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Report on the implementation of new detectors for various applications in attosecond science

Lead Beneficiary: FORTH

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Deliverable Nature	
R = Report, P = Prototype, D = Demonstrator, O = Other	R
Dissemination Level	
PU = Public PP = Restricted to other programme participants (incl. the Commission Services) RE = Restricted to a group specified by the consortium (incl. the Commission Services) CO = Confidential, only for members of the consortium (incl. the Commission Services)	PU

A. Abstract / Executive Summary

The deliverable concerns the development of detectors defined as *XUV optics, detection and diagnostic techniques,* such as detectors for 3D many-particle detection, imaging detectors and coincidence detection of ions and electrons, second-order autocorrelation based techniques for isolated as pulses, XUV surface SHG pulse diagnostics, novel XUV Ramsey type spectroscopic tools. During the implementation of the deliverable several achievements have been made including:

- Full characterization of the polarization state of harmonic XUV radiation exploiting circular dichroism, and specifically molecular frame photoelectron angular distributions measured with COLTRIMS
- Observation of spatially resolved two XUV photon ionization of He towards single shot attosecond pulse characterization
- Modeling and assesement o single shot 2nd order XUV autocorrelator geometries
- Realization of an ultra-stable vacuum Michelson interferometer for enhanced resolving power of Ramsey-type spectroscopy in the XUV
- Development of an XUV imaging detector with spectral and spatial resolution and use of it in the study of harmonic generation
- Development of an angle-resolved time-of-flight detector for attosecond photoelectron spectroscopy

B. Deliverable Report

1 Introduction

Advanced XUV and attosecond sources have been developed in recent years and keep being continuously improved in the last decade. Source parameters such as spatiotemporal coherence, beam profiles, photon energies, pulse durations and pulse energies but also characterization instrumentation and techniques have made significant progress in a concerted action of several laboratories. I parallel notable progress has been made in advanced XUV spectroscopic approaches, which utilize the above XUV sources both in the spectral and time domain, in part as a result of joint research activities of collaborating research groups and institutions. Further improvement of these sources and related spectroscopic tools, require the development of innovative XUV optics, detection and diagnostic techniques. These developments is the subject of the present deliverable.

2 Objectives

Design, production and testing of ***as*** XUV optics in order towards shaping spectrally/temporally ***as*** pulses. Development of autocorrelation-like techniques and comparison with other measurement techniques. Development of laser imaging of atomic and molecular processes. Advancement of 3D-recoil of correlated electrons and ions. Development of new schemes alternative to frequency combs to provide high-spectral resolution in the XUV by Ramsey or Fourier Transform spectroscopic techniques with HHG. Development of single shot XUV characterization techniques as well as non-linear processes, 2nd order autocorrelation based on split-mirror and ion imaging, and 2-XUV-photon FROG.

3 Work performed / results / description

In the framework of the implementation of new detectors for various applications in attosecond science, in collaboration with Institut des Sciences Moléculaires d'Orsay (ISMO), **CEA-LIDyL-SLIC [**Note : SLIC (Saclay Laser-matter Interaction Center) is the name of the laser facility at Laboratory Interactions, Dynamics and Lasers (LIDyL). CEA-LIDyL-SLIC is official partner #3 of Laserlab under SLIC acronym] has undertaken photoionization (PI) studies for fully characterizing the polarization state of the high harmonic radiation from

various generating media (SF_6, N_2 molecules) using the PLFA XUV beamline at SLIC. The "molecular polarimetry" method [Veyrinas et al, 2013] exploits circular dichroism in PI of linear molecules, and specifically molecular frame photoelectron angular distributions (MFPAD) using COLTRIMS electron/ion spectrometer of ISMO. In particular, it allows quantifying the possible depolarization of light. In the above research the following persons have been involved: Sébastien Weber (postdoc), Vincent Gruson (PhD), Lou Barreau (PhD), Pascal Salières

Furthermore a new multi-particle time and position sensitive detector, previously developed by Institut des Sciences Moléculaires d'Orsay (ISMO) and Université de Louvain-la-Neuve (UCL), has been successfully tested for electron detection, using the PLFA XUV beamline at SLIC and the COLTRIMS electron/ion spectrometer of ISMO. Persons involved in the above research are: Marie Géléoc, Sébastien Weber (postdoc)

CNRS-CELIA implemented an imaging system providing both spectral and spatial resolution on a single shot basis and has observed many spatio-spectral structures in the XUV harmonic beam that are the signatures of spatio-temporal coupling during the generation process. The prominent spatio-spectral structures observed at CELIA have been further studied with the single shot, spectrally and spatially resolved detection system. They have been interpreted as the signature of the evolution of the generating medium on the few femtosecond time scale.

FORTH in collaboration with **MPQ** has achieved to measure spatially resolved two-XUV-photon ionization of He atoms, a central prerequisite towards single shot 2nd order autocorrelation. Furthermore FORTH in collaboration with **MPQ** has developed a method for the spatially resolved monitoring of the HHG process. The approach has been used in the observation of quantum path interferences of recolliding electron wavepackets and the measurement of travel time and trajectory length differences between the long and short trajectories. Additionally **FORTH** using an non-linear XUV autocorrelator/delay line has demonstrated the first XUV-pump-XUV-probe study of 1fs scale molecular dynamics. Finally **FORTH** in collaboration with **MPQ** has modelled and assessed geometries of a single shot non-linear XUV autocorrelator. This research results have been obtained by the following persons: P. Tzallas, P.A. Carpeggianni, D. Gray, G. Kolliopoulos, E. Skantzakis, D. Charalambidis.

LENS realized an ultra-stable vacuum Michelson interferometer with large (meter range) and controlled (nm accuracy) arm unbalancing for the production of accurately time-delayed pulses at 800nm. The positioning accuracy and stability of the system is designed to significantly enhance the resolving power of Ramsey-type spectroscopy in the XUV with high-order harmonics produced by such time-delayed pump pulses. M. Bellini, C. Corsi, S. Cavalieri, R. Eramo and I. Liontos have implemented the above project.

In a collaboration with **TU München**, **MPQ** is setting up an angle-resolved time-of-flight detector for attosecond photoelectron spectroscopy. The detector is tested and is part of a UHV attosecond beamline for time resolved investigation of electron transport in solids and surfaces.

4 Conclusions

Methods for (i) the full characterization of the polarization state of high and (ii) for XUV-pump-XUV-probe studies of 1fs scale dynamics have been experimentally demonstrated. Towards single shot non-linear autocorrelation of attosecond pulses (i) an approach and set up has been modelled and assessed and (ii) spatially resolved two-XUV-photon ionization of He has been experimentally demonstrated. An imaging system with spatial and spectral resolutions is successfully implemented, a "detector" (method and apparatus) of electron trajectory interference has been experimentally demonstrated and an angle-resolved time-of-flight detector for attosecond electron spectroscopy is constructed and tested.

5 References

Molecular polarimetry: complete determination of the state of elliptically polarized light by electron-ion vector correlations K. Veyrinas, C. Elkharrat, S. Marggi Poullain, N. Saquet and D. Dowek, R.R. Lucchese, G.A. Garcia and L. Nahon, Phys. Rev. A 88, 063411 (2013)

6 Publications

(Publications resulting from the JRA need to indicate DOI and whether open access will be/is granted (yes/no). Remember the obligation to acknowledge EC support through Laserlab-Europe, EC-GA 284464)

"A zero dead-time multi-particle time and position sensitive detector based on correlation between brightness and amplitude", Urbain X, Bech D, Van Roy J-P, Géléoc M, Weber SJ, Huetz A and Picard YJ, Review of Scientific Instruments. Vol. 86(2), pp. 023305 - (2015), doi: 10.1063/1.4908597

“An ultrastable Michelson interferometer for high-resolution spectroscopy in the XUV”
C. Corsi, I. Liontos, S. Cavalieri, M. Bellini, G. Venturi, and R. Eramo, Optics Express, 23, 4106-4113 (2015). DOI: 10.1364/OE.23.004106

“Disclosing intrinsic molecular dynamics on the 1-fs scale through extreme-ultraviolet pump-probe measurements” P. A. Carpeggiani, P. Tzallas, A. Palacios, D. Gray, F. Martín and D. Charalambidis, Phys. Rev. A89, 023420 (2014)
DOI: http://dx.doi.org/10.1103/PhysRevA.89.023420

“Single-shot autocorrelator for extreme-ultraviolet radiation” G. Kolliopoulos, P.Tzallas, B. Bergues, P. A. Carpeggiani, P. Heissler, H. Schröder, L. Veisz, D. Charalambidis and G. Tsakiris. J. Opt. Soc. Am. B 31, 926 (2014) DOI: 10.1364/JOSAB.31.000926

“Revealing quantum path details in high-field physics” G. Kolliopoulos , B. Bergues, H. Schröder, P. A. Carpeggiani, L. Veisz, G. D. Tsakiris, D. Charalambidis and P. Tzallas Phys. Rev. A90, 013822 (2014) DOI: http://dx.doi.org/10.1103/PhysRevA.90.013822