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Spatial Distribution of the Electron Dose and the Effects on Beam Damage in STEM

Daniel Nicholls[1], Mounib Bahri[1], B. Layla Mehdi[1,2,3], and Nigel D. Browning[1,2,3,4]

[1.] Department of Mechanical, Materials and Aerospace Engineering, University of Liverpool, Liverpool, L69 3GH, United Kingdom

[2.] Physical and Computational Science Directorate, Pacific Northwest National Laboratory, Richland, WA 99352, USA

[3.] The Faraday Institution, Quad One, Harwell Science and Innovation Campus, Didcot OX11 0RA, United Kingdom

[4.] Sivananthan Laboratories, 590 Territorial Drive, Bolingbrook, IL 60440. USA

[*] Corresponding author: d.nicholls@liverpool.ac.uk

Recent applications of compressive sensing (CS) for scanning transmission electron microscopy have returned positive results for both reducing the dose rate required to form images [1], and by extension reducing the beam damage, and increasing the framerate at which data can be acquired [2]. This is done by the combination of probe subsampling, the direct manipulation of the electron beam probe to form incomplete images, and an inpainting algorithm to form complete images from subsampled data [3]. Experimental data regarding low-dose acquisitions often state the electron dose or electron dose rate which was used to form the image. While appropriate for raster type scanning images, which the majority of regular STEM analysis produces, in which the dose is distributed evenly throughout the space-filled square of the scanning pattern, the metric of electron dose (rate) falls short when considering subsampled images. As the dose is non-uniformly distributed across the sample, the local electron dose at any one location in the subsampled scan may be different to another, and the damage localised to high-intensity areas.

In an attempt to explain and study probe subsampling, a model was created using MATLAB which simulates probe trajectories across a thin film in which energy is deposited at the probe locations and then diffuses through the material. This energy is modelled as ‘beam influence’, the accumulation of which causes irreparable long-term damage to the sample. The accumulation occurs when successive scanned positions are too close to one another, and the beam overlap from prior exposed spots diffuses and overlaps with successive positions. This is called beam overlap [4]. The model incorporates many microscope parameters to allow the study of the effects of each parameter, such as acceleration voltage, beam current, dwell time, sample composition and thickness, and scanning pattern.

This model was then extended to include a chemical model of the radiolysis of water [5] to study how subsampling effects the formation of hydrogen bubbles during in-situ liquid STEM experiments. Linehop subsampling was shown to reduce the amount of hydrogen produced not due to a reduced number of electrons, but due to a more efficient distribution of electrons resulting in a reduction in the amount of beam overlap that occurs [6].

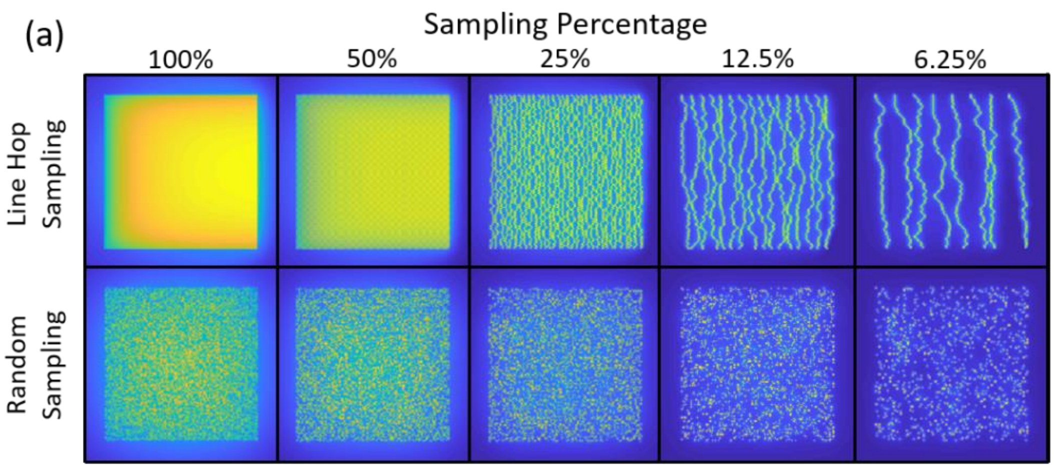

Figure 1 (a) Line hop sampling provides an approximately equivalent distribution to random sampling at the same sampling percentage. The irradiated area is 128 × 128 pixels.

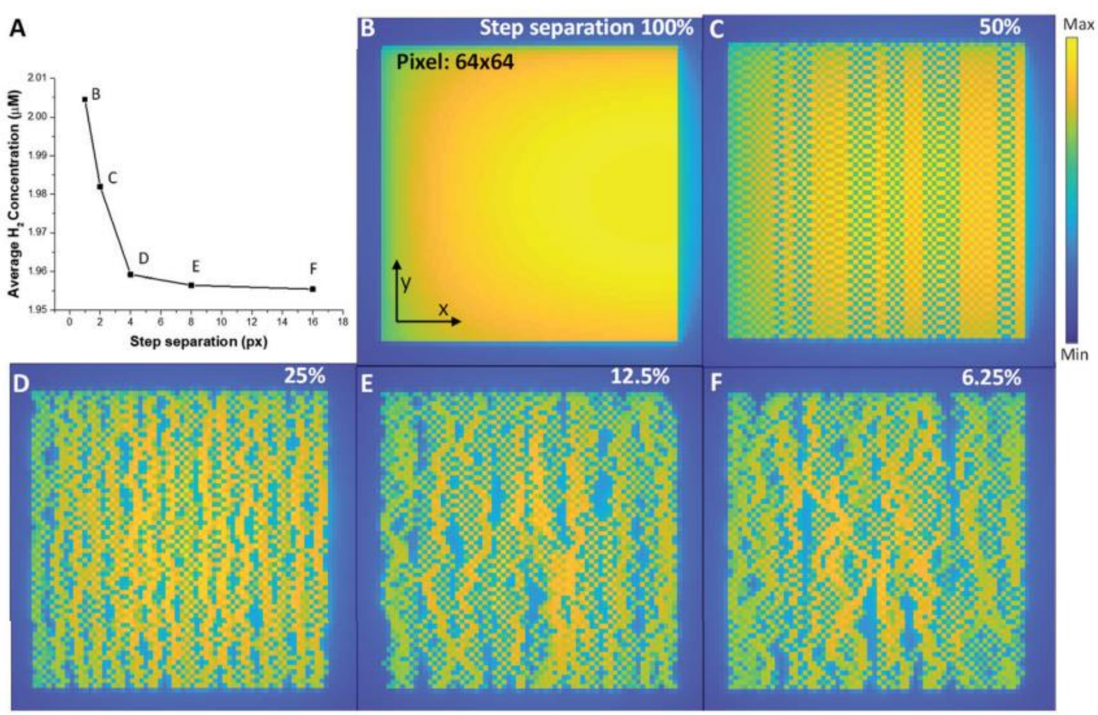

Figure 2 (A) The average H2 concentration produced from a series of scans obtained with a step separation of 1 pixel (B), 2 pixels (C), 4 pixels (D), 8 pixels (E) and 16 pixels (F). For all scans the total beam dose and dose rate was kept constant with the only difference being the spatio-temporal profile of the beam delivery, i.e. the separation in space and time of the electrons hitting the liquid cell [6].

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