Capillary-Based High-Harmonic Generation Driven by Different Laser Systems

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High-harmonic generation (HHG), where a short-pulse high-power laser ionises a gas which upon recombination emits high energy radiation, is an exciting option for table-top sources of coherent X-rays and XUV light for imaging and spectroscopy. Traditionally, the pump lasers have been femtosecond Ti:Sapphire lasers. As more high-power ultrafast pump laser systems are becoming commercially available, for example fibre lasers and wavelength shifted systems based on OPAs, it is important to understand how their different operating regimes (wavelength, pulse length, peak power, repetition rate) affect HHG efficiency and flux.

We use large scale computer simulations on an HPC cluster to investigate these effects on HHG in gas-filled capillaries where the extended interaction length leads to coherent build-up of high harmonic radiation [1] but at the same time dispersive and nonlinear pump propagation effects can significantly alter the pump pulse depending on the laser parameters. Our numerical model includes pump pulse propagation via a multimode nonlinear Schrödinger equation [2], HHG at every point in the capillary via a time-dependent wavefunction Schrödinger equation, and high harmonic propagation to the end of the capillary via a spectral method.

Fig.1 shows some samples of our simulation results. Here, three pump sources are compared: a Ti:Sapphire [3], a frequency doubled Ti:Sapphire [4], and a mid-IR OPCPA pumped by an Yb:YAG laser [4]. Our simulations show clearly how the nonlinear distortion, ionisation-induced blue shifting, and capillary-mode dispersion of the pump pulse lead to broadening, energy shifting, and intensity oscillations of the generated harmonics, respectively. Thus, different harmonic spectra are generated depending on the position within the capillary and are subsequently further modified by the energy-dependent re-absorption during propagation. We also note the different spacing of harmonic orders for different pump wavelengths and the varying cut-off energies of the harmonic spectra which scale with peak pump intensity and the square of pump wavelength ($E_{cutoff} \sim I\lambda^2$). All these effects contribute to generate significantly different dynamics of HHG for different pump sources.

In conclusion, we analyse the performance of capillary-based HHG for a range of different pump laser systems (three of which are shown in Fig.1). Our a priori simulations give insight into the different pump pulse propagation dynamics, HHG efficiencies, and identify spatial and spectral effects in this highly nonlinear system. The simulations thus provide essential guidance for the optimised design of future HHG systems.

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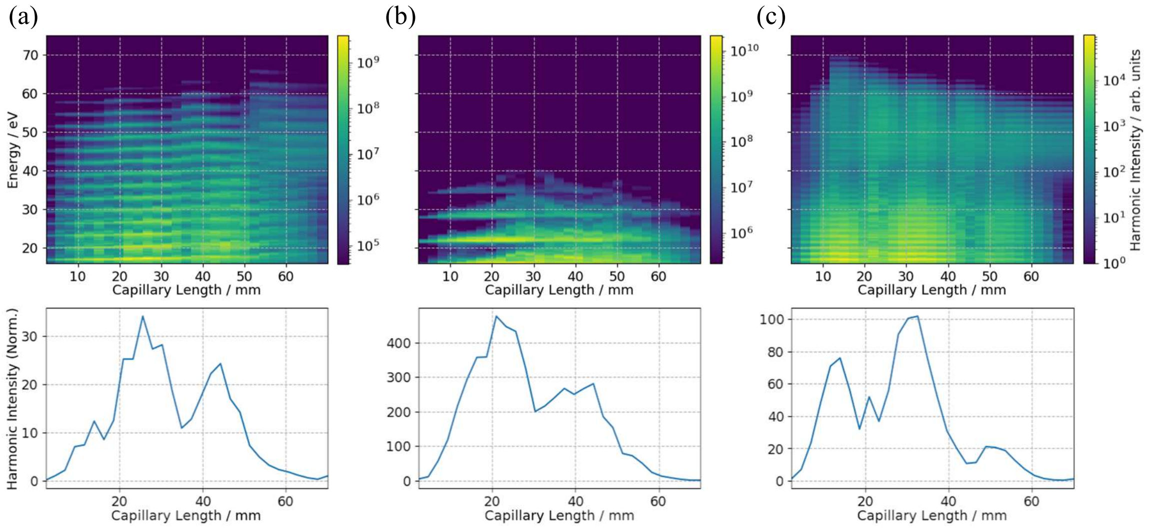

Fig. 1. High-harmonic spectra depending on position in an argon-filled capillary (7cm, 150μm diameter) (top row) and radially integrated harmonic power in 20-45eV normalised to capillary output (bottom row) for three different pump laser systems: (a) Ti:Sapph (800nm, 50fs, 1mJ, 1kHz), (b) frequency-doubled Ti:Sapph (400nm, 40fs, 2mJ, 1kHz), (c) mid-IR OPCPA laser (1700nm, 50fs, 0.17mJ, 100kHz).

References

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