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Electron single pixel imaging enabled by ultrafast optical modulation of the illuminating wavefunction

Dr. Cameron Duncan[1], Beatrice Ferrari[1], Irene Ostroman[1], Maria Giulia Bravi[1], Sang Tae Park[2], Daniel Masiel[2], Jean Christophe Olaya[3], Paolo Rosi[4], Enzo Rotunno[4], Vincenzo Grillo[4], Giovanni Maria Vanacore[1]
[1]Unversità degli Studi di Milano-Bicocca, Milan, Italy, [2]JEOL-IDES, Pleasonton, United States of America, [3]Holoeye Photonics, Berlin, Germany, [4]Istituto Nanoscienze, Consiglio Nazionale delle Ricerche, Modena, Italy

Background inc. aims

Transmission electron microscopy (TEM) provides sub-angstrom imaging resolution unmatched by alternative modalities, but cumulative radiation damage to soft-matter specimens can pose an obstacle to applying TEM in the life sciences. Electron Single Pixel Imaging (ESPI) is a computational imaging technique with the potential to dramatically reduce the electron dosage needed to produce high-resolution images [1]. The key idea behind ESPI is to carefully imprint patterns onto the illuminating wavefunction and record the dependence of total scattering on pattern choice [2]. Controlling the illumination in this way ensures that every scattering event contributes useful information toward image reconstruction [3]. The outstanding instrumentation challenge when implementing ESPI is to modulate the electron probe. Here we report a novel, versatile method for imprinting arbitrary patterns onto the electron wavefunction that allows new patterns to be selected several times per second. We show proof-of-principle experimental results demonstrating image reconstruction of a MAX-phase nanoparticle.

Methods

Our modified JEOL TEM, shown in Fig. 1. is operated in pulsed mode: we drive electron emission via femtosecond laser pulses at repetition rates up to 600 kHz. Our column includes a secondary sample holder with a view port located directly below the acceleration section and above the primary specimen holder. In this secondary location, an electron-transparent, optically reflective metal film intercepts both the probe electron pulse and a control laser pulse, mediating an interaction between probe electrons and optical near fields. A Spatial Light Modulator (SLM) imprints a pattern onto the control laser, and the near fields at the metallic film transfer the SLM pattern to the electron beam. The patterned electron beam then scatters off the principal specimen, and diffraction-mode electron optics at long camera length enable detection of the total scattering of the modulated beam.

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Results

Figure 2.a. shows a specimen of Ti3Al0.4Sn0.6C2 imaged with conventional TEM. Figure 2.b. shows a representative set of near-field modulated probe illumination patterns, while Fig. 2.c. shows the result of the image reconstruction algorithm applied to this basis set of patterns.

Conclusion

We are actively developing the ESPI technique, in particular, improving the coupling efficiency between control laser and electron probe pulses to provide sensitivity on the level of single-photon exchange. Simulation results suggest that by placing the specimen in the fourier plane of the electron-laser interaction point, we can achieve beam patterning with nanometer feature sizes given a sufficiently coherent probe. We anticipate performing experiments on Li-based electrochemical samples and biologically embedded gold nanoparticles to demonstrate this capability.

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Graphi

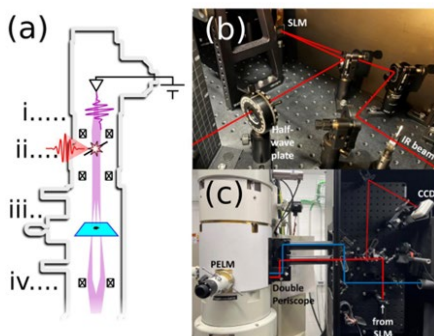

Figure 1. Experimental method. (a) Modified TEM column, showing i. photoexcitation of electron pulses via UV light, ii. optical modulation of electron pulses at a metallic interface, iii. patterned illumination of the specimen, iv. electron optics to collect the total scattering. (b) Optical path of the control laser, showing the spatial light modulator (SLM). (c) Photoemission laser (purple) and control laser (red) enter the microscope column through a viewport.

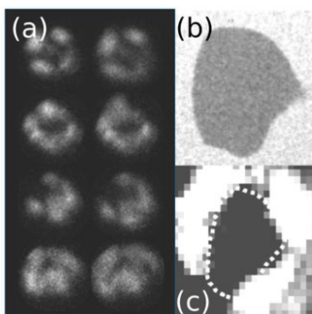

Figure 2. (a) Illumination patterns for Electron Single Pixel Imaging, (b) test specimen view under conventional TEM illumination. (c) Reconstructed image using the basis patterns in panel (a).

Keywords:

Ultrafast electron microscopy, single-pixel imaging

Reference:

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