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Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Real-Time Monitoring of Structural Dynamics

Thomas W. Hansen[1]*, William Bang Lomholdt[1], Matthew Helmi Leth Larsen[2], Cuauhtémoc Núñez Valencia[2], and Jakob Schiøtz[2]

1. DTU Nanolab, Technical University of Denmark, DK-2800, Kgs. Lyngby, Denmark
2. Dept. of Physics, Technical University of Denmark, DK-2800, Kgs. Lyngby, Denmark

Understanding the atomic-scale structure of materials and devices, as well as the potential structural changes that may occur during use in real-world operating conditions, is essential to developing next- generation functional materials. A core challenge when characterizing such materials is how to extract information under operating conditions with high spatial resolution as well as high temporal resolution, without affecting them by the imaging process [1, 2]. State-of-the-art transmission electron microscopy techniques can routinely satisfy both these requirements, even in the presence of gases and liquids. However, making these observations application-relevant requires minimization of electron beam effects and unbiased data analysis.

Minimizing electron dose rate during data acquisition reduces the impact of imaging. However, it could be at the expense of high temporal resolution due to reduced signal to noise ratio of the acquired data. The result is often that the data becomes so noisy that it is not analyzable using a manual approach. An automated approach which has gathered significant traction over the last decade is machine learning [3]. Well-trained networks, where noisy data is included in the training sets have shown promising performance, even on in situ data. Figure 1 shows a gold nanoparticle imaged at in 4.5 Pa carbon monoxide at 300°C [4, 5]. The positions of atomic columns have successfully been located using a convolutional neural network. Analyzing sequences of such frames reveals the dynamic nature and structural variations due to changes in the environmental conditions. Data analysis by means of convolutional neural networks is also efficient for analyzing images of low-Z materials with poor contrast.

Here we will discuss the challenges of imaging materials in a noninvasive way and how to mitigate them while maintaining the strengths of the (STEM) as a highly versatile characterization tool.

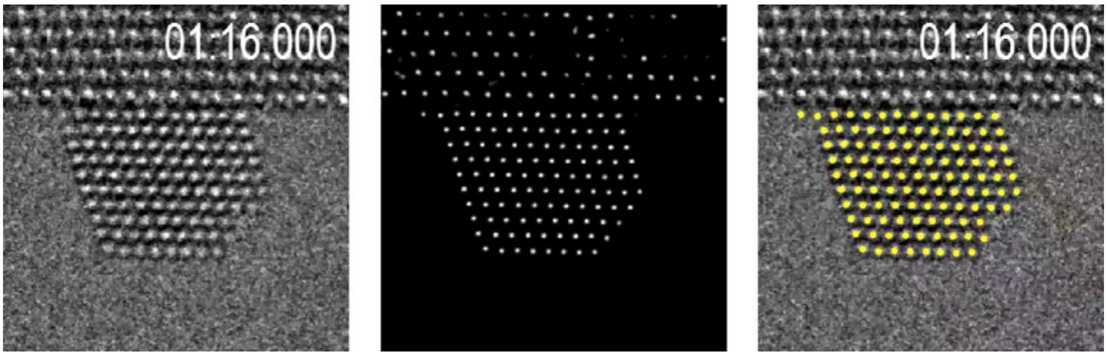

Figure 1. Au/CeO_2 in 4.5 Pa CO@250°C. Left: raw data; middle, output of neural network; right: Overlay.

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