Modeling Attosecond Pulse Formation in Strongly Ionized Gaseous Media

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Synopsis: We present the results obtained in modeling single attosecond pulse (SAP) as well as attosecond pulse trains (APT) formation as a result of femtosecond laser pulse interaction with rare gas atoms. A non-adiabatic model is used for solving the laser and harmonic field propagation, while strong field approximation is used to calculate the single dipole response. Quantum trajectories of the electron are generated and their phases are used in a time-dependent phase matching analysis. The role of the propagation can be beneficial in SAP generation as it contributes to the elimination of spurious bursts. APT characteristics will bear the signature of the distorted laser field, which will generate less, shorter and shifted to earlier time wagons.

High-order harmonic generation (HHG) is taking place when an atom/molecule is ionized by a high intensity laser field, and, after acceleration in the laser field, the electron recombines with the core to emit a harmonic burst of radiation [1]. Depending on experimental conditions the radiation is emitted either in a single attosecond pulse (SAP) or in successive bursts developing an attosecond pulse train (APT) synchronized with the optical cycle of the laser pulse.

In performing this study we first had in mind that HHG is most frequently investigated from the perspective of the single atom effect, while it is intrinsically a macroscopic process. For example the formation of the attosecond pulses in a gas jet/cell can be viewed as a coherent sum of many individual transient phenomena *i.e.* the atomic dipole bursts. As dipoles emit all over the interaction region with different amplitudes, durations and phases, it is essential to understand the role of single atom response and the role of collective effects in building the macroscopic signal which, in the end, is available from experiments.

In line with the above, we recently investigated the mechanism of formation of APT and SAP in strongly ionized gases by using a three dimensional non-adiabatic model [2] in which the propagation equation for the laser and the harmonic field are solved numerically by using the Fourier transform method and the strong field approximation for the single dipole response. A classical trajectory calculation was also used to study the phase matching and APT formation in the far field. The present results are obtained by generating the quantum trajectories of the electron using the saddle point equations.

In studying SAP formation we show that the atomic dipole emission (ADE) developed during laser-atom interaction is quite different from the final harmonic field. In particular, in the polarization gate schemes studied by us [3] ADE is composed of three or more bursts of radiation. We found that phase matching and three-dimensional (3D) propagation effects contribute to cleaning the total harmonic emission so that SAP can occur in the macroscopic medium.

For longer laser pulses ADE is depending on the optical cycle in which the process takes place, as the driving intensity is changing from cycle to cycle. Moreover, not only the dipole emissions but also the phase matching conditions are different for different optical cycles and depend on the spatial position, so that the intensity and emission properties of the resultant harmonic field are different for different pulses in the APT and for different locations in the interaction region. In these conditions, the process of APT formation is found to be the result of an interlace among the driving laser field, single atom response, phase matching effects in the near field and burst interference in the far field. The computed results compare very well with the FROG measurements. This enables us to understand better the underlying physics and to draw useful conclusions concerning the optimization control of the spectral, temporal and intensity characteristics of the APT.

References

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