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Johannes Schötz

Attosecond Experiments on Plasmonic Nanostructures

Principles and Experiments

With a Preface by Prof. Dr. Matthias Kling

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To my family, friends and colleagues

Preface

Attosecond nanophysics is a new research field merging ultrafast science with time scales reaching into the attosecond domain with studies on nanoscale materials. An attosecond is incredibly short. To put it in perspective, one attosecond (one attosecond = 10^{-18} seconds) compares to one second roughly as one second compares to the age of the universe. Within one attosecond even light only travels a distance of 0.3 nanometer (1 nanometer = 10^9 meter). Attosecond time and nanometer length scales are thus inherently connected. The attosecond timescale is particularly important for electrons, which are light enough to move so fast that they must be clocked with attosecond precision to track their motion. These fast electron dynamics govern the interaction of light with matter and form the basis for optoelectronics. The possibility to steer electronic processes in nanomaterials with tailored lightwaves can be exploited in ultrafast nanoelectronic circuitry with switching frequencies approaching the petahertz domain (many orders of magnitudes above conventional electronics). This potential has motivated the rapid growth of attosecond nanophysics.

The master thesis of Johannes Schötz discusses an important experimental advance in this young field, namely the ability to measure the evolution of fields on the nanoscale in real-time, i.e. attosecond timescales. He describes both experimental and theoretical advances towards the realization of the attosecond streak-camera technique on the nanoscale. While the attosecond streak-camera has become a standard tool in attosecond physics, and related measurements on electron dynamics in atoms, molecules, and extended surfaces, its realization for measurements of nanostructures is not straightforward.

The reasons are discussed in detail in the thesis, with a special emphasis on metallic nanotips, which Johannes Schötz has investigated in his work.

In attosecond streaking, electrons are photoemitted through an attosecond light pulse in the extreme ultraviolet and are accelerated by an external field provided by e.g. a synchronized optical light pulse (with a duration of a few cycles). While in conventional attosecond streaking the external fields are spatially homogenous, the near-fields of nanostructures are inhomogenous. The ramifications of the nanometer spatial inhomogeneity are non-trivial and therefore typically detailed simulations of the streaking process and its application in real-time measurements of nanoscale near-fields are required. Johannes Schötz performed such simulations and shows them in his thesis.

The thesis not only describes the first steps into the new territory of attosecond resolved measurements on nanostructures, but it is also written such that it provides guidance to a newcomer. The thesis of Johannes Schötz is of high relevance to future research in attosecond nanophysics and I wish that his ground breaking work will find the wide and interested readership that it certainly deserves.

Prof. Matthias Kling

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The Laboratory of Attosecond Physics (LAP)

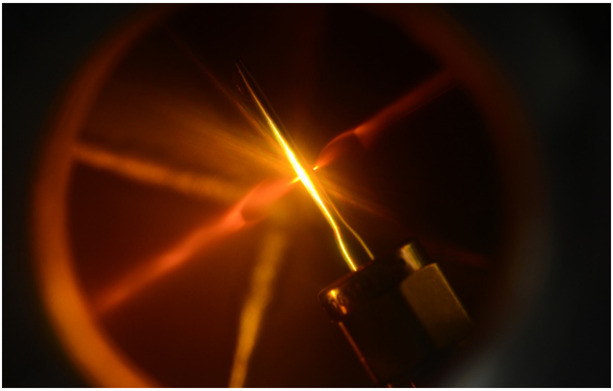

Figure 0.1: Generation of attosecond pulses at LAP (Thorsten Naeser, MPQ)

The Laboratory of Attosecond Physics (LAP) is a unique facility for research on ultrafast particle motions outside of the atomic core. LAP is a joint facility of the Max Planck Institute of Quantum Optics (MPQ) and the Ludwig-Maximilians-Universität (LMU) Munich. The LAP team includes 150 scientists and students. Many of them are organized within the DFG cluster of excellence Munich-Centre for Advanced Photonics (MAP). The scientists are mainly interested in the motion of electrons, which change their probability density in quantum mechanical steps within attoseconds. In order to record such motion, the physicists have developed light flashes that last only attoseconds in duration. One attosecond is a billionth of a billionth of a second.

Physicists led by Prof. Dr. Ferenc Krausz, the current leader of the LAP team, generated and measured such extremely short light flashes for the first time in 2001. Since then, impressive insight into the mostly unknown world of electron motion has been gained world-wide, where the real-time dynamics of these particles can be followed after light-induced excitation.

The LAP research group Ultrafast Nanophotonics, which also Johannes Schötz is part of, is led by Prof. Dr. Matthias Kling. The research group investigates how electrons in complex materials collectively behave under the influence of intense laser light. In particular the physicists are interested in the dynamics and the control of electrons in molecules and nanostructures. Such light-induced electron motion occurs, for example, in semiconductors and dielectrics within attoseconds. Technically, the research could advance light-controlled nanoelectronics. With light frequencies in the Petahertz regime (10^{15} Hz) ultrafast switching times of electronic circuits could be achieved. This would advance current electronics by many (up to about 5) orders of magnitude.

Thorsten Naeser

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