Statistical analysis of pump-pulse propagation in gas-filled capillaries for high-harmonic generation

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Driving high-harmonic generation (HHG) with ultrashort pulses confined to gas-filled capillaries is an efficient method of generating extreme ultraviolet and x-ray radiation. In-situ pulse compression can significantly enhance HHG efficiency [1] but requires operation in the high-ionisation limit, leading to high sensitivity to initial conditions and causing the Gaussian driving pulse to break up into a train of subpulses as it propagates. Our previous studies [1,2] have focused on the most intense subpulse, which can be very short (<10 fs). Here, we perform statistical analysis of all pulse components predicted by numerical simulation, including the contribution of the weaker subpulses, with the aim of predicting generated HHG profiles.

First, a numerical algorithm identifies the significant subpulses in the driving pulse intensity distribution. This allows for the collection of subpulse statistics (spatio-temporal distribution, compression level, peak intensity, etc.). Selecting only subpulses exceeding the semiclassical intensity threshold for the generation of specific harmonics identifies where and when in the capillary different harmonics can be generated. Second, we analyse the phase of the driving field corresponding to these subpulses. By overlaying the aforementioned intensity-based thresholding onto the phase profile, one can quickly identify the level of phase matching in regions that have high enough intensity to generate harmonics. We investigate the parameter dependence of these statistical measures and show that while instantaneous driving pulse profiles are highly parameter-sensitive the statistical properties are smooth. In a next step, we will combine our pump-propagation analysis with a semiclassical model of HHG to predict the generated high-harmonic spectrum.

[1] T.J. Butcher et al., Phys.Rev.A 87, 043822 (2013)

[2] P.N. Anderson et al., Phys.Rev.A 89, 013819 (2014)