Controlling Ultra-Fast Electron Emission

XYZ-Positioning of a Sharp Tip with attocube's ANPx101/UHV and ANPz101/UHV Nanopositioners

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Introduction

Attosecond science (1 attosecond = 10^{-18} s) has enabled insights into ultrafast fundamental processes in atoms and molecules [1,2]. It is based on the steering of electrons with the electric field of ultra-short, intense laser pulses. Usually, atoms or molecules in the gas phase are used as electron source. Recently it was shown that the regime necessary for attosecond science can also be reached with nanometer-scale metal tips [3].

In this application, we have investigated the dynamics of electrons emitted from a sharp tungsten tip triggered by femtosecond laser pulses [4].

Setup

The setup consists of a sharp tip, which is mounted on a stack of UHV compatible attocube systems' positioners and brought into the pre-aligned focal spot of an off-axis-parabolic mirror (see Figure 1).

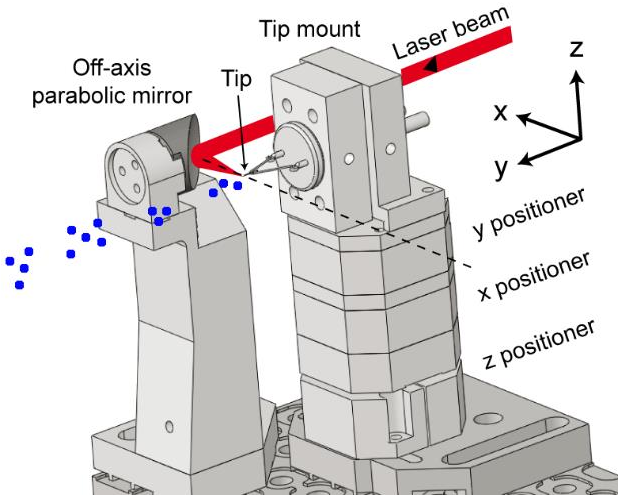

Figure 1: Sketch of the experimental setup. Femtosecond laser pulses (red) irradiate the tungsten tip and electrons (blue) are photo-emitted from the tip. An electron spectrometer (not shown) records photoelectron spectra. The tip is positioned in the microscopic focal spot of the off-axis parabolic mirror with a set of xyz-positioners.

The whole setup is situated in an UHV chamber at p = 10^{-10} mbar pressure. The tungsten tip has been produced from single crystal tungsten wire by electro-chemical etching and has a radius of curvature at the apex of about 10 nm (as confirmed by SEM imaging).

Using attocube's positioners in scan mode (applying DC voltages), the tip can be positioned to test and measure the focal spot of the laser beam in situ. Its size is typically about 2.4 µm (1/e2 intensity radius).

Measurement Results

At a laser intensity of 4 · 10^{11} W/cm^2, photoelectron spectra are recorded with a spectrometer. The phase between carrier wave and intensity envelope (carrier-envelope phase, see explanation in Figure 2) is varied in small steps.

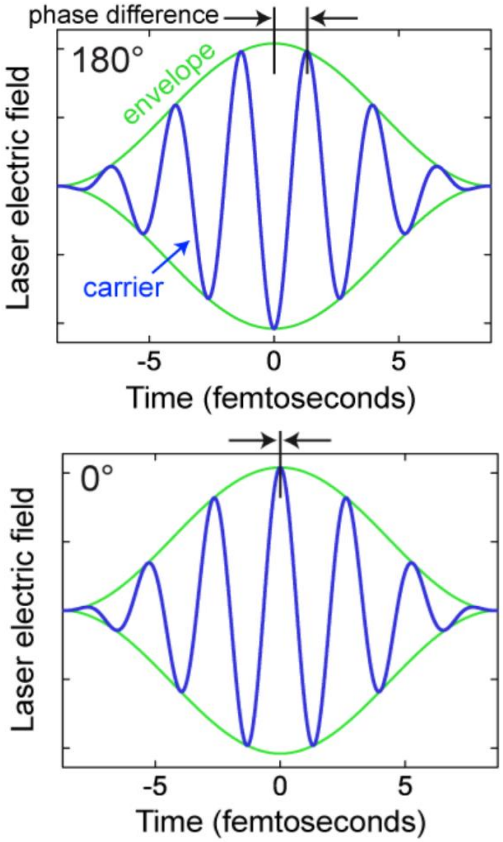

Figure 2: Electric field of a few-cycle femtosecond laser pulse. The phase difference between the maximum of carrier wave and envelope is the carrier-envelope phase.

Figure 3 shows two electron spectra, recorded with a phase difference of 180 degrees. In a), pronounced peaks are visible caused by interference of two electron wave packets emitted during subsequent optical cycles. In b), no peak structure is visible; only one electron wave packet contributes.

This energy domain effect allows conclusions about the time dynamics of the electrons. By shaping the laser electric field with the carrier-envelope phase, the dynamics of the electrons can be controlled with attosecond precision. Semi-classical calculations confirm this notion [4].

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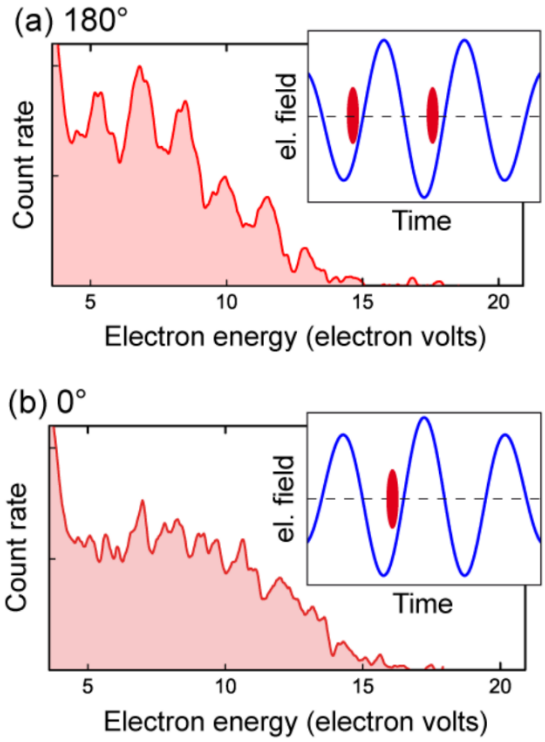

Figure 3: Electron spectra for two different carrier-envelope phases. Peaks are visible in a) due to two interfering wave packets generated during the pulse (marked in red in the inset), whereas in b) no interference peaks are visible.

Conclusion

In summary, this application describes an experimental setup for studying ultrafast electron emission from a sharp metal tip. The presented system enables control over photoelectrons from a metal tip in space (nanometer scale) and time (attosecond scale). The spatial confinement is enabled by the size of the electron emission area and the precise positioning control provided by attocube systems' positioner stack.

References

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[3] M. Schenk, M. Krüger, and P. Hommelhoff, Phys. Rev. Lett. 105, 257601 (2010).
[4] M. Krüger, M. Schenk, and P. Hommelhoff, Nature 475, 78 (2011).