Using fast-readout pixel detectors to overcome the multiple scattering problem in scanning transmission electron microscopy

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Electrons interact strongly with matter via the Coulomb force, making the modern electron microscope a powerful tool for studying very small amounts of material, including nanoparticles and monolayers, which is sensitive to changes in atomic structure unit cell by unit cell. A downside of this strong interaction is that electron microscope datasets can be non-trivial to interpret since the electron will typically undergo significant multiple elastic and inelastic scattering within even very thin specimens. For example, studies of electron bonding using differential phase contrast (DPC) STEM, which attempts to reconstruct the specimen potential with the assumption that the specimen scatters in a single plane, are only valid for specimens less than about 50 Ångstrom thick [1]. In this talk we present a solution to the multiple scattering problem that uses data recorded with fast-readout pixel detectors, a recent innovation [2,3], in scanning transmission electron microscopy (STEM) to reconstruct the projected electrostatic potential of a crystalline specimen at sub- Ångstrom resolution. Fast-readout pixel detectors are capable of recording an electron diffraction pattern on a time-scale equivalent to the dwell time of the probe in a STEM scan. In this talk we show how this enables an aberration corrected STEM instrument to record sufficient data for a direct inversion of the multiple scattering to reconstruct the projected potential of a crystalline specimen.

A STEM image recorded by a detector with small acceptance angle placed at position (kx,ky) in the diffraction plane is equivalent to a conventional transmission electron microscope (CTEM) image with plane wave illumination tilted such that its transverse wavevector is (-kx,-ky) [4]. This means that a STEM dataset recorded by a pixel detector is formally equivalent to recording many thousands of CTEM images. An example set of these detectors are indicated by black circles atop a simulated position averaged convergent beam electron diffraction (PACBED) pattern in Fig. 1(a). A focal series of pixel detector STEM datasets allows the exit surface wave function (both intensity and phase) for every one of the different orientations of the electron beam to be reconstructed, using for example the iterative wave function reconstruction (IWFR) method [5]. Example results are shown in Fig. 1(b). As depicted in Fig. 1(c), this information can be collated into a matrix referred to as a scattering or S matrix: a mathematical quantity from which the multislice and Bloch wave solutions to multiple elastic scattering can be derived. For crystalline structures, information from this S-matrix can be used to formulate a set of linear equations for the Fourier coefficients of the projected potential, a deterministic solution for the crystal structure in the presence of strong multiple scattering [6].

We demonstrate this technique on simulated data and discuss progress toward experimental implementation of the technique.

References

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This work was supported by the Australian Research Council (ARC) Grant DP140102538 and instrumentation funded by ARC Grant LE0454166

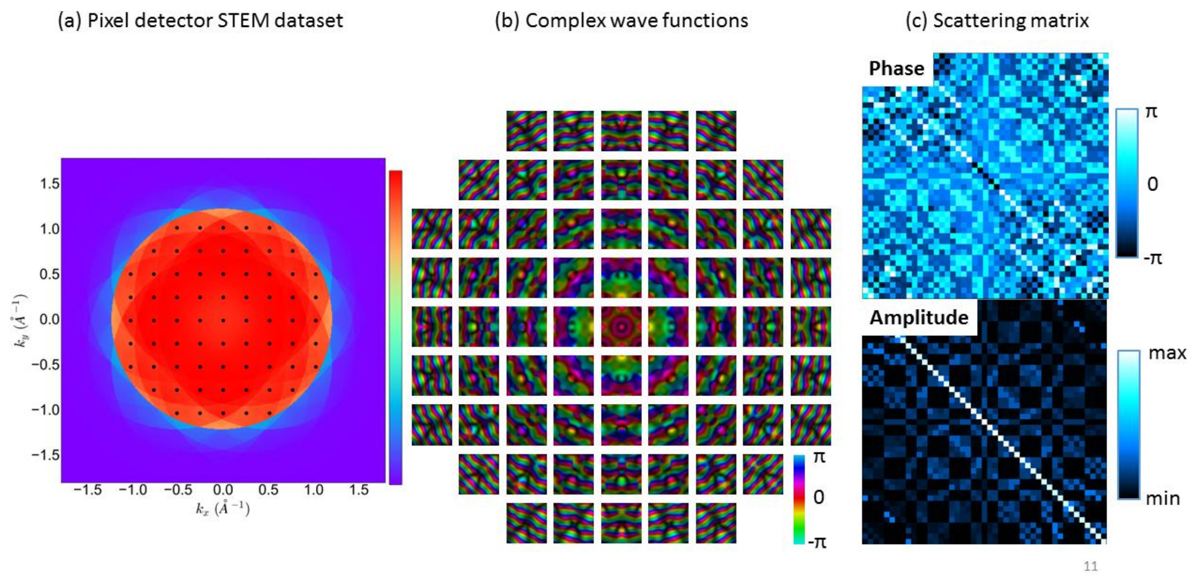

Figure 1 A schematic representation of key steps in the multiple scattering inversion algorithm as applied to a simulated $SrTiO_3$ dataset. (a) STEM images are synthesised from a pixelated STEM dataset using a set of point detectors. (b) A through focal series is used to reconstruct the phase of the exit surface wave-functions corresponding to the STEM images and (c) this information put into a scattering (S) matrix, visualised as an array of the phases and amplitudes of the matrix elements.