Compressed sensing and other beam strategies to reduce electron dose in (S)TEM

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In depth characterization of materials in transmission electron microscopy is in many cases hampered by their sensitivity to the high energy electron beam. This is especially true for biological samples or soft materials. The current strategy to overcome this problem consists in reducing the incoming electron dose, typically presented as electrons/Å. Here, we discuss the experimental use of compressed sensing and other beam strategies to reduce the incoming total electron dose while still obtaining sufficient information and avoiding beam damage in so-called beam sensitive samples.

Issued from signal processing theory, compressed sensing mainly consists of expressing a signal into a mathematical basis where it appears sparse and where it can be encoded using less information [1,2]. These types of algorithms are extensively used in image compression. Pushed to the extreme, the compressed sensing theory also allows images to be recorded with fewer pixels. In this particular case, also known as inpainting, the signal is recorded only on a random set of pixels whose ratio to the total pixel number will define the compression rate. The later reconstruction step to recover the full image follows the principles of the compressed sensing theory. Skipping measurement pixels holds the promise of reducing the total dose while still being able to reconstruct the signal. This was successfully implemented in a scanning transmission electron microscope (STEM) [3] where images presenting a compression rate of 20% or lower could be faithfully reconstructed.

However, in the important case of Poisson noise limited images, as relevant e.g. in high angle annular dark field (HAADF) STEM images, the efficiency of compressed sensing compared to standard imaging with equivalent total electron dose turned out questionable from a theoretical point of view [4]. However, we show here experimental images of a zeolite structure which could be acquired, using a compressed sensing strategy, allowing an up to four times higher dose before damage sets in. This discrepancy with theory can only be explained by assuming a particular relaxation mechanism where beam damage can heal when samples are not continuously exposed to the electron beam. Potential mechanisms will be discussed based on results from polymer films. The effect of alternative beam scan strategies on beam damage will also be considered.

The results confirm the potential of the compressed sensing technique to image beam sensitive materials in STEM. To make this attractive, real time reconstruction of compressed images should be implemented. We show preliminary results on fast reconstruction based on neural network algorithms. Moreover, the influence of compressed sensing on the recovery of quantitative information, such as in strain measurement or electron tomography will be investigated.

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