(Invited) Imaging light elements in beam sensitive materials using electron ptychography

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The development of high-speed direct-detection pixelated detectors for the scanning transmission electron microscope is allowing the recording of the 4D STEM data set to become increasingly routine. The data set comprises the two real-space dimensions of the probe scan and the two reciprocal-space dimensions of the diffraction pattern recorded at the STEM detector plane. A powerful and increasingly used application of the 4D data set is the reconstruction of the specimen complex transmission function using electron ptychography. An advantage of the focused-probe mode is that the common incoherent STEM imaging modes, such as annular dark-field (ADF) imaging or energy-dispersive X-ray mapping, can used simultaneously with ptychography for a single STEM scan [1].

Here we consider the use of focused-probe electron ptychography for the imaging of beam sensitive samples that contain light elements. For focused-probe ptychography, a key parameter for controlling the electron irradiation fluence is the detector frame time which dictates the probe dwell time. Data recorded at frame rates up to and exceeding 10 kHz and with beam currents of less than 1 pA will contain only few hundred electrons. For a typical detector size, most pixels will receive no electrons, and a minority will detect one or more electrons, as shown in Fig. 1a. Despite this very sparse data, ptychographic images with substantial signal to noise ratio compared to other STEM modes can be formed (Fig 1b and c) [2].

We go on to consider how both the sample signal and noise are transferred in ptychography and other 4D STEM methods, and explore how different 4D STEM methods can be compared. By way of illustration, we demonstrate the application of electron ptychography to a range of samples including polymers, lithium-ion battery cathode materials, zeolites and 2D materials. We also explore how the sensitivity of ptychography to charge redistribution can be compared with density functional theory calculations using a variety of exchange correlation functionals [3].

[1] H. Yang et al., Nature Communications **7** (2016) 12532.
[2] C.M. O'Leary et al., Applied Physics Letters **116** (2020) 124101.
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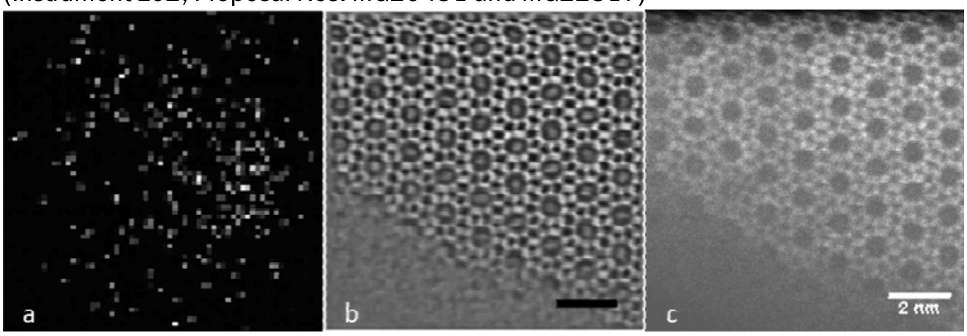

Figure 1. (a) A single detector frame from a high-speed direct electron detector (4D Canvas on a JEOL ARM200CF) demonstrating single-electron detection recorded at a dose of approximately 4000 e-/Å^2. (b) A ptychographic image of zeolite ZSM-5 and (c) the simultaneously recorded ADF image.