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DeepSTEM: Deep-Learning-Based Object Function Reconstruction for In Situ STEM

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In situ scanning transmission electron microscopy (STEM) with atomic-resolution has provided atomic-scale dynamics that are ubiquitous in two-dimensional (2D) materials and allow the use of electron beams to control their structures [1]. Utilizing in situ STEM to understand and control various phenomena in 2D materials requires accurate identification of atomic-scale structures with high temporal resolution. However, precise determination of the structure requires a high dwell time of the electron beam on the specimen, limiting the identification of atomic-scale dynamic mechanisms at high temporal resolution.

Here, we propose 'DeepSTEM', which is a deep-learning framework reconstructing the object function of the high-angle annular dark-field (HAADF) STEM imaging for accurate determination of the atomic structure with high temporal resolution (Figure 1) [2-4]. The DeepSTEM was trained by the experimental atomic-resolution STEM image dataset. The DeepSTEM regards the experimental probe function measured by the Zemlin tableau and reconstructs the object function from the experimental image by convolutional autoencoder using the linear image model. We applied the DeepSTEM to in situ STEM experiments where identifying sulfur atoms was difficult due to elevated temperature, drift, and relatively low atomic number. The DeepSTEM enabled in situ STEM study on formation and grain merging processes of 2D MoS_2 derived from thermolysis of $(NH_4)_2MoS_4$ precursor at a temperature of 500 °C (Figure 2). Low dose and high temporal resolution exploiting the DeepSTEM will be useful in in situ STEM for atomic manipulation and shows the potential of deep learning in electron microscopy [5].

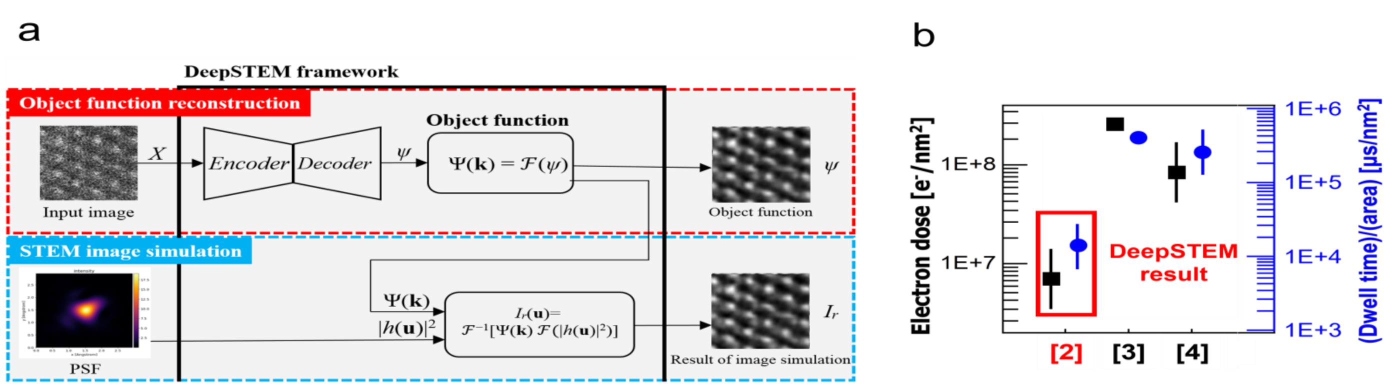

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Figure 1. (a) The schematic of the DeepSTEM and (b) DeepSTEM result comparison of the electron dose and dwell time per area with DeepSTEM result and other STEM images in literature [2-4]. Figure 1a is reprinted with permission from [2], Copyright 2021 American Chemical Society.

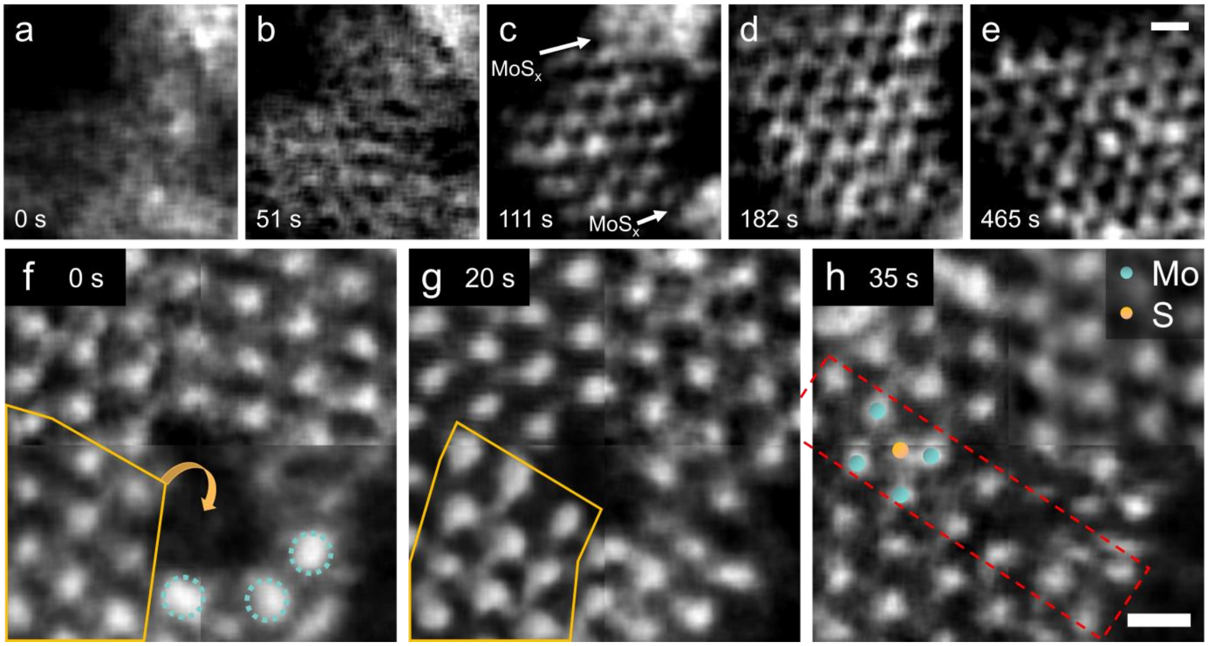

Figure 2. Time-lapse micrographs of the reconstructed object function from the DeepSTEM illustrating (a-e) formation and (f-h) merging of MoS_2 cluster(s) at the temperature of 500 °C. Solid Mo and yellow sphere indicate Mo and Sulfur, respectively. The Dashed-cyan circle indicates Mo adatom. The scale bars are 0.5 nm. Adapted with permission from [2], Copyright 2021 American Chemical Society.

References:

[1] Y. Zhu et al., Nano Res. **14** (2021), p. 1650–1658, doi: 10.1007/s12274-020-3034-z
[2] Y. Lee et al., ACS Omega **6** (2021), p. 21623-21630. doi: 10.1021/acsomega.1c03002
[3] R. Zan et al., ACS Nano **7** (2013), p. 10167-10174, doi: 10.1021/nn4044035
[4] J. Chen et al., Nanoscale **11** (2019), p. 1901-1913, doi: 10.1039/C8NR08821G
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