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Spatial shaping of femtosecond beam for controlling attosecond pulse

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Abstract

When an intense femtosecond (fs) pulse non-linearly interacts with ionizing matter, it leads to the generation of bursts of extreme ultra violet (XUV) coherent irradiations having ultrashort pulse duration in attoseconds. Here, we present systematic experiments to show how the high-order harmonics generation is modulated with a spatially shaped fs-laser beam. The spatial shaping of fs-pulses has been induced with the alteration in hard aperture from 8-25 mm diameter. The experimental parameters such as incident power and gas pressure has been optimized to efficiently generate the harmonics in our system. While changing the aperture size of intense fs- beam, we observed unique space-time coupling effects in the shapes of individual harmonics beam.

1 Introduction

Attosecond science facilitates direct coherent control of electronic processes in atoms or molecules [1, 2]. Generally, an attosecond pulse train is synthesized from phase-locked high harmonics which is inherently synchronized with the driving IR pulse owing to ionization, acceleration and subsequent recombination of electrons in gas. The phenomenon of pulse generation has been explained by the semi-classical three-step model [3, 4]. In last decades, the attosecond pulses are well characterized, ideally they may serve as the fastest camera, enabling frozen snapshots of ultra-fast electron dynamics occurring in atomic, molecular, solid state and plasma medium, as well as in condensed material. Devising new approaches for temporal characterization/control has much interest and is actively explored. For example, spatial modification in intense fs-beam using irises, it may be possible to illustrate the spatial modifications in the XUV pulse, demonstrating a rich variety of space-time coupling effects. Since details of space-time coupling effects are rather sensitive to experimental geometry, we shall present iris-control og HHG in our first custom-built set-up.

2 Material and Methods

Fig. 1 (a) illustrates the schematic of attosecond pulse generation setup. We hereby illustrate the generation and characterization of attosecond light pulses by focusing femtosecond (fs) pulses in an Argon-filled capillary (800 nm, 25 fs, 1 kHz). The experimental conditions for generation and propagation of harmonics are intensity (>10^{14} W/cm^2), high vacuum (5 x 10^{-8} mbar), 2f-to-2f astigmatism free toroidal mirror focusing ($f = 25\ cm$). The harmonics were spectrally resolved using a spherical gratings on micro-channel plate (MCP) detector and imaged using a CCD camera. The high harmonic spectrum is shown in Fig. 1 (b). In order to determine the threshold of harmonics generation, the laser power was varied from 0.1–0.9 mJ, at constant gas pressure in the capillary constant about 9.0 mbar. For smooth propagation of harmonics the pressure

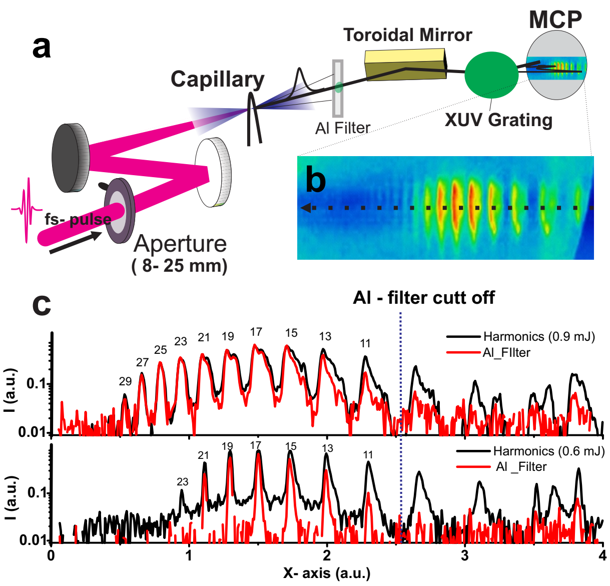

Figure 1. (a) Schematic of experimental setup for attosecond pulse generation, (b) Image of spectrally resolved harmonics. (c) Harmonics spectra. Parameters are: average input power 0.9 mJ, λ = 800 nm, pulse width = 25 fs. Calibration of XUV pulses at 0.9 and 0.6 mJ pulse energies without (in black) and with Aluminum (Al) filter (in red).

at harmonics chamber, toroidal chamber and sample chamber was maintained in the range of 10^{-4} mBar, 10^{-5} mbar and 10^{-6} mbar, respectively. For optimal HHG yield, the backing Ar-pressure in the capillary-line is also optimized. Lastly, to study the spatial change in XUV pulses, the spatial shaping of fs- beam was done by changing the aperture diameter from 8 mm to 25 mm (fully opened) in steps of 0.5 mm, simultaneously the high resolution images of harmonics was captured with CMOS Thorcam (THORLABS, USA). The $1/e^2$ diameter of incident fs-beam is about 20 mm, while at HHG focus after toroidal mirror is about 100 μm.

The calibration of XUV pulses was done by inserting 200 nm thick Aluminium (Al) filter (Lebow, USA)) in the XUV path. The Al-filter blocks harmonics below 80 nm or 11^{th} order. Fig.1 (c) shows the harmonics up to 23^{rd} order with 0.6 mJ) and increased up to 29^{th} order with increase in incident energy 0.9 mJ. After the inserting the Al- filter, the harmonics below 80 nm (11^{th}) disappear.

3 Results and Discussion

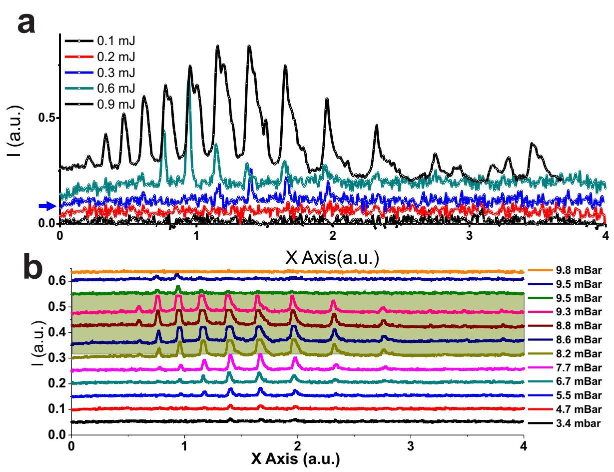

Figure 2. (a) Plot of harmonics as a function of laser power (mJ) variation from 0.1- 0.9 mJ where the input gas pressure is (9.2 mbar) kept constant (b) Plot of harmonics as a function of argon gas pressure (3.4 - 9.8 mbar) in the capillary at a constant average input laser power (0.6 mJ)

Pulse energy and gas pressure optimization : The harmonics generation was optimized while varying the average laser pulse energy form 0.1 mJ to 0.9 mJ at constant gas pressure of 9 mBar (Fig. 2 (a)). The threshold of harmonics generation was about 0.3 mJ, where we may observe the harmonics up to 19th order. With increment in the incident pulse energy 0.6 mJ and 0.9 mJ, order of harmonics increased up to 23 and 29, respectively. In our experiment, the HHG generation capillary is placed approximately at the laser focus. The input gas pressures the can be independently adjusted typically from 3.4 mbar to tens of mbar in the capillary (Ar). In Fig. 2(b), HHG spectra from Ar is plotted as a function of the seeding pressure for constant driving intensity (0.6 mJ). The threshold of seeding pressure is about 3.4 mbar, beyond this value no spectra has been observed. As the seeding pressure increases, the harmonics signal increases up to 9.0 mbar and declined further. After or at 9.5 mbar seeding pressure, the signal is significantly declined, probably due to increase in absorption of harmonics while propagating. Additionally, at such seeding pressure, gas load in all the chambers is increases results in lowering of propagation vacuum and increase the absorption of harmonics. [5].

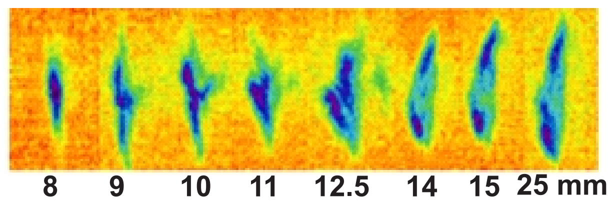

Figure 3. Spectra of 15th harmonic as a function of aperture diameter at constant pulse energy (0.9 mJ) and constant gas pressure 9 mbar. The diameter is varied from 8 to 25 mm. Spatial and spectral distortion in harmonics can be seen below the 14 mm aperture diameter.

Spatial shaping in fs-beam is induced by closing the aperture diameter from 8 to 25 mm (fully opened) with a step of 0.5 mm. The images of harmonics was captured and analyzed using gwyddion software. Individual harmonic at each aperture diameter was compared (Fig. 3). We observe the distortion in both spatial axis (y-axis) and spectral axis (x-axis) as a of function aperture diameter. The HHG shaping is seen at the aperture diameter 12.5 mm in the spatially resolved measured spectra and exhibits patterns that are comparable to [6]. The observed patterns are stable and reproducible in our setup. Generally, the XUV pulses have a complex space-time structure, thus while studying the temporal variations such structures are lost in averaging and not able to be retrieved. This method enable us to study the spatio-temporal homogeneity in the far field and provide a way to optimize the generation process for further careful experiments.

4 Acknowledgements

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