IP083: Transient Electric Field Effect-Based Characterization of an Ultrafast Electron Gun Suitable for Electron Diffraction and Microscopy

Leon Brauns[1], Johannes Otto[1,2], Armin Feist[1], Jan Gerrit Horstmann[1], Murat Sivis[1] and Claus Ropers[1,2]

[1]*Max Planck Institute for Multidisciplinary Sciences, Am Faßberg 11, 37077 Göttingen*
[2]*Max Planck School of Photonics*
Email: leon.brauns@stud.uni-goettingen.de

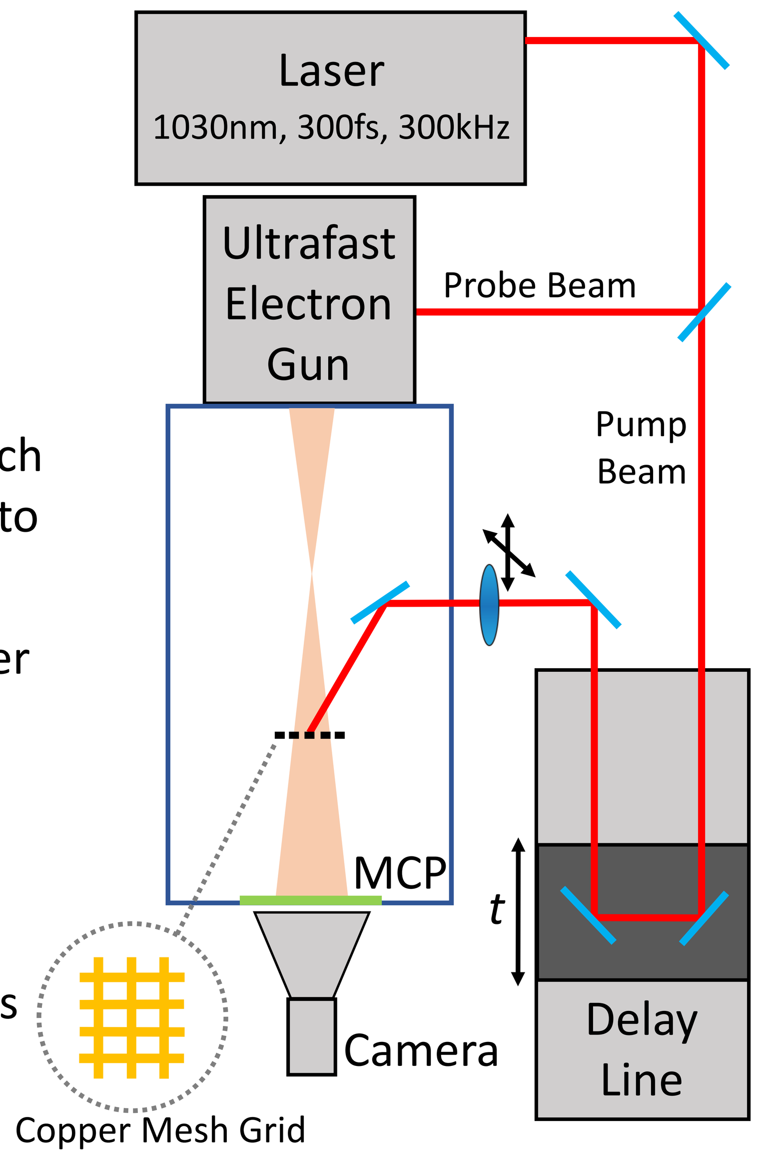
MAX PLANCK INSTITUTE FOR MULTIDISCIPLINARY SCIENCES

Motivation

- Following the growing interest in the investigation of novel 2D materials, electron diffraction in the medium energy range up to 15kV is becoming more attractive [1]
- For the study of transient structural dynamics in such materials, ultrafast electron diffraction (UED) presents itself as a very promising technique
- The electron source characteristics thereby play a crucial role in the achievable spatial and temporal resolution
- Here we present an accessible and efficient approach to characterize the electron pulse duration of a 15kV ultrafast electron gun using the transient electric field effect
- We subsequently compare it with UED measurements of tantalum disulfide

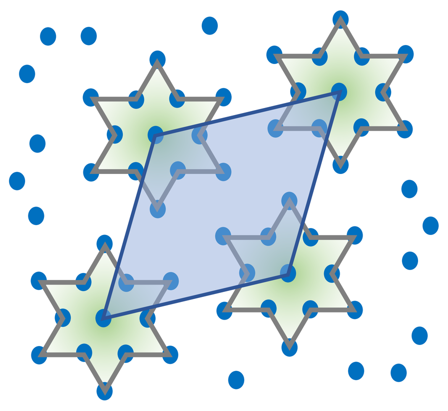
Experimental Setup

- The output of an ultrafast laser is split into a probe and pump beam path
- The probe pulse is fed into a laser-triggered ultrafast electron gun
- The pump pulse transverses a delay line, which allows the adjustment of the delay *t* relative to the probe pulse
- The pump pulse is then focused onto a copper mesh grid with a fluence of up to 20mJ/cm²
- Spatial overlap can be tuned by shifting the focusing lens
- The electron beam emitted from the gun is focused in front of the mesh grid and projects it onto a microchannel plate (MCP)

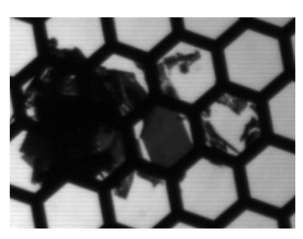


Ultrafast Electron Diffraction of 1T-TaS_2

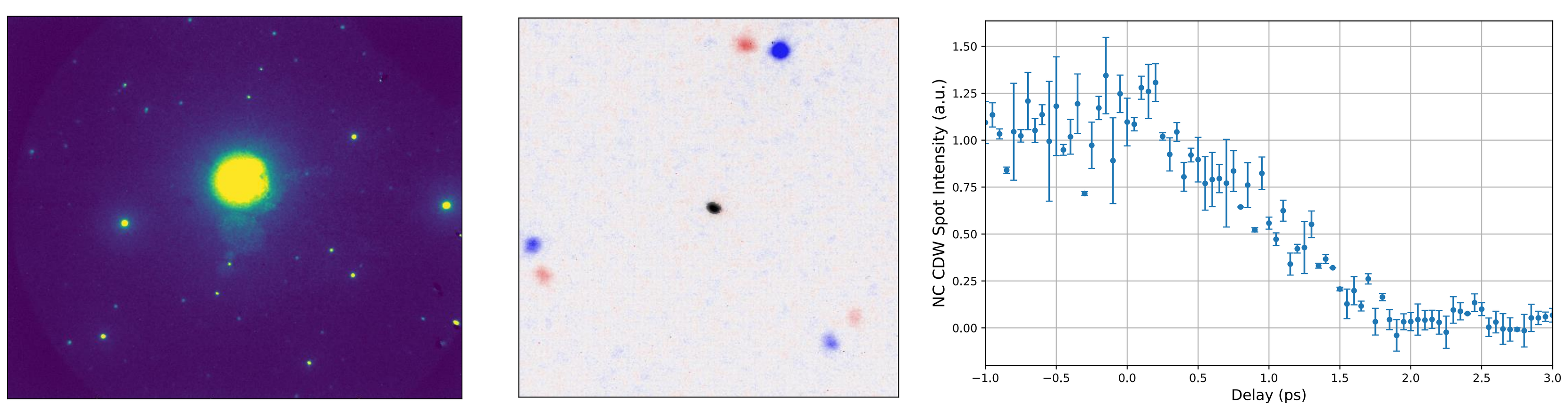
- 1T-polytype tantalum disulfide (1T-TaS_2) is a quasi-two-dimensional van der Waals material with multiple charge density wave (CDW) phases [4]
- Heating due to the laser pump pulse induces a CDW phase change which is detectable by a change in the diffraction image



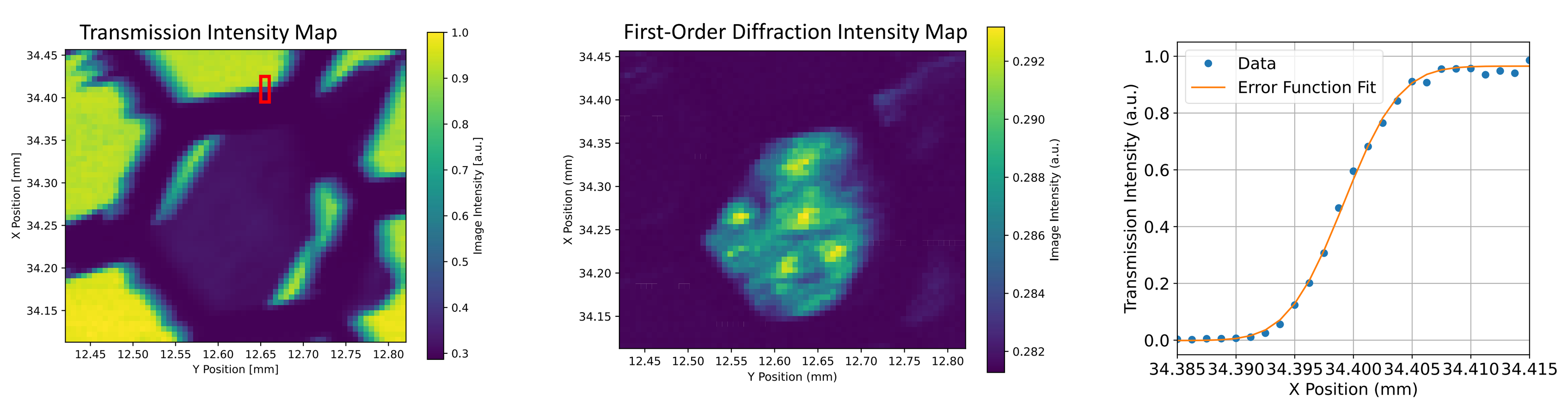
Superstructure caused by the periodic distortion of Ta atoms in 1T-TaS_2



Optical microscope image of an approximately 40nm thick 1T-TaS_2 flake on a 100-mesh grid, used as a sample for diffraction



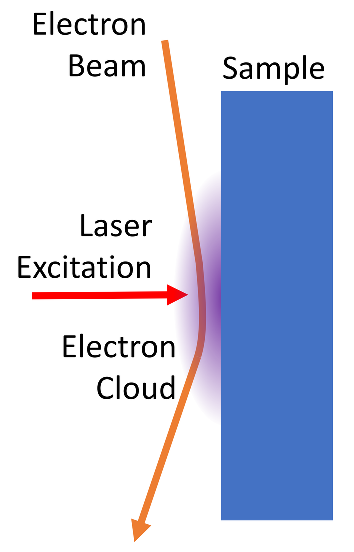
Left: Electron diffraction image of 1T-TaS_2. Center: First-order diffraction spot (black), surrounded by CDW spots of the nearly commensurate (NC, red) and commensurate (IC, blue) phase after laser excitation. Right: Intensity of a NC CDW spot in relation to the delay t



Raster Scan of a 1T-TaS_2 flake with the intensity given by the transmission spot (left) and by a first-order diffraction spot (center). The intensity profile across the line marked in the transmission image is shown on the right. From an error function fit a spatial resolution of 12.5(4)µm (FWHM) is calculated

Transient Electric Field Effect

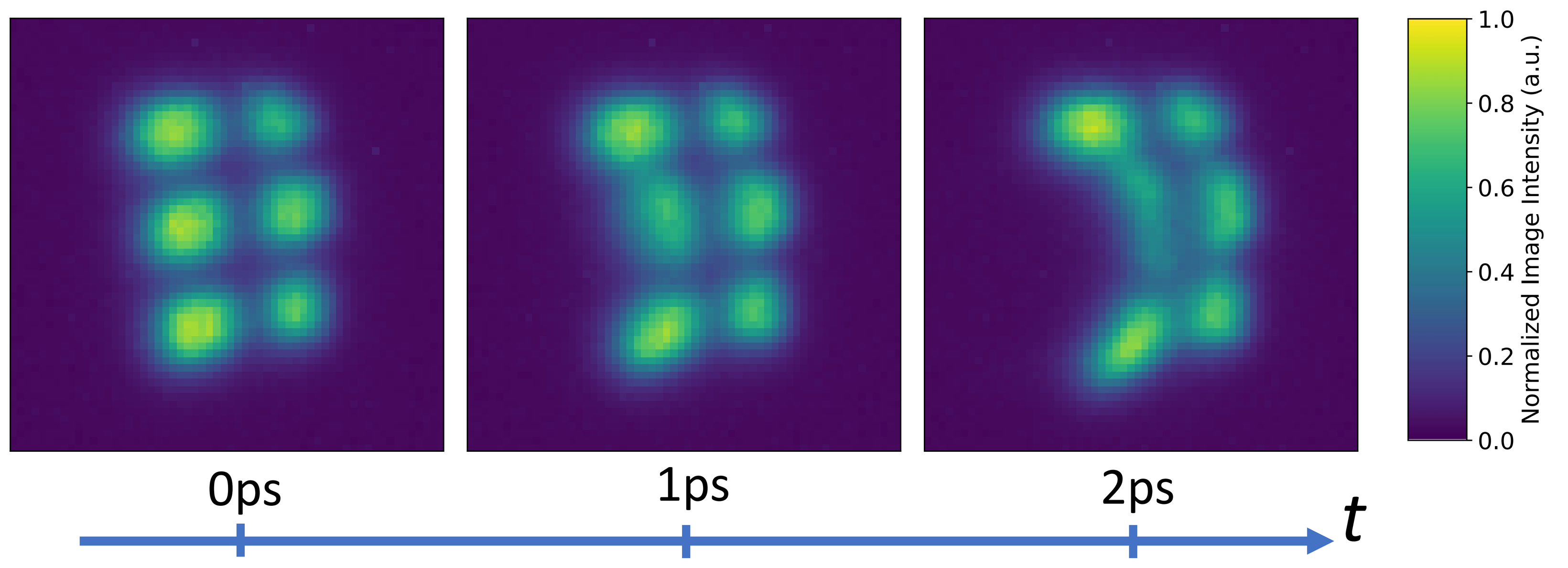
- Through ultrafast laser excitation of a surface, electrons are emitted similarly to thermal emission, as well as through multiphoton photoemission and thermally assisted multiphoton photoemission [2]
- The emerging electron cloud has a rise time in the order of a picosecond [3]
- The emitted electrons induce a transient electric field, capable of deflecting an incoming electron beam



Schematic of the transient electric field effect

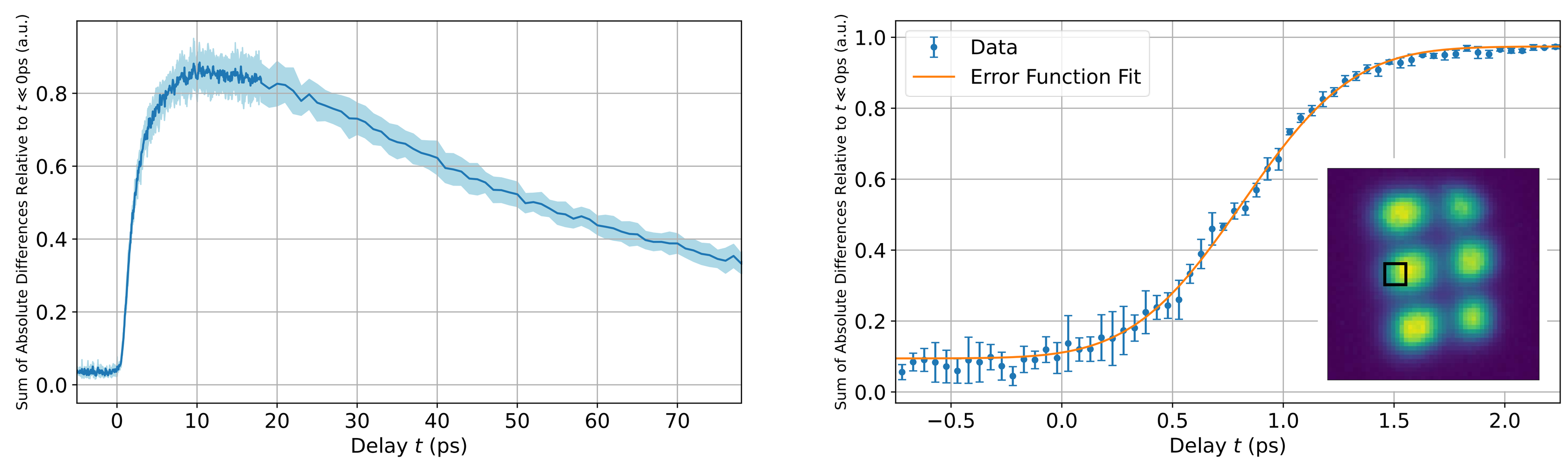
Measurement and Analysis

DASK xarray



MCP images of the projected mesh grid for different delays t between laser pump and electron probe beam

- Deflection by the transient electric field is visible for *t* > 0ps
- Spatial overlap is easily distinguished and achieved by raster scanning the pump focus spot over the sample surface
- Snapshots of the imaged mesh grid are captured for different delays *t* for an analysis of the dynamics



MCP Image intensity change relative to t≪0 for different delays t for the whole mesh grid projection (left) and within a selected area (right)

- The expanding electron cloud is clearly observable with a rise time within 10ps and a slow decay duration of more than 100ps
- To characterize the electron pulse duration, the intensity change enclosed in a small area within the mesh cell closest to the origin of the emerging electron cloud is analyzed
- An error function is fitted to the data, from which the full width at half maximum (FWHM) of the electron pulse length is determined to be 1.31(3)ps

Discussion

- Due to the drastic intensity change, the transient electric field effect is well suited as a straightforward and easy method for determining the spatial and temporal overlap in pump-probe experiments using electron probe and optical pump pulses
- The possibility of using high laser fluences up to the damage threshold (and beyond) and the fast recovery allow for high repetition rates and thus fast data acquisition
- It is an accessible method for electron pulse duration measurements, but due to the rather slow dynamics of the electron cloud, only an upper limit on electron pulse duration may be derived
- Faster processes are needed for a more precise determination of the pulse duration, e.g., CDW phase change in 1T-TaS_2 [5]

References and Acknowledgments

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