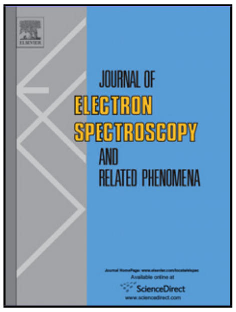

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Development of a high-flux XUV source based on high-order harmonic generation

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Highlights

- Experimental results on high-order harmonic generation in different focusing geometries have demonstrated that the medium length which provides efficient harmonic generation is close to Rayleigh range of the focused beam.
- Energy on target for optimal harmonic generation as well as medium length scale as f-number squared, while optimal pressure is inversely proportional to second power of f-number.
- The divergence of generated beam is inversely proportional to f-number.
- Regardless f-number conversion efficiency of generation process is constant for particular gas species and fixed pulse duration and central wavelength of driving laser in optimized phase-matching conditions.

Abstract

An experimental study of the scaling laws for optimal driving conditions and output properties of the beam generated through high-order harmonic generation on the f-number of laser focusing is presented. Alteration of experimental parameters for focal lengths from 0.3 m to 5 m, in optimal conditions for phase-matching (in terms of driving laser intensity, gas cell length and gas pressure) was carried out, enabling the experimental verification of the scaling laws for output parameters, such as XUV pulse energy, conversion efficiency and divergence of the harmonic beam. In order to improve the yield of the harmonic signal, allowing the source to become convenient for applications that require pulses with high photon numbers, a loose focusing geometry with high peak-power driver pulses was implemented. A high harmonic beam with energy up to 40 nJ per pulse was generated in Ar with a focal length of 5 m. Application of the scaling laws verified within this study allows the estimation of parameters for a future high harmonic source that is being implemented at ELI Beamlines facility.

Keywords
High harmonic generation; HHG; laser; XUV radiation; phase-matching; conversion efficiency

1. Introduction

Development of coherent light sources is of much interest since it allows researchers to carry out wavelength-limited imaging and observation of various characteristics of matter, exploiting the coherence properties of light. In view of this, designing such sources in the extreme ultraviolet (XUV) spectral domain is a very attractive proposition as it has the potential to probe various effects in physics, biology or chemistry at nanometer-scale. Highly nonlinear interaction of intense femtosecond laser pulses with matter leading to high-order harmonic generation (HHG) is one of the possible means to generate such radiation. A major benefit of sources based on HHG lies in their compactness and low cost, enabling wide availability for researchers.

Besides the high degree of coherence, HHG exhibits collimated beams [1] with Gaussian-like transverse energy distribution and a nearly diffraction-limited wavefront [2], allowing an efficient focusing of the light onto the samples to investigate their characteristics or engineer their structure. Moreover, the emitted radiation is fully polarized and the state of polarization can be tuned [3].

From a spectral point of view, high harmonic emission has been demonstrated over a very wide range of wavelengths from tens of nanometers to a few angstroms [4]. The wavelength can be noticeably tuned, which enables it to meet the requirements of a broad scope of applications. Additionally, those sources can deliver ultrashort pulses that have been demonstrated down to the attosecond range (1 as = 10^{-18} s) [5] making it possible to get an insight into the ultrafast dynamics of matter at the nanometer scale. Moreover, these ultrashort coherent XUV sources allow the monitoring of transient elementary processes in atoms and molecules occurring on the sub-femtosecond timescales. Other possible applications include ultrafast magnetization effects [6] and molecular physics [7].

Depending on the technology of the laser driver, HHG sources can be operated in single shot mode or at very high repetition rates. The first mode of operation makes it possible to conduct pump-probe experiments with samples that are non-renewable, whereas operation at high repetition rates favors studies (such as spectroscopy) where accumulation of the signal is required to eliminate shot-to-shot fluctuations.

The possibility for study of atomic and molecular ultrafast dynamics using XUV pump – XUV probe schemes with high number of photons on a sample was already demonstrated and is currently in development in several research groups [8 - 9].