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Quantum phase modulation and retrieval in an ultrafast transmission electron microscope

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Background incl. aims

Coherent phase modulation of the free-space electron wavefunction has the potential to dramatically extend the applications of electron microscopy by enabling, e.g., enhanced image contrast in Cryo-Electron Microscopy [1], Single Pixel Imaging [2] and quantum information processing [3]. Measuring the phase degree of freedom is challenging because conventional approaches to electron detection are sensitive to deposited energy. Pump-probe ultrafast electron microscopy allows for the implementation of phase retrieval algorithms by comparing pre and post-excitation images, using the pre-excitation image to define a reference phase. Here we demonstrate phase retrieval performed on a probe beam passing through a fast moving, dilute free electron gas.

Methods

Our specimen in pump probe experiments is shown in Fig. 1 a. and consists of a nanometer thin gold film suspended on a standard 3 mm gold TEM grid. We illuminate the specimen with point projection optics (i.e., Lorentz microscopy) and collect the scattered beam at long diffraction camera length, so that the electron intensity on the detector mixes momentum and real-space information, a critical experimental detail for enabling phase reconstruction. We pump the specimen with 1030 nm, 290 fs laser pulses, emitting a low energy cloud of electrons in the path of the probe beam. We record changes in the detected probe caused by the electron cloud as a function of pump-probe delay. The specimen geometry is invariant in one of the two directions transverse to the probe beam trajectory and we improve signal to noise by averaging along the invariant direction, as indicated in Fig. 1 a.

Results

Figure 1. b. shows the modulation of the transmitted beam intensity as a function of position on the sample and delay time. Relying on charge conservation, a deflection angle is computed from the local change in beam intensity as a function of delay as shown in Fig. 2, and from this deflection angle the phase-change of the electron beam is calculated. Figure 3. shows

the phase shift as a function of delay time and position using a 2π periodic colormap.

Conclusion
We have demonstrated how the combination of pump-probe specimen modulation with point projection electron optics (Lorentz microscopy) enables phase retrieval. In subsequent experiments, phase retrieval has allowed us to go further and extract key experimental observables from our data, e.g., the charge density of the specimen gas.

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Graphic:

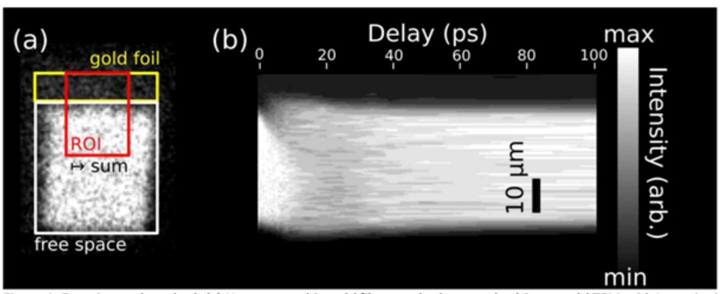

Figure 1. Experimental method. (a) Nanometer thin gold film attached to standard 3 mm gold TEM grid. Intensity is summed along the horizontal direction (b) Pump-probe data series, space on the vertical axis, time on the horizontal axis.

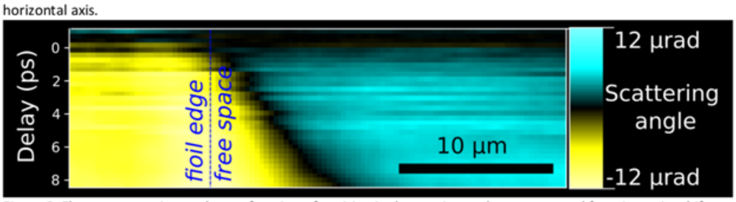

Figure 2. Electron scattering angle as a function of position in the specimen plane, computed from intensity shifts shown in Fig. 1 b. Space shown on the horizontal axis, time the vertical axis.

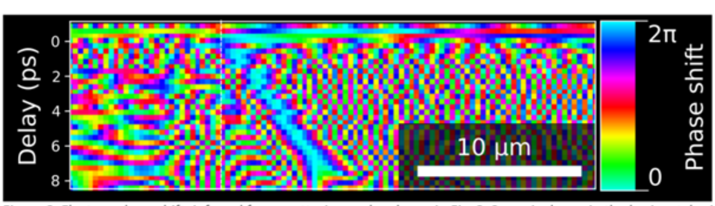

Figure 3. Electron phase shift, inferred from scattering angles shown in Fig. 2. Space is shown in the horizontal axis, time on the vertical axis.

Keywords:

Pump-probe electron phase retrieval

Reference:

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