Spectral and spatial characterization of high-order harmonics in the XUV region

Application Note

S. Eyring, C. Kern, J. Lohbreier, R. Spitzenpfeil, C. Spielmann, University Jena (October 2009)

Introduction

Laser-driven high-order harmonic generation is an important table top source of XUV radiation. The unprecedented temporal and spatial properties [1] make it a perfect source for various experiments and applications. High-order harmonic radiation originates from a quantum-mechanical process which can be described by a semi-classical model. This model assumes the ionization of an atom, the nearly free propagation of the produced electron in the vacuum and its recombination with the parent ion. The resulting radiation is the coherent interaction of many single atoms which are excited in this way. Therefore high-order harmonic radiation inherits the temporal and spatial (coherence) properties of the driving laser pulse. In other words the near-infrared or visible laser pulses are upconverted into the XUV or soft X-ray range, i.e. high-order harmonic sources are the only source delivering spatially and temporally coherent short wavelength radiation

A disadvantage of this process is the low quantum yield. Our goal was to improve the brilliance of the source by optimizing the generation process [2]. To further investigate this process a XUV spectrometer and a Hartmann-type wavefront sensor are employed. Both devices are based on an imaging sensor which is in our case a back-illuminated CCD camera.

Setup

The XUV source consists of a Ti:Sapphire femtosecond amplifier laser system (1 kHz, 800 nm, 1 mJ, 20 fs) and a vacuum chamber in which the high-order harmonic generation takes place. The generation happens in a small tube filled with argon gas at a defined backing pressure. The generated XUV radiation is filtered through a thin aluminum foil blocking the remaining fundamental laser light.

Spectrometer

To analyze the generated radiation a custom-made grating spectrometer is used. As a detector we used an Andor DO420-BN back-illuminated X-ray CCD with 1024 x 255 pixels. The CCD chip is cooled down to -60 °C to minimize noise and to allow for long exposure times.

Wavefront

To measure the spatial properties of the high-order harmonics a Hartmann-type wavefront sensor (Figure 1) is used.

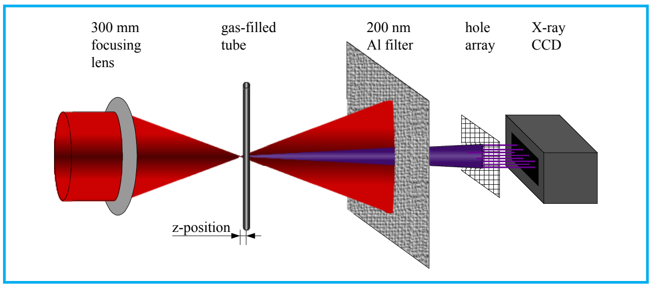

Figure 1: Experimental setup for the harmonic characterization measurements. The laser pulse is focused into the nickel tube where the harmonics are generated. Fundamental and harmonic beam co-propagate, are spectrally filtered, and the XUV beam casts a shadow of the hole-array onto the X-ray CCD camera.

The wavefront sensor consists of a hole-array in front of the back-illuminated X-ray CCD. By illuminating the mask with the XUV radiation the hole-array casts a shadow on the CCD. The position of each spot on the CCD depends on the local wavefront tilt at the position of the hole. Therefore the wavefront of the incident beam can be reconstructed by evaluating the local shift of the shadow. For this method the spot position has to be measured precisely. The size and spacing of the holes on the array has to be matched to the pixel size and resolution.

Experiments

To investigate the influence of different experimental parameters, such as gas pressure and laser beam shape [2,3], we have applied different detection schemas.
In this report we restrict on the characterization of the spectrum and a detailed investigation of spatial properties of the XUV beam.

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Spectrometer
A typical spectrum of the high-order harmonic radiation (Figure 2) can be acquired with the CCD in full-vertical binning mode to improve the detection speed.

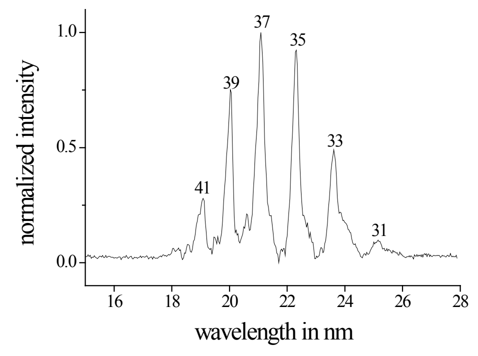

Figure 2: Typical high-order harmonic spectrum with a gas pressure of about 100 mbar Ar gas and pulse energies of 500 µJ at a pulse duration of 30 fs detected behind an Al filter.

Wavefront
In order to investigate the influence of the gas pressure on the generation process we measured the wavefronts of the harmonic beam at different backing-pressures (Figure 3). As one can see the beam profile of the harmonics is very similar whereas the astigmatism changes notably in amplitude and orientation.

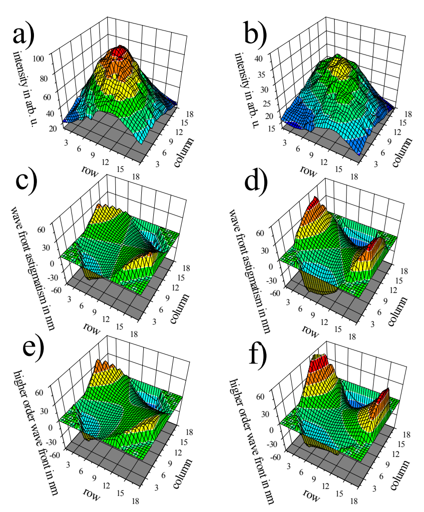

Figure 3: Experimental results of spatial beam profile (a, b), wavefront astigmatism (c, d) and higher order wavefront distortions (e, f) at two different gas pressures (a, c, e: 120 mbar; b, d, f: 220 mbar).

With the help of the CCD camera it is possible to study the influence of different parameters on the spectrum, the beam profile and the wavefront of high-order harmonic radiation.

References

[1] C. Winterfeldt et al, Rev. Mod. Phys. 80, 117 (2008)

[2] J. Lohbreier et al, New J. Phys. 11, 023016 (2009)

[3] R. Spitzenpfeil et al, Appl. Phys. A 96, 69-81 (2009)

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