Attosecond science on the nano-scale

Michael Krüger[1]
[1]*Department of Physics and Solid State Insitute and Helen Diller Quantum Center, Technion – Israel Institute of Technology, 3200003 Haifa, Israel*
krueger@technion.ac.il

Attosecond science probes ultrafast quantum dynamics using precisely controlled laser fields. Many-body quantum phenomena that go beyond the single-electron picture are found in condensed matter systems with a strong geometric confinement in one or more dimensions, such as nanowires. However, while access to these phenomena is possible using laser fields and ultrafast optical spectroscopy, achieving (sub-)nanometer spatial resolution remain challenging.

Electron pulses offer an alternative avenue for studying such dynamics in space and time thanks to the small de-Broglie wavelength of electrons. The coherent modulation of swift electron beams with strong laser fields has enabled the generation of attosecond electron pulses [1]. Here we study a simple alternative, the production of electron pulse trains directly at the source, a metal nanotip [2]. In our experiment, we trigger tip photoemission by plasmonic nanofocusing [3] and find signatures of attosecond tunneling emission. Our numerical simulations show that the electrons can retain the sub-cycle temporal fingerprint in a point-projection microscope setup due to low matter-wave dispersion [4]. We report on the current status of this experiment and our efforts to image many-body electron dynamics in nanowires.

In a second experiment, we integrate a conventional scanning tunneling microscope (STM) with ultrafast two-color femtosecond laser pulses, inspired by time-resolved THz-STM studies [5]. We show that the electron transport mechanism in the tunneling gap is dominated by laser-driven nonlinear currents and its magnitude and direction can be controlled using the relative phase of the two colors. Theory simulations shows that the observed current consists of sub-femtosecond bursts. The underlying mechanism can be understood using a novel strong-field model, which also provides physical intuition in terms of a three-step process, the hallmark effect of attosecond science. This innovation promises simultaneous ångström and attosecond observations of plasmonic dynamics and ultrafast quantum many-body phenomena in nanostructures.

References

[1] A. Feist et al., Quantum coherent optical phase modulation in an ultrafast transmission electron microscope, Nature 521, (2015), 200-203
[2] M. Krüger et al., Attosecond control of electrons emitted from a nanoscale metal tip, Nature 475, (2011), 78-81
[3] J. Vogelsang et al., Plasmonic-nanofocusing-based electron holography, ACS Photonics 5, (2018), 3584-3593
[4] M. Eldar et al., Sub-optical-cycle electron pulse trains from metal nanotips, J. Phys. B: At. Mol. Opt. Phys. 55, (2019), 074001
[5] T. L. Cocker et al., Tracking the ultrafast motion of a single molecule by femtosecond orbital imaging, Nature 539, (2016), 263-267