



# PhD Thesis Defense NICOLA DI PALO 'Ultrafast Carrier and Structural Dynamics in Graphite Detected via Attosecond Soft X-ray Absorption Spectroscopy?'

NICOLA DI PALO

March 26, 2020

11:00

Online (Teams)

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Thursday, March 26, 2020, 11:00. Online

**NICOLA DI PALO**

Attoscience and Ultrafast Optics

ICFO-The Institute of Photonic Sciences

Understanding most of the physical and chemical phenomena determining the world around us requires the possibility to interrogate their main characters on their natural scale in space and time. The insulating or conductive behavior of matter, its magnetic properties or the

nature of chemical bonds are strongly dependent on the nuclear and electronic structure of the atoms, molecules or solids considered. Hence, tools are needed to probe electrons and nuclei directly at the atomic scale with a temporal resolution allowing the observation of electron dynamics (on the attosecond-to-femtosecond timescale) and structural dynamics (on the femtosecond-to-picosecond timescale) in real time.

Attosecond science offers unique opportunities to investigate electronic and structural dynamics at the heart of important processes in atomic, molecular and solid-state physics. The generation of attosecond bursts of light, in the form of train of pulses or of isolated pulses, has been achieved on table-top sources by exploiting the high-order harmonic generation (HHG) process. The photons constituting the attosecond emission have energies that range from the extreme ultra-violet (XUV) up to the soft X-ray (SXR) region of the spectrum, allowing to interrogate the electronic structure of the probed material directly at the level of the inner electronic shells. Because of this property of accessing the characteristic electronic structure of the elements constituting the target, XUV and, especially, SXR spectroscopy are considered element-specific techniques. Attosecond pulses have already proven to be able to observe ultrafast phenomena in atoms, molecules or solids previously inaccessible.

In this thesis, the application of time-resolved X-ray absorption fine-structure (XAFS) spectroscopy using attosecond SXR pulses to the study of carrier and structural dynamics in graphite is reported. In chapter 1, an introduction to the field of attoscience and the presentation of the state of the art of ultrafast dynamics in graphite are given. The established technique to generate attosecond pulses is described and a review of the most significant application of attosecond pulses to the study of electron dynamics is presented. The electronic and structural properties of graphite are then discussed, highlighting some of the most representative experiments detecting electron and lattice dynamics.

The experimental setup developed at ICFO in the group of Prof. Dr. Jens Biegert and used for this Ph.D. thesis project is described in details in chapter 2. The system needed for the generation, propagation and detection of the attosecond SXR radiation is presented. The performances of the SXR source in terms of spectral tunability, photon flux and stability are discussed. The implementation of a IR pump - SXR probe scheme is reported, allowing beams' recombination in both collinear and non-collinear fashion. To conclude, the results of an attosecond streaking experiment are presented, through which a temporal characterization of the HHG emission has been achieved.

A discussion on the spectroscopic capabilities of XAFS technique to interrogate the electronic and lattice structure of the observed material is presented in chapter 3. The

potential of this technique has been demonstrated with an experimental investigation of a graphite thin film, with the results showing the possibility to probe the first unoccupied electronic bands and the characteristic distances defining the lattice structure.

Finally, the XAFS capabilities have been exploited in a time-resolved experimental study of graphite to observe light-induced carrier and lattice dynamics, presented in chapter 4. The interpretation of the experimental data reveals insights on the ultrafast interaction of the pump laser field with charge carriers and on the effects of carrier-carrier and carrier-phonon scattering following photoexcitation.

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Thesis Advisor: Prof Dr Jens Biegert

**Hosted by:** Prof. Dr. Jens Biegert



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