zone axis can be more than 50% lower than kinematic predictions at a specimen thickness of only 2 nm, while for graphite the phase shift can be close to zero or even negative at a zone axis that lies in the plane of the graphene layers. In fact, for certain values of specimen thickness and tilt, the phase shift of graphite can be larger than that of Au. Additional important aspects to consider include charging of the specimen as a result of electron beam irradiation and the presence of adsorbates on the specimen surface. Both effects are particularly relevant when applying electron holography to the characterization of electrostatic potentials in supported metal particles of interest for heterogeneous catalysis.

The situation is even more challenging when considering small magnetic phase shifts. A single Bohr magneton in a uniformly magnetized sphere with a typical atomic diameter is associated with a step in phase of ~$2\pi/10^5$ radians, while even a 2 nm ferromagnetic particle produces a phase shift of only ~2π/1000 radians. Fortunately, it is possible to measure certain physical quantities without the need to interpret the local phase shift itself. For example, the magnetic moment of a nanocrystal can be measured quantitatively from a phase image by making use of the relationship between the volume integral of the induction and the true magnetic moment. This relation can be utilized to study particles of arbitrary shape and magnetization state to yield a measurement of the magnetic moment that is free of most artifacts [1]. Our assessment of the relationship between the phase noise and the error in the measurement of the magnetic moment suggests that it may be possible to measure magnetic moments of nanoparticles that are below 100 μ_B, both in projection and in three dimensions.

[1] Beleggia M., Kasama T., Dunin-Borkowski R.E., *Ultramicroscopy* **110** (2010) 425-432

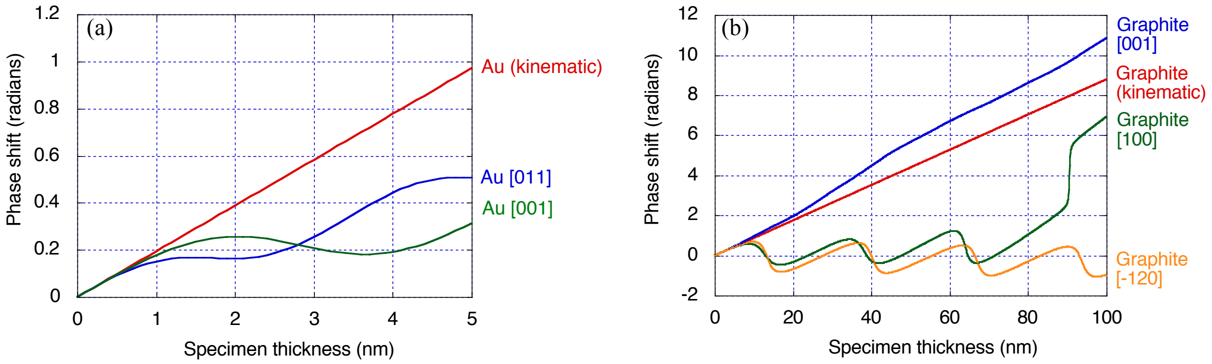

FIG. 1. Dynamical calculations of phase shifts of the 000 beam plotted for the indicated zone axis orientations of (a) Au and (b) graphite, for an accelerating voltage of 300 kV. Each calculation is performed using a multislice calculation with a single projected potential created using neutral atom scattering factors and no absorption. Kinematic predictions are also shown. Note the different specimen thickness ranges and vertical axes in the two graphs.