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Tomography of High-Harmonic Generation and Direct Phase-Matching Condition Measurement

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High-harmonic generation (HHG) from laser-irradiated gas target has been demonstrated as ultrashort coherent extreme-ultraviolet or soft x-ray source. The emission of high energy photons is due to the bound electrons in the atoms driven by the intense laser field to ionization, acceleration, and then recombination [1]. In addition to the single-atom response, the phase matching between the driving laser field and the harmonic field affected by various dispersion effects critically determines the overall conversion efficiency. Several methods had been demonstrated to achieve phase matching in the weak ionization regime.

In this paper, we demonstrate a tomographic measurement based on transverse selective zoning method [2] to investigate the growth of HHG yields as the interaction length increasing. Furthermore, the 3-D phase-matching profiles due to the neutral gas dispersion, plasma dispersion, geometrical phase shift, and intrinsic dipole phase variation are calculated from the individual measurements of local Ar gas density, plasma density, and driving pulse beam profile. To verify the tomographic measurement, a concise simulation on the basis of the phase-matching profiles is performed to reconstruct the HHG conversion process including the emission and the propagation, which reproduces the HHG growth curve and the far-field beam profiles precisely. Both experiment and simulation results indicate that the HHG yields increase monotonically with the interaction length increasing under the phase-matching condition and the major contribution of HHG yield is from the short-trajectory emission at the central region of the driving laser beam.

Figure 1 shows the experiment setup including the four diagnostic tools: (1) Forward relay image system; (2) 2-D EUV spectrometer; (3) Wavefront sensor and (4) HHG tomography.

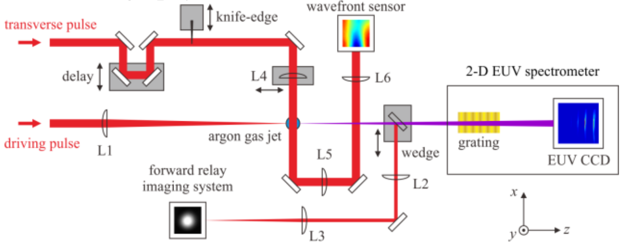

Figure 1. Experiment setup.

Based on the selective-zoning method, a transverse disruptive pulse scrambles the phase of the driving pulse to suppress the HHG emission. By adjusting the exposure area of disruptive pulse on the gas jet, the interaction length of HHG process can be tuned to achieve the tomography of HHG, as shown in Fig. 2 (a). Figure 2 (b) shows the spectra with and without the disruptive pule. For HHG q=27, 94% of signal is suppressed due to selective-zoning method. Furthermore, the measurements of driving pulse profile before and after the gas jet by the relay image system and the measurements of gas density and plasma density by wavefront sensor help us to calculate the total phase accumulation due to neutral gas dispersion, plasma dispersion, geometrical phase shift and intrinsic dipole phase variation, as shown in Fig. 2 (c). Hence, we can reconstruct the HHG process in the gas jet. The experiment and simulation results are shown in Fig.2 (d).

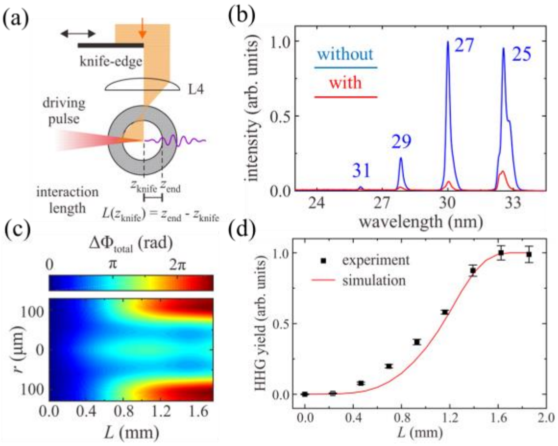

Figure 2. (a) Illustration of selective-zoning method; (b) the vertical summation of HHG spectra with and without the transverse beam; (c) The total phase accumulation; (d) The HHG tomography and the simulation result under the condition of driving pulse intensity $I = 1.05 \times 10^{15}\ \mathrm{W/cm^2}$ and backing pressure $P = 75$ psi.

The results indicate that the phase-matching conditions along the longitudinal propagation direction and across the driving pulse transverse profile are both non-uniform, which affect the overall growth of the harmonic yield and determine the final far-field beam profile. The detailed information and understanding benefit the exploration of HHG for shorter wavelength and higher efficiency by quasi-phase matching of HHG.

Reference

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