Realizing attosecond core-level X-ray spectroscopy for the investigation of condensed matter systems

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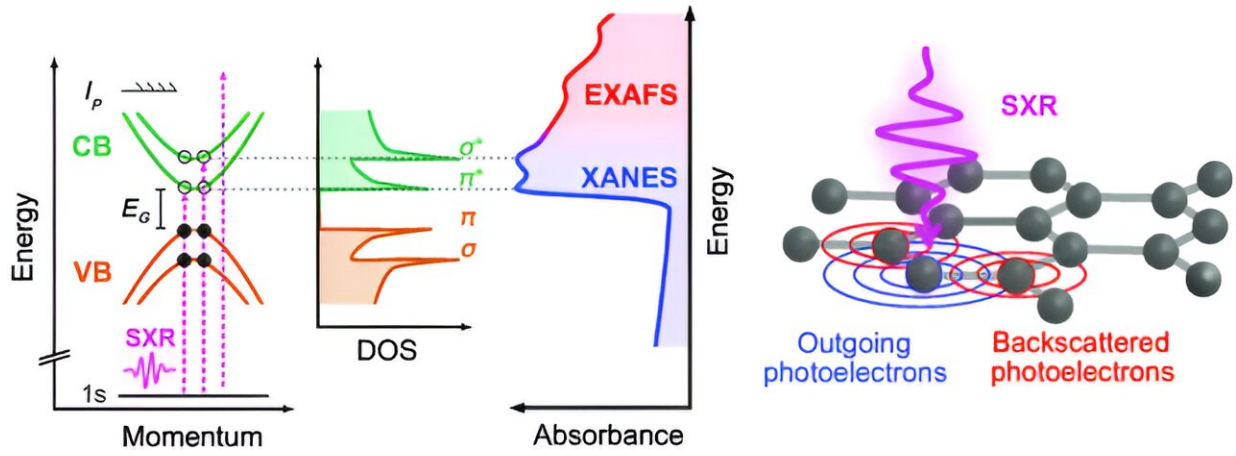

Schematic representation of the x-ray absorption fine structure (XAFS) spectroscopy in a solid-state material. XAFS absorption can be understood as arising from the individual atomic contribution (in blue) and a contribution due to scattering of the photoelectron wave packet with the neighboring atoms (in red). The former, known as x-ray absorption near-edge structure (XANES), probes bound states and provide a mapping of the unoccupied density of states that are depicted along with a representative schematic of the band structure. The latter, termed extended XAFS (EXAFS), is modulated in amplitude because of the interference of the outgoing and backscattered photoelectron wave packets above the ionization potential and provides information about the spatial position of nuclei. CB, conduction band; VB, valence band; SXR, soft x-ray; DOS, density of states. Credit: *Ultrafast Science* (2023). DOI: 10.34133/ultrafastscience.0004

The many-body interaction of charges (electrons) and nuclei (phonons) plays a critical role in determining the properties and functionalities of molecules and solids. The exact correlated motion of these particles gives rise to different conductivity, energy storage capabilities, phase transitions, and superconductivity. Now, the team of ICREA Prof. at ICFO Jens Biegert has developed attosecond soft X-ray core-level spectroscopy as a method to observe the correlated interaction between charges and phonons in real time.

Attosecond soft X-ray spectroscopy relies on the use of ultrashort pulses with photon energies that cover the entire water-window range. Through high-order harmonic generation with an intense few-cycle short-wavelength infrared pulse, the team has successfully generated a bright 165 attosecond pulse with photon energies of up to 600 eV. By directing this ultrashort soft X-ray pulse into the sample, the high-energy photons can excite the electrons in the K-shell or L-shell to unoccupied or continuum states.

This soft X-ray absorption spectroscopy provides researchers with a powerful tool for unraveling the electronic and structural characteristics of the material at the same time.

This technique allows for the capture of atomic-scale snapshots with attosecond resolution, offering unprecedented insights into the intertwined behaviors of electrons and phonons. Since understanding the nature of nonequilibrium and correlated interactions is essential for progress in condensed matter science and the design of smart materials with tailored properties, this knowledge serves as the foundation for various applications, including efficient light harvesting, energy storage, and information processing.

The study is published in the journal *Ultrafast Science*.

More information: Adam M. Summers et al, Realizing Attosecond Core-Level X-ray Spectroscopy for the Investigation of Condensed Matter Systems, *Ultrafast Science* (2023). DOI: 10.34133/ultrafastscience.0004

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