doi:10.1017/S1431927622002446
Microsc. Microanal. 28 (Suppl 1), 2022

Fast Ptychographic Reconstruction for Sparse Binary Ptychography Data.

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4D STEM has flourished in recent years as hardware developments in fast-pixelated detectors have caught up with the theory [1]. The high sensitivity and fast readout-speed of modern pixelated detectors means that low dose 4D STEM can be performed by allowing reduced probe dwell times. Combined with the high dose efficiency 4D STEM techniques such as ptychography this has opened up new areas of materials science to 4D STEM imaging. In particular a strong focus has developed on dose efficient method of imaging highly beam sensitive materials including, battery materials, zeolites and biological samples [2, 3, 4].

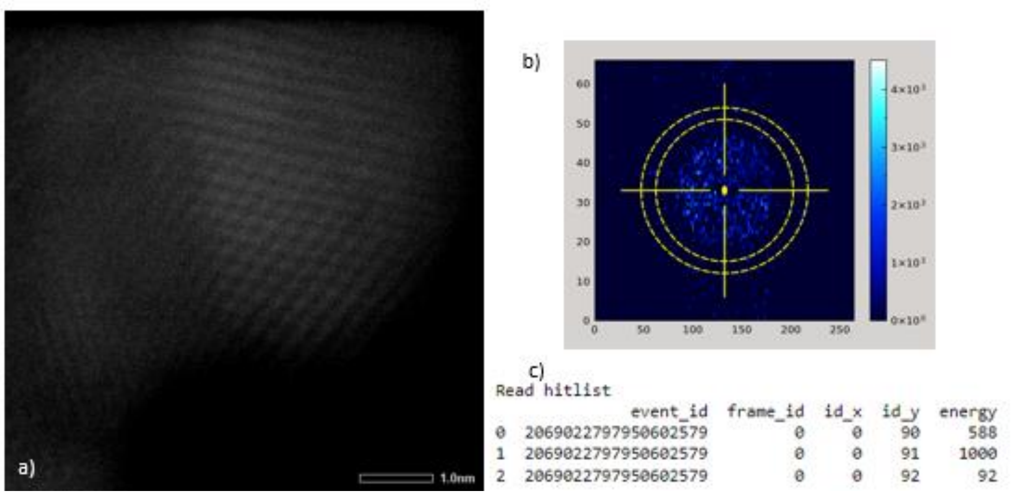
It has previously been demonstrated by O'Leary et al. that high quality ptychographic reconstructions can be obtained from sparse binary CBED patterns such that within individual diffraction patterns electron events recorded by the detector do not overlap and cumulative doses as low as 1000eÅ^{-2} [3]. It was demonstrated that despite the very low bit-depth in the diffraction information that high quality reconstructions could be obtained by single side band reconstruction.

One of the major challenges which has persisted with the expansion of 4D-STEM and in particular ptychography is that the post-acquisition steps to obtain the full reconstruction can be slow and the data sets can be very large. In this study we demonstrate methods which can be utilised to improve the data analysis workflows based on the data acquired being both sparse and binary. Ultimately we aim to demonstrate that this will speed up the ptychographic reconstruction using the widely used single side band method. These methods will decrease the memory required for data storage and processing and increase the throughput of datasets in the ptychographic reconstruction step.

The JEOL 4D Canvas used here is a charge integrating detector with a high sensitivity, therefore to reduce the data to a binary list of electron detection events with a pre-set threshold level for the integrated signal to be registered as an electron detection event. Instead of storing the entire pixel array we transform the dataset into an event-stream of 4D-coordinates where electrons are detected. An example of a low dose image (a) and relevant 4D-STEM diffraction pattern (b) with a summary of the initial lines of the 4D-hitlist (c) is shown in Figure 1.

The slowest step in the ptychographic reconstruction process usually the Fourier Transform of the square modulus of 4-dimensional dataset which is recorded by the detector. This can be very fast in the case of sparse binary data, especially when the number of electrons detected in very low since the speed of the Fourier Transform scales linearly with the number of events being recorded.

In this presentation we will demonstrate the memory and time improvement potential in this workflow for low dose ptychographic reconstructions and demonstrate that there is no decreased performance in terms of the quality of reconstruction. We will demonstrate the advantages of this method for processing data from highly beam sensitive materials such as cathodes for Li-ion batteries. We will harness this low dose capability of ptychography and demonstrate the improve work flow to understand structural changes in cathodes materials which result in performance degradation [5].



```
Read hitlist
                  event_id  frame_id  id_x  id_y  energy
0  2069022797950602579         0     0    90     588
1  2069022797950602579         0     0    91    1000
2  2069022797950602579         0     0    92      92
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Figure 1. a) Low dose ADF image of Au nanoparticle. b) Individual diffraction pattern acquired on *JEOL 4D Canvas equipped with a pnCCD® (S)TEM Camera® System*. c) Short edit of 4D-hitlist of electron interaction events.

References:

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[5] The authors acknowledge use of characterization facilities within the David Cockayne Centre for Electron Microscopy, Department of Materials, University of Oxford and in particular the Faraday Institution (FIRG007, FIRG008), the EPSRC (EP/K040375/1 "South of England Analytical Electron Microscope") and additional instrument provision from the Henry Royce Institute (Grant reference EP/R010145/1).