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Quantitative Atomic Resolution Differential Phase Contrast Imaging Using a Segmented Area All Field Detector

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The quest for novel functionalities in material science has often been determined by reducing dimensionality and designing nanostructured systems that exploit new physical effects. Most phenomena occurring at these nanometric length scales are ruled by the physical properties of small active regions, such as interfaces, domain walls and grain boundaries. In these regions, strong confined electromagnetic fields may arise, for example at the interfaces of ferroelectric complex-oxide-based heterostructures and from the piezoelectric polarization response present at interfaces in III-IV semiconductor quantum wells. Harnessing the physical properties occurring in such systems at the atomic-scale will be necessary to control the charge, spin and ionic transport properties of future devices.

Differential phase contrast (DPC) imaging in the electron microscope has enabled the study of such fields at nanometer resolution in magnetic materials [1] and semiconductor devices [2]. Recently, atomic resolution DPC imaging of a ferroelectric material has been accomplished using a segmented area all field (SAAF) detector in an aberration-corrected scanning transmission electron microscope [3]. This achievement brings the possibility to analyze highly localized fields, and even to visualize individual electric diploes within a unit cell. Unfortunately, the conventional picture of a rigid deflection of the bright field disk in the presence of a long-range field has been shown to be far too simplistic, especially at atomic resolution. In fact, complex features due to multiple electron scattering and coherent interference appear in the central part of the diffraction pattern, as shown in Fig. 1, requiring more elaborate analysis for understanding and quantification.

The intensity redistribution at the diffraction plane can be related to the interaction of the incident probe with the specimen potential. Within the phase object approximation, it is possible to extract quantitative information using a first-moment detector, i.e. calculating the center of mass of the intensity distribution in the diffraction pattern. It has been suggested recently [4, 5] that it is possible to approximate a first-moment detector using a segmented detector, combining the signals from different segments to reconstruct the two perpendicular coordinates of the diffraction pattern center of mass.

Here we present an experimental approach to quantitative atomic resolution DPC imaging. We have analyzed the prototypical ferroelectric perovskite $BaTiO_3$ using a SAAF2 detector, composed of 16 segments, in a JEOL JEM-ARM300F. We have measured the position of the center of mass, as shown in Fig. 2, and estimated the atomic electrostatic potential and the charge density distribution within the unit cell, probing the sensitivity of the technique to the ferroelectric polarization in the material. The main advantages and limitations of using a segmented detector for these studies will be thoroughly discussed.

References:

[1] J. N. Chapman *et al*., Ultramicroscopy, **3** (1978), pp. 203–214.
[2] N. Shibata *et al*., Scientific Reports, **5** (2015), 10040.
[3] N. Shibata *et al*., Nature Physics, **8** (2012), pp. 611–615.
[4] A. Lubk and J. Zweck, Phys. Rev. A **91** (2015), 023805.
[5] R. Close *et al*., Ultramicroscopy, **159** (2015), pp. 124–137.
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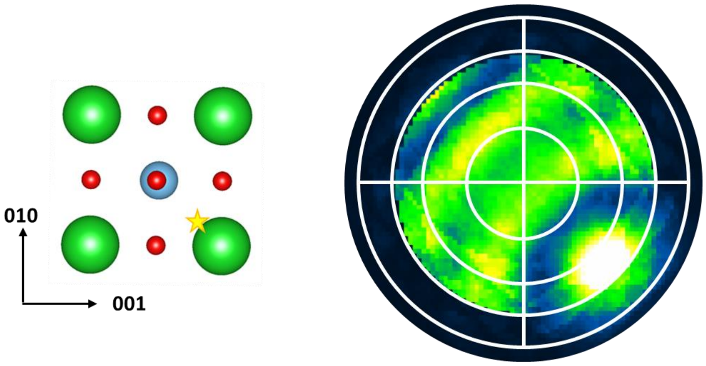

Figure 1. Simulated Convergent Beam Electron Diffraction pattern for 50Å thick $BaTiO_3$ specimen down the [100] direction with the probe position as indicated by the yellow star in schematic on the left. An accelerating voltage of 300 kV and a probe forming aperture of 24 mrad are assumed.

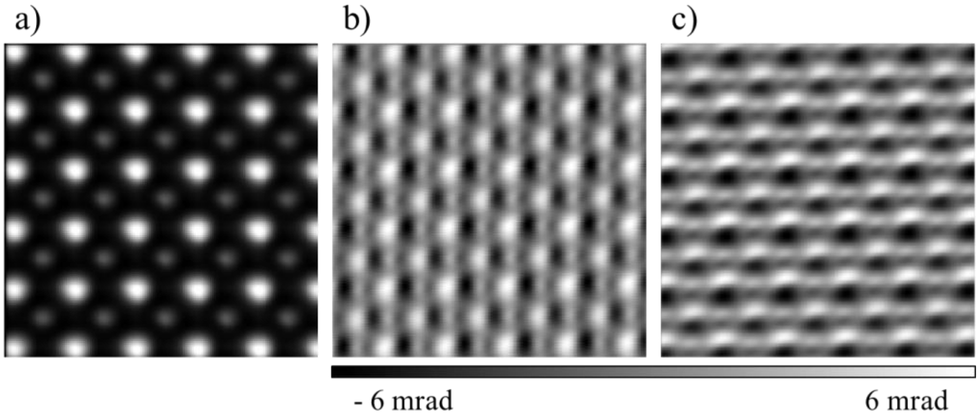

Figure 2. a) Repeat unit averaged high angle annular dark field image of ferroelectric tetragonal $BaTiO_3$ down the [100] direction. b), c) Repeat unit averaged images of the center of mass position in mrad for the [001] (b) and [010] (c) directions. All images were acquired in a JEOL JEM-ARM300F equipped with a SAAF2 detector.