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Stroboscopic Imaging Using RF Strip-Line Technology

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The study of complex correlated materials dynamics has been pushed to extraordinary spatiotemporal limits through advancements of ultrafast electron microscopy (UEM). Alternate to laser based UEM, a pulsed electron probe can be formed using a RF strip-line cavities to sweep the electron beam across a chopping aperture (CA) [1]. Further, the transverse coherence and modulation of the electron beam can be compensated *via* a second RF strip-line after the CA. The advantages compared to laser driven photoemission include emission retention from the original source, higher frequency excitations and signal-to-noise amplification due to the inherent duty cycle. One excitation mechanism alternate to lasers is travelling RF, where each image captures a discrete temporal position along the phase of a sinusoidal modulation rather than a decay. Ultimately, time-resolved imaging and damage reduction are the primary motivation for pulsed beam imaging, but the limits of the instrumentation have yet to be described.

Here, we explore stroboscopic imaging advancements and newly developed timing schemes with alternative pump-probe combinations in laser free UEM. The TEM has been modified to fit additional shielding and a high-resolution pole piece that improve the spatial resolution during operation of the Euclid Techlabs, LLC ultrafast pulser. We have achieved spatial resolutions of as small as 0.2 nm and demonstrate substantial improvements in mono-directional coherence comped to a continuous electron beam. One example is displayed in Figure 1b and Figure 1c through the imaging capabilities of two different lattice planes in gold nanoparticles. The primary consequence of imaging with a pulsed electron beam is intensity. This is expected due the temporal profile of the electron pulse train discarding nearly 80% of the initial signal. However, the retention of lattice measurements through image analysis and FFT refinement are unaffected by the modulated source. Here, we have adjusted the electron dose for each image to fairly evaluate the phase contrast present. Notably, the sweeping direction causes a monodirectional distortion in the electron beam but can be compensated with large modifications to the objective and condenser astigmatism. We also evaluated the beam coherence using Fresnel fringes interfering from the edge of a thick 5μm silicon hole as shown in Figure 1e and Figure 1f. We can resolve high order fringes at positions where the circular hole is parallel to the beam sweeping direction. In contrast, fringes aligned perpendicular to the beam sweeping direction are completely blurred. We also used a 6.5 μm permalloy square to evaluate whether the pulser distorts the induction maps produced by Lorentz phase TEM (Figure 1d). The intensity of the magnetic domain walls and vortex cores is decreased due to the duty cycle, but the spin information is unaltered. Lastly, the imaging capabilities of the pulser are essential to progress time-resolved studies into sub-nanometer spatial domains. We will present time-resolved experiments that explore the process of electrical and magnetic excitation to reveal structural dynamics. One example is time-resolved imaging of electrostatic breathing along a silicon interdigitated comb. Transmitted RF induces an electrostatic field surrounding the comb that deflects electrons. Additionally, we will use RF electromagnetic waves to induce structural transitions and spin dynamics. Periodic excitation of the travelling RF causes time-dependent switching of the direction of the field. Using the pulser, we can image the response along the RF phase as it transmits through the sample.

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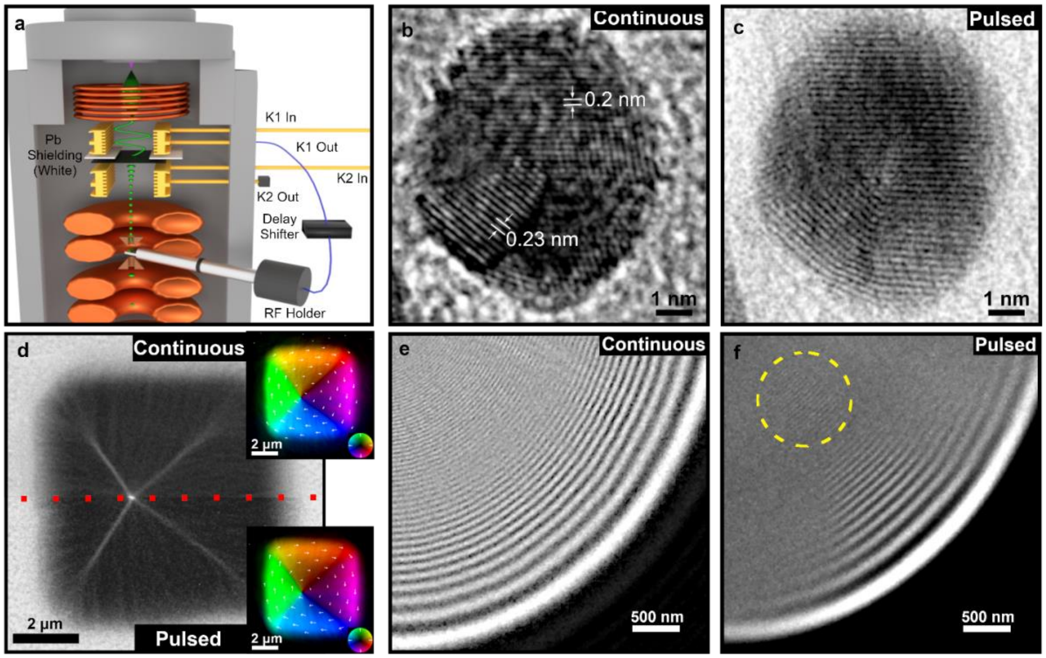

Figure 1. Representative schematic for various UEM methods. (a) Rendering of an RF strip line pulser positioned in a traditional TEM. (b, c) High resolution images of gold nanoparticles using continuous (b) and pulsed (c) electron beams the lattice spacings for two different sets of panes are indicated and visible in both imaging conditions. (d) Lorentz phase TEM image of a 6.5 µm square permalloy sample taken with a defocus of 3.1 mm. The top and bottom halves are acquired with a continuous and pulsed electron beam, respectively. The insets are the corresponding induction maps from sets of over- and under-focus images using the continuous and pulsed beams. Color maps represent the spin direction and magnitude. (e, f) Fresnel defocused images of a 5µm silicon hole using a continuous (e) and pulsed (f) electron beam. Imaging using the pulsed electron beam exhibits monodirectional coherence retention as indicated by high order fringes present in the yellow circle. All the high order fringes are only visible when they are parallel to the beam sweeping direction of the pulser. In all panels, the pulsed beam acquisitions have been enhanced to achieve similar signal-to-noise levels.