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Technology Offer

Ultrafast Low-Energy Electron Microscopy for Surface Structural Dynamics

Ref.-No.: 0707-6350-BC

Abstract

This invention presents an advanced ultrafast low-energy electron microscopy (ULEEM) system designed to probe structural dynamics at surfaces with high temporal and spatial resolution. The innovation integrates a miniaturized electron source with a pump-probe laser excitation scheme, allowing for example femtosecond-resolved real-space imaging of surface phenomena. Unlike existing diffraction-based methods, this approach provides direct surface sensitivity and spatially resolved structural dynamics. Utilizing a laser-driven Schottky field emitter operating more stable under relaxed vacuum conditions can be guaranteed. The technology holds significant potential for investigating ultrafast phase transitions, topological defect dynamics, and non-equilibrium states in low-dimensional systems, such as transition metal dichalcogenides. The ULEEM platform marks a major advancement in nanoscale surface science and ultrafast electron imaging.

Background

Surface and interface phenomena are central to modern nanotechnology and condensed matter physics, influencing catalysis, electronics, and quantum materials. Traditional low-energy electron microscopy (LEEM) and low-energy electron diffraction (LEED) provide essential surface sensitivity but lack the temporal resolution to capture ultrafast dynamics. Meanwhile, ultrafast transmission electron microscopy (UTEM) and time-resolved photoemission techniques offer high temporal resolution but are limited in surface specificity or spatial imaging. Emerging research in charge-density waves and structural phase transitions in materials has demonstrated the need for an instrument combining real-space imaging, surface sensitivity, and ultrafast temporal resolution. The presented ULEEM system addresses this gap by integrating low-energy electron optics with laser-driven ultrafast excitation and detection, enabling novel insights into transient surface phenomena.

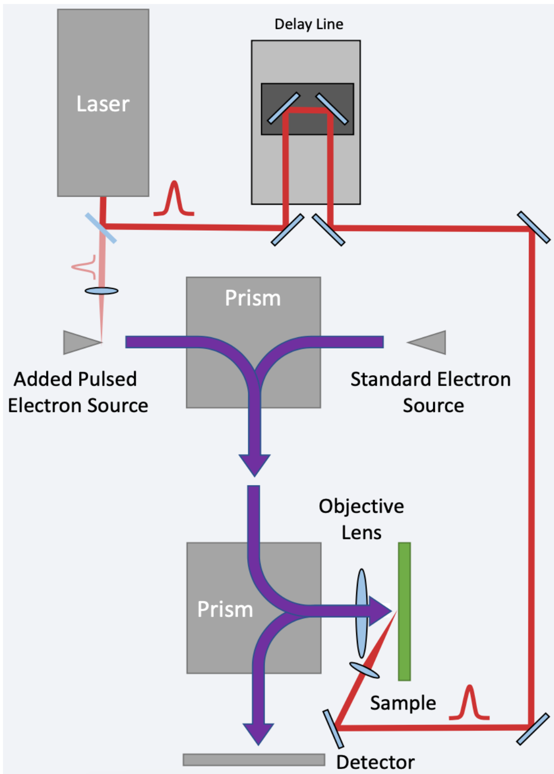

Figure 1: Schematic of the ULEEM setup. A femtosecond laser pulse is split and delayed via a delay line before illuminating a photocathode to generate pulsed electron bunches. These electrons are injected into a low-energy electron microscope via an added pulsed electron source. Prisms and electron optics guide the beam toward the sample. Reflected or emitted electrons are detected to reconstruct ultrafast changes in the sample surface structure.

Technology

The invention introduces a modular ULEEM system that utilizes a tip-shaped photoemitter for generating linearly modulated electron pulses. Unlike conventional ultrafast sources based on nonlinear multiphoton emission, this design enables direct, proportional control of the electron emission via the intensity of the excitation laser. This approach simplifies the setup, reduces thermal stress on the emitter, and supports a wider range of laser types-including continous-wave and modulated sources.

Max-Planck-Innovation GmbH
Arnulfstr. 58
80335 München
www.max-planck-innovation.de

Electrons are emitted with high spatial coherence and low energy spread, ideal for surface-sensitive imaging. The electron pulses can be synchronized with optical, electrical, or magnetic sample excitation using a delay control stage, enabling femtosecond-resolved pump-probe experiments. Optional integration of static electron mirror allows for tempporal pulse compression down to approx. 100-200 fs. The system is compatible with existing LEEM architectures, offering an upgrade path for time resolved studies of surface phenomena with enhanced energy and temporal resolution.

Advantages

- **Real-space surface imaging** with nanometer resolution and picosecond temporal precision.
- **Surface-specific sensitivity** due to low electron energies and high coherence.
- **Pump-probe integration** for dynamic studies of photo-induced phase transitions.
- **Compact and modular design** for laboratory-scale ultrafast experiments.
- **Versatility in sample environments,** supporting variable temperature and materials.

Potential applications

- **Time-resolved studies of surface phase transitions,** such as Charge-Density Wave (CDW) systems (e.g., 1T-TaS_2).
- **Real-space imaging of topological defect dynamics** at surfaces and interfaces.
- **Ultrafast catalysis and reaction pathway analysis** on functional surfaces.
- **Development of ultrafast electronic and memory devices** using non-equilibrium states.
- **Educational and research instrumentation** for advanced surface science laboratories.

Patent Information

WO2024188471A1 (Application 16.03.2023)

Contact

Dr. Bernd Ctortecka

Senior Patent- & License Manager, Physicist
Phone: +49 (0)89 / 29 09 19 – 20
eMail: ctortecka@max-planck-innovation.de

Max-Planck-Innovation GmbH
Arnulfstr. 58
80335 München
www.max-planck-innovation.de