Attosecond Chronoscopy of the Photoemission Near a Band Gap of a Single-Element Layered System

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The generation of single isolated attosecond pulses in the extreme ultraviolet (XUV) together with fully synchronized few-cycle infrared (IR) laser pulses allowed to trace electronic processes on the attosecond timescales. A pump/probe technique was used to investigate electron dynamics on surfaces and layered systems with unprecedented resolution.

The attosecond streaking method [1] is the most established technique in attosecond science. Photoelectrons generated by laser-based attosecond extreme ultraviolet pulses (XUV) are exposed to a dressing electric field from well-synchronized laser pulses. The energy shift experienced by the photoelectrons by the dressing field is dependent on the delay between the XUV pulse and the dressing field and makes it possible to measure the respective delay in photoemission between electrons of different type (core electrons *vs* conduction band electrons). The information gained in such experiments on tungsten [2] triggered many theoretical activities leading to different explanations on the physical reason for the delay. Attosecond streaking experiments have been performed on different solids [3,4], leading to different delays – also depending on the excitation photon energy.

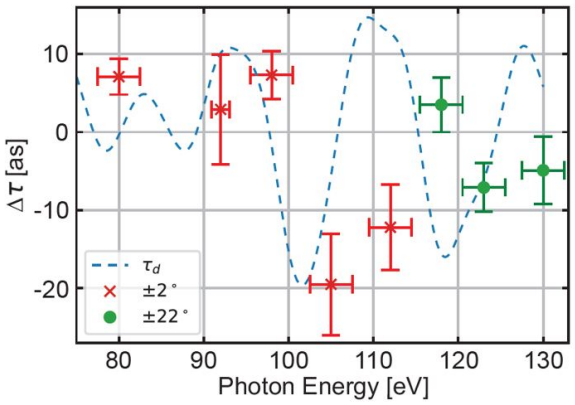

Figure 1: Experimental data (dots/crosses with error bars) and simulation for the relative time delay between p-electrons and s-electrons of the HOPG valence band as a function of excitation energy

Here, we present the fundamental influence of an energetic bandgap on the time delay of the photoelectric effect, i.e. the retardation of electron ejection from a solid after excitation via ultraviolet or x-ray radiation. We achieve this by being the first to investigate the photoemission time delay of a single-element layered system (Highly Ordered Pyrolytic Graphite, HOPG) by attosecond chronoscopy. The reported measurements prove that the timescale of the photoelectric effect exhibits a significant energy dependence if the final energy of the photoelectrons lies in the bandgap region of the investigated solid (Fig.1). Thereby, we can unambiguously attribute the identified energy-dependent phase shifts to the scattering of the photoelectrons at the periodic potential of the crystal, which we explain as the Eisenbud-Wigner-Smith (EWS) time delay. We thus disentangle an important contribution to the complex interplay between electronic structure and the attosecond dynamics of the fundamental light-matter interactions underlying the photoelectric effect. In addition, our experiment opens up the use of attosecond streaking spectroscopy as another technique to identify and characterize band gaps even in the difficult-to-access region of high energies above 80 eV.

References

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