SFB1242

SFB 1242 Nichtgleichgewichtsdynamik kondensierter Materie in der Zeitdomäne

UNIVERSITÄT DUISBURG ESSEN

Open-Minded

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Campus Duisburg

The Ultrafast Electron Imaging Lab: From Time-Resolved Electron Diffraction to Liquid-Phase Electron Microscopy

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In our Ultrafast Electron Imaging Lab (UeIL), we are dedicated to capturing the “atomic movie” - moving beyond static structural snapshots to witness the fundamental dance of atoms in real time. We specialize in developing homemade instrumentation because the growing demand for accessible, laboratory-scale instruments highlights a critical need for compact solutions that large-scale MeV ultrafast electron diffraction (UED) facilities cannot always provide [1]. By engineering our own compact electrostatic UED instruments, we bridge the gap between sub-angström spatial resolution and femtosecond temporal precision. Our current laboratory-scale platform (Fig. 1A, 1B) operates at a maximum cathode voltage of 150 kV and produces electron pulses of approximately 200 fs (full- width-at-half-maximum, FWHM), with the potential to approach the 50-fs instrument response threshold through enhanced high-voltage conditioning and ultrashort laser excitation [1]. Representative results are shown in Fig. 1C-1F.

The core of our research infrastructure is built upon the synergy between UED and Liquid Phase Electron Microscopy (LPEM) [2]. While UED has become a cornerstone for resolving structural dynamics at the atomic scale, achieving these insights depends critically on producing ever-shorter electron pulses that can overcome broadening from space-charge effects [1]. To extend these capabilities to chemical and biological systems in their natural environments, we have developed proprietary nanocontainers and an “air-free, solvent-vapour-saturated” sample loading method (Fig. 2A-2C). By using straightforward drop-casting and silicon nitride window membranes as thin as 5 nm, our LPEM approach eliminates common issues like window bulging and liquid overflow that plague commercial systems. This allows us to maintain a stable, controlled environment for imaging low-contrast specimens, such as vesicles (Fig. 2D) and plasmid DNA, with high throughput and reproducibility [2].

The relevance of our work spans the frontiers of condensed matter physics, chemistry, and materials science. By building our own instruments and proprietary devices, we gain the unique ability to directly observe photoinduced transformations and phase transitions in non-equilibrium systems using a balance of high pulse brightness and multi-kilohertz repetition rates. Furthermore, our focus on liquid-phase dynamics will provide unprecedented insights into catalysis and protein function- processes essential for developing next-generation technologies. We do not simply use technology; we redefine it to ensure our discoveries are guided by ambitious hypotheses rather than the limitations of off-the-shelf equipment. Through this integrated approach to instrumentation development, we provide the structural foundation for understanding how matter evolves in real time.

[1] Netzke, S., Viernes, C., Pichigin, K., Keramati, S., Jiang, J., Miller R. J. D., Sciaini, G. et al. Reassessing the Practical Resolution Limits in Compact Ultrafast Electron Diffraction. Ultrafast Science **6**, 0148 (2026).
[2] Shaw, N. A., Lott, T. S., Petruk, A. A., Pichugin, K. & Sciaini, G. Streamlined Liquid-Phase Electron Microscopy: Engineered Nanocontainers and Air-Free Loading for High-Resolution Imaging of Biospecimens. Microscopy Today **33**, 34–38 (2025).

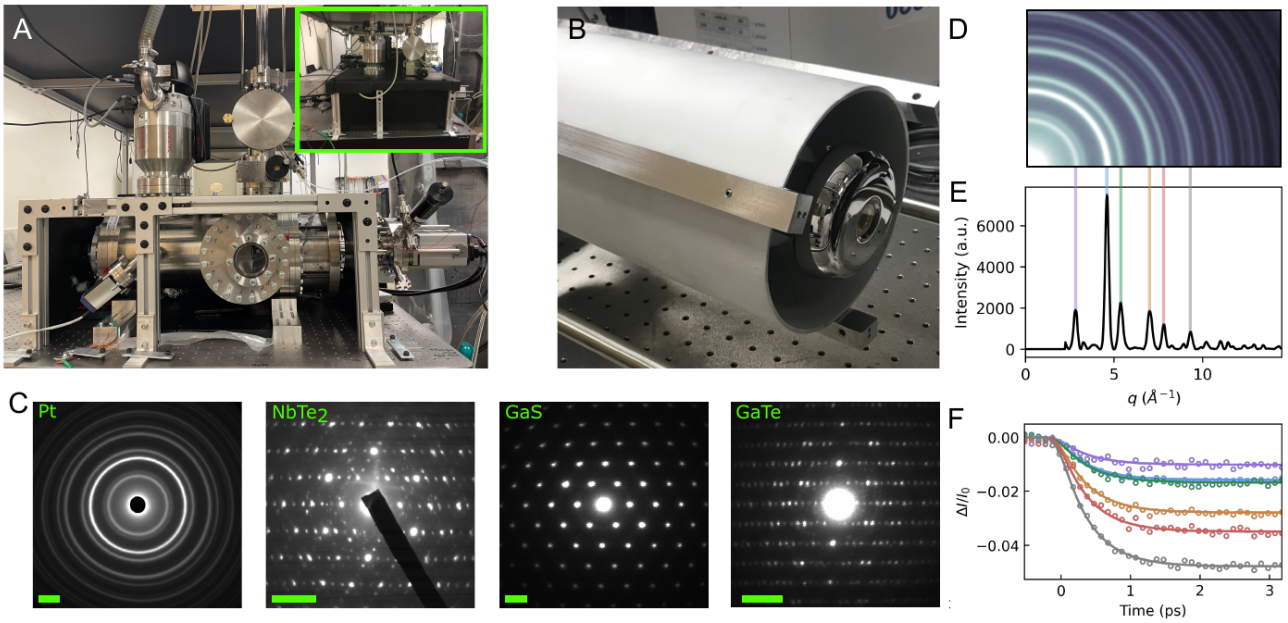

Figure 1: A. Photograph of the electron diffractometer on the optical table at the University of Waterloo. The inset shows the chamber inside of its lead enclosure. B. Photograph of the electron gun head surrounded by an aluminum shield. C. UED images of different samples. The scale bars represent 2 Å^{-1}. D. Top-right sector of a raw diffraction image obtained from the Pt sample plotted on a log-intensity scale. E. Single line profile extracted after background subtraction. Vertical lines indicate the positions of selected Bragg reflections. F. Relative intensity changes as a function of time delay (colour-coded as in F). Figure adapted from [1].

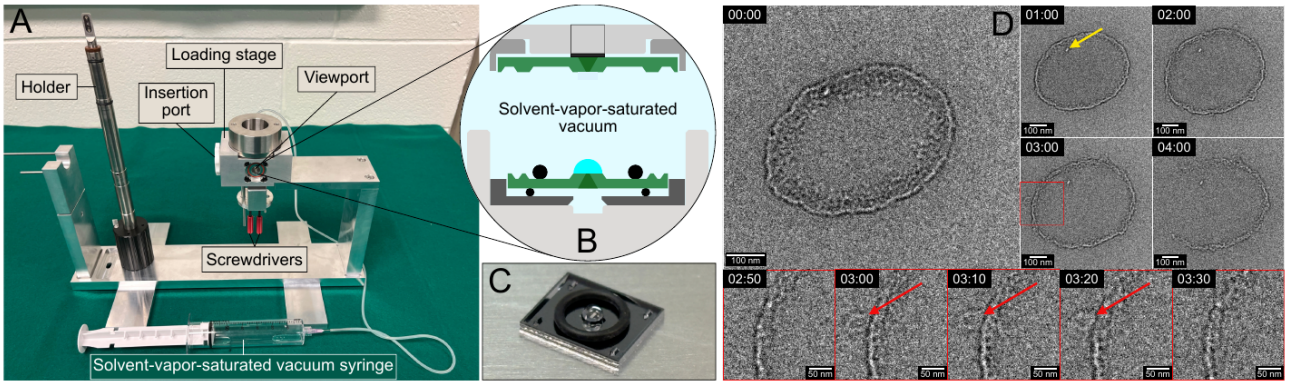

Figure 2: A. Photograph of the latest sample loading station and JEOL LPEM holder. The syringe is used to create a solvent-vapor-saturated vacuum, enabling the removal of air. B. Illustration of the cross-section of the NFC in position before closure and sealing. C. Close-up view of the NFC carrier, showing the dispensed liquid droplet and the internal O-ring. D. Beam-induced rupture of an unstained vesicular structure. Two apoferritin molecules are indicated by the yellow arrow. The formation of a small liposome during rupture is indicated by red arrows. Images were obtained with 300 keV electrons at a magnification of 11,000$\times$ with a dose rate of approximately 5 electrons $\text{Å}^{-2}\text{s}^{-1}$, utilizing an NFC with a nominal spacer of 200 nm and chips combining 10nm and 5 nm thick SiN_x membranes. Figure adapted from [2].

Für diese Zeit steht eine Kinderbetreuung nach vorheriger Anmeldung zur Verfügung.

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