Atomic resolution STEM image contrast based on local point symmetry

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Recent developments in fast, radiation hard pixelated detectors is enabling a rapid expansion in the information available from scanning transmission electron microscopy (STEM) experiments. These detectors can now be used in a practical way to image the full diffraction pattern for each probe position in STEM within minutes. By recording the diffraction pattern, pixelated detector STEM data not only resolves different probe positions but also the angular distribution of the scattered electrons. This additional information has been used in techniques like ptychography [1], atomic field measurements [2], strain measurements [3] and Lorentz microscopy [4], to obtain information difficult or impossible to obtain in standard STEM that uses conventional integrating disc and annular detectors.

In this paper, we demonstrate a new atomic resolution STEM imaging modality using pixelated detectors. This utilises the additional information on angular distribution provided by the detector to generate STEM image contrast sensitive to local point symmetry in crystalline samples. A double-aberration corrected Titan^3 FEG-S/TEM equipped with a fast pixelated detector is used to image the convergent beam electron diffraction (CBED) pattern for each position of the scan over the crystalline sample. The resulting dataset is then analysed with a novel approach that resolves symmetry in atomic resolution CBED patterns. This is achieved by post processing of the distribution of the signal to generate image contrast sensitive to the local point symmetry for each scan position. The algorithm is implemented by GPU processing which allows for very fast analysis, i.e. images in Fig 1 were generated within 2 seconds on a high end consumer graphics card. Fig 1 is an example of a 300 kV STEM scan of $SrTiO_3$ reconstructed from a 4D dataset, for which the dimensions were 128x128 probe positions with 128x128 pixel 32bit image of the diffraction patterns. Acquisition time was 1 ms per probe position. Fig 1a) shows the sum of the total signal detected for each point of a scan, effectively showing a bright field STEM signal with Sr and TiO_2 columns look dark. Figs 1b) and 1c) show contrast generated by an analysis of 4 fold and 2 fold local point symmetry present in the CBED central disk. This symmetry-sensitive image contrast provides a very different type of contrast mechanism which has some desirable properties - i.e. such as the detection of light and heavy atomic columns and no contrast reversal with specimen thickness. We are also examining applications of this method for imaging of strains, dopants and imperfections.

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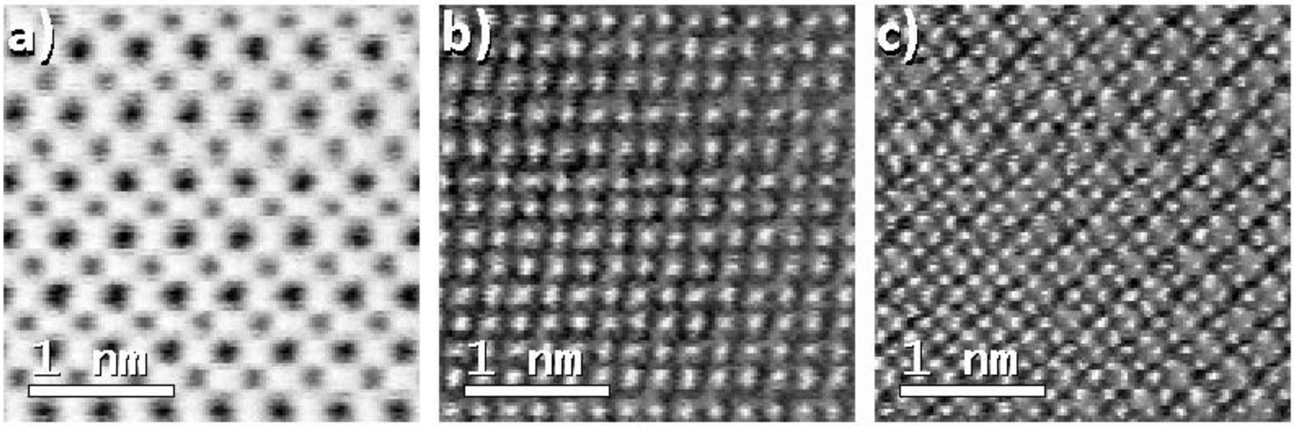

Fig 1: Reconstruction of a pixelated STEM CBED scan over a $SrTiO_3$ crystalline specimen, a) is reconstructed from a sum of each diffraction pattern and it shows Sr and TiO_2 columns as dark. b) and c) show the result of 4 fold and 2 fold symmetry analysis within the central CBED disk for each position of the scan. White contrast shows sites in the crystalline lattice which can be associated with a given symmetry element. The scan included 128x128 probe positions with a 128x128 pixel detector size. The $Titan^3$ 80-300 FEG-TEM was operated at 300kV, with a convergence semi-angle of 15 mrad and camera length of 722 cm.