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Editorial

Emerging attosecond technologies

Guest editors
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Abstract

The quest for fundamental scientific knowledge triggers technological advancement. This has been particularly true for attosecond science in recent years: we assisted in the development of many new approaches—both experimentally and theoretically—that will have a high impact, not only on atomic and molecular physics, but also on optical technology. This special issue collects several of these contributions.

Attosecond science [1] studies the motion of electrons on their natural timescale, which is typically of the order of attoseconds (1 as $= 10^{-18}$ s). Since the first demonstration in 2001 [2, 3], this research field has grown exponentially and it has captured the attention of the scientific community with the exciting promise of deepening our understanding of fundamental processes occurring in atoms and molecules. This field has already provided a number of seminal experiments, including the measurement of Auger decay [4], autoionization [5], time-delay in photoionization [6, 7], electron re-collision [8, 9], electronic superpositions [10] and charge migration in molecules [11] among others.

Attosecond science relies on the generation of attosecond pulses through the process of high-order harmonic generation (HHG). High-order harmonics are generated due to the strong nonlinear interaction when an intense laser pulse is focused in a gas medium and very high odd-order harmonics of the driving pulse frequency can be generated [12, 13]. This nonlinear interaction leads to the production of a train of light bursts in the extreme ultra-violet (XUV) spectral region with attosecond duration [14]. Commercial table-top HHG sources nowadays generate a coherent flux of XUV photons comparable to synchrotron sources with higher peak brightness. The pulses in the attosecond pulse train generated through HHG are separated by half of the period of the driving electric field. For probing electron dynamics, it is often necessary to isolate a single pulse in the train and synchronize it with another optical pulse. This is done by isolating a single emission event for the driving pulse in the HHG process. Different schemes have been demonstrated for gating the HHG process, i.e. isolating a single ionization event, in order to achieve the generation of isolated attosecond pulses. The selection of one emission event can be achieved in different ways, notably by spectral [15] or temporal gating [16, 17].

Until a decade ago, Ti:sapphire lasers were the only sources available for the exploration of molecular dynamics in the few-femtosecond and attosecond regime, because of their unsurpassed amplification bandwidth, which allowed intense pulse compression down to the single-cycle domain [18]. Because both the maximum photon energy in the harmonic spectrum and the spectral bandwidth of the attosecond pulse increase as the square of the driving field wavelength, longer driving wavelengths extend the HHG cutoff up to the water window (300–500 eV) and beyond [19–21]. State of the art isolated attosecond pulses as short as 50 as have been generated in this spectral range.

Due to the increase of knowledge that attosecond science may provide in fundamental molecular processes, it is also one of the strategic areas of investments by the European Community. The Extreme Light Infrastructure is a European Strategy Forum on Research Infrastructures ESFRI project for the

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investigation of light–matter interactions at highest intensities and shortest time scales and the Hungarian pillar is completely devoted to attosecond science [22].

Recently, several exciting new routes have been explored in attosecond science. The study of chiral molecules has been allowed by the manipulation of HHG polarization and the generation of circularly polarized harmonics [23, 24]. Attosecond pulse trains and isolated attosecond pulses have allowed transient absorption and reflection measurements with extreme temporal resolution. In this framework, one of the 'hot topics' is indeed the study of electron dynamics in solids, such as the real-time study of electron transfer from valence to conduction band in semiconductors [25, 26], the electron and hole dynamics in germanium [27] and the core-exciton dynamics in SiO_2 [28].

Experiments on solids are complemented by another emerging hot-topic regarding the interaction of intense fields with crystals. In recent years, many strong-field phenomena occurring in gases have indeed been observed to occur in solids too, such as strong-field excitations leading to field-controlled ultrafast currents [29] and the generation of high-order harmonics [30, 31].

Last but not least, the demonstration of very short pulses down to the attosecond regime is expected to happen at free electron lasers (FELs) soon, following the demonstrated operation of FELs in the single-spike mode [32].

All these exciting advances in attosecond science would not have been possible without cutting edge technological developments in the driving laser sources and in the approaches for the generation and detection of HHG and isolated attosecond pulses. Furthermore, a strong effort is needed for the interpretation of these very complex experiments. This special issue is devoted to the most recent and intriguing developments in these attosecond technologies.

The first crucial aspect that is addressed here is the next generation driving sources for strong field applications [33–37]. New approaches for high order harmonic generation and detection [38, 39], recent developments in the generation and characterization of attosecond pulses [40, 41] and the emerging role of FELs in the attosecond framework [42, 43] are also presented.

A large section of the special issue is finally devoted to the discussion of innovative approaches for studying attosecond dynamics [44–56].

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