PRESS-RELEASE
Munich-Centre for Advanced Photonics
and
Ludwig Maximilian University of Munich

Garching, 22 April, 2016

Movies out of the microcosm: better, faster and shorter

Physicists of the Laboratory for Attosecond Physics from the Ludwig-Maximilians University and the Max-Planck Institute of Quantum Optics have succeeded in controlling ultrashort electron pulses with terahertz radiation.

Seeing how atoms and electrons in a material respond to external stimuli can give scientists insight into mysteries of solid-state physics, like how high temperature superconductors and other exotic materials work. Short pulses of electrons can be used to film such motions. When an electron scatters from a crystal, due to its quantum mechanical wave-like properties, it interferes with itself to create a diffraction pattern. By recording these patterns, researchers can see the atomic and electronic structure of the material, resolving details smaller than the size of an atom. Short electron pulses are, however, difficult to generate, because electrons carry a charge and move slower than the speed of light. In particular, electron pulse technology is still far away from the time resolution required to see the motions of electrons inside a material. Now, a team headed by Dr. Peter Baum and Prof. Ferenc Krausz from the Laboratory for Attosecond Physics (LAP), the Ludwig-Maximilians University (LMU) and the Max-Planck Institute of Quantum Optics (MPQ) has succeeded in developing a new technique for controlling ultrafast electron pulses. While, to date, microwave technology has been used to control electron pulses, the LMU and MPQ researchers have for the first time used optically-generated terahertz radiation. Using the new technique, the physicists have succeeded in significantly shortening electron pulses. This terahertz method offers the potential of visualizing not only atoms but also electrons in motion.

Observing atoms and their motions requires special techniques. Electron microscopy and electron diffraction can provide the spatial resolution to see atoms, but filming atomic motions requires ultrashort shutter speeds as well - the shorter the electron pulses are, the sharper the images from the microcosm. Electron pulses with durations of femtoseconds or attoseconds (10^{-15}-10^{-18} s) would be ideal to observe processes inside matter with the required resolution in space and time, i.e. in four dimensions. While it is already possible to generate extremely short light pulses with lasers, optical pulses do not have the short wavelength required to make atoms or charges in molecules and solids directly visible. Electrons are superior to light thanks to their 100,000-times shorter wavelength, but the generation of short pulses is much more difficult than for light. This is because electrons, unlike photons, have charge and rest mass.

Now, a team headed by Dr. Peter Baum and Prof. Ferenc Krausz from the Laboratory for Attosecond Physics, the Ludwig-Maximilians University and the Max-Planck Institute of Quantum Optics has invented a novel technique for generating and measuring ultrashort electron pulses with terahertz radiation. Like visible light, terahertz radiation is a form of electromagnetic radiation. The wavelength of terahertz radiation is much longer, however, falling in the range between microwaves and infrared light. The researchers directed the terahertz radiation and the electron beam onto a special antenna, where the electrons and terahertz can interact. They oriented the electric field of the terahertz radiation so that electrons arriving earlier were slowed down, and electrons arriving later were sped up. Under these conditions, as the electron pulse continues to propagate, it becomes shorter and shorter, reaching a minimum duration at the location where it scatters from the material sample under study.

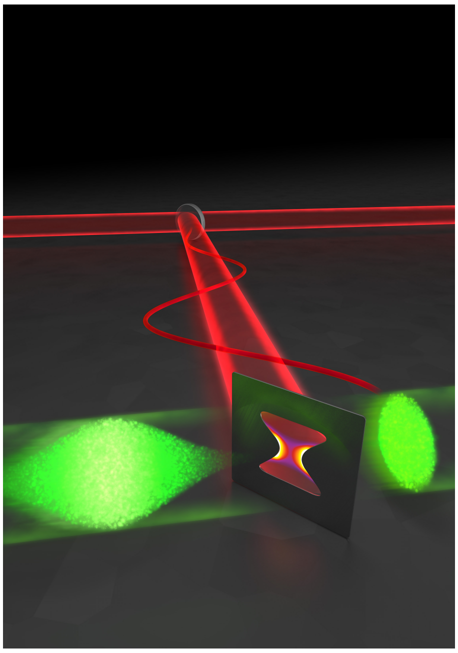

Image description: *Pulses from electrons (green, coming from the left) meet a micro-structured antenna which runs on laser-driven terahertz radiation (red). Thus the duration of the electron pulses shorten to few femtoseconds. The shorter the duration of the electron pulses, the better the films of atoms inside of solids or molecules.*
Graphics: Christian Hackenberger

The researchers measured how long the electron pulses are when they arrive at the sample position. To do this, the electron pulses were forced to interact a second time with terahertz radiation, but this time so that the terahertz electromagnetic fields gave a sideways deflection to the electron that depended on the exact time it interacted with the terahertz pulse. Hence, the physicists created a virtual terahertz-stopwatch for the electron pulses.

The research team is excited about the new technique for a fairly technical reason: to make movies of atoms in motion, not only do they need very short electron pulses, they also need to know very accurately what time the electron pulses arrived at the sample. So far, the conventional approach to compress electron pulses has been based on less precise microwave technology.

The new technology puts the physicists in a position to shorten the electron pulses even more and record ever faster atomic and eventually electronic motions. The aim is to track the attosecond motions of charged clouds in and around atoms in order to better understand the fundamentals of the interaction between light and matter. Such insights may eventually lead to new kinds of photonic and electronic materials and devices, driving the technologies of tomorrow.

Thorsten Naeser

Original publication:
C. Kealhofer, W. Schneider, D. Ehberger, A. Ryabov, F. Krausz, P. Baum
All-optical control and metrology of electron pulses
Science 22. April 2016, doi: 10.1126/science.aae0003

For further information please contact:

Dr. Peter Baum
Ludwig-Maximilians-University Munich
Am Coulombwall 1, 85748 Garching, Germany
Tel: +49 89 28914102
E-Mail: peter.baum@lmu.de
www.ultrafast-electron-imaging.de

Prof. Ferenc Krausz
Max-Planck Institute of Quantum Optics, Garching
Tel: +49 89 32905-600
Fax: +49 89 32905-649
E-Mail: ferenc.krausz@mpq.mpg.de
www.attoworld.de