Smart Control of Electron Beams at the Atomic Scale in 2D Materials

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The electron beam in a scanning transmission electron microscope (STEM) is able to routinely probe matter at the individual-atom scale due to advances in aberration correction technologies that allows to achieve sub-Ångstrom beam sizes. While typically undesirable, the electron beam can also break chemical bonds and knock atoms out of lattice positions through momentum transfer, scenarios collectively coined as "beam damage," which are particularly frustrating for studying 2D materials. Efforts to minimize beam damage are on-going, where e.g., detector technology has seen recent significant progress with direct electron detection, reducing the required number of incident electrons for measurements. Intelligent control of the electron beam position, however, is a different approach for studying matter carefully at the atomic scale. In this talk, I will discuss workflows that leverage recent progress in deep learning in electron microscopy that enable rapid object detection in a variety of 2D materials. Knowledge of the atomic landscape in real-time enables dose-efficient, precise positioning of the electron beam to acquire measurements of specific atomic and defect classes that might otherwise be destroyed by a traditional measurement scheme. Moreover, this approach allows to manipulate matter in a highly controlled manner, where multiple instances will be presented in common 2D material systems. Finally, a fully autonomous self-driving microscope will be demonstrated where machine learning methods are employed on-the-fly that allow to collect data and perform experiments in a fundamentally different manner.