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Correcting Scan Distortions in Cryogenic 4DSTEM Acquisitions using Affine Transformations

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In quantum materials, exotic quantum states occur at low temperatures, undergoing changes in structural and ferroelectric phases or adopting new properties such as superconductivity and spin liquids. Because of its ability to gain various information such as electric field, charge density, and magnetic structures simultaneously in one dataset, four dimensional scanning transmission electron microscopy (4DSTEM) has gained favor in cryogenic experiments to investigate a material's temperature dependent properties and phase transitions. However, 4DSTEM detectors typically require a dwell time of on the order of milliseconds to acquire the data for each probe position. Consequently, the stage instabilities associated with cryogenic electron microscopy can result in a severely distorted 4DSTEM acquisition with real probe positions that deviate from the assumed locations. It is therefore necessary to utilize a form of image post-processing to correct the aberrant probe positions before data analysis can be performed.

In this work, we have corrected the scan distortions associated with cryogenic 4DSTEM through a series of affine transformations. Because cryogenic scan distortions are strongly a function of scan acquisition time, a traditional STEM image acquired with a short dwell time per probe position may be treated as a base truth to which the 4DSTEM acquisition may be compared. Thus, if key features, such as atomic columns, can be observed in a set of 4DSTEM and STEM images, these features may serve as vertices from which to reconstruct the 4DSTEM acquisition to most closely fit the STEM image. Each vertice will possess a 1-to-1 pair between the two acquisitions and, if sufficient vertices can be identified, these can be used to create a two-dimensional mesh that can be stretched to adjust the 4DSTEM probe positions.

This method has been implemented successfully on a set of experimental 4DSTEM and STEM images of the [100] zone axis of $EuAl_4$ acquired using an aberration correct STEM (JEOL NEOARM) operating at cryogenic temperatures with an accelerating voltage of 80 kV. [2] The probe dwell time of the STEM and 4DSTEM acquisitions was 1 µs and 250 µs, respectively. A 4D-Canvas PN detector was used to collect the 4DSTEM data. Beginning with the initial distorted 4DSTEM and undistorted STEM images in Figure 1, the resulting corrected 4DSTEM image in Figure 2 possesses reasonable probe positions and improves our ability to analyze the material [1].

References:

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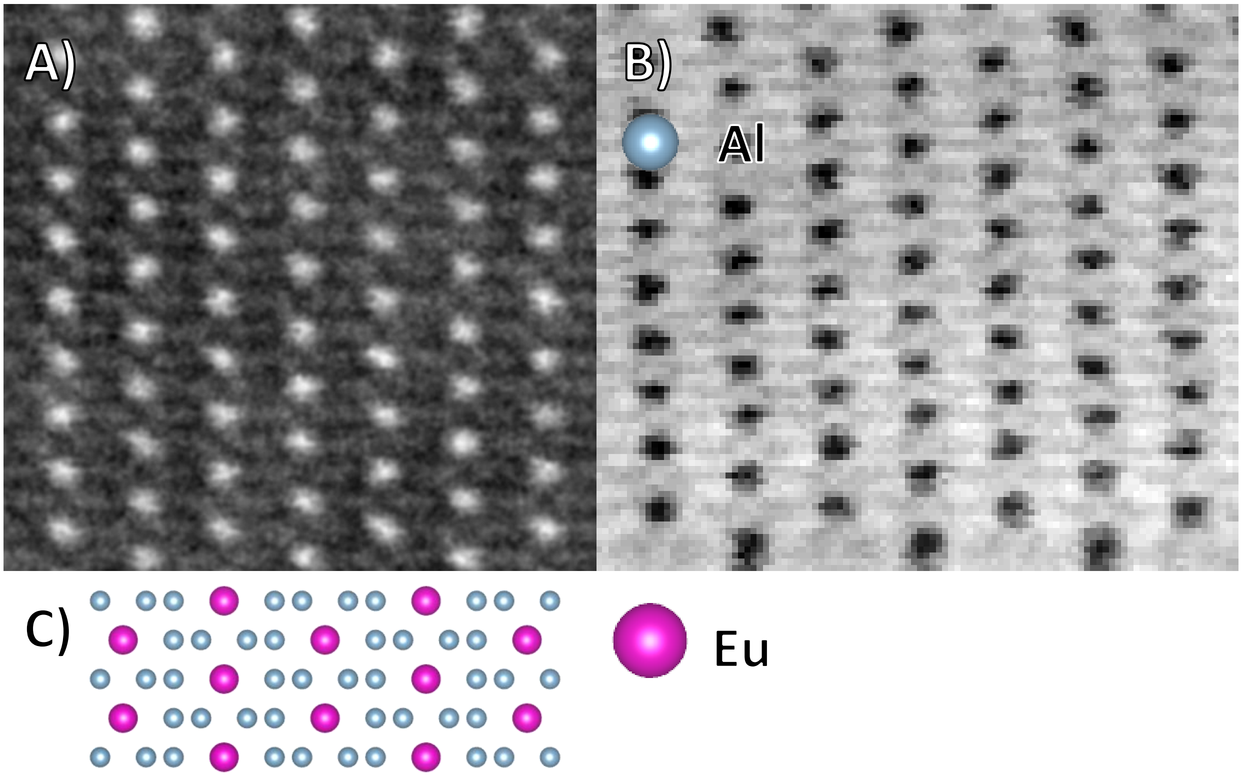

Figure 1. A) A HAADF-STEM image of the area of interest that displays no severe scan distortions and was used as a reference image for distortion correction of the 4D-STEM dataset. B) A severely distorted 4DSTEM acquisition with incorrect probe positions. C) An atomic model of $EuAl_4$ viewed along the [100] zone axis.