doi:10.1017/S143192762101028X
Microsc. Microanal. 27 (Suppl 1), 2021

Transient lensing from an electron gas imaged by ultrafast electron microscopy

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Transmission electron microscopy (TEM) has become a powerful technique to study the structure of materials at the nanoscale. The time resolution in TEM, however, is typically limited by the maximum frame rate of the detector, which is at best in the kHz regime. Ultrafast TEM combines the high time resolution of laser spectroscopy with the excellent spatial resolution of electron microscopy techniques. The structural and electronic changes in the material are initiated by fs laser pulses, which are followed by similarly short photoelectron pulses for probing the dynamics by means of imaging, diffraction, or electron spectroscopy. In this talk I will present our dynamic environmental TEM setup at UIUC, and I will demonstrate its first application in the field of "plasma lensing" [1]. In our experiment, we generated a hot three-dimensional electron gas by two-photon emission from a copper surface in vacuum. After a prompt Coulomb explosion, the subsequent dynamics is characterized by a rapid oblate-to-prolate shape transformation of the electron gas, and periodic and long-lived electron cyclotron oscillations inside the magnetic field of the objective lens. In this regime, the collective behavior of the oscillating electrons causes a transient, mean-field lensing effect and pronounced distortions in the images. We derive an analytical expression for the time-dependent focal length of the electron-gas lens, and perform numerical electron dynamics and probe image simulations to determine the role of Coulomb self-fields and image charges. This work inspires the visualization of cyclotron dynamics inside two-dimensional electron-gas materials and enables the elucidation of electron/plasma dynamics and properties that could benefit the development of high-brightness electron and X-ray sources.

Work was in part supported by a Packard Fellowship in Science and Engineering from the David and Lucile Packard Foundation and by the National Science Foundation (NSF) CAREER awards #1751725 and #1855009. R.M.V. gratefully acknowledges support from the Department of Chemistry at UIUC and John and Margaret Witt.

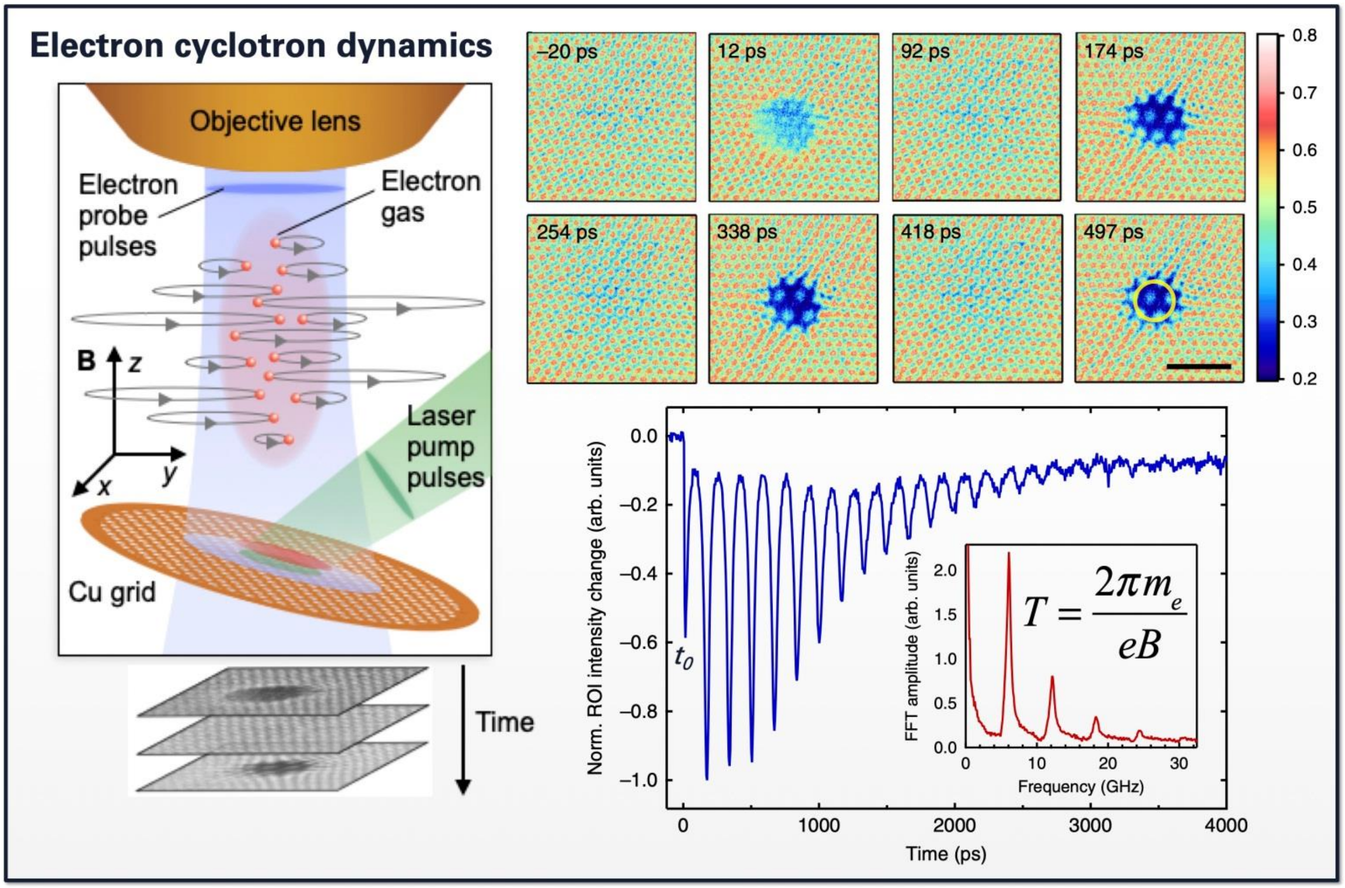

Figure 1. (left) A hot electron gas (red), created by means of two-photon emission from a copper grid, acts as a diverging lens to the probe electron pulses. After initial Coulomb explosion, the electron gas executes cyclotron oscillations (gray orbits) inside the magnetic field of the objective lens, which are resolved by changing the relative timing of the pump and probe pulses. (top right) Series of 3000 mesh copper grid images extracted from a ps-resolved UEM movie (528 nm, 200 fs, 30 mJ/cm2 laser excitation) with an objective lens current of 0.7 A. The time delays correspond to the first few local maxima and minima in the region-of-interest (ROI)difference intensity trace at the bottom right. The difference images were generated by subtracting an averaged image before time zero ($\Delta t = 0$). A typical region-of-interest (ROI) circle that is used to make plots of the intensity changes due to lensing is indicated in the last frame. The scale bar at the bottom right is 50 μm and applies to all images. (bottom right) ROI difference intensity (relative to before time zero) as a function of time delay. The inset shows the FFT of the trace, with a fundamental frequency of 6.05 GHz (i.e. T = 165 ps). The objective lens current was set to 0.7 A.

References

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