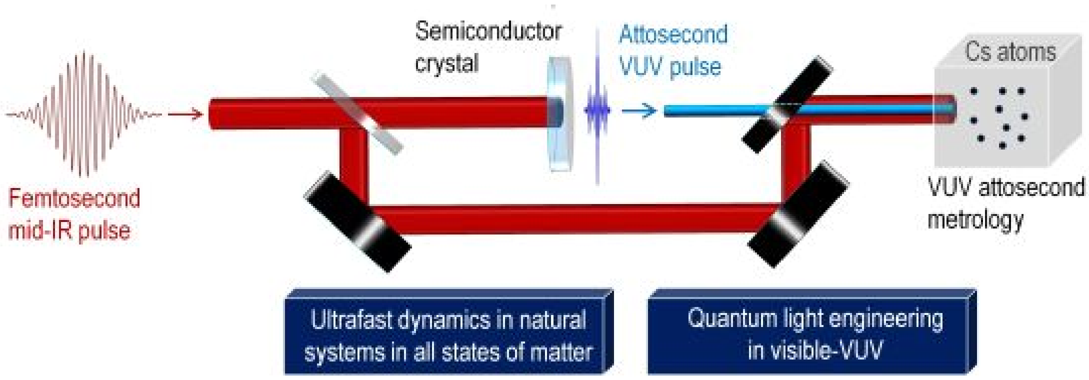

Scientists create vacuum-ultraviolet attosecond pulses to track ultrafast processes of natural systems

A team of researchers has presented a new technique in Nature Communications capable of generating and characterizing vacuum-ultraviolet attosecond (10-18 seconds) light pulses using semiconductor crystals illuminated by strong laser fields. With these pulses, the study of ultrafast dynamics in natural systems in all states of matter becomes possible.

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Electrons in atoms interact with each other and with other particles, changing their motion, energies, and other features at incredibly fast timescales, on the order of attoseconds (10-18 seconds). Capturing these ultrafast changes demands ultrafast light pulses. The pulse's duration needs to be more or less the same as the effect's; otherwise, it would be like trying to capture a hummingbird's wing motion with a slow, long-exposure camera.

At the end of the XIXth century, physicists thought that only femtosecond pulses (10-15 seconds) were technically possible. That started to change in the late 1980s, when physicists linked high harmonic generation with attoscience. High harmonic generation (HHG) is a process that upconverts low-frequency photons to higher frequencies, and what these researchers showed was that, when multiple harmonics are emitted, they can combine to form an attosecond pulse of light -something that was finally realized in 2001.

Attosecond science was born by generating and then employing extreme-ultraviolet (XUV) pulses, and as a consequence the methods developed to detect and characterize them focused in this frequency range. More than 20 years later, the creation of attosecond pulses to perform attoscience tasks remains XUV centered. Despite the many advances that XUV attosecond pulses have provided, they also pose a challenge. Most atoms, when hit by such an energetic light source, loose one or more electrons and become positively charged - a process known as ionization. But many worth studying processes in nature occur with non-ionized atoms, which remain in the so-called bound state. Since XUV light does not provide access to the bound states of the natural systems, their study has remained out of reach for attoscience. To address this, a source delivering less energetic attosecond pulses (for instance, in the vacuum-ultraviolet spectral range) and new methods to measure their main features (duration, intensity, etc.) are needed.

This has now been done by an international team of researchers from ELI-ALPS, Guangdong Technion- Israel Institute of Technology, Technische Universitat Wien, Universite de Bordeaux-CNRS-CEA, Foundation for Research and Technology-Hellas (FORTH)and ICFO researchers, **Philipp Stammer**, **Dr. Javier Rivera-Dean** and **ICREA Prof. Maciej Lewenstein**. For the first time, the team has demonstrated that **semiconductors illuminated by strong mid-infrared laser light emit vacuum-ultraviolet (VUV) attosecond pulses**, has retrieved the pulses' temporal shape and has measured their total duration. These unprecedented results, published in Nature Communications, establish the basis of a novel technique for probing the ultrafast changes that occur in most natural systems, preserving their bound state rather than inducing their ionization.

Producing and characterizing VUV attosecond pulses

To confirm the generation of attosecond VUV pulses and understand their properties, researchers designed and implemented a setup that combined semiconductor materials with strong laser fields.

In the experiment, a mid-infrared (mid-IR) light beam illuminated a semiconductor crystal. This generated high harmonics, whose superposition formed VUV attosecond pulses. These VUV pulses were directed to cesium atoms, one of the few species that, in clear contrast with those used in conventional attoscience schemes, can be ionized by VUV light. As expected, in the presence of the mid-IR field, VUV pulses ionized the cesium atoms. By detecting and analyzing the ejected electrons, the researchers could measure the attosecond synchronization of the high harmonics constituting the VUV pulses, which was key to extract

information about them.
The experimental results coincided with the theoretical predictions **confirming the generation of VUV pulses with duration of 950 attosecond**.

Potential for future techniques

Their findings, thus, introduce **semiconductors** illuminated by strong lasers as **new attosecond sources** and showcases their potential for studying ultrafast processes in a wider range of materials. i¿½We have developed the tools for tracing ultrafast bound sta
e dynamics -which occur very often in nature- in all states of matter, including atom
, molecules-in gas and liquid phase and solidsi¿½, explains Dr. Paraskevas Tzallas, F
RTH researcher and corresponding author of the artic
e. The authors also highlight that, according to previous studies, HHG radiation coming from atoms can produce quantum light, showing features like entanglement or squeezing.
heir research represents a crucial step toward experimentally demonstrating th
s in semiconductors, which once achieved would enable new applications in several qu
ntum information processing t
sks. Overall, Dr. Tzallas thinks thati¿½ **these new tools and methodology could be used for conducting studies in natural systems, investigating their ultrafast dynamics and even possibly using them to engineer novel quantum light states.**i¿

Reference:
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