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Optimal Control of High-Harmonic Generation

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Abstract. A static electric field added at each spot of the interaction region controls high-order harmonic generation. The method is all-optical and susceptible to feedback-loop control schemes.

We show that high-harmonics can be selectively enhanced using a quasi-phase matching (QPM) scheme based on the single-atom microscopic dipole phase modulation. We use spatial distributions of dc electric fields to shape the laser field at each spot of the interaction volume [1, 2]. By tracking the coherence length variation of the different harmonics along the propagation direction, specific harmonics near the cutoff region can be enhanced.

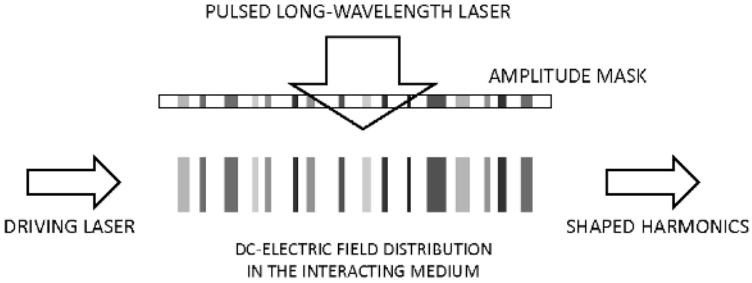
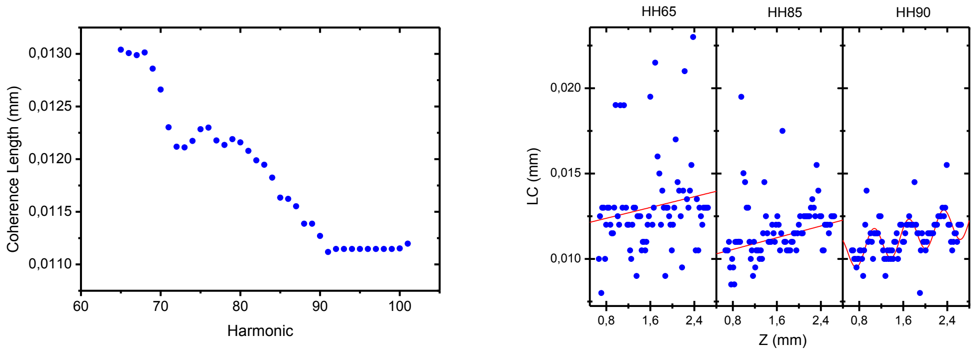


Fig. 1. Schematic illustration of a static-electric-field distributed along the driving pulse propagation direction. A pulsed long-wavelength laser - such as e.g. a pulsed terahertz or CO_2 laser, is sent through an amplitude mask whose amplitude pattern generates the desired field distribution. Both the long-wavelength laser and the driving laser are linearly polarized in the direction orthogonal to the plane of the figure.

In [2] it was shown that a periodic weak dc electric field configuration added to the interaction volume in a high-order harmonic generation process controls the phase of the short and long quantum electron trajectories generating the harmonics, which results in a macroscopic QPM effect. We observed that only the long trajectories contribute to the enhancement of the harmonics on axis in the plateau region, so that a filtering effect of the two main path contributions in that region is obtained.

The results commented above have been optimized in the present contribution by tracking the change of the coherence length of different harmonics along the propagation direction. We have considered a laser pulse linearly polarized with Gaussian temporal and spatial distributions of 5 fs and 40 μm diameter of focus (FWHM), and central wavelength of 800 nm, which propagates in a capillary filled with neon at 20 mbar. In Figure 2 (a) we show the coherence lengths of the harmonics which have been averaged along a propagation of $z = 2$ mm. Near the cutoff region (≃ 140 – 160 eV) the mean value tends in this case to ≃ 11.2 μm.



(a) (b)

Fig. 2. (a) Averaged coherence length for a propagation of z=2 mm. (b) Coherence length for some harmonics along propagation together with different fits (red lines).

The variation of the coherence length of some harmonics along the propagation direction is shown in Figure 2 (b). Its behavior can be fitted with a linear regression for the harmonics in the plateau region and with a sinusoid for the harmonics near the cutoff [red lines in Figure 2 (b)]. Indeed, we observe that the evolution of the coherence length along propagation becomes progressively oscillatory as the harmonics enter the cutoff region. Also, we observe that it tends to increase in average along the propagation direction, as shown by the positive slope of the different fits. By tracking this specific coherence length variation with the appropriate dc electric field spatial distribution we demonstrate that different regions of the harmonic spectrum can be selectively enhanced.

In the simulations shown in Figure 3, we have considered a dc electric field pattern with a spatial periodicity along the propagation direction that matches the linear fits obtained for several harmonics. In this case the ratio between the dc electric field and the driving pulse peak amplitude is $\beta = 0.0075$, and we have considered a propagation such as $z = 2$ mm. The black line shows the enhancement obtained with constant spatial dc electric field periodicity.

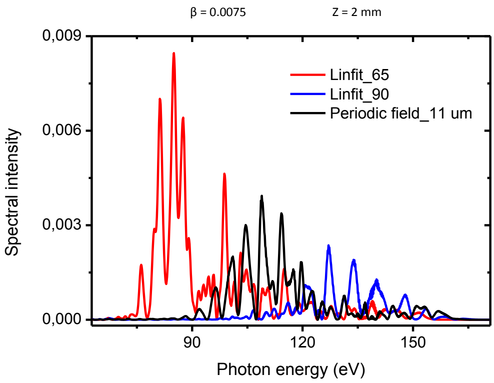
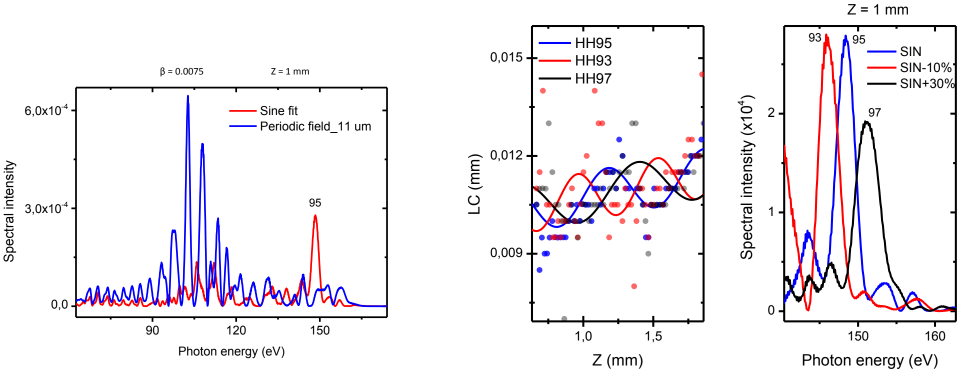


Fig. 3. Tuning of the enhanced region by using a linear fit.

The selection of a particular harmonic can be obtained near the cutoff region by using a sine function to fit the evolution of the coherence length of the harmonics in that region. In Figure 4 (a) the enhancement of the harmonic 95 at z = 1 mm is shown (red line). The blue line shows the spectrum obtained when a dc electric field distribution of constant periodicity is used instead.

We finally show the tuning possibilities of this control method by fine-adjusting the period of the sine fit for the harmonics near the cutoff. Figure 4 (b) shows the coherence length variation of the harmonics 93, 95 and 97, together with different sine-fits that have been considered (left panel). In the panel at right, the resulting frequency shifts of the enhanced region of the spectrum are shown.



(a) (b)

Fig. 4. (a) Specific enhancement of the harmonic 95 obtained by using a sine fit. (b) Tuning of the enhanced harmonic by fine-adjusting the period of the sine fit.

We have thus presented a coherent control scheme for the generation of high-order harmonics that is based on adding a dc electric field spatial distribution along the interaction region. The strength of the applied dc-field is sufficiently weak so that the quantum phase of the electrons travelling to the continuum in the high-harmonic generation process is mainly affected. By tracking the variation of the coherence length of the different harmonics along the propagation direction, high-selectivity on the QPM-based enhancement has been obtained in our numerical simulations.

References

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2. C. Serrat, “Control of high-order harmonics for attoscience using a static-electric-field pattern”, Phys. Rev. A **84**, 061803(R) (2011).