(Invited) New phase contrast and diffractive imaging methods enabled by 4D-STEM

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Traditional scanning transmission electron microscopy (STEM) detectors are large, monolithic regions that integrate a subset of the transmitted electron beam signal scattered from each electron probe position. These STEM imaging experiments record only 1-5 values per probe position, throwing away most of the diffracted signal information. With the introduction of extremely high speed direct electron detectors, we can now record a full image (2D data) of the diffracted electron probe scanned over the sample (2D grid of positions), producing a four-dimensional dataset we refer to as a 4D-STEM experiment. These diffraction images of the electron probe are extremely rich in atomic-scale information, such as the sample structure, orientation, composition, phonon spectra, defect structure and more. The spacing between adjacent STEM probes can be varied from below one Angstrom to hundreds of micrometers, allowing us to probe the functional length scale of materials and devices. In this talk, I will discuss several 4D-STEM applications in materials science. I will show several examples of nanobeam electron diffraction used to measure sample structure, orientation and strain, for samples ranging from metallurgical alloys to conductive polymers. I will also briefly describe phase contrast imaging methods such as differential phase contrast, ptychography and STEM holography. Finally, I will also show how the scattering matrix (S-matrix) formalism can be used both to numerically invert sample structure under conditions of multiple scattering of the electron beam, and also for very fast simulation of large 4D-STEM datasets.