THz-Controlled Photoelectron Emission from Nanotips

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Abstract: We introduce terahertz gating and streaking of photoelectron emission at a single nanostructure. The THz-near-field enhancement allows for far-reaching electron trajectory control, including phase-resolved streaking by the momentary THz field and propagation-induced spectral reshaping.

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Introduction

The high localization of nanostructure field-enhancement leads to unique photoelectron dynamics [1]. Suggestions to use such dynamics in streaking-type experiments have been theoretically discussed in detail [2, 3]. Typically, streaking experiments employ a diffraction-limited focus, which imprints the vector potential of the streaking pulse onto the photoelectron kinetic energy [4]. If the electrons leave the field-enhanced region of a nanostructure within a fraction of an optical half-cycle, their kinetic energy is determined by the instantaneous near-field rather than the time-integrated THz-field. This allows not only for a direct characterization of the spatio-temporal near-field, but also to widely tailor ultrashort electron pulses in terms of emitted the charge and the kinetic energy distribution [5]. This THz-field-driven electron pulse control bears potential for optimizing electron pulses in ultrafast electron microscopy and diffraction experiments.

Experimental Methods

In a two-color streaking experiment, few-cycle THz transients and 50-fs near-infrared (NIR) pulses are focused onto a single metal nanotip as shown in Fig. 1a. The NIR-emitted electrons propagate through the enhanced THz-near-field and are moderately biased with a static voltage. The photocurrent and the electron kinetic energy are detected by detector assembly comprising a multichannel-plate and a retarding voltage grid. The delay between both pulses is scanned to map the impact of the THz field on the photoelectrons. In-situ characterization of the THz transient with electro-optic sampling enables a direct comparison of the incident THz field with its impact on the electron spectra.

Results & Discussion

An experimental streaking spectrogram is shown in Fig. 1d. The electron energy is strongly modulated by the THz-field. The electron acceleration by the THz-pulse not only affects the kinetic energy distribution, but also the detected photocurrent (Fig. 1c). Depending on the relative delay between the NIR and THz pulses, the THz-transient enhances or suppresses the photocurrent due to an instantaneous THz modulation of the work function (Schottky effect).

The phase of the transient detected by electro-optic sampling (Fig. 1b) is imprinted onto the photocurrent trace and the kinetic energy spectrogram. We find only a very minor phase-shift between the electro-optic field maxima and the maxima in kinetic energy, which is characteristic for the field-driven interaction between the THz-pulse and the photoelectrons at sharp nanostructures. In particular, this in-phase behavior results from the extremely short, sub-cycle interaction time of the photoelectrons with the THz near-field.
At longer interaction time, e.g. for lower THz-field strength or a spatially less confined field, propagation effects arise that reshape the initial kinetic energy distributions and allow for strong spectral modulations. A temporally increasing streaking field transfers more energy to those electrons with low initial energy than to faster electrons, which leave the field enhanced region more rapidly. The same considerations explain the spectral broadening for temporally decreasing fields. This mechanism is achieved in the transition region to field-driven dynamics.

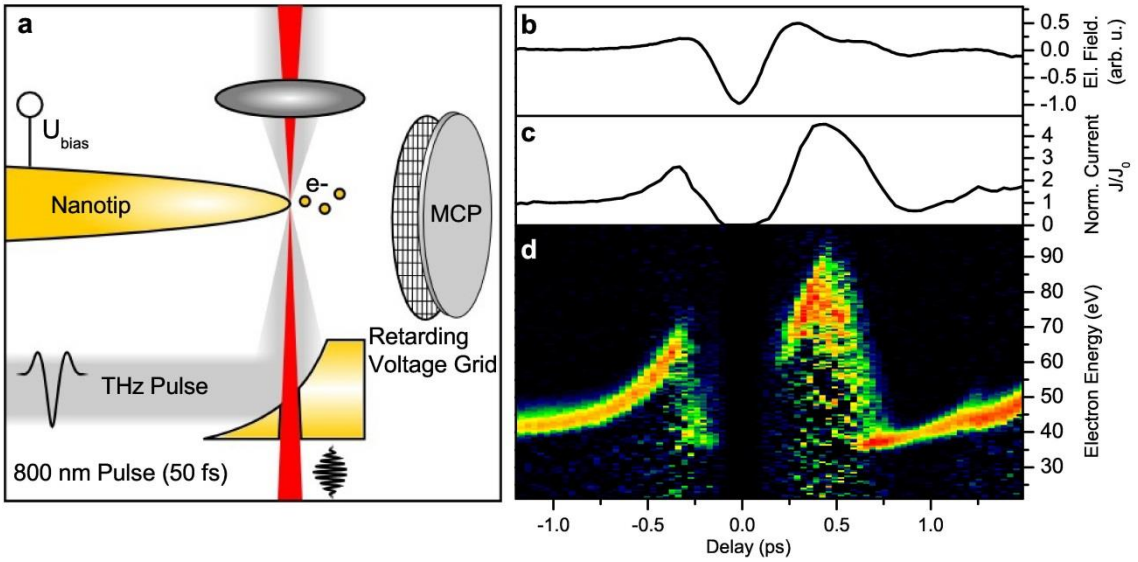

Fig. 1 a) Schematic of the experimental setup. Single-cycle THz transients and near-infrared femtosecond pulses are collinearly focused onto a metal nanotip at variable delay. The photoelectrons are detected by a MCP detector combined with a retarding voltage electron spectrometer. **b)** Incident electric field of the THz pulse detected by electro-optic sampling. **c)** Normalized photo-current as a function of pulses delay. **d)** Streaking spectrogram for a sharp tip (bias voltage -40 V, radius of curvature 20 nm): photoelectron spectrogram formed by recording energy spectra as function of relative pulse delay.

The streaking measurements can be reproduced in detail by simulations based on the propagation of the NIR-induced photoelectrons in a temporally and spatially varying THz near-field and a static bias potential. In these simulations, initial energy distributions are included as measured in the absence of a THz field.
In conclusion, we demonstrate nanostructure gating and streaking experiments utilizing the high field localization of THz transients at nanostructures that give direct access to the phase-resolved near-field. Further control over the propagation dynamics can be achieved by modifications in the THz generation conditions and a tailoring of the static bias voltage. This opens up new prospects for nanoscopic electron pulse shaping to be used in ultrafast electron diffraction or microscopy.

References

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