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Ultrafast electron microscopy and diffraction with laser-driven field emitters

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Ultrafast structural dynamics in solids and nanostructures can be investigated by an increasing number of sophisticated electron and x-ray diffraction techniques. Electrons are particularly suited for this purpose, exhibiting high scattering cross-sections and allowing for beam control by versatile electrostatic or magnetic lens systems. The capabilities of time-resolved electron imaging techniques critically depend on the employed source of laser-driven ultrashort electron pulses. Nanoscopic sources offer exceptional possibilities for the generation of electron probe pulses with very short durations and high spatial beam coherence. In this talk, I will discuss recent progress in the development of ultrafast electron microscopy and diffraction based on nanoscopic photocathodes. In particular, we implemented ultrafast low-energy electron diffraction (ULEED) and ultrafast transmission electron microscopy (UTEM) driven by nonlinear photoemission from field emission tips. ULEED enables the study of structural changes with high temporal resolution and ultimate surface sensitivity, at sub-keV electron energies. As a first application of this technique, we studied the structural phase transition in a stripe-like polymer superstructure on freestanding monolayer graphene.[1] An advanced UTEM instrument was realized by custom modifications of a standard transmission electron microscope, leading to electron focal spot sizes in the microscope's sample plane of about 10 nm and electron pulse durations of less than 700 fs. Utilizing these features, we investigate the quantum-coherent interaction between the ultrashort electron pulse and the optical near-field of an illuminated nanostructure.[2] Finally, further applications and prospects of ultrafast electron imaging, diffraction and spectroscopy using nanoscale field emitters will be discussed.

[1]M. Gulde *et al.*, Science **345**, 200 (2014)
[2]A. Feist *et al.*, submitted