

Attosecond insight tracks electron motion

Attosecond pulses could allow us to explore the ultimate limits of many modern technologies including semiconductor electronics and optoelectronics. **Marie Freebody** speaks to Reinhard Kienberger about the progress so far and what to expect in the future.

Reinhard Kienberger currently heads up the attosecond dynamics independent junior research group at the Max-Planck-Institute of Quantum Optics in Garching, Germany. His research on sub-femtosecond pulse generation has led to the first measurement of single extreme ultraviolet (XUV) pulses with a duration of less than 1 fs. Kienberger has been involved in using XUV pulses for steering electron wavepackets on an attosecond timescale. He also made leading contributions to the development of the attosecond streak camera, a device that is able to record atomic transients.



Probing deeper into matter: Reinhard Kienberger.

control changes in molecular structure via the control of electron motion? Will a better understanding and control of charge transfer processes improve solar cells? And can we time-resolve interference effects in spectroscopy? Attosecond research is in its childhood and we hope that the next decade will bring results that the public will profit from. However, who could have predicted the outcome when the scientific investigation of semiconductors started?

What would you say is the most important recent advance?

Recently, time-resolved measurements proved that different types of electrons, such as valence band and core level electrons, may need different amounts of time to reach the surface of a solid from the point of ionization. A precise measurement of the absolute time that the electrons need for their journey may be very important for understanding the electronic dynamics that take place in solids.

What are the key challenges left to overcome in this field?

Both the photon flux and the photon energy of attosecond pulses need to be increased in the future. Higher photon flux together with suitable optics would allow for XUV pump/XUV probe experiments in which the temporal resolution could be increased and the interpretation of measurement data could be simplified. Higher photon energies towards the keV regime or above would make it possible to investigate inner shell dynamics and more importantly, time-resolved attosecond diffraction techniques.

What do you think the next big breakthrough in this area will be?

I think that attosecond pulses in the keV energy range with reasonable flux will be available in the near future, making attosecond physics interesting for many different fields of science.

Can you summarize how attosecond pulses are produced?

Attosecond pulses can only be generated at wavelengths shorter than the visible range. This is because a pulse cannot be made shorter than one oscillation of the carrier wave, which is about 2.5 fs for red light. At present, the most successful way to generate attosecond pulses in the XUV or X-ray range is by frequency conversion from ultrashort laser pulses using a process known as high-order harmonic generation (HHG). In HHG, intense laser pulses impinge on a gas target for example, which ionizes the atoms. The electrons then accelerate back to the ions releasing energy as a burst of X-ray photons that last only a few hundred attoseconds or less. To produce an isolated burst, the driving laser field must be extremely short, lasting just a few optical cycles. Within the cycles, only one should have the dominant amplitude. The highest-order harmonics are produced near the intensity peak of the laser pulse where the re-collision energy of the electrons is highest and the laser field is largest. Passing the harmonics through a filter that transmits only the highest frequencies allows you to select radiation near the peak of the pulse. This method has been used to generate pulses in the range of 100 as.

Why is attosecond physics an important area of research?

Quantum mechanics teaches us that the velocity of processes in microcosm depends on the energetic separation of quantum states. The deeper you go into matter, the larger these energy separations get – from the vibrational states in molecules to electronic states in atoms. Consider, for example, the binding potential of electrons to the atomic core. If we want to resolve these processes on an attosecond timescale we require pulses of comparable duration. This is equivalent to using a short exposure time in photography in order to avoid taking a blurred image of a fast process. Attosecond physics provides us with insight into the dynamics of ultrafast electronic processes that until now were not accessible.

What are the main applications and when do you expect them to occur?

Capturing and controlling electronic processes that occur on attosecond timescales in real time will allow us to explore the ultimate limits of many modern technologies. This includes semiconductor and molecular electronics, optoelectronics, plasmonics, spintronics and optical nanostructuring. Attosecond physics may answer questions such as: Are we able to