High-power laser pulse compression for optimized high-harmonic generation in short hollow fibers

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High-harmonic generation (HHG) driven by high-power femtosecond lasers is a promising route towards tabletop sources of coherent radiation at extreme ultraviolet (XUV) and soft X-ray wavelengths. In order to maximize conversion efficiency and to obtain attosecond pulse lengths of the harmonics, pump pulse lengths down to the few-cycle regime are required. Traditionally, this has been achieved by nonlinear spectral broadening in gases and subsequent dispersion compression or by self-compression in laser-induced filaments. Here we investigate an alternative method that is simpler to implement experimentally, based on multimode non-linear propagation effects in short, centimeter-length, gas-filled hollow fibers operating in the high-ionization regime.

We use an advanced multimode generalized nonlinear Schrödinger equation that includes ionization and plasma effects to simulate pulse propagation in such a system [1]. We show how plasma defocusing and modal interference effects lead to spatio-temporal compression of 50-fs input pulses to the few-cycle regime. The simulations predict that highly compressed pulses are generated and maintained for significant propagation distances over a wide range of parameters such as input pulse energy, gas pressure, and capillary diameter. We also extend the scheme to novel wavelengths and driving pulse lengths. As an example, we demonstrate how few-hundred femtosecond pulses from a state-of-the-art high repetition rate fiber laser can be compressed in hollow-core fibers by reducing the core diameter. Microstructured hollow core fibers provide significant advantages in this situation compared to capillaries by allowing us to reduce the propagation losses by orders of magnitude.

Based on our simulations we have recently implemented an improved design of our experimental setup for investigating HHG in short capillaries. This has resulted in a 40-fold increase of the observed flux of generated high-harmonic radiation around 29 nm wavelength reaching up to 1.5×10^9 photons per pulse [2].

In a next step, we are now combining our model of pump pulse propagation with simulations of the time-dependent Schrödinger equation of the electron wavefunction of single gas atoms [3]. While this is an extremely demanding problem computationally, it will provide a full 3+1 dimensional ab-initio model of HHG in hollow fibers. Preliminary results predict that isolated attosecond XUV pulses can be generated on-axis using the pulse compression technique described above where both pump compression and HHG occur within the same short (4 cm long) hollow fiber.

References

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