Coherent control and attosecond spatial interferometry in the extreme ultraviolet range

G. Sansone[*][†][1]

[*] Dipartimento Fisica Politecnico Milano, Piazza Leonardo da Vinci 32, 20133 Milano Italy
[†] Physikalisches Institut Albert-Ludwigs Universität Stefan-Meier-Str. 19 79104 Freiburg, Germany

Exploitation and manipulation of the the amplitudes and phases of quantum paths connecting the same initial and final states is a well-studied and widely-implemented approach to control the outcome of quantum processes. The application of coherent control schemes in the extreme ultraviolet (XUV) and X-ray spectral range was so impossible, due to the lack of coherent multi-color sources in these energy domain. With the operation of the first seeded-Free Electron Laser (FEL) [1], XUV pulses with these characteristics become available and open the way for the first demonstration of coherent control of the photoionization process in neon atoms [2]. In the experiment the combination of the first (20 eV) and second harmonic (40 eV) of the FEL FERMI (Elettra, Trieste) were jointly used to photoionize neon atoms either through a single-photon or a two-photon process. The different symmetry of the final states reached by the two pathways corresponds to a preferential emission direction, which can be controlled by changing the relative phase between the two harmonics. We will present additional ideas and schemes on how extending this concepts for the synthesisation and measurement of fully controllable attosecond waveform using FERMI.

Two-source interferometry is a widely used technique due to its sensitivity. We recently applied this technique to the extreme ultraviolet range using pairs of isolated attosecond pulses to retrieve the full electric field of few-cycle pulses with a complex time-dependent ellipticity [3]. Two closely spaced isolated attosecond pulse were generated using a binary plate and the polarisation gating technique. The *weak* infrared pulse to be characterised was overlapped with one of the spot. The perturbation induced on the generation of one of the two attosecond pulses is registered in a change of modulation depth (amplitude) and in the shift (phase) of the XUV interference pattern measured in the far field. By changing the relative delay between the pair of isolated attosecond pulses and the unknown field, we demonstrate the full reconstruction of pulses with an energy as low as few tens of nanojoules. We will also present experimental evidences that only the component of the unknown electric field parallel to the motion of the electronic wave packet leading to the generation of the isolated attosecond pulses, can effectively perturb the characteristics of the emitted XUV radiation. Therefore, the electronic motion in the continuum acts as an attosecond directional filter, which allows one to sample unknown fields with a temporal resolution of few hundreds of attosecod along a controllable direction. This experimental observation is fully confirmed by theoretical simulations based on the Strong field Approximation and on the Lewenstein Model [4, 5].

Combining the electric field reconstruction along two (perpendicular) directions, we will present measurements demonstrating the full three-dimensional of few-cycle electric field presenting a complex polarisation pattern.

These results pave the way for the full reconstruction of the weak laser pulses usually implemented in infrared and visible spectroscopy.

References

[1] E. Allaria *et al.* 2012 *Nature Photon.* **6** 699-704

[2] K. Prince *et al.* 2016 *Nature Photon.* **10** 176-179

[3] P. Carpeggiani *et al.* 2017 *Nature Photon.* **11** 383-389

[4] M. Lewenstein *et al.* 1994 *Phys. Rev. A* **49** 2117

[5] G. Sansone *et al.* 2004 *Phys. Rev. A* **70** 013411

[1]E-mail: giuseppe.sansone@polimi.it; giuseppe.sansone@physik.uni-freiburg.de